UNITED
NATIONS

EP

United Nations
Environment
Programme

Distr.
GENERAL

UNEP/OzL.Pro/ExCom/85/9
9 May 2020

ORIGINAL: ENGLISH

EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Eighty-fifth Meeting
Montreal, 25-29 May 2020
Postponed to 19-22 July 2020*

STATUS REPORTS AND REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS

1. The present document serves as a follow-up to the issues raised in the last annual progress and financial reports submitted to the 84th meeting,[1] and in relation to projects and activities for which specific reports were requested in previous meetings.

2. The document consists of the following five sections:

Section I: Projects with implementation delays and for which special status reports were requested

Section II: Reports on projects with specific reporting requirements for which there are no outstanding policy, cost or other issues, for which the Executive Committee may wish to take decision on the basis of the Secretariat's recommendations without further discussion ("blanket approval"). The report of the meeting of the Executive Committee will present each report contained in this section individually, together with the decision adopted by the Committee

Section III Reports on projects with specific reporting requirements for individual consideration by the Executive Committee

Section IV: List of enterprises funded under HPMPs with delays and/or subject to changes in the implementation plan and enterprises for conversion to low-GWP technologies with delays due to issues related to their availability in the local market and/or higher costs (decisions 84/27 and 84/42)

Section V: HFC-related investment projects and enabling activities funded using the additional contributions by a group of 17 non-Article 5 Parties (decision 84/12(b))

* Due to coronavirus disease (COVID-19)
[1] UNEP/OzL.Pro/ExCom/84/16-21

SECTION I: PROJECTS WITH IMPLEMENTATION DELAYS AND FOR WHICH SPECIAL STATUS REPORTS WERE REQUESTED

Implementation delays

3. At the 84th meeting, five ongoing projects (one under UNEP's implementation and four under UNIDO's implementation) were classified as projects with implementation delays. These projects, shown in Annex I to the present document, are subject to the procedure for project cancellation, and cannot be removed from the list for monitoring prior to final completion, in line with decision 32/4.

4. Both UNEP and UNIDO had indicated that some progress has been achieved since the last progress report, and that they would continue to monitor these projects until their completion.

Projects for which additional status reports were requested[2]

5. At its 84th meeting, the Executive Committee requested additional status reports for 58 projects (decision 84/12(a)(iii)). In line with decision 84/12(a)(iii), relevant bilateral and implementing agencies submitted the requested reports to the 85th meeting. During the review process, the Secretariat noted that progress had been made in 27 projects. Of the remaining 31 projects, five projects with outstanding issues related to the Democratic People's Republic of Korea are being considered under Section III of the present document; the remaining 26 projects with outstanding issues are listed in Annex II to the present document.

Recommendation

6. The Executive Committee may wish:

(a) To note:

(i) The implementation delay reports and status reports submitted by bilateral and implementing agencies, contained in document UNEP/OzL.Pro/ExCom/85/9;

(ii) That bilateral and implementing agencies would report to the Executive Committee at the 86th meeting on five projects with implementation delays and on 26 projects recommended for additional status reports as contained in Annexes I and II, respectively, to the present document as part of the 2019 annual and financial progress report of the bilateral and implementing agencies; and

(b) To approve the recommendations on ongoing projects with specific issues listed in the last column of the table in Annex II to the present document.

REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS

7. Table 1 lists the reports on projects with specific reporting requirements submitted to the 85th meeting recommended for blanket approval.

Table 1: Reports on projects with specific reporting requirements recommended for blanket approval

Country	Project title	Paragraphs
ODS waste disposal projects		
Lebanon	Pilot demonstration project on ODS waste management and disposal: Final report	9 – 13

[2] Institutional strengthening (IS), halon banking, customs training, recovery and recycling (R&R), and demonstration projects are not subject to procedures for project cancellation. Nevertheless, the Executive Committee has decided to continue to monitor them as appropriate (decision 36/14(b)).

Country	Project title	Paragraphs
Temporary use of high-global-warming-potential (GWP) technology in approved projects		
Lebanon	HPMP (stage II): Report on the status of the conversion of the of the remaining beneficiary enterprises in both the foam and air-conditioning manufacturing sectors	14 – 20
Reports related to HCFC phase-out management plans (HPMPs)		
Argentina	HPMP (stage II): Update on the financial viability of the enterprise Celpack	21 – 23
Brazil	HPMP (stage I): Report on the temporary use of high-GWP technology at UTech system house and final progress report	24 – 44
Brazil	HPMP (stage II): Status of implementation of the projects in the room air-conditioning (AC) manufacturing sector	45 – 52
Costa Rica	HPMP (stage I): Progress report	53 – 62
Honduras	HPMP (stage I): Progress report on implementation of activities under the UNEP components	63 – 73
India	HPMP (stage II): Update on the assessment of continuous-foam-panel-manufacturing enterprises regarding adherence to the ban	74 – 78
Indonesia	HPMP (stage I): Update on status of conversion of the refrigeration and air-conditioning manufacturing enterprises and revised plan of action	79 – 93
Malaysia	HPMP (stage II): Change in technology at 14 enterprises	94 – 100
Morocco	HPMP (stage I): Progress report	101 – 115
Republic of Moldova	HPMP (stage II): Detailed report on the status of implementation of the demonstration projects for using CO_2–based technology in the commercial refrigeration sector	116 - 126
Demonstration projects for low-GWP alternatives to HCFCs		
Argentina and Tunisia	Demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets: Final report	127 – 147 (Report in Annex III)
Global	Demonstration project on refrigerant quality, containment and introduction of low-GWP alternatives (Eastern Africa and Caribbean regions): Final report	148 – 168 (Report in Annex IV)
Regional: Europe and Central Asia	Development of a regional centre of excellence for training and certification and demonstration of low global-warming potential alternative refrigerants: Final report	169 – 180 (Report in Annex V)
Saudi Arabia	Demonstration project for the phase-out of HCFCs by using HFO as a foam blowing agent in spray foam applications in high ambient temperatures: Final report	181 – 193 (Report in Annex VI)
Saudi Arabia	Demonstration project on promoting HFO-based low-global-warming-potential refrigerants for the air-conditioning sector in high ambient temperatures: Progress report	194 – 202
West Asia	Demonstration project on promoting alternative refrigerants in air-conditioning for high ambient temperature countries (PRAHA II) : Final report	203 – 217 (Report in Annex VII)
Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors in China		
China	Process agent II – Additional information on activities to be undertaken	218 – 230
Requests for extension of enabling activities		231 – 233

8. Table 2 lists the reports on projects with specific reporting requirements submitted to the 85th meeting for individual consideration and a brief explanation of related issues.

Table 2: Reports on projects with specific reporting requirements for individual consideration

Country	Project title	Issue	Paragraphs
Reports related to HCFC phase-out management plans (HPMPs)			
Democratic People's Republic of Korea	HPMP (stage I): Progress report on implementation of activities	Request for guidance in view of the challenges in implementing activities in light of the United Nations Security Council resolutions	234 – 244
Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors in China			
China	Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors	Return of balances from CFC production, polyurethane foam, refrigeration servicing and solvent sectors	245 – 250

SECTION II: REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS RECOMMENDED FOR BLANKET APPROVAL

ODS waste disposal projects

Lebanon: Pilot demonstration project on ODS waste management and disposal (final report) (UNIDO)

Background

9. At its 73rd meeting, the Executive Committee approved the pilot demonstration project on ODS waste management and disposal for Lebanon at the amount of US $123,475, plus agency support costs of US $11,113 for UNIDO.

10. At its 79th meeting, the Executive Committee requested, *inter alia*, bilateral and implementing agencies to submit final reports on outstanding ODS disposal pilot projects other than those for Brazil and Colombia, and to return to the 82nd meeting the remaining balances for projects for which reports had not been submitted to the 80th or 81st meeting (decision 79/18(d)). Subsequently the Secretariat prepared a synthesis report on the pilot ODS disposal projects considered by the Executive Committee at its 82nd meeting. At its 82nd meeting, the Executive Committee extended the pilot demonstration project for Lebanon to June 2019 with the final report due at the 84th meeting, and balances returned at that meeting (decision 82/15(c)).[3]

Secretariat's comments

11. The Secretariat received the final report for the pilot ODS disposal project for Lebanon for consideration of the 85th meeting on 5 May 2020, five weeks after the deadline of submission. Due to the late receipt of this document, the Secretariat was unable to review the submission and will provide a summary of this report at the 86th meeting.

12. Based on the financial status provided as part of the final report, UNIDO will return the balance of US $7,701 to the 85th meeting.[4]

[3] To approve the extension, to 30 June 2019, of the pilot demonstration project on ODS waste management and disposal for Lebanon (LEB/DES/73/DEM/83), on the understanding that the final report and the project completion report would be submitted no later than the 84th meeting and that the balances would be returned in line with decision 28/7.

[4] UNEP/OzL.Pro/ExCom/85/4

Recommendation

13. The Executive Committee may wish to take note of the submission by UNIDO of the final report for the pilot demonstration project on ODS waste management and disposal for Lebanon, which will be reviewed and presented by the Secretariat at the 86th meeting.

Temporary use of a high-global-warming potential technology in approved projects[5]

Lebanon: HCFC phase-out management plan (stage II – report on the status of the conversion of the remaining beneficiary enterprises in both the foam and air-conditioning manufacturing sectors) (UNDP)

Background

14. On behalf of the Government of Lebanon, UNDP as designated implementing agency has submitted a progress report on the implementation of conversions of enterprises in the foam and air-conditioning (AC) manufacturing sectors, updates on securing the supply of low-global-warming potential (GWP) alternative technology, and the results of the testing of two alternatives in the foam sector, in line with decision 84/29(b).[6]

Progress report

15. With regard to the conversion of the two remaining enterprises and the technical assistance for the conversion of 11 small sized enterprises in the foam sector, the availability of HFOs continues to be a challenge. While a technical foam consultant had been identified, and trials of methylal and methyl formate as blowing agent were to be conducted at a few selected enterprises in early 2020, the actual security and economic situation prevailing in the country has made it impossible to conduct these trials. Furthermore, the situation with COVID-19, has further delayed implementation. It is expected to undertake the trials with various blowing agents including HFO-based systems, once the situation in the country improves with regard to COVID-19; conversion of the 11 small foam enterprise could be completed by the first quarter in 2021, and the remaining individual enterprises (SPEC and Prometal) by June 2021.

16. At the 84th meeting, it was reported that the two remaining enterprises in the AC manufacturing sector (i.e., CGI Halawany and ICR) were still deciding whether to use HFC-32 or another low-GWP alternative as the replacement refrigerant. These enterprises finally decided to convert to HFC-32. Conversion will commence during the third quarter of 2020 and is expected to be completed by the first quarter of 2021; no issues are expected with the selected technology and the cost of the conversion.

Secretariat's comments

17. UNDP reiterated that the Government of Lebanon is committed to issuing the ban on imports of HCFC-141b by 1 January 2021. This would allow for the completion of the trials with various blowing agents and the conversion of all foam enterprises by end of 2020; in case, the conversion is completed during the first quarter of 2021 (mainly due to COVID-19), the enterprises would be allowed to import and

[5] Report related to the temporary use of a high-GWP technology in approved projects for Cuba is included in the project proposal document (UNEP/OzL.Pro/ExCom/85/23).
[6] Decision 84/29(b): To request UNDP to continue assisting the Government of Lebanon in securing the supply of low-GWP alternative technology, and to report, at the 85th meeting, on the results of the testing of two alternatives in the foam sector and, at the same meeting and each meeting thereafter until the technology originally selected or another technology with low-GWP had been fully introduced, on the status of the conversion of the remaining beneficiary enterprises in the foam manufacturing sector (SPEC, Prometal and the small enterprises) and in the air-conditioning manufacturing sector (CGI Halawany and ICR).

stockpile HCFC-141b before the ban takes place.

18. With regard to two remaining AC enterprises (CGI Halawany and ICR), UNDP mentioned that the Government is confident that these enterprises would complete their conversion by the first quarter of 2021.

19. The Secretariat noted the efforts taken by UNDP to assist the remaining foam enterprises and the two AC enterprises in completing their conversions to non-ODS alternatives.

Recommendation

20. The Executive Committee may wish:

(a) To note the report provided by UNDP and the Government of Lebanon, contained in document UNEP/OzL.Pro/ExCom/85/9, describing the continued challenges being faced by the Government in sourcing commercially available alternatives with low-global-warming potential (GWP) alternatives, such as HFOs, and the efforts made by the Government and UNDP to facilitate the supply of technology with low-GWP to the enterprises funded under stage II of the HCFC phase-out management plan for Lebanon; and

(b) To request UNDP to continue assisting the Government of Lebanon in securing the supply of low-GWP alternative technology, and to report at the 86th meeting and each meeting thereafter until the technology originally selected or another technology with low-GWP has been fully introduced, on the status of the conversion of the remaining beneficiary enterprises in the foam manufacturing sector (SPEC, Prometal and the small foam enterprises); and in the air-conditioning manufacturing sector (CGI Halawany and ICR).

Reports related to HPMPs[7]

Argentina: HCFC phase-out management plan (stage II – update on the financial viability of the enterprise Celpack) (UNIDO)

Background

21. At its 84th meeting, the Executive Committee considered the request for funding the second tranche of stage II of the HPMP for Argentina.[8] The tranche request included a progress report on the implementation of the activities approved under the first tranche; the report *inter alia* indicated that the conversion of the XPS foam enterprise Celpack, from HCFC-22 to CO_2, had been delayed due to economic difficulties that the enterprise was facing, and its interest in evaluating butane as an alternative to HCFCs. In approving the funding tranche, the Committee requested UNIDO to submit at the 85th meeting an update on the financial viability of the enterprise and whether it would be assisted by the Multilateral Fund, on the understanding that the funds from the conversion would be returned in the event that the enterprise were removed from the project (decision 84/64(d)(ii)).

22. In response to decision 84/64(d)(ii)), UNIDO informed the Secretariat that the Government of Argentina and UNIDO had not been able to conclude the assessment regarding the financial viability of Celpack. UNIDO explained that the procedure to assess the financial viability of Celpack, which consists of the appointment of a trustee and the verification of debts and negotiations with creditors, had been initiated; by the end of March 2020, Celpack's debts were being verified. A follow-up visit that was planned by the national ozone unit has been postponed until the isolation measures established by the Government

[7] Report related to the HPMP for Uruguay is included in the project proposal document (UNEP/OzL.Pro/ExCom/85/52).
[8] UNEP/OzL.Pro/ExCom/84/39

owing to COVID-19 are removed. It is expected that negotiations with the creditors will be completed and the financial viability will be assessed during the second half of 2020. The report would therefore be submitted to the 86th meeting.

Recommendation

23. The Executive Committee may wish to request the Government of Argentina, through UNIDO, to provide to the 86th meeting the update on the financial viability of the enterprise Celpack funded under stage II of the HCFC phase-out management plan, a decision on whether the enterprise would be assisted by the Multilateral Fund, in line with decision 84/64(d)(ii), and to return the funds associated with the conversion to the 86th meeting in the event that the enterprise was removed from the project.

<u>Brazil: HCFC phase-out management plan (stage I – report on the temporary use of high-GWP technology at U-Tech systems house and final progress report)</u> (UNDP and the Government of Germany)

Background

24. On behalf of the Government of Brazil, UNDP as the lead implementing agency has submitted to the 85th meeting[9] the final report on the implementation of the work programme associated with stage I of the HPMP and the project completion report,[10] in line with decision 84/32(b)(i).[11]

HCFC consumption

25. The Government of Brazil reported a consumption of 826.26 ODP tonnes of HCFC in 2018, which is 38 per cent below the HCFC baseline for compliance. The Government also reported HCFC sector consumption data under the 2018 country programme implementation report that is consistent with the data reported under Article 7 of the Protocol. HCFC consumption for 2019 is not available yet.

Final report on the implementation of stage I of the HPMP

Polyurethane (PU) foam manufacturing sector

<u>*Conversion of 12 stand-alone PU foam enterprises (79.71 ODP tonnes)*</u>

26. Eleven enterprises (with consumption of 76.74 ODP tonnes of HCFC-141b) in the continuous panel and integral skin/flexible moulded applications completed their conversions (three opted for hydrocarbon (HC), three for methyl formate, three for methylal, one for methylene chloride and one for water-based technology). One enterprise (Panisol) with a total consumption of 3.0 ODP tonnes of HCFC-141b withdrew from the HPMP and consequently, the consumption associated with the enterprise was not phased out under stage I. The funding balance of US $301,695 (plus agency support costs of US $22,627) is to be returned to the Multilateral Fund no later than at the 86th meeting.

[9] As per the letter of 26 March 2020 from the Ministry of Environment of Brazil to UNDP.

[10] The fifth and final tranche of stage I of the HPMP was approved at the 75th meeting at a total cost of US $2,035,094, consisting of US $1,470,700, plus agency support costs of US $110,303 for UNDP, and US $409,091, plus agency support cost of US $45,000 for the Government of Germany. At its 80th meeting, the Committee approved the extension of the completion date of stage I to 31 December 2019, on the understanding that no further extension would be requested (decision 80/12(b)).

[11] The Government of Brazil, UNDP and the Government of Germany were requested to submit, at the 85th meeting, the final report on the implementation of the work programme associated with stage I of the HPMP up to its completion and the project completion report.

Conversion of 11 systems houses and 370 downstream foam users (89.1 ODP tonnes)

27. Out of the 11 systems houses included in the project, 10 completed their conversions and developed and introduced low-global-warming potential (GWP) formulations in their associated downstream foam users. US $179,300 plus agency support costs of US $13,448 corresponding to one enterprise (Arinos), which during project implementation was identified as ineligible for funding, was returned at the 75th meeting. In addition, US $135,300 plus agency support costs of US $10,148 allocated to one systems house (Polysystem) that withdrew from the HPMP is to be returned to the Multilateral Fund no later than at the 86th meeting.

28. In line with decision 84/32(b)(ii), UNDP included in the report the list of downstream foam users included under stage I, along with their HCFC-141b consumption phased out, sub-sector, baseline equipment and technology adopted. The report indicates as follows:

(a) 225 enterprises completed their conversions to low-GWP alternatives, phasing out 85.11 ODP tonnes of HCFC-141b;

(b) 39 downstream foam enterprises (8.48 ODP tonnes) withdrew from the HPMP; the consumption of HCFC-141b associated with these enterprises has been phased out;

(c) 22 downstream foam enterprises were found to be ineligible for funding (consumption not available);

(d) During project implementation, it was found that 84 downstream foam enterprises identified at the time of the submission of stage I of the HPMP had inadvertently been accounted for more than once, because they were buying polyols from several systems houses; and

(e) A fund balance of US $1,597,282 corresponding to the downstream foam enterprises that did not convert due to ineligibility or non-participation in the HPMP.

29. Thus, the total fund balance from the implementation of all individual and group projects in the PU foam sector is US $2,034,278, to be returned no later than at the 86th meeting in line with decision 84/32(b)(iii).

Refrigeration servicing sector

30. All planned activities in the refrigeration servicing sector were completed as detailed in previous reports and the total amount spent was US $4,090,909. There are no fund balances to be returned to the Fund.

Project implementation and monitoring unit (PMU)

31. The PMU continued to support the national ozone unit in implementing the HPMP activities during the finalization of stage I of the HPMP. The amount spent on the PMU between 2012 and 2019 was US $800,000.[12]

[12] Details on the cost structure of the PMU will be provided with the request of the next tranche of stage II of the HPMP at the 86th meeting.

Level of fund disbursement

32. As of December 2019, of the US $19,417,866 approved for stage I,[13] US $17,323,588 (90 per cent) had been disbursed (i.e., US $13,292,679 for UNDP and US $4,090,909 for the Government of Germany). UNDP is still undertaking minor final payments from the balance of US $2,034,278 and a fund balance in the order of US $2 million will be returned to the Fund (Table 3).

Table 3: Financial report of stage I of the HPMP for Brazil

Agency	Funds approved (US $)	Funds disbursed		Balance (US $)
		(US $)	(%)	
UNDP	15,326,957	13,292,679	87	2,034,278
Government of Germany	4,090,909	4,090,909	100	0
Total	**19,417,866**	**17,383,588**	**90**	**2,034,278**

33. UNDP confirmed that all activities under stage I were completed by December 2019, in line with decision 80/12(b).

Secretariat's comments

PU foam sector

<u>*Completion of the project and return of balances*</u>

34. The Secretariat notes with appreciation the thorough work carried out by the Government of Brazil and UNDP to verify the eligibility of a large number of small and medium-sized foam enterprises included in stage I and to complete the project by the extended date of December 2019.[14]

35. Regarding the 84 enterprises that were not accounted for in the final report, UNDP confirmed that during project implementation, 76 enterprises were indeed accounted for in the final list; at the time of preparation of the HPMP, some enterprises were inadvertently counted more than once because they were buying polyols from several systems houses. This uncertainty was acknowledged at the time of approval of the HPMP, and for this reason, one of the key tasks during implementation was to verify the information in the field and make a detailed inventory of eligible enterprises and baseline equipment at the participating downstream foam enterprises. Upon verification of such repeated cases, UNDP consolidated their consumption and addressed them as one downstream foam enterprise through only one systems house. This explains the reason for fewer enterprises in the final inventory.

36. UNDP also confirmed that all payments made to downstream foam users followed strictly the funding levels approved by the Executive Committee (i.e., US $15,000 for new dispensers or retrofit of high-pressure dispensers, US $10,000 for retrofit of low-pressure dispensers, US $3,000 for technical assistance, trials and training for enterprises with consumption above 500 kg/year, and US $1,300 for enterprises below 500 kg/year). The type of equipment and its eligibility (particularly with regard to the cut-off date) at each participating enterprise was identified during project implementation as agreed during project preparation. The final list of enterprises submitted by UNDP includes the baseline equipment of each enterprise and the assistance provided (retrofit of dispenser, new dispenser or no action).

37. UNDP also highlighted that although the verified number of downstream foam enterprises in the final inventory was lower than that in the initial inventory, a total of 86.06 ODP tonnes were phased out by assisted downstream foam enterprises, which represents more than 95 per cent of the funded 89.1 ODP tonnes to be phased out by these enterprises, and there is a fund balance of close to

[13] Excluding US $179,300US $ returned to the Fund that was associated with a non-eligible enterprise.
[14] Stage I of the HPMP for Brazil has been extended twice; to December 2017 (UNEP/OzL.Pro/ExCom/75/40) and to December 2019 (decision 80/12(b)).

US $1.6 million from this component. The HCFC-141b consumption associated with the ineligible enterprises will be phased out with funding outside the Multilateral Fund.

38. Based on the detailed data and explanations provided by UNDP, the Secretariat notes that UNDP followed rigorously the agreed principles of the project and achieved the phase-out goal at a better cost-effectiveness than the approved proposal. A summary of the implementation of stage I of the HPMP for Brazil is presented in Table 4 below.

Table 4: Summary of the implementation of stage I of the HPMP for Brazil

Activity	As approved				As implemented				Balance (US $)
	No. of enterprises	ODP tonnes	Approved (US $)	CE (US $/kg)	No. of enterprises	ODP tonnes	Disbursed (US $)	CE (US $/kg)	
Integral skin	11	47.34	2,238,819	5.20	11	47.34	2,238,819	5.20	-
Continuous panels	4	32.35	2,218,791	7.54	3	29.39	1,917,095	7.18	301,696 **
Group project	11 SH 370 DSU	89.03	9,949,347*	12.29	10 SH 225 DSU	85.11	8,216,765	10.62	1,732,582 ***
Total foam	**396**	**168.73**	**14,406,957**	**9.39**	**249**	**161.84**	**12,372,680**	**8.41**	**2,034,278**
Regulatory action	n/a	1.50	120,000	4.40	n/a	1.50	120,000	4.40	-
Servicing sector	n/a	50.00	4,090,909	4.50	n.a	50.00	4,090,909	4.50	-
PMU	n/a		800,000		n.a		800,000		-
Total		**220.23**	**19,417,866**	**7.86**		**213.34**	**17,383,588**	**7.22**	**2,034,278**

C.E.: Cost effectiveness; SH: Systems house; DSU: Downstream foam users.
* Includes a deduction of US $179,300 to the fifth tranche (75th meeting) corresponding to the SH Arinos found ineligible.
** Funds from the enterprise Panisol (3.0 ODP tones) that withdrew from the HPMP.
*** This balance includes US $135,300 from the SH Polysystem that withdrew from the HPMP, and approximately US $1,597,282 from DSU.

39. The remaining fund balance will be returned at the 86th meeting. UNDP clarified that there were minor final payments still ongoing, but provided reassurance that the amount to be returned will be in the order of US $2 million.

Temporary use of high-GWP technology

40. At the 80th meeting, UNDP explained that two systems houses (Shimtek and U-Tech) had requested the temporary use of HFC-based polyol systems with high-GWP-based blowing agents, as HFOs were not yet available on a commercial scale in the country. Both systems houses had signed a commitment to stop the temporary use of HFC blends once HFOs were commercially available and the systems had been developed and optimized, at no additional cost to the Multilateral Fund.

41. Accordingly, the Executive Committee requested UNDP to continue assisting Shimtek and U-Tech in securing the supply of the alternative technologies selected, on the understanding that incremental operational costs (IOCs) would not be paid until the alternative technology selected or another low-GWP-based technology had been fully introduced. UNDP was also requested to report on the status of use of the interim technology until the technology originally selected or another low-GWP-based technology had been fully introduced (decision 80/12(e)), along with an update from the suppliers on progress made toward ensuring that the selected technologies, including associated components, were available on a commercial basis in the country (decision 81/9). At the 83rd meeting, UNDP reported that Shimtek had opted for water-based technology to replace the use of HFOs for flexible foam production, using the systems house's own resources for the necessary adjustments made in the formulations, as the prices of HFOs in the market continued to be very high, disallowing the supply of systems at competitive prices. The enterprise is no longer using HFCs.

42. In line with decision 84/32(c), UNDP reconfirmed that the reconversion of the systems house U-Tech was completed and the use of HCFCs in its polyols systems was phase out. U-Tech adopted methyl

formate to replace the use of HCFC-141b in all its applications, except for the production of Froth System, where it intended to replace HCFC-22 by HFO, but it is temporarily using HFC-134a. U-Tech tested formulations with HFO (based on samples received at a price of US $22.00/kg) over a six-month period to evaluate the product's stability, and that U-Tech and the supplier (Honeywell) are discussing final arrangements for the supply of the blowing agent and associated chemical components. However, based on an estimated final price of HFO at US $19.75/kg, as informed verbally by the supplier, the cost of the polyol systems will increase by 33 per cent, making its market share unfeasible.

43. The Secretariat notes that stage I of the HPMP is completed and therefore no IOCs will be paid to downstream users associated to the conversion of Froth System to low-GWP technology supplied by U-Tech. Noting that U-Tech is also included in stage II of the HPMP, the Secretariat recommends that UNDP continue reporting on additional progress by U-Tech to introduce a low-GWP alternative technology in the production of Froth System.

Recommendation

44. The Executive Committee may wish:

(a) To note:

(i) The final report on the implementation of the HCFC phase-out management plan (HPMP) (stage I) for Brazil, submitted by UNDP and contained in document UNEP/OzL.Pro/ExCom/85/9;

(ii) That there is an estimated balance of US $2,034,278 from the implementation of projects in the polyurethane foam sector, and that UNDP will return the actual funding balance to the Multilateral Fund at the 86th meeting; and

(b) To request UNDP to continue assisting the Government of Brazil in securing the supply of alternative technologies with low-global-warming potential (GWP) to the systems house U-Tech, on the understanding that any incremental operating costs related to the conversion of Froth System applications would not be paid under stage II until the technology originally selected or another technology with low-GWP had been fully introduced, and to provide, at each meeting until the technology originally selected or another technology with low-GWP had been fully introduced, a report on the status of the conversion, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available on a commercial basis in the country.

Brazil: HCFC phase-out management plan (stage II – status of implementation of the projects in the room air-conditioning (AC) manufacturing sector) (UNIDO, UNDP, Governments of Germany and Italy)

Background

45. At the 82nd meeting, the Government of Brazil and UNIDO informed the Executive Committee that the three room AC enterprises included in stage II of the HPMP had not started their conversions to R-290 due to the uncertainty about the regulations on the use of flammable refrigerants, market acceptance of those refrigerants, fear of higher prices of the converted AC units, and the potential unavailability of AC components on the market. Accordingly, in approving the third tranche of stage II, the Executive Committee requested UNIDO *inter alia* to report at the 84th meeting on the status of implementation of the projects in the room AC manufacturing sector (decision 82/62(c)).

46. In response to decision 82/62(c), UNIDO reported at the 84th meeting that to address the concerns of the room AC enterprises regarding the introduction of the R-290 technology, UNIDO organized in March 2019 a workshop for over 60 representatives of the AC sector on the use of alternative refrigerants in room AC equipment. Furthermore, in coordination with the Ministry of Environment, UNIDO planned to undertake a second workshop in late 2019 and a market study in 2020 addressing *inter alia* market acceptability, consumer perception assessment, evaluation of existing safety standards, cost and availability of components, and possible obstacles.

47. The Executive Committee noted the report submitted by UNIDO on the status of implementation of the projects in the room AC manufacturing sector[15] and requested UNIDO to report again at the 85th meeting on the status of implementation of the projects in the room AC manufacturing sector.

Progress report

48. UNIDO submitted a progress report to the 85th meeting recalling that the most relevant concerns for the three room AC enterprises were related to the acceptability of equipment with flammable fluids in the Brazilian market; the difficulty of tracking the product in the aftermarket stage, claiming that accidents could occur due to poor installation and maintenance, harming the enterprise's image; and the need to establish training and capacity-building programmes to deal with new equipment.

49. In order to address these issues, in November 2019 UNIDO organized the second workshop for room AC manufacturing enterprises on experiences and perspectives in relation to using R-290 as refrigerant in room AC equipment. The meeting included sessions on the field experiences of enterprises already working on converted equipment (e.g., Midea China and Godrej India) and contributed to raise the awareness of stakeholders on the technology. The Government and UNIDO also issued a tender to hire an enterprise to undertake the market study planned for 2020 addressing market acceptability, consumer perception assessment, evaluation of existing safety standards, cost and availability of components, and possible obstacles. The study is expected to be completed in September 2020.

Secretariat's comments

50. The Secretariat notes with appreciation the additional efforts made by the Government of Brazil and UNIDO to assist the room AC enterprises in addressing their concerns to select a low-GWP technology for their conversion.

51. Noting that concerns about the adoption of a flammable refrigerant persist among AC enterprises, and considering the Government of Brazil's and UNIDO's efforts in avoiding the adoption of R-410A technology, the Secretariat recommends that the Government and UNIDO continue working with the AC enterprises to introduce the selected technology and to submit a progress report on the status of the selection of the technologies by the room AC enterprises to the 86th meeting.

Recommendation

52. The Executive Committee may wish:

(a) To note the report on the status of implementation of the projects in the room air-conditioning (AC) manufacturing sector of stage II of the HCFC phase-out management plan (HPMP) for Brazil, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9; and

[15] Decision 84/33(a)(i) and (c). The report is contained in document UNEP/OzL.Pro/ExCom/84/22

(b) To request UNIDO to report at the 86th meeting on the status of implementation of the projects in the room AC manufacturing sector of stage II of the HPMP for Brazil.

Costa Rica: HCFC phase-out management plan (stage I – progress report) (UNDP)

Background

53. At its 83rd meeting, the Executive Committee approved the fifth and final tranche of stage I of the HPMP for Costa Rica and requested the Government and UNDP as designated implementing agency to submit a progress report at the 85th meeting on the implementation of the work programme associated with the final tranche of stage I of the HPMP and the project completion report to the first meeting of the Executive Committee in 2022 (decision 83/49).

54. Subsequently, on behalf of the Government of Costa Rica, UNDP has submitted the progress report to the 85th meeting.

Progress report

HCFC consumption

55. The Government of Costa Rica reported under country programme implementation report a consumption of 6.31 ODP tonnes of HCFCs for 2019, which is 55 per cent below the HCFC baseline for compliance. The 2015-2019 HCFC consumption is shown in Table 5.

Table 5: HCFC consumption in Costa Rica (2015-2019 Article 7 data)

HCFC	2015	2016	2017	2018	2019*	Baseline
Metric tonnes						
HCFC-22	155.69	155.40	152.56	138.20	92.96	181.88
HCFC-123	19.93	0.00	0.00	(0.64)	0.00	0.36
HCFC-124	2.10	1.50	0.48	0.48	0.00	3.95
HCFC-141b	2.45	20.30	15.22	10.88	10.88	32.59
HCFC-142b	0.67	0.45	0.14	0.14	0.00	6.17
HCFC-225ca	0.00	0.00	0.00	0.00	0.00	-
HCFC-225cb	0.00	0.00	0.00	0.00	0.00	-
Total (mt)	**180.84**	**177.65**	**168.40**	**149.06**	**103.84**	**224.94**
HCFC-141b in imported pre-blended polyols*	10.00	11.50	4.49	3.66	3.31	164.64**
ODP tonnes						
HCFC-22	8.56	8.55	8.39	7.60	5.11	10.00
HCFC-123	2.19	0.00	0.00	(0.01)	0.00	0.01
HCFC-124	0.14	0.10	0.03	0.03	0.00	0.09
HCFC-141b	0.05	2.23	1.67	1.20	1.20	3.58
HCFC-142b	0.01	0.01	0.00	0.00	0.00	0.40
HCFC-225ca	-	0.00	0.00	0.00	0.00	-
HCFC-225cb	-	0.00	0.00	0.00	0.00	-
Total (ODP tonnes)	**10.96**	**10.89**	**10.10**	**8.82**	**6.31**	**14.10**
HCFC-141b in imported pre-blended polyols*	1.10	1.27	0.49	0.40	0.36	18.11**

* Country programme data.
** Starting point established in the Agreement with the Executive Committee.

56. The HCFC consumption has been decreasing due to the enforcement of the licensing and quota system, the implementation of phase-out activities in the refrigeration servicing sector under the HPMP, the conversion of the largest user of HCFC-141b contained in imported pre-blended polyol systems, and the introduction of non-HCFC-22based refrigeration and air-conditioning (RAC) equipment.

Activities implemented for the fifth and final tranche of stage I of the HPMP

57. The following activities were implemented between July 2019 and March 2020:

(a) A draft regulation which would regulate the activities of RAC service technicians and make RAC technician certification mandatory is under review; the Instituto Nacional de Aprendizaje (INA) currently issues a certificate of good practice to those RAC technicians that have completed the training on good practices in servicing in a satisfactory manner;

(b) A new set of standards for the safe use of ammonia and hydrocarbons (HCs) in the RAC sector is under preparation by the National Technical Committee (NTC) in cooperation with the national ozone unit (NOU);

(c) A technical tour for students, technicians and owners of RAC equipment was carried out with the NTC, to showcase alternative technologies in different RAC applications that have been introduced in the country (e.g., NH_3/CO_2 in Pinova, R-290 chillers); to demonstrate the higher energy efficiency, fewer maintenance interventions, lower rates of refrigerant leakage and lower costs of refrigerants associated with the technologies; and to support the adoption of the national standard for ammonia;

(d) Continued implementation of the programme for the destruction of refrigerant gases, where the agreement between the Ministry of Environment and Energy (MINAE) and the cement kiln that has been adapted for destruction of refrigerants (Holcim) has been extended for two additional years; and coordination with a network of authorized companies to aggregate refrigerant gases collected from potential clients for destruction by Holcim; and

(e) Two technical consultants who will assist the NOU in monitoring the implementation of the activities in the HPMP, as part of the project management unit, have been selected.

Level of fund disbursement

58. As of December 2019, of the total funds approved of US $1,153,523 (i.e., US $593,523 for the foam conversion project and US $560,000 for the activities in the servicing sector), all funds for the foam sector and US $491,000 for the servicing sector had been disbursed (91 percent of the total funds). The balance of US $69,000 will be disbursed in 2020.

Secretariat's comments

59. UNDP noted that the contraction in the economy that occurred in the second half of 2019 and the impact of COVID-19 could delay the completion of some activities of the HPMP, in particular the adoption of low-global-warming potential (GWP) and energy efficient technologies.

60. The work plan for the final tranche included the training of customs officers and service technicians, and workshops for end-users which had not been implemented yet. UNDP mentioned that the training for technicians and the workshops for end-users was scheduled for the first quarter of 2020; however, due to COVID-19 implementation of these activities has been delayed. While no training was completed for customs officers, coordination was done with the Ministry of Finance, the General Directorate of Customs, the Ministry of Health, and the MINAE Environmental Management Directorate to plan for the training to be carried out when the situation normalizes. UNDP also indicated that the stakeholders and partners are ready to facilitate the efficient completion of these activities when required.

61. The Secretariat noted the efforts by UNDP to ensure that the activities planned under the final tranche of the HPMP would be implemented, and that the required planning and coordination has been done to ensure that all the activities can be completed when the situation returns to normal.

Recommendation

62. The Executive Committee may wish:

(a) To note the progress report on the implementation of the fifth and final tranche of stage I of the HCFC phase-out management plan (HPMP) for Costa Rica, submitted by UNDP and contained in document UNEP/OzL.Pro/ExCom/85/9; and

(b) To request the Government of Costa Rica and UNDP to submit a final report on the implementation of stage I of the HPMP to the first meeting of the Executive Committee in 2022, along with the required project completion report.

Honduras: HCFC phase-out management plan (stage I – progress report on implementation of activities under the UNEP components) (UNEP)

Background

63. At its 81st meeting, the Executive Committee approved (under the list of projects for blanket approval) the fourth tranche of stage I of the HPMP for Honduras, and the corresponding 2018-2020 tranche implementation plan on the understanding: that UNEP and the Government of Honduras would intensify efforts to implement the training activities for refrigeration technicians; that UNEP would submit a progress report to each meeting on the implementation of activities under UNEP's components including disbursements achieved, until the submission of the fifth tranche of stage I; and that the disbursement targets for the total amount of funds approved for the UNEP components of the first, second and third tranches were 50 per cent by 30 September 2018, 80 per cent by 31 March 2019, and 100 per cent by December 2019, and that the disbursement targets for the UNEP component of the fourth tranche were 20 per cent disbursement by 31 March 2019 and 50 per cent disbursement by December 2019.

64. Subsequently, UNEP submitted progress reports to the 82nd, 83rd, and 84th meetings. Although the Government of Honduras and UNEP had implemented some training activities for refrigeration technicians, other activities did not progress as expected, and the disbursement targets set at the 81st meeting were not achieved. As there were still commitments that required further action, at its 84th meeting the Committee noted that the fifth tranche of stage I could be submitted only once the following conditions had been met:

(a) Completion of training for customs and enforcement officers, covering 31 customs entry points, on the control of imports of HCFCs and HCFC-based equipment;

(b) Completion of establishment of an electronic system for the registration of importers, suppliers and end-users;

(c) Substantive progress in the revision of technical standards, including safety measures for flammable refrigerants; and

(d) Disbursement of 100 per cent of the total funds approved for the UNEP components of the first, second and third tranches of stage I of the HPMP and disbursement of 70 per cent for the UNEP component of the fourth tranche.

65. The Committee also requested UNEP to continue to submit, to each meeting until submission of the fifth tranche of stage I of the HPMP, a progress report on implementation of all the activities under the UNEP components, including the disbursements made (decision 84/18).

66. In line with decision 84/18, UNEP has submitted to the 85th meeting a progress and financial report on the implementation of UNEP's activities under stage I.[16]

Progress report

67. The following activities have been implemented since the 84th meeting:

(a) An international consultant prepared a training programme for customs and enforcement officers;

(b) Arrangements were made to hire a regional expert by April 2020 to develop the electronic system for registration of importers, suppliers and end-users; the content for the online learning modules was prepared; and the database is expected to be completed and fully operational by August 2020;

(c) Three NOU staff and nine instructors from the national training institute (INFOP) were certified in good practices in handling refrigerants and lubricants in Colombia;[17] the NOU and INFOP held a workshop to continue development of the national certification scheme for refrigeration technicians in line with the relevant Honduras Labour Standard;[18] and public awareness activities on good refrigeration practices including preparation of information materials for technicians on the certification process were conducted;

(d) In total, 129 students and 98 technicians were trained in good refrigeration practices and safe-handling of ODS alternatives; and

(e) The use of recycling and reclaim centres was promoted during the seminars and workshops; and discussions were held to establish three additional refrigeration reclaim centres covering geographic areas with the highest refrigerant consumption.

Level of fund disbursement

68. As at 15 March 2020, of the total amount of US $175,000 of funds approved for the first three tranches for UNEP, US $144,514 (82.6 per cent) had been disbursed, and of the total amount of US $50,000 of funds approved for the fourth tranche for UNEP, US $8,213 (16.4 per cent) had been disbursed,[19] as shown in Table 6.

Table 6: Financial report of stage I of the HPMP for Honduras (US $)

Tranche	Approved	Disbursed*	Disbursement rate (%)	Advanced**	Total	Disbursement + advance rate %
First	75,000	67,047	89.4	7,953	75,000	100.0
Second	50,000	49,467	98.9	0	49,467	98.9
Third	50,000	28,000	56.0	22,000	50,000	100.0
Sub-total	**175,000**	**144,514**	82.6	**29,953**	**174,467**	**99.7**
Fourth	50,000	8,213	16.4	25,900	34,113	68.2

* Recorded in Umoja.
** Funding advanced from UNEP to the Government of Honduras, and not yet recorded in Umoja.

[16] The fifth and final tranche of stage I the HPMP for Honduras submitted to the 85th meeting by UNIDO, as lead implementing agency, was withdrawn during the project review process, as not all the conditions under decision 84/18 had been met.
[17] Colombia Labour Standard 280501022.
[18] Honduras Labour Standard (code B712703) on "Good practices in refrigeration and air conditioning" was adopted in September 2019.
[19] Including funds committed or advanced by UNEP to Honduras (funds not yet recorded in Umoja - the enterprise resource planning software used by UNEP). As of 15 March 2020, the amount of funds disbursed and advanced or committed from the first three tranches is US $174,467 (99.6 per cent) and from the fourth tranche is US $18,107 (68 per cent).

Update on the implementation plan for stage I of the HPMP

69. The following activities are planned until December 2020:

(a) Completion of training for customs and enforcement officers, covering 31 customs entry points, on the control of imports of HCFCs and HCFC-based equipment;

(b) Finalization of the electronic system for registration of importers, suppliers and end-users, and development of online learning modules;

(c) Implementation of the certification scheme for refrigeration technicians and promoting its application, and updating technical and public awareness information material;

(d) Development of a certification standard for handling flammable refrigerants;

(e) Certification of 100 refrigeration technicians in good service practices; and

(f) Awareness raising on the value of reclaiming of refrigerants, training in use of natural refrigerants, enhancing the certification programme for refrigeration technicians, establishment of an end-user programme to promote refrigerant containment, leakage control and good refrigeration practices, and provision of technical updates to the recovery and recycling centre.

Secretariat's comments

70. The conditions set in decision 84/18(b) for the submission of the fifth tranche of stage I of the HPMP have not yet been fulfilled; specifically, the training programme for customs and enforcement officers scheduled to start in March 2020 has been delayed due to the COVID-19 outbreak; the electronic database for the registration of importers, suppliers and end-users is expected to be operational by August 2020; the formulation of a standard for handling flammable refrigerants is planned to start in August 2020; and the end-user programme to promote refrigerant containment had not yet been established.

71. Furthermore, the disbursement rates for the first three tranches (at 100 per cent) and the fourth tranche (at 70 per cent), were not met. UNEP has US $55,853 committed to be disbursed upon completion of ongoing activities, and an additional US $16,420 that has not been committed.

72. UNIDO had also submitted the request for the fifth tranche of stage I of the HPMP for Honduras to the 85th meeting. However, noting that several of the commitments set out in decision 84/18 were not met, the funding tranche could not be considered by the Executive Committee. UNEP and UNIDO expect that the final funding tranche of stage I could be submitted together with stage II of the HPMP for Honduras to the 86th meeting.

Recommendation

73. The Executive Committee may wish to note:

(a) The progress report on the implementation of activities within the UNEP components of stage I of the HCFC phase-out management plan (HPMP) for Honduras, submitted by UNEP and contained in document UNEP/Ozl.Pro/ExCom/85/9; and

(b) That the fifth and final tranche of stage I of the HPMP could be submitted only once the conditions set out in decision 84/18(b) had been met.

India: HCFC phase-out management plan (stage II – update on the assessment of continuous-foam-panel-manufacturing enterprises regarding adherence to the ban) (UNDP, UNEP and the Government of Germany)

Background

74. The Government of India introduced a ban on the use of HCFCs, including HCFC-141b pure and contained in pre-blended polyols, in the manufacturing of insulation foam for domestic refrigerators and of continuous sandwich panels, as of 1 January 2015. However, at the 82nd meeting[20] UNDP submitted the request for the second tranche of stage II of the HPMP,[21] and reported that two continuous-sandwich-panel manufacturers had signed a memorandum of agreement (MOA) with the Government. In view of that, UNDP clarified that the Government was assessing whether those enterprises complied with the ban.

75. Accordingly, the Executive Committee requested the Government of India, through UNDP, to provide at the 83rd meeting an update on the assessment of whether the enterprises manufacturing continuous foam panels had adhered to the HCFC ban, noting that if the Government were to determine that the enterprises were not in compliance with the ban, the MOA with the enterprises would be terminated and any funding disbursed would be returned to the Multilateral Fund, in line with decision 77/43(d)(ii).[22] It was also noted that no continuous-foam-panel-manufacturing enterprise would be included in stage II until its eligibility had been assessed by the Executive Committee.[23]

76. At the 83rd meeting, UNDP reported that the assessment by the Government was still underway; accordingly, the Committee requested the Government, through UNDP, to submit the assessment at the 84th meeting.[24] Similarly, at the 84th meeting, UNDP indicated that the assessment was still underway, and confirmed that no disbursement had been made to these enterprises, and that the funds would be returned should it be determined that the two enterprises had breached the 1 January 2015 phase-out targets. UNDP further mentioned that the assessment needed to go through the due legal and governmental processes in India and that it was not possible to determine when that would be completed. Accordingly, the Executive Committee requested the Government of India, through UNDP, to provide by the 85th meeting its assessment of whether the enterprises had adhered to the ban, in line with decision 82/74(b) and (c).[25]

77. In preparation for the 85th meeting, UNDP informed that it was not possible to confirm the status of the assessment and an updated status could not be submitted on time due to COVID-19.

Recommendation

78. The Executive Committee may wish to request the Government of India, through UNDP, to provide by the 86th meeting, the assessment by the Government of whether the continuous-foam-panel-manufacturing enterprises had adhered to the ban, as of 1 January 2015, on the use of HCFC-141b, in line with decision 82/74(b) and (c).

Indonesia: HCFC phase-out management plan (stage I - update on status of conversion of the refrigeration and air-conditioning manufacturing enterprises and revised plan of action) (UNDP)

79. On behalf of the Government of Indonesia, UNDP as the lead implementing agency, has submitted to the 85th meeting:

---

[20] 3-7 December 2018.
[21] Stage II of the HPMP was approved at the 77th meeting.
[22] Decision 82/74(b)(i)
[23] Decision 82/74(c)
[24] Decision 83/21
[25] Decision 84/34(b)(ii)

(a) A report on the status of enterprises temporarily manufacturing high global-warming potential (GWP)-based refrigeration and air-conditioning (RAC) equipment at enterprises that received funding to convert to low-GWP alternatives, in line with decisions 77/35, 81/11(c), and 83/22(c); and

(b) A revised plan of action for the conversion of the enterprises Gita Mandrin Teknik, Fata Sarana Makmur and Sumo Elco Mandiri, and a further request to extend the completion date of stage I of the HCFC phase-out management plan (HPMP), in line with decision 84/35(d)(ii).

Background

80. Stage I of the HPMP included conversion of 48 enterprises in the RAC manufacturing sector to low-GWP technologies. However, during implementation, 28 enterprises (16 in the air-conditioning (AC) sector and 12 in the commercial refrigeration sector) decided to convert to high-GWP technology with their own resources, and returned US $3,134,216, plus agency support costs, to the Multilateral Fund.

81. At the 83rd meeting, it was reported that of the remaining 20 enterprises, only one (Panasonic) was manufacturing ACs based on HFC-32 technology. Eight medium- and large-sized enterprises had manufactured HFC-32-based prototype equipment; eight small-sized enterprises had not received orders for HFC-32-based equipment; and the three remaining enterprises were still waiting for the market for HFC-32-based equipment to improve before undertaking their conversion. At the time, the 19 enterprises were manufacturing equipment based on high-GWP refrigerants.

82. At the 84th meeting, UNDP reported that eleven enterprises[26] had decided to withdraw from the project. In addition, one commercial refrigeration manufacturer (Aneka Cool) had decided to outsource its HCFC-141b-based polyurethane foam insulation process. Accordingly, the Executive Committee noted the withdrawal of the eleven enterprises from the project, and that the associated funding (US $764,842, plus agency support costs of US $57,363 for UNDP) would be returned to the 85th meeting (decision 84/35(b)(i)); and that the funding (US $60,500, plus agency support costs of US $4,538 for UNDP) associated with the enterprise that outsourced its foam insulation process would be returned to the 85th meeting (decision 84/35(b)(ii)).

83. UNDP also reported the following two enterprises experienced technical challenges during their conversion:

(a) Metropolitan Bayu Industri, a manufacturer of commercial ACs, had built a prototype based on HFC-32 refrigerant; however, further improvement in design was needed. UNDP therefore proposed to continue to provide technical assistance and to disburse incremental operation costs (IOCs) when manufacturing with HFC-32 was initiated; and

(b) Rotaryana Prima, a manufacturer of refrigerators and freezers, had built prototype units based on HFC-32 refrigerant, but with low performance. Based on the recent updates to the International Electrotechnical Commission Standard 60335-2-89, which allow a charge of up to 500 g of A3 refrigerants,[27] the enterprise decided to convert to R-290 refrigerant. On this basis, the Committee approved the change of technology at no additional cost to the Fund (decision 84/35(c)).

[26] Three in the commercial refrigeration sector (Mentari Metal Pratama, Polysari Citratama, and Inti Tunggal) and eight in the commercial refrigeration assembly sub-sector (Sabindo Refrigeration, Global Technic, AVIS Alpin Servis Tr, Aneka Froze Triutama, Graha Cool Technic, United Refrigeration, Gaya Technic Supply and Ilthabi Mandiri Tech).
[27] A3 refrigerants exhibit flame propagation at 60°C and 101.3 kPa, and have a lower flammability limit less than or equal to 0.1 kg/m^3 or heat of combustion greater than or equal to 19,000 kJ/kg.

84. UNDP further reported that three additional enterprises, namely, Gita Mandrin Teknik, Fata Sarana Makmur and Sumo Elco Mandiri, manufactured under both their enterprise's brand and an original equipment manufacturer (OEM) brand, the latter of which was based on high-GWP refrigerants, while the former was based on HFC-32. Accordingly, UNDP had proposed that the proportion of approved IOCs associated with manufacturing under the enterprise's brand would be released upon confirmation of manufacturing with HFC-32, while the proportion associated with OEM manufacturing would be returned to the Multilateral Fund to the 85th meeting. Finally, a further three enterprises, namely, Industri Tata Udari, Alpine Cool, and Aneka Cool, had decided to remain in the project and convert their manufacturing to HFC-32; those enterprises did not manufacture for an OEM.

85. Following informal discussions among interested members, the Executive Committee decided *inter alia:*

(a) To note that Gita Mandrin Teknik, Fata Sarana Makmur and Sumo Elco Mandiri had decided to convert their production lines to HFC-32 technology, would manufacture HFC-32-based equipment under their enterprises' brands and would temporarily manufacture high-GWP refrigerant-based equipment upon orders from OEMs;

(b) To extend the completion date of stage I of the HPMP for Indonesia until 30 June 2020, on the understanding *inter alia* that UNDP would submit, at the 85th meeting, a revised plan of action for the conversion of those enterprises, and a possible further request to extend the completion date of stage I of the HPMP; and

(c) To consider at the 85th meeting the potential impact on the starting point for sustained aggregate reductions for HFC consumption, in line with decision 82/30(g)(ii) (decision 84/35).

<u>Progress as at the 85th meeting</u>

86. UNDP provided the following update on the status of conversion of the five RAC enterprises that did not manufacture for OEMs:

(a) The conversion at Industri Tata Udari had been completed, including the conversion with the heat exchangers and sheet processing lines and the adaptation required in the assembling line. Prototype units were manufactured and approved by clients, and the enterprise is marketing HFC-32-based units. IOCs (US $14,161) are expected to be disbursed by December 2020;

(b) Metropolitan Bayu Industri had improved the design of the heat exchanger, with prototype units expected to be deployed and IOC (US $14,287) disbursed by December 2020;

(c) Rotaryana completed its manufacturing line conversion to R-290; initial prototype units were deployed and were reported to be fully functional. The enterprise was working on improved design to improve the energy efficiency of the units, as well as providing further training to staff and end-users on safe use and maintenance. IOCs (US $25,296) are expected to be disbursed by December 2020; and

(d) Alpine Cool and Aneka Cool completed the conversion to HFC-32 refrigerant, prototype units were designed and tested at clients, and units are being marketed. IOCs (US $40,160 for Alpine Cool and US $17,510 for Aneka Cool) are expected to be disbursed by December 2020.

87. Regarding the three enterprises that had also manufactured for OEMs, UNDP reported:

(a) Due to the declining market share of the OEM equipment manufactured by Gita Mandiri Teknik and the higher costs of that equipment, the enterprise committed to no longer manufacture for the OEM and to exclusively manufacture equipment under its own brand based on HFC-32;

(b) Due to lack of demand from the OEM, Fata Sarana Makmur currently does not manufacture high-GWP-based equipment for its OEM, and the contract with the OEM, set to expire in June 2020, will not be renewed. The enterprise will exclusively manufacture equipment under its own brand based on HFC-32; and

(c) Sumo Elco Mandiri manufactured equipment for two OEMs. One of those OEMs was based in a non-Article 5 country that had ratified the Kigali Amendment; given the phase-down of HFCs in that country, and the challenges that would have resulted from continuing exports of high-GWP-based equipment to that country, the OEM decided to terminate the contract with the enterprise; the other OEM closed its operation in Indonesia in January 2020 given export market restrictions, while the parent company is keeping the parts and components supply business in Indonesia through its distributors. Since January 2020 all manufacturing at the enterprise is for its own brand and will be based on HFC-32.

88. All three enterprises had completed their conversion to HFC-32 refrigerant. Gita Mandiri and Sumo Elco were already marketing HFC-32-based units in Indonesia, while Fata Sarana Makmur expects to start marketing HFC-32-based units by June 2020, when the OEM contract will expire. IOCs (US $249,738) for the three enterprises are proposed to be released to the enterprises by December 2020 with the completion of the project. In order to allow the remaining enterprises to manufacture low-GWP-based equipment, the Government of Indonesia proposed to extend the implementation of stage I of the HPMP to 31 December 2020.

89. In line with decision 84/35(b), and as reported in the Report on balances and availability of resources,[28] UNDP returned US $825,342, plus agency support costs of US $61,901, to the 85th meeting.

Secretariat's comments

90. The Secretariat noted with appreciation the efforts of the Government, industry and UNDP to address the challenges in introducing low-GWP equipment into the market, and noted in particular that there was no more manufacturing of high-GWP-based RAC equipment by enterprises that decided to stay in the project. The Secretariat noted that the release of remaining IOCs would be based on manufacturing with the agreed technology, and recommends the proposed extension of stage I of the HPMP to 31 December 2020.

91. Regarding the potential impact on the starting point for sustained aggregate reductions for HFC consumption (decision 82/30(g)(ii)), the Secretariat recommends that no change to the starting point be made as there was no more manufacturing of high-GWP-based RAC equipment by enterprises that decided to stay in the project.

92. Noting that the enterprises remaining in the project had converted to low-GWP technologies, the Secretariat recommended that, in lieu of submitting annual progress reports, UNDP submit a single comprehensive final progress report to the 88th meeting, with the understanding that it would include

[28] UNEP/OzL.Pro/ExCom/85/4.

aggregated data on the sales of HFC-32-based and R-290-based RAC equipment manufactured by the enterprises that remained in the project.

Recommendation

93. The Executive Committee may wish:

94. To note the update on the status of conversion of the refrigeration and air-conditioning manufacturing enterprises and the revised plan of action for stage I of the HCFC phase-out management plan (HPMP) for Indonesia, submitted by UNDP, contained in document UNEP/OzL.Pro/ExCom/85/9;

(a) To extend the completion date of stage I of the HPMP for Indonesia until 31 December 2020; and

(b) To request the Government of Indonesia and UNDP to submit a final progress report on the implementation of stage I of the HPMP that would include aggregated information on the sales of low global-warming potential-based equipment manufactured by the enterprises participating in the project, and the project completion report, by 30 June 2021.

Malaysia: HCFC phase-out management plan (stage II – change in technology at 14 enterprises) (UNDP)

Background

95. At its 77th meeting, the Executive Committee approved in principle, stage II of the HCFC phase-out management plan (HPMP) for Malaysia[29] for the period 2016 to 2022 to reduce HCFC consumption by 42.9 per cent of its baseline, in the amount of US $6,138,063, plus agency support costs of US $429,665 for UNDP.

96. Stage II included funding for the conversion of 67 polyurethane (PU) foam enterprises, of which 57 are small- and medium-sized enterprises (SMEs), to low-global-warming potential (GWP) alternatives; an additional 10 non-eligible enterprises will phase out their consumption without support from the Multilateral Fund, which will lead to complete phase-out of HCFC-141b in the PU foam sector by 1 January 2022. A stage approach was used, whereby enterprises with consumption of 20 metric tonnes (mt) or higher would convert to cyclopentane or cyclopentane pre-blended polyol systems, and smaller-size enterprises would convert under the second and third tranches to reduced hydrofluoroolefins (HFOs) formulations, though some might convert to methylal.

97. At the 84th meeting, UNDP reported that memoranda of agreement were signed with 12 enterprises, two of which have completed their conversion to cyclopentane with an associated phase-out of 12.32 ODP tonnes of HCFC-141b; the conversion of a further eight enterprises was advancing and would result in the phase-out of 28.99 ODP tonnes of HCFC-141b; and two smaller enterprises, with consumption of 2.54 ODP tonnes of HCFC-141b, were expected to complete their conversion in 2020.

98. UNDP further reported that given concerns about the stable supply of HFO blowing agents in the near-term and the immediate commercial availability of cyclopentane pre-blended polyol systems from four systems houses in the country, seven enterprises (i.e., Allied Foam, Astino, Century, Gai Hin, Hewgant, Insulated Box, and Roto Speed) were considering to change technology from HFOs to pre-blended cyclopentane; however, those enterprises had not yet made a decision given ongoing tests of different formulations. The Secretariat assessed the eligible incremental costs to convert to cyclopentane pre-blended polyol systems, which confirmed that there would be no savings associated with such a change in technology. UNDP also confirmed that the enterprises would co-finance any additional costs associated with the change in technology. Accordingly, the Executive Committee decided that those enterprises would

[29] UNEP/OzL.Pro/ExCom/77/54

have flexibility to change technology to pre-blended cyclopentane during implementation, on the understanding that the conversions would not be delayed and any additional costs would be covered by the enterprises; and UNDP would report on this matter when submitting the request for the third tranche of the HPMP (decision 84/77(b)).

Request for change of technology

99. In accordance with paragraph 7(a)(v) of the Agreement between the Government of Malaysia and the Executive Committee, the Government through UNDP has submitted to the 85th meeting a request to change the technology for 14 enterprises from HFOs to pre-blended cyclopentane polyol systems, listed in Table 7. UNDP confirmed that the enterprises would co-finance any additional costs associated with the change in technology.

Table 7: Enterprises to convert from HFO to cyclopentane pre-blended polyol systems

Enterprise	**Application**	**HCFC-141b (mt)**	**Approved funding (US $)**
Komiya Roofing (M) Sdn Bhd	Discontinuous panels	9.00	55,731
Power Cool Engineering S/B	Commercial refrigeration	8.40	52,393
Coolaxis sdn Bhd	Discontinuous panels	7.80	49,054
CoolMax Refrigeration Industries	Discontinuous panels	7.00	44,603
SJ Classic Industries Sdn Bhd	Discontinuous panels	6.91	44,092
PS Coldroom Panels Supplies	Discontinuous panels	6.80	43,491
Hi-tech Preinsulated Pipes S/B	Pipes	6.11	39,652
Ngui Soon ColdRoom & Refrigeration (Snowfall)	Transportation	6.00	39,040
P.K.T Insulation Trading	Discontinuous panels	6.00	39,040
NYC Products Sdn bhd	Discontinuous panels	5.75	37,649
Top Amity Sdn Bhd	Discontinuous panels	5.01	33,532
Chong Brothers Coldroom Eng. Sdn Bhd	Discontinuous panels	5.00	33,476
Perniagaan Nam Sing S/B	Commercial refrigeration	3.00	22,349
Lian Pang Refrigeration & Electrical S/B	Commercial refrigeration	1.20	12,334
Total		**83.98**	**546,436**

Secretariat's comments

100. The seven enterprises that had requested flexibility to change technology to pre-blended cyclopentane at the 84th meeting have since completed the testing and decided to switch to pre-blended cyclopentane. The Secretariat undertook a detailed assessment of the eligible incremental costs to convert the 14 enterprises to pre-blended cyclopentane polyol systems, which confirmed that there would be no savings associated with the change in technology. Accordingly, and noting the commercial availability of pre-blended cyclopentane systems from the four systems houses in the country and the successful conversion of other foam enterprises to that alternative, the Secretariat recommended approval of the change in technology.

Recommendation

101. The Executive Committee may wish:

(a) To note the request submitted by UNDP on behalf of the Government of Malaysia for the change in technology in 14 foam enterprises, from hydrofluoroolefins (HFOs) to pre-blended cyclopentane polyol systems in the context of stage II of the HCFC phase-out management plan (HPMP) contained in document UNEP/OzL.Pro/ExCom/85/9; and

(b) To approve the change in technology for those 14 foam enterprises, from HFOs to pre-blended cyclopentane polyol systems on the understanding that the conversions would not be delayed and any additional costs would be covered by the enterprises.

Morocco: HCFC phase-out management plan (stage I - progress report) (UNIDO and UNDP)

Background

102. On behalf of the Government of Morocco, UNIDO as the lead implementing agency has submitted the annual progress report on the implementation of the work programme associated with the third and final tranche of the HPMP,[30] in line with decision 83/57(d).[31]

HCFC consumption

103. The Government of Morocco estimated an HCFC consumption of 25.50 ODP tonnes for 2019, which is 38 per cent below the target in its Agreement with the Executive Committee for the same year, and 50 per cent below the HCFC baseline of 51.35 ODP tonnes.

Verification report

104. Prior to the submission of the progress report associated with the third funding tranche of the HPMP, the verification on HCFC consumption for 2019 had been planned; however, due to contingencies associated with the COVID-19 pandemic, by the time of issuance of the present document, the verification had not been conducted.

Manufacturing sector

105. Conversion of foam manufacturing at Manar Company has been completed, resulting in the phase-out of 11.00 ODP tonnes of HCFC-141b. The ban on the import of HCFC-141b pure went into effect on 1 January 2015; and the import of HCFC-141b has been zero since 2014.

Status of implementation of the planned activities for the third tranche

106. In line with the third tranche implementation plan, 26 additional refrigerant identifiers have been procured for delivery in April 2020, to be distributed to customs, the Refrigeration Association and the training centre in the capital city (Rabat). A training workshop on the use of refrigerant identifiers is planned to be conducted upon the arrival of the identifiers.

107. Two international consultants have been identified to deliver theoretical and practical training for servicing technicians. The focus of the training will be on the latest technologies and market penetration, safety issues and proper management of flammable refrigerants during maintenance, and best practices in servicing, including recovery and recycling.

108. The procurement of refrigeration servicing tools and equipment for distribution to trained technicians, including recovery and recycling units, had been initiated but has been put on hold due to the COVID-19 pandemic. Once the procurement process resumes, it will be completed in a few weeks. It is expected that the equipment will be distributed no later than the end of 2020.

[30] Approved at the 83rd meeting at a total cost of US $35,000, plus agency support costs of US $2,625 for UNIDO.
[31] To request the Government of Morocco and UNIDO to submit progress reports on the implementation of the work programme associated with the third and final tranche, on a yearly basis until the completion of the project, verification reports until approval of stage II of the HPMP and the project completion report to the first meeting of the Executive Committee in 2022.

109. The awareness-raising material on the quality of refrigerants is being updated, and will be translated into the local language and distributed among stakeholders.

110. Stage I of the HPMP for Morocco will be completed by the end of 2020 as planned.

Level of fund disbursement

111. As of March 2020, of the US $335,000 approved, US $192,635 (58 per cent) had been disbursed. A balance of US $142,365 will be disbursed by December 2020 as shown in Table 8.

Table 8: Financial report of stage I of the HPMP for Morocco as of March 2020 (US $)

Tranche	Approved	Disbursed	Percent disbursed (%)	Balance
First	80,000	77,078	96	2,922
Second	220,000	115,557	53	104,443
Third	35,000	0	0	35,000
Total	**335,000**	**192,635**	**58**	**142,365**

Secretariat's comments

112. At the time of the submission of the funding request for the third tranche of the HPMP, HCFC consumption for 2018 was based on the consumption reported under the verification report (i.e., 23.24 ODP tonnes),[32] as consumption under Article 7 of the Montreal Protocol and under the country programme (CP) implementation report had not been reported. Subsequently, the Government of Morocco reported HCFC consumption of 25.66 ODP tonnes under Article 7 and under the CP report. In explaining the data discrepancy, UNIDO indicated that the data reported under Article 7 and the CP report was the total quota issued for 2018, which was higher than the quantity actually imported as confirmed by the verification report. UNIDO has advised the Government on the need to revise the Article 7 and CP data for 2018. UNEP (implementing agency for institutional strengthening) will assist the Government to submit a request to correct the 2018 consumption data based on the 2018 verification report.

113. The progress report of the third tranche of stage I of the HPMP requires the submission of a verification report. Noting that the completion of the verification report would be delayed given the constraints arising from the COVID-19 pandemic, and that the 2019 HCFC consumption was 50 per cent below the baseline, the Secretariat is recommending, approval of this progress report, on an exceptional basis and without setting a precedent, on the understanding that:

(a) UNIDO had committed to submitting the verification report no later than twelve weeks prior to the 87th meeting together with the progress report of the implementation of the third tranche;

(b) The recommendations included in the verification report would be addressed during the implementation of the third tranche and that the actions implemented towards that end would be included in the progress report of stage I of the HPMP; and

(c) In the unlikely event of non-compliance by the Government of Morocco with its Agreement with the Executive Committee, relevant actions would be taken by the Executive Committee.

114. The Secretariat inquired about the incorporation of ozone protection training into the curriculum of the routine training of customs officers. UNIDO reported that this was envisaged to be included in stage II of the HPMP. The Government also plans to strengthen the professional training institutes and to develop

[32] UNEP/OzL.Pro/ExCom/83/32

a certification programme during stage II to sustain the training of refrigeration and air-conditioning technicians.

115. With regard to the progress in developing an inventory of HCFC-22-based equipment and introducing energy-efficiency standards, UNIDO reported that those standards for energy labelling of refrigeration equipment and air conditioners have been published; standards for energy labelling of other products including water heaters, dryers and storage water heaters are currently under development. These are expected to contribute to the energy-efficiency improvement of the HCFC-22-based equipment.

Recommendation

116. The Executive Committee may wish to note the progress report on the implementation of stage I of the HCFC phase-out management plan (HPMP) for Morocco, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9, on the understanding that:

(a) UNIDO had committed that the verification report would be submitted to the Secretariat not later than twelve weeks prior to the 87th meeting, that the recommendations included therein would be addressed during the implementation of the third tranche of stage I of the HPMP, and that the actions implemented towards that end would be included in the progress report of stage I of the HPMP; and

(b) In the event that the verification report confirmed that Morocco had not been in compliance with the Montreal Protocol and its Agreement with the Executive Committee, the Secretariat would inform the Executive Committee so that relevant actions, *inter alia*, the application of the penalty clause, could be considered accordingly.

Republic of Moldova: HCFC phase-out management plan (stage II – detailed report on the status of implementation of the demonstration projects for using CO_2–based technology in the commercial refrigeration sector) (UNDP)

Background

117. At its 84th meeting, the Executive Committee approved funding for the second tranche of stage II of the HPMP for the Republic of Moldova, on the understanding that the Government, through UNDP, will submit to the 85th meeting a detailed report on the status of implementation of the demonstration projects for using CO_2–based technology in the commercial refrigeration sector (decision 84/55(a)). Subsequently, UNDP has submitted the report on status of implementation of the demonstration projects.

118. The objectives of the demonstration projects are: to promote energy and cost savings associated with *inter alia* reduction on refrigerants consumption; to demonstrate the safe use of the innovative technology; to create awareness of end-users about available technologies and how using CO_2–based technology results in an increase in space availability inside the facility; and to demonstrate both the ozone and climate related environmental benefits associated with the technology.

119. After a bidding process, the following two enterprises were selected:

(a) Forward International SRL, engaged in cold storage operations. The refrigeration capacity of the equipment to be installed is 189.6 kW for cooling approximately 11,000 cubic metres of storage space; and

(b) STS Trading SRL, engaged in retail grocery operations, were selected. The refrigeration capacity of the equipment to be installed is 5 kW in one room with four counters.

120. Forward International SRL has already imported the equipment and is finalizing all construction and refurbishing works. The equipment will be tested and is expected to be operating by the end of March 2020. Regarding STS Trading SRL, the contract for equipment procurement, assembly on-site, commissioning and initial maintenance has been signed, refurbishing work is ongoing and the equipment is expected to be imported by middle of March 2020.

121. Both projects are expected to be operational and completed by end of June 2020; however, there could be delays on account of COVID-19 that affects availability of components. Dissemination of the results and lessons of the demonstration projects along with a seminar will be conducted in the latter half of 2020.

Secretariat's comments

122. On a question on regulations to promote adoption of natural refrigerants, UNDP explained that the Government of the Republic of Moldova harmonizes gradually its regulatory framework with the European Union legislation including the regulatory framework in the refrigeration and air-conditioning sector; the Government also intends to ratify the Kigali Amendment to the Montreal Protocol in 2021. The Government will develop an action plan for HFC phase-down and will further strengthen the regulatory framework to support the gradual transition to technologies based on low-global-warming potential (GWP) refrigerants such as hydrocarbons, ammonia and CO_2 and alternative technologies such as free cooling and not-in-kind.

123. With regard to energy efficiency, gains of about 20 per cent are expected; however, the actual gains will be known after measurement of results over multiple seasons.

124. On scaling-up the adoption of technology, UNDP explained that the Government is planning to take steps for awareness and outreach on the experiences of the beneficiaries, and implement training and mandatory certification of technicians working with natural refrigerants. Larger scale adoption of new technologies will be a longer-term process as new knowledge and experience are gained on natural refrigerants and costs become comparable with available technologies.

125. The Secretariat requested clarification on the differences in the levels of co-financing by the two enterprises, noting that US $32,000 from the project was provided to each of the enterprises, and that Forward International SRL and STS Trading SRL provided co-financing of US $192,000 and US $18,000, respectively. UNDP explained that these two enterprises were the only enterprises that decided to participate in the demonstration projects; therefore, the grant provided from the project was equally split. Because of the difference in the equipment configuration and component infrastructure at each enterprise, the total costs for the conversion and the levels of co-financing were different.

126. UNDP also clarified that the balance of US $2,000 would be used for technical support and awareness raising of the results of the demonstration projects.

Recommendation

127. The Executive Committee may wish to note the detailed report on the status of implementation of the demonstration projects for using CO_2–based technology in the commercial refrigeration sector of stage II of the HCFC phase-out management plan for the Republic of Moldova, submitted by UNDP, contained in document UNEP/Ozl.Pro/ExCom/85/9.

Demonstration projects for low-GWP alternatives to HCFCs

Argentina and Tunisia: Demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets (final report) (UNIDO)

Background

128. At its 76th meeting, the Executive Committee approved the demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets (Argentina and Tunisia)[33] in the amount of US $846,300 plus agency support costs of US $59,241 for UNIDO (decision 76/27).

129. The project was approved to assist the introduction of trans-critical CO_2 refrigeration technology in Article 5 countries by removing the barriers such as the lack of knowledge about trans-critical CO_2 refrigeration systems, the limited availability of equipment components, and the high initial cost of conversion. It would also evaluate the performance and energy efficiency of trans-critical CO_2 technology in a real-case scenario and provide information on technical viability, cost of conversions, environmental benefits, and energy efficiency of the use of CO_2 in centralized supermarket refrigeration systems.

130. The demonstration project includes the introduction of trans-critical CO_2 refrigeration systems in two selected supermarkets in Argentina and Tunisia, both located in moderately warm climatic conditions. The project is expected to be replicated in other countries, thereby promoting the use of low-GWP refrigerants in the assembly sector.

131. The sub-project designed for the supermarket La Anonima in Lincoln, Argentina was successfully implemented; however, the sub-project designed for the supermarket Monoprix in Tunisia was cancelled after the initial design phase due to a lack of interest.[34] The remaining funding balance from both sub projects will be returned to the Fund no later than 31 December 2020.

132. On behalf of the Government of Argentina, UNIDO has submitted the final report of the demonstration project (the final report is attached in Annex III to the present document).

Project implementation

133. The sub-project in Argentina introduced a trans-critical CO_2 booster system with parallel compression and a sub-cooling system using R-290 in the supermarket La Anonima, which operated central refrigeration systems with low and high temperatures using HCFC-22 and a number of self-contained freezer units (islands and upright reach-in cabinets) using HFC-404A. Electricity consumption by the refrigeration systems at La Anonima was separately measured before and after conversion to compare the electricity consumption of the baseline system with the converted system. Data on temperatures and general climate conditions were also taken from the nearest meteorological station for the duration of the measuring period.

134. The trans-critical CO_2 system design was developed by EPTA[35] with the assistance of its headquarters in Italy and the United Kingdom according to the technical requirements provided by UNIDO and the NOU. The equipment of the trans-critical CO_2 central refrigeration systems, the evaporators and the sub-cooler were manufactured by EPTA Italy and delivered to the site; and all piping calculations were adjusted locally.

135. The layout of the supermarket and the configuration of the new refrigeration systems are nearly identical to the baseline system. The stand-alone R-404A units were replaced and integrated into the CO_2

[33] UNEP/OzL.Pro/ExCom/76/56
[34] Paragraph 157 of UNEP/OzL.Pro/ExCom/82/20, and decision 82/22(d).
[35] EPTA refrigeration: https://www.eptarefrigeration.com/en

centralized system. The refrigeration capacity of the new system is 78.32 kW (68.79 KW for the medium-temperature circuit and 9.53 kW for the low-temperature circuit); which is slightly smaller than the original system of 82.14 kW (72.09 kW for the HCFC-22 positive-temperature cabinets and cold room and 10.05 kW for the R-404A low-temperature cabinets and cold rooms).

136. A multi-compressor central refrigeration system was installed to meet the refrigeration demand. To increase the energy efficiency during the warm periods of the year, a R-290 sub-cooler (1.7 kg refrigerant charge) was installed in an open area. The pipelines were changed to withstand higher operating pressures in the loop and to harmonize the system to the lower refrigerant charge. To ensure safety associated with the use of CO_2, safety valves were installed to release the pressure when it exceeds 120 bar. Leak detectors and alarms were installed to detect CO_2 leaks and trigger the system to close the electronic valves to avoid suffocation hazards through a build-up of CO_2 concentration.

137. The new refrigeration system was installed in December 2017 and has been in operation since January 2018. Data was collected to assess the system's performance and energy consumption. The CO_2 system has not leaked since its operation. If leakage occurs in the future, CO_2 refrigerant can be supplied locally. The implementation of the conversion process was completed without interrupting the operation of the supermarket. The baseline machinery was dismantled only after successful start-up and trial runs of the new system.

138. The staff of La Anónima received training from equipment manufacturers on installation, start-up, operation and maintenance of the system, including procedures to intervene on a CO_2 system under pressure; maintenance procedures such as filter and oil replacement and sight-glass control; management of electronic controls of the refrigeration rack and system; and operation of the monitoring system. The NOU also conducted training on good practices in handling low-GWP refrigerants including CO_2 and more than 700 technicians received training. A workshop was organized on the margins of the Open-ended Working Group meeting in July 2019 in Bangkok to disseminate the results of the project.

Results of the demonstration

139. The implementation of the sub-project in Argentina led to the following results:

(a) The trans-critical CO_2 refrigeration system is technically viable for use in supermarket applications in climate conditions similar to those of Lincoln, Argentina; and all the components used in the system are available either locally or internationally at a reasonable price;

(b) Based on industrial experience and technical literatures, the initial investment of a trans-critical CO_2 refrigeration system is higher than HFC-based system due to high pressure requiring stronger piping and better welding during installation; at current prices, the investment of a similar system using R-404A is approximately 20 per cent lower than trans-critical CO_2 system, and 10-13 per cent lower if using HFC/glycol system;

(c) The electricity consumption of the trans-critical CO_2 system was 27.64 per cent lower than the baseline HCFC-22/R-404A system[36] based on measurements over a 11-month period (from January to November) prior to and after conversion in 2017 and 2018. The electricity bill (including other energy use) resulted in yearly savings of approximately US $9,200;

[36] Calculated based on the cumulative yearly electricity consumption in 2017 (prior to conversion) and in 2018 (after installation of the trans-critical CO_2 system); the data for the first 11 months (from January to November) was measured and the last month data was extrapolated data using the 11-month measurements.

(d) The reduction in greenhouse gas emissions calculated by UNIDO amounted to 856.33 tCO_2eq, from direct emission,[37] reduction of 834.90tCO_2eq from the replacement of HCFC-22 and R-404A, and indirect emission[38] of 21.43tCO_2eq from electricity savings of 68,453kW;

(e) The lower leakage rate of the CO_2 system, the lower price of CO_2 refrigerant as compared to synthetic refrigerants, as well as the lower electricity consumption appears to lead to lower operating costs; and

(f) The frequency of preventive maintenance of the trans-critical CO_2 system is similar to that of HCFC-22/R-404A systems.

140. Based on the good results of the demonstration project, La Anónima has reached an agreement with EPTA to adopt trans-critical CO_2 as the default technology for new facilities as well as the replacement technology for its existing 162 facilities in 85 cities of Argentina. So far, the number of supermarkets using trans-critical CO_2 systems in Argentina has increased to 13 in seven supermarket chains. At the regional level, EPTA has installed three more systems in Chile, one in Colombia and 12 in Ecuador since 2017.

Financial report

141. Out of the funds of US $527,169 approved for the sub-project in Argentina, US $508,135 has been disbursed. The sub-project in Tunisia was cancelled after technical experts were mobilized and the terms of reference had been prepared and approved by all partners; a cost of US $20,000 was incurred for this initial preparation work. The remaining balance will be returned to the Fund by the end of 2020, in line with decision 82/22. The actual expenditures under the demonstration project as compared to the planned budget is presented in Table 9.

Table 9: Cost breakdown of the demonstration project for trans-critical CO_2 refrigeration systems (US $)

Item	Approved budget	Disbursements	Balance
Sub-project in Argentina			
New refrigerating equipment	389,866	484,372	
Food display cabinets	102,303		
Engineering and transport	15,000		
Workshops to disseminate results of the project	20,000	23,763	
Subtotal Argentina	**527,169**	**508,135**	**19,034**
Sub-project in Tunisia			
New refrigerating equipment	245,347	0	
Food display cabinets	43,784	0	
Engineering and transport	10,000	0	
Workshops, consultant, meetings and traveling	20,000	20,000	
Subtotal Tunisia	**319,131**	**20,000**	**299,131**
Totals (Argentina + Tunisia)	**846,300**	**528,135**	**318,165**

Secretariat's comments

142. The Secretariat noted that the project was originally planned to be completed in 30 months. In order to obtain the data on the energy-efficiency improvement of the trans-critical CO_2 refrigeration system, the electricity consumption by the refrigeration system was measured prior to and after the conversion. This is the first project to measure the actual electricity consumption in a refrigeration system and provide

[37] Assuming no leakage of CO_2 and R-290 in trans-critical CO_2 refrigeration system.
[38] Using 313 tCO2eq/kWh for power generation intensity in Argentina.

first-hand data on energy efficiency gain from the conversion of a HCFC/HFC system to a trans-critical CO_2 refrigeration system in supermarkets.

143. The implementation of the project has significantly increased the know-how in the design, installation, start-up, operation and maintenance of the trans-critical CO_2 refrigeration system in supermarkets. The project demonstrated that the trans-critical CO_2 refrigeration technology is economically and technically viable to be implemented in Article 5 countries in mild climate conditions and helped create confidence in adopting the technology to replace HCFC- and HFC-based systems in supermarkets in Article 5 countries.

144. Based on the information in the final report, the higher cost in initial investment can be offset, over a reasonable time frame, by the savings from reduced electricity consumption and possible reduced refrigerant leakage during operation.

145. The adoption of the technology will lead to permanent emission reduction of greenhouse gasses and will have a positive impact on the climate. The demonstration provided a sustainable technological option for HCFC and HFC phase-out in supermarkets and the technology is being adopted in several countries in the region, which will contribute to the sustainable phase-out of HCFCs and HFCs overall.

146. The Secretariat inquired about the safety measures required around the sub-cooler installation in an open area. UNIDO clarifies that it is important to demarcate the area around the sub-cooler, where heat, sparks, open flames, hot surfaces, and no smoking is allowed; and to design appropriate safety measures, according to national safety rules and the charge size, at the installation site as R-290 is a flammable refrigerant. For the sub-project in Argentina, the sub-cooler was installed on the roof where there is a good natural ventilation, so there was no need to install special sensors.

147. The Secretariat noted that the final report provided the cost of refrigeration equipment, food display cabinets, engineering and transport in one lump figure without a detailed cost breakdown as in the proposed budget. UNIDO reported that the project was contracted to EPTA, which considers the detailed cost information as confidential and has not shared it with UNIDO. The Secretariat noted that the demonstration project is the first project in the region aimed at quantifying the energy-efficiency improvement of the technology; and the detailed cost could change as more such systems installed. In addition, the overall cost of the trans-critical CO_2 refrigeration system in the report has provided an indicative level of initial cost.

Recommendation

148. The Executive Committee may wish:

(a) To note, with appreciation, the final report on the demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets in Argentina and Tunisia submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9; and

(b) To invite bilateral and implementing agencies to take into account the final report of the demonstration project referred to in sub-paragraph (a) above, when assisting Article 5 countries in preparing projects in commercial refrigeration sectors.

Global (Eastern Africa and Caribbean regions): Demonstration project on refrigerant quality, containment and introduction of low-GWP alternatives in the RAC sector (final report) (UNIDO)

Background

149. At its 76th meeting, the Executive Committee approved the demonstration project in the Eastern Africa and Caribbean regions on refrigerant quality, containment and introduction of alternatives with

low-global-warming potential (GWP), in the amount of US $425,650, consisting of US $50,000 plus agency support costs of US $6,500 for UNEP, and US $345,000 plus agency support costs of US $24,150 for UNIDO, in line with decision 72/40 (decision 76/36).

150. At its 82nd meeting, the Executive Committee cancelled the component implemented by UNEP (as no progress was achieved) and extended to 31 July 2019 the completion date for the component implemented by UNIDO, on the understanding that no further extension would be requested, and UNIDO was requested to submit the final report no later than the 84th meeting (decision 82/22(c)). At the same meeting, UNEP returned the total funding of its component (i.e., US $56,500).

151. In line with decision 82/22(c), UNIDO submitted to the 84th meeting a progress report on the demonstration project. In reviewing the progress report, the Secretariat noted that additional information was required, *inter alia*: safety aspects when retrofitting HCFC-22-based equipment to flammable refrigerants; results on the performance and servicing of the hydrocarbon (HC)-based units installed in each country in the Caribbean; consideration of the impact of regulations and standard on the uptake of the technology in these countries; conclusions on the tools needed to operate with flammable refrigerants based on the experience of the regional centre in Grenada; relevance of the counterfeit refrigerant issue for the national ozone units (NOUs); lessons learnt on practical measures to ensure refrigerant quality in the domestic markets; the monitoring and enforcement actions needed to reduce the risk of the imports and local sales of counterfeit refrigerants; and a detailed financial report.

152. Noting the limited time available to address the comments raised by the Secretariat, the Executive Committee decided to note that UNIDO would submit a final report on the project, as well as the project completion report, to the 85th meeting, and that unused balances would be returned to the 86th meeting (decision 84/24).

Final report

153. In line with decision 84/24, UNIDO submitted the final report of the demonstration project, which is attached as Annex IV to the present document.

Eastern Africa component

154. The project component related to the African region covering Eritrea, Kenya, Rwanda, the United Republic of Tanzania, and Zambia was to demonstrate the availability of counterfeit refrigerants in the local markets, the regulatory gaps and the lack of awareness on the matter; and to propose a strategy to ensure refrigerant quality in the market, as it will improve the efficiency of the operation of refrigeration and air-conditioning (RAC) equipment, thereby extending equipment life span and reducing the need for new refrigerant. Given the United Republic of Tanzania's geographical location, larger size and bigger population, it was selected as the pilot country for the implementation of specific technical activities.

155. Activities carried out under the project included surveys on refrigerant availability; training for refrigeration technicians, customs officers, environmental inspectors and importers; provision of refrigerant identifier equipment to stakeholders; establishment of refrigerant testing centres; and supporting awareness activities. The project achieved its goal of taking stock of the counterfeit refrigerants in the region, and identified the gaps leading to regional market penetration of counterfeit refrigerants. Stakeholders were trained in the use of refrigerant analysers, identification of counterfeit refrigerants, and measurement of the performance of RAC equipment using pure and counterfeit refrigerants. The project strengthened refrigerant testing centres through the provision of tools and equipment, and raised awareness on the availability of counterfeit refrigerants in local markets and the consequences of using them.

156. The consequences of using counterfeit refrigerants included: additional energy consumption with associated indirect CO_2 emissions; damage of system components including the compressor; reduction in

performance and life span of the equipment; inadvertent use of flammable or toxic refrigerants; likely venting of the refrigerant during servicing as it cannot be recycled or reclaimed; potential increase in virgin refrigerant consumption; potential increase of leaks if higher-pressure refrigerant is charged; loss of credibility for the technicians; and potential safety risks.

157. The results of this component revealed that counterfeit refrigerant was widely present in many Article 5 countries and that there was a lack of regulations to address the issue; there was also a lack of awareness among customs officers and importers. Therefore, these issues should be addressed during the implementation of the HPMPs and enabling activities for the phase-down of HFCs, as all kinds of refrigerant being recovered are being bottled and sold or exported as new.

158. The demonstration project also detailed measures to prevent counterfeit/contaminated refrigerants from entering local markets, *inter alia* permanent interaction between NOUs and refrigerant importers to increase transparency and information exchange; continuous capacity building programmes for customs officers, environmental authorities and NOU officers; inter-agency collaboration between NOUs, standard offices, customs departments, port authorities and other enforcement officials; refrigerant identifiers at entry points; use of the harmonized coding system by customs, including use of UN number,[39] chemical formula and ASHRAE[40] number among others; involvement of refrigeration associations and technicians in awareness campaigns to minimize imports and use of counterfeit refrigerants; incentives/awards to customs officers who seize counterfeit refrigerants; and awareness material to be displayed at all border points to guide customs officers and NOUs on the chemical composition of the various refrigerants during analysis.

Caribbean component

159. The project component related to the Caribbean region covering the Bahamas, Grenada, Saint Lucia, Saint Vincent and the Grenadines and Suriname was to facilitate the introduction of low-GWP refrigerants in the servicing sector by: enhancing the expertise of technicians and training specialized trainers; upgrading the training curricula at vocational centres; providing basic equipment at the regional training centres (i.e., HC-based air-conditioning units, manifolds with gauges for HCs, electronic leak detectors for flammable refrigerants, portable charging stations for HCs, propane and butane gas cylinders, and other tools); providing in-country training sessions and providing information to stakeholders on the latest HC-based equipment available on the market.

160. The activities implemented included design of a training curriculum on safe handling of low-GWP flammable refrigerants; a regional workshop for policy makers and curriculum developers with representatives from NOUs and training providers; equipping the regional training centre in Grenada with tools and equipment suitable for low-GWP flammable refrigerants; holding a regional train-the-trainers workshop in Grenada where participants received training on theoretical aspects of refrigeration servicing, including the safe handling of alternative refrigerants; designing a regional training and certification curriculum to ensure that only qualified technicians handle and service equipment and flammable refrigerants; delivering two R-290-based air-conditioners to four countries; and holding a regional expert group meeting back-to-back with the ozone officers' meeting in Suriname.

161. As a result of the project, in 2019 the regional training centre became fully operational for the RAC technicians of Grenada, and will be open to technicians of other countries of the region in 2020. At the end

[39] Four-digit numbers, assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods, that identify hazardous materials and articles in the framework of international transport.
[40] American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

of the training course, an assessment was carried out and successful participants received the "F-gas" and the "REAL alternatives" certifications.[41]

162. Based on observations from project implementation, recommendations include adoption of the curriculum developed by the project by all countries; regular assessment of the Grenada regional training centre capacity; considering the need for a second regional training centre in another country if capacities are not sufficient; developing mechanisms and partnerships to encourage international suppliers or manufacturers of HC-based equipment and tools to offer a stronger presence in the region; considering regional procurement of HC-based equipment and tools; considering the creation of a regional refrigeration association; attracting additional financial support from international funding bodies for the introduction of low-GWP alternative refrigerants; considering developing eco-labelling schemes for cooling appliances and/or reward schemes when consumers buy green cooling appliances; considering imposing fees on imports of high-GWP-based equipment; considering compulsory technical requirements for designing, constructing or retrofitting civil buildings (e.g., offices, hotels, hospitals, schools, apartment blocks, and service facilities) with a floor space above a certain size; carrying out technical assessments with R-290-based appliances to examine how they operate under 110V/60Hz electricity; and developing platforms for information sharing among technicians.

Secretariat's comments

163. Based on the observations and results of the Eastern African component, the Secretariat requested more information on how technicians and end-users could be encouraged to report in a safe manner cases of use of counterfeit refrigerant, and what could be appropriate punitive measures for importers or local distributors selling counterfeit refrigerant.

164. UNIDO explained that it was expected that technicians and other stakeholders report through the refrigeration technicians' association. In cases where there is no association, the technicians have been invited to report directly to the country's NOU. UNIDO has explained the results of the demonstration project to other NOUs. Punitive measures for violators vary between countries. Some countries start with public awareness campaigns, including distribution of UNIDO brochures, and later follow with fines. UNIDO also considers that information on the subject can be exchanged during the regional network meetings organized by UNEP Compliance Assistance Programme (CAP).

165. On whether implementation of HPMPs in Article 5 countries had been adjusted as a result of the project, UNIDO indicated that the issue of refrigerant quality is included in the training provided to technicians; the training includes basic methods to identify potential counterfeit refrigerant and, where possible, a demonstration of equipment performance with pure refrigerant and locally purchased fake refrigerant. The subject has been welcomed by NOUs and technicians but it requires more awareness.

166. In further explaining the main contribution of the Caribbean component of the project to the participating countries and its impact on the implementation of their HPMPs, UNIDO reported that the project demonstrated the need to strengthen regional cooperation to make HC-based equipment available in the participating countries. More specifically:

(a) The development of a training curriculum with reference material on flammable refrigerants that can be incorporated into the HPMP strategies once they have been adapted to specific countries where needed;

(b) The creation of a well-equipped training center in Grenada available to technicians from the region to learn how to safely operate flammable refrigerants. The capacities of training

[41] These are globally recognized certifications of the competence level of technicians for handling refrigerant gases - in this case, F-gases and flammable refrigerants.

facilities in other countries have also been reinforced. The regional center and upgraded training facilities in each country have already delivered training sessions for technicians that complement the training workshops carried out under the HPMPs; and

(c) The establishment of a pool of trainers from each participating country capable of training RAC technicians as part of the HPMPs, as is already being done in the Bahamas, Grenada and Suriname.

167. Regarding the availability of the critical tools needed by technicians to operate with flammable refrigerants,[42] UNIDO indicated that, to date, these tools were unavailable on the regional markets and countries remained dependent on HPMPs and other initiatives to access them on the international market. There is also a need for more appliances using flammable refrigerants to be used as training models to increase and replace the capacity installed in the training facilities of the region. UNIDO included the details on the most necessary equipment for training and servicing of flammable refrigerants in the curriculum attached as Annex I to the Caribbean component of the final report.

168. In line with decision 84/24, UNIDO confirmed that there was a balance of US $709, which would be returned to the 86[th] meeting

Recommendation

169. The Executive Committee may wish:

(a) To note the final report on the global (Eastern Africa and Caribbean regions) demonstration project on refrigerant quality, containment and introduction of low-global-warming potential alternatives in the refrigeration and air-conditioning sector, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9; and

(b) To invite bilateral and implementing agencies to take into account the report referred to in sub-paragraph (a) above when assisting Article 5 countries in preparing and implementing projects in the refrigeration servicing sector.

<u>Regional (Europe and Central Asia): Development of a regional centre of excellence for training and certification and demonstration of low-global-warming potential alternative refrigerants (final report)</u> (Russian Federation)

Background

170. At its 76[th] meeting, the Executive Committee approved a demonstration project in the Europe and Central Asia (ECA) region for the development of a regional centre of excellence for training and certification and demonstration of alternative refrigerants with low global-warming potential (GWP), in the amount of US $591,600, plus agency support costs of US $75,076 for the Government of the Russian Federation (decision 76/35).

171. The objective of the project was to improve the technical capacity of the refrigeration and air-conditioning (RAC) sectors of the countries in Eastern Europe and Central Asia to overcome barriers to the adoption of low-GWP refrigerants; improve servicing practices; reduce the levels of F-gas emissions from RAC equipment; and provide technicians and equipment manufacturers with understanding of energy efficient design and operation of RAC equipment. The Government of the Russian Federation requested the assistance of UNIDO to implement this project.

[42] Manifold with gauge for flammable refrigerants, electronic leak detectors for flammable refrigerants, and cylinders suitable for flammable refrigerants.

172. UNIDO as the designated agency submitted the final report on the establishment of a regional centre of excellence for training and certification and demonstration of low-GWP alternative refrigerants in line with decision 83/30(c).[43] The full report is attached as Annex V to the present document.

Final report

173. The regional centre of excellence was established in Armenia in the International Scientific-Educational Complex of “Shirakatsy Lyceum”, under the Ministry of Nature Protection. It was launched in September 2019 in a ceremony with more than 50 participants that included ministers and deputy ministers of the Interstate Ecological Council of the Commonwealth of Independent States (CIS) countries, representatives of UNIDO, RAC associations and companies, technical experts and students.

174. The regional centre is now operational and provides training and advisory services for countries in the ECA region, including training programmes, certification schemes, and training of instructors; and providing a common curriculum for vocational and academic studies that could be adopted by individual countries during implementation of their HCFC phase-out management plan activities.

175. Other activities completed under the project include the following:

(a) Five trainers were trained and certified under the F-gas and real alternatives certification systems, and a special agreement on cooperation with a Moscow training centre was signed to provide training courses and certification for learners on *inter alia* electrical safety, works at heights, pressure receptacles and soldering skills, valid on the territory of Russia and Eurasian Economic Union states;

(b) Translation of the draft F-gas regulation harmonized with the EU regulation No. 517/2014 into Russian and development of the simplified technician certification system on F-gas regulations to facilitate launching certification systems in each of the ECA countries;

(c) Provision of advisory services and technical assistance for the harmonization of national legislation and regulation after ratification of the Kigali Amendment through the Interstate Technical Council of National Refrigeration Associations;

(d) A demonstration project with flammable refrigerants used in fruits and vegetables storage facilities s was implemented in the province of Kotayk, Armenia; and safety requirements for operating and maintaining the equipment were established and demonstrated through the equipment installation and operations. Energy efficiency improvement achieved through the new equipment was about 34 per cent, and replication of the demonstration project could result in the replacement of about 500 installations per year in the countries in the Eastern Europe and Central Asia region;

(e) Nine technical assistance programmes including e-based learning, practical sessions at the regional centre of excellence and practical demonstration of operations of new technologies with support from manufacturers of equipment through a common curriculum for vocational and academic studies were developed; women trainees were encouraged to participate in the training programmes at the centre and 77 RAC practitioners were trained in the centre; and

(f) A website (http://hvaccenter.am/) was developed to provide a setting for remote online training.

[43] A progress report on the project was considered at the 83rd meeting, and noting the substantial progress the project completion date was extended to 31 December 2019 (decision 83/30(b).

176. The development and operationalising the training centre were publicised through regional consultative meetings of technical personnel, national ozone units and other consultative meetings; and the establishment of the centre was publicised through print and electronic media among stakeholders in the region.

177. The funds approved amounting to US $591,600 were fully disbursed for developing and operationalising the training centre (US $184,044), implementation of the demonstration project (US $188,261), translation of regulations in English and Russian (US $55,500), website development for e-based training programmes and outreach (US $92,795), and information outreach and awareness activities and other project management activities (US $71,000).

Secretariat's comments

178. On project delays, UNIDO clarified that the main reason was in allocation of funding for implementation of the project and, to a lesser extent, for infrastructure upgradation of training facilities at the centre, change in beneficiary for the demonstration project, and changes in the decision makers in the Government of Armenia.

179. Upon request for clarification, UNIDO explained that the demonstration project involved replacement of equipment used in storage of fruits and vegetables as the previously installed equipment was very old. The beneficiary provided co-financing of about US $30,000, which included site preparation, civil and electrical works for installation of equipment, public awareness activities and securing national permits and safety certificates/inspections. The project is expected to have scalability potential in the region and for faster adoption of low-GWP refrigerant technologies; individual countries would adopt national regulations to promote such low-GWP technologies.

180. Overall, the project has achieved its objective of establishing a regional centre of excellence for training technicians and engineers in the safe handling and demonstrating the applications of low-GWP refrigerants in RAC systems in countries in ECA.

Recommendation

181. The Executive Committee may wish:

(a) To note the final report on the development of a regional centre of excellence for training and certification and demonstration of alternative refrigerants with low-global-warming potential for the Europe and Central Asia (ECA) region, submitted by the Government of the Russian Federation and UNIDO, and contained in document UNEP/Ozl.Pro/ExCom/85/9; and

(b) To encourage bilateral and implementing agencies to make full use of the resources provided by the regional centre referred to in sub-paragraph (a) for the implementation of HCFC phase-out management plans and HFC consumption reduction projects in the ECA and neighboring regions.

<u>Saudi Arabia: Demonstration project for the phase-out of HCFCs by using HFO as a foam blowing agent in spray foam applications in high ambient temperatures (final report)</u> (UNIDO)

Background

182. At its 76th meeting, the Executive Committee *inter alia* approved the demonstration project for the phase-out of HCFCs using HFO as foam blowing agent in spray foam applications in high ambient temperatures, at the amount of US $96,250, plus agency support costs of US $8,663 for UNIDO, and

requested the Government of Saudi Arabia and UNIDO to complete the project within 16 months of its approval and to submit a comprehensive final report soon after project completion (decision 76/31).[44]

183. At the 83rd meeting, UNIDO submitted a progress report on the demonstration project, noting that additional activities, including field testing (e.g., adhesion strength, water absorption, closed cell content, durability of thermal resistance and compression strength against ageing/degradation), would need to be implemented before the project could be completed. In order to complete the remaining activities that would provide valuable information, and noting that considerable progress had been achieved, the Executive Committee agreed to extend the project completion date to 31 October 2019, on the understanding that no further extension of project implementation would be requested. The Committee further requested UNIDO to submit, no later than at the 84th meeting, the final report of the project (decision 83/35(b) and (c)).

184. In line with decision 83/35(c), UNIDO submitted the final report of the demonstration project on 11 November 2019. The Executive Committee took note of the submission, which would be reviewed by the Secretariat and presented at the 85th meeting.[45] The present section contains the Secretariat's review of the report and its findings.

Final report

185. The project was approved to demonstrate the benefits, applicability and replicability of the use of HFO-1233zd(E) and HFO-1336mzz(Z) co-blown with water in spray polyurethane (PU) foam applications in high ambient temperatures, as well as to analyse capital and operating cost reductions obtained by co-blowing with water and by considering changes in foam density and thermal conductivity.

186. The project was implemented at Sham Najd International, a local producer of rigid polyurethane (PUR) and polyisocyanurate spray foam (PIR) for insulating and waterproofing building structures (e.g., walls, ceilings, roofs, and floors). The only blowing agent tested was HFO-1233zd(E), because HFO-1336mzz(Z) was not commercially available.

187. Based on the test results, the spray foam formulation with HFO-1233zd(E) appears to be a potential alternative to replace both HCFC and HFC formulations, as it has similar technical and physical attributes, combined with a low GWP and zero ODP. The conclusions of the demonstration project are as follows:

(a) The performance of HFO-1233zd(E) matched that of HCFC-141b in adhesion, thermal conductivity, dimensional stability, paintability, overall foam density and compression strength;

(b) The sprayed surface based on HFO-1233zd(E) displayed more pinholes than that based on HCFC-141b, but still met customer expectations;

(c) HFO-1233zd(E) did not require new foaming equipment; all testing was performed with Sham Najd's existing baseline equipment (i.e., Graco E-XP1 Applicator);

(d) Due to its low boiling point (19.5 °C), HFO-1233zd(E) should be mixed in the reactor at a temperature lower than 18 °C, preferably at 15 °C, in order to avoid loss of the blowing agent during the mixing process;

(e) A smaller amount of HFO-1233zd(E) can be blended in the polyol, as the boiling point of the polyol mix will also be lower than the boiling point of HCFC-141b;

[44] At the 80th meeting, the project completion date was extended to 31 December 2018 (decision 80/26(i)).
[45] Paragraph 120 of UNEP/OzL.Pro/ExCom/84/75.

(f) The HFO-1233zd(E) pre-blended polyol was stored for a total of five months by the systems house and the end user with no reactivity changes observed. The blend has to be stored at a maximum of 28 °C due to the low boiling point of HFO-1233zd(E), which would cause evaporation / boiling of the chemical at higher temperatures;

(g) The HFO-1233zd(E) pre-blended polyol system needs a special package of additives (surfactants and catalysts) in order to avoid deterioration of the polyol blend; the catalyst package provides a shelf life of beyond eight months;

(h) The incremental operating cost (IOC) of the HFO-1233zd(E)-based system is US $4.30/kg higher than that of the HCFC-141b-based system. However, including the lower thermal conductivity (better insulation) and lower density of the foam produced with HFO-1233zd(E), the IOC was reduced to US $0.33/kg; and

(i) The price of HFO-1233zd(E) paid for the implementation of the project was US $9.50/kg; however, the actual price when small quantities are purchased is US $15/kg; which would increase the IOC. It is expected that these costs will be reduced within a few years, as the price of HFO-1233zd(E) decreases and that of HCFC-141b increases due to reduced availability.

Results of the additional field tests

188. The final report included the results of tests undertaken by an independent laboratory in Finland 18 months after the application of the HFO-based spray foam in high-ambient temperature (HAT) conditions. Based on the results, UNIDO concluded that HFO-1233zd(E)-based PU foam demonstrated at least similar behavior to HCFC-141b-based PU foam. Furthermore, the ageing period of 18 months on spray foam applied at HAT conditions did not significantly change any foam performance indicators, and the foam still met all specifications.

189. Workshops in Jeddah, Riyadh and Dammam were held in June 2019, to provide information on the results of the HFO-1233zd(E)-based PU spray and pour-in-place foam applications, comparison with other technologies and cost analysis.

Secretariat's comments

190. While the Secretariat noted some variations in the values obtained in the tests after 18 months in comparison with the original tests, the physical properties of the foam were still comparable to those of the HCFC-141b-based foam. UNIDO provided an interpretation of the data obtained in each test, which the Secretariat found valuable and suggested adding to the report. The revised final report is attached as Annex VI to the present document.

Technology availability and adoption

191. In clarifying the origin and availability of the formulations used to test HFO-1233zd(E), UNIDO indicated that the formulation used for the first tests was fully developed by Covestro (a global polymer supplier in the United Arab Emirates) and was not available to any other systems house in the country. All foam formulation details are systems houses' own developments, which are generally secret. However, the suppliers of additives (i.e., Evonik and Momentive) and of the blowing agent (i.e., Honeywell and Chemours) actively provide support to the formulators at systems houses. Since the spray foam systems are

now available locally in Saudi Arabia, there will be further local spray foam system use by all spray foam applicators.

192. In describing the main obstacles to mainstreaming the use of this technology in Saudi Arabia, UNIDO indicated that while the HFO-based systems for spray foam are currently available and can be used for all construction applications, fully formulated HCFC-141b-blown systems and stocks of pure HCFC-141b are widely available at systems houses. Market acceptance of the new low-GWP spray foam formulations is limited due to negative publicity about the expected poor performance of these formulations. Under the HPMP, UNIDO and UNEP are planning a quality standard and certification programme aimed at using only certified foam systems, which could help overcome current hurdles to wider adoption of the technology.

Co-financing

193. The total cost of the demonstration project for the Multilateral Fund was US $94,000, out of which US $28,000 were used on consultancy services and travel; US $48,000 on equipment and chemicals; and US $18,000 on the laboratory tests and the dissemination workshop. Upon request, UNIDO reported that, according to available information, the beneficiary systems house contributed with an investment of US $250,000 in equipment and chemicals.

Recommendation

194. The Executive Committee may wish:

(a) To note the final report on the demonstration project for the phase-out of HCFCs by using HFO as a foam blowing agent in spray foam applications in high ambient temperatures in Saudi Arabia, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9; and

(b) To invite bilateral and implementing agencies to take into account the report referred to in sub-paragraph (a) above when assisting Article 5 countries in preparing and implementing polyurethane foam projects.

Saudi Arabia: Demonstration project on promoting HFO-based low-global-warming-potential refrigerants for the air-conditioning sector in high ambient temperatures (progress report) (UNIDO)

Background

195. On behalf of the Government of Saudi Arabia, UNIDO submitted to the 85th meeting a progress report on the demonstration project on promoting hydrofluoroolefin (HFO)-based low-global-warming potential (GWP) refrigerants for the air-conditioning (AC) sector in high ambient temperatures.

196. The project was approved at the 76th meeting to manufacture, test and optimize pilot model air conditioners with low-GWP HFO/HFC blends as well as R-290, to undertake a demonstration production run and to convert a production line, at the amount of US $1,300,000, plus agency support costs of US $91,000 for UNIDO.

197. At its 80th meeting, the Executive Committee agreed to extend the project, from May 2018 to 31 December 2018, on the understanding that no further extension would be requested, and to request the implementing agencies to submit the final report no later than the 83rd meeting (decision 80/26(g)). Subsequently, a succinct progress report was submitted to the 82nd meeting documenting substantial progress on many activities, including procurement of equipment and delivery of components (e.g.,

compressors), with delivery of production equipment and production of first R-290 units still pending. Those activities were expected to be completed by December 2018.

198. At the 83rd meeting, it was reported that while manufacturing equipment was delivered, installation was still pending as the enterprise had decided to move the manufacturing line. The enterprise was planning to nonetheless preliminarily install the equipment so that a test run could be undertaken and personnel trained; the line would be moved by September 2019. Further testing and optimization of the units was required. Completion of those activities, as well as a workshop to disseminate the project results, was expected by December 2019. Accordingly, the Executive Committee decided to extend, on an exceptional basis, noting the advanced progress in implementation and the potential replicability of the results in several Article 5 countries, the completion date of the project to 31 December 2019, on the understanding that no further extension of project implementation would be requested; and requested UNIDO to submit the final report for the project no later than the 85th meeting and to return all remaining balances by the 86th meeting (decision 83/33).

Progress report

199. Further testing and optimization of the units was undertaken, including optimizing the condenser with 5 mm outer-diameter inner-grooved copper tubing (IGT), for which the enterprise upgraded its heat-exchanger manufacturing line to allow for in-house manufacturing, providing an economic advantage relative to microchannel heat-exchangers that would need to be purchased from suppliers. A fully functional prototype R-290 mini-split AC unit with a capacity of 18,000 British Thermal Unit (1.5 tonnes of refrigeration) that uses the 5 mm IGT condenser was developed; no further condenser optimization is needed. The unit has exceeded the local minimum energy performance standards (MEPS) requirements with an energy efficiency rating of 12.5 at 35 °C (T1) and 9.36 at 46 °C (T3) conditions. However, third-party testing has not yet been performed pending the receipt of new batch of prototype compressors and finding a suitable laboratory. The developed mini-split R-290 unit is compliant with the new proposed MEPS by the Saudi Standards, Metrology and Quality Organization, further optimization will be undertaken. To that end, a new batch of 48 R-290 compressors with improved designs was ordered to further test R-290 split AC prototypes.

200. The manufacturing line was moved, civil works completed and all the equipment, including a complete quality control system, has been installed. However, commissioning of the line, which had been expected in February 2020, was delayed given the COVID-19 pandemic; testing of the manufacturing line is planned as soon as travel restrictions that have been imposed due to COVID-19 are lifted. Similarly, while the laboratories and real-life testing rooms have been upgraded with the required equipment and instrumentation, commissioning was delayed. Other outstanding activities include conducting the training of the technicians on the manufacturing line and the final workshop to disseminate the project results to stakeholders.

Secretariat's comments

201. Given the COVID-19 pandemic, the project could not yet be completed. UNIDO provided a tentative timeline for the completion of the project that included travel by an expert for the commissioning and training in May 2020, testing of prototypes based on a new batch of 48 R-290 compressors with improved design in June-August 2020, and the final workshop in September 2020.

202. Noting that the proposed timeline was tentative and would depend on the COVID-19 situation, including whether international travel would be permissible, the Secretariat recommends to extend the project to 15 December 2020, and to request UNIDO to submit the final report for the project no later than 1 January 2021, and to return all remaining balances by the 87th meeting.

Recommendation

203. The Executive Committee may wish:

(a) To note the progress report on the demonstration project on promoting hydrofluoroolefin-based low-global-warming-potential refrigerants for the air-conditioning sector in high ambient temperatures in Saudi Arabia, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/85/9;

(b) To extend the completion date of the project referred to in sub-paragraph (a) above to 15 December 2020 on an exceptional basis given the COVID-19 pandemic and the advanced progress achieved; and

(c) To request UNIDO to submit the final report of the project referred to in sub-paragraph (a) above no later than 1 January 2021 and to return all remaining balances by the 87th meeting.

West Asia region: Demonstration project on promoting alternative refrigerants in air-conditioning for high ambient temperature countries (PRAHA-II) (final report) (UNEP and UNIDO)

204. At its 76th meeting, the Executive Committee approved the demonstration project on promoting alternative refrigerants in air-conditioning (AC) for high ambient temperature (HAT) countries in West Asia[46] better known as PRAHA-II, at a total cost of US $771,500, consisting of US $375,000, plus agency support costs of US $48,750 for UNEP, and US $325,000, plus agency support costs of US $22,750 for UNIDO. UNEP and UNIDO submitted the comprehensive final report of the project which is contained in Annex VII to the present document.[47]

205. The project aimed to build on the progress of the demonstration project to promote low-global-warming potential (GWP) alternatives for the AC industry in HAT countries in West Asia (PRAHA-I).[48] PRAHA-II had three main elements: to build the capacity of the local industry to design and test AC equipment using low-GWP flammable refrigerants; to evaluate and optimize the prototypes built for PRAHA-I; and to build a risk assessment model for the HAT countries.

206. To build local capacity, the AC prototypes that were developed in PRAHA-I were analysed and optimized by acquiring performance maps for components (compressors, fans); evaluating heat exchanger design configurations, including micro-channel heat exchangers; performing engineering optimization to match or exceed the baseline unit performance, which included installing new upgraded compressors, for same refrigerants used in PRAHA-I, and which were not available at the time PRAHA-I prototypes were built; or compressors for refrigerants not tested under PRAHA-I. Optimized units were tested with low-GWP refrigerants (namely, R-290, HFC-32, and certain HFO blends), and the leak recharge effect on the performance of high-glide[49] alternatives were analysed. Training workshops for designing prototypes, consultations between local AC equipment manufacturers and technology providers, field visits at industry and research centres in China and Japan, and a study tour in the United States of America were organized. A risk assessment model suitable for use patterns and operating conditions prevalent in countries with HAT

[46] Bahrain, Egypt, Kuwait, Qatar, Oman, Saudi Arabia, and the United Arab Emirates. No funding was provided for the United Arab Emirates, and the local industry built the prototypes and attended the PRAHA sessions at their own expense.

[47] The report was submitted to the 84th meeting but due to the limited time available, the Secretariat could undertake a review of the report and present its findings to the 85th meeting (paragraph 122 of document UNEP/OzL.Pro/ExCom/84/75).

[48] Approved at the 69th meeting for implementation by UNEP and UNIDO (UNEP/OzL.Pro/ExCom/69/19). The final report of that project can be found in document UNEP/OzL.Pro/ExCom/76/10

[49] Temperature glide is the temperature difference between the saturated vapour and the saturated liquid temperatures at constant pressure.

was developed in cooperation with local institutes and the Japan Refrigeration and Air Conditioning Industry Association (JRAIA).

Findings and recommendations

207. Results of the optimization of PRAHA-I prototypes, demonstrated that improvements in system performance can be achieved through modeling, component design and selection. Component re-design focused on the compressor, condenser and expansion valve. PRAHA-I prototypes mostly used compressors sized specifically for R-410A or HCFC-22, which presented an opportunity for a better compressor selection since a compressor designed for a particular refrigerant will improve the energy efficiency (EE) of the unit. Reducing the heat exchanger tube/channel diameter allows a reduction in charge size since heat transfer coefficients are inversely proportional to tube diameters; however, reduced diameters increase the pressure drop. In addition, while reductions in diameter or other changes to the heat exchanger design would allow for higher system efficiency and a reduced charge, changes to the design of a heat exchanger are constrained by allowed envelope dimensions: a complete system re-design would provide an opportunity for designing heat exchangers with even higher efficiency. While selection of fans and blowers can similarly improve EE, those were not considered given cost and time considerations, and since 80-90 per cent of the power consumption comes from the compressor.

208. Tests of optimized units showed a considerable reduction in power consumption at the HAT test condition (46 °C). The simulation analysis showed that refrigerant with wider saturation curves tend to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed, however, that by making appropriate component selection, such as compressors with larger displacement volumes and higher mass flow rate, the cooling capacities and overall performance of the other refrigerants were of the same order of magnitude.

209. The results of tests of high-glide alternatives found that refrigerant fractionation as evidenced by the leak tests does not appear to be a significant concern since less than 2 per cent change in cooling capacity was observed after the system's recharge, and changes to EE are expected to be minimal.

210. The work on risk assessment required consideration of the different AC use and servicing practices in HAT relate to installation and servicing practices and technicians' skill levels; temperature has no direct effect on the risk. In cooperation with experts from JRAIA, as well as input from experts from the Refrigeration Technical Options Committee and the Halons Technical Options Committee, a risk assessment model was developed, and subsequently applied as an example of a 5.3 kW (1 tonne of refrigeration) split AC system using an A2L refrigerant with the following:

(a) During use in an office where sources of ignition include charcoal and a lighter used for incense burning, an aroma candle, as well as cigarettes and lighters. The probability of ignition from those events was assessed at approximately 10^{-9}; and

(b) During the repair stage during brazing with sources of ignition including the brazing burner, a cigarette and a lighter. The probability of ignition was approximately 10^{-3}, highlighting the importance of safe servicing practices (including banning smoking in the service area).

211. The key recommendations of PRAHA-II include:

(a) Capacity-building provided a platform of cooperation between governments, research institutes, industry associations, and industry; became a platform for sharing information and results on the design, placing into markets and servicing of AC equipment working with low-GWP refrigerants; helped stakeholders gain knowledge about working with lower-GWP refrigerants; helped manufacturers build or engage in collaborative research projects, allowed industry to evaluate long-term alternatives, and increased awareness for the need for the selection of alternatives. Study tours exposed stakeholders to the latest refrigeration technology. As feasible, this process should continue;

(b) Replacing refrigerants is viable and can be competitive to high-GWP refrigerants but doing so requires proper component design and selection (particularly, compressor and expansion device). Drop-in replacement without hardware change is never recommended. Numerical simulations and some soft optimization analyses will provide information for redesign at much lower costs than gradual trial-and-error changes;

(c) A tailored risk assessment is essential in better understanding safety implications associated with deploying alternative refrigerants, considering the specifics of different types of equipment and life stages, including transportation, storage, installation, use, servicing and decommissioning. The risk assessments of other stages matching cultural and lifestyle aspects should be studied. Measures to mitigate risks would depend on type of standards and codes in each country, as well as the servicing practices. Article 5 countries could benefit from the PRAHA-II's experience in developing the risk assessment model to leapfrog technical difficulties and quickly develop a model; and

(d) Optimization of PRAHA-I prototypes showed that components, and compressors in particular, designed for low-GWP alternatives were not available at the time, and in many instances are still not widely available. A process to ensure that manufacturers are continually informed of new developments will help manufacturers make an informed decision.

Secretariat's comments

212. At its 83rd meeting, the Executive Committee decided *inter alia* to extend, on an exceptional basis, the date of completion of the project to 15 November 2019 in order to complete the testing of air-conditioner prototypes, validate the test-optimization results and risk-assessment model and disseminate the project results, and requested UNEP and UNIDO to return all remaining balances by the 85th meeting. All those activities have been completed except that the sixth international symposium on alternative refrigerants for HAT countries that had been scheduled for March 2020 in Dubai had to be postponed due to the COVID-19 pandemic. That symposium has been tentatively rescheduled to December 2020 or in the first quarter of 2021, depending on the COVID-19 situation. In the meantime, UNEP and UNIDO plan to disseminate the project results to HAT countries through a special webinar, tentatively scheduled in June 2020. UNEP and UNIDO have obligated all needed funds by 15 November 2019. While unobligated funds could be returned, there is pending unliquidated payment that has not yet been disbursed due to the postponement of the symposium. Accordingly, it was agreed to request UNEP and UNIDO, on an exceptional basis, to return all remaining balances by the 86th meeting.

213. The finding that refrigerant fractionation of high-glide alternatives in the leak-refrigerant recharge cycle is likely to have a small effect on equipment cooling capacity and EE is significant and may facilitate the uptake of such refrigerants.

214. One of the key findings of PRAHA-I, which was confirmed with PRAHA-II is that the process of improving EE standards for AC equipment in HAT countries is progressing more rapidly than the process of assessing and selecting alternative refrigerants; therefore, there is an urgent need to jointly address EE and lower-GWP alternatives in order to avoid promoting higher-GWP alternatives. PRAHA created a process to enable industry to engage in research and development, and sharing of information and best practices related to the transition to energy efficient and low-GWP-based AC equipment. UNEP also created a platform for internal cooperation between NOUs and energy authorities through the ozone/energy twinning programme that was implemented during 2018-2019 and created local cooperating arrangements

in many countries. Moreover, the difference in the rate at which EE standards are updated versus the process of developing and deploying low-GWP refrigerants in AC manufacturing has been taken into consideration at the national level (e.g., AC conversion project in Egypt approved at the 84th meeting[50]).

215. The Secretariat noted that UNEP and UNIDO intend to transform the PRAHA initiative into a live process with continued feedback and support to HAT countries and sought to understand how PRAHA would be sustainable. PRAHA has included capacity-building functions that involved HAT and non-HAT countries, such as:

(a) Study tours to China and Japan that engaged participation of experts from Algeria, Bahrain, Egypt, Jordan, Kuwait, Pakistan, Saudi Arabia, and the United Arab Emirates;

(b) Special sessions at regional network meetings to share knowledge and information about PRAHA;

(c) A series of five HAT symposia that were widely attended by HAT and non-HAT countries, as well as industry experts, and a sixth symposium while being postponed, documentation and materials will be shared through a special webinar, and project lessons will be made available at UNEP and UNIDO websites; and

(d) Special sessions at Open-Ended Working Groups and relevant international heating, ventilation, AC, and refrigeration (HVACR) conferences.

216. To date, PRAHA focused on HAT countries with AC manufacturing; however, the majority of HAT countries do not have local AC manufacturing but are technology recipients. UNEP and UNIDO intend to address this issue through:

(a) Continued use of the resources generated from PRAHA to assist countries and build their knowledge about alternatives; and

(b) Submission to the Executive Committee of a new project that will focus on providing technical assistance for deployment of alternatives, including risk assessment for HAT countries with no AC manufacturing, technical support in building a market acceptance strategy and deployment plan for equipment using lower-GWP refrigerants, designing a model HVACR code and enforcement tools to facilitate sound use of lower-GWP refrigerants, and a training programme for local authorities regulating, authorizing or monitoring equipment and projects that use lower-GWP refrigerants.

217. The Secretariat noted, however, that the Executive Committee has not opened an additional framework for further HCFC demonstration projects.

Recommendation

218. The Executive Committee may wish:

(a) To note with appreciation the final report of the demonstration on promoting alternative refrigerants in air-conditioning (AC) for high ambient temperature (HAT) countries in West Asia (PRAHA-II) submitted by UNEP and UNIDO, contained in document UNEP/OzL.Pro/ExCom/85/9;

[50] UNEP/OzL.Pro/ExCom/84/49.

(b) To request UNEP and UNIDO to return all remaining balances by the 86th meeting instead of the 85th meeting, given the delay in holding the sixth international symposium on alternative refrigerants for HAT countries due to the COVID-19 pandemic; and

(c) To invite bilateral and implementing agencies to share the final report of the demonstration project mentioned in sub-paragraph (a) above, when assisting Article 5 countries in preparing projects in AC sectors in HAT countries.

Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors in China

China: Process agent II – Additional information on activities to be undertaken (World Bank)

Background

219. At the 84th meeting, the Government of China had proposed to undertake the following activities to enhance the long-term monitoring and management of ODS given unallocated balances of approximately US $1.24 million in the process agent II sector plan:

(a) Construction and upgrade the on-line monitoring system on carbon tetrachloride (CTC) production. This system would complement the ODS management information system by focusing on the CTC production, conversion, sales and stockpile among all the chloromethane producers;

(b) Investigations of CTC production and feedstock uses. This activity will complement the study on the production of CTC and its use for feedstock applications, that was submitted in line with decision 75/18, and will include an on-site survey and verification for CTC production and feedstock uses. Perchloroethylene (PCE) plants would not be covered;

(c) Support to enterprises on development and supply of the necessary reagent (substitute of CTC) that is applied by the amended national standard. This activity would support reagent manufactures to set up purifying facilities of PCE to meet the requirements of the new standard and market demand;

(d) Training and capacity building on ODS supervision and enforcement for the local Ecology and Environment Bureaus (EEBs). The activity is to conduct regular training courses to staff from provincial, municipal and county-level EEBs on ODS management, inspection, supervision and enforcement;

(e) Market supervision and information collection on ODS sales. A consulting firm will be contracted to collect information of ODS sales and market, and to identify suspected illegal sales. The information related to such sales will be reported to the Ministry of Ecology and Environment (MEE) for further action; and

(f) Technical, policy and law support on ODS management, inspection, supervision, enforcement, as well as ODS disposal. Individual experts will be hired to provide such support to relevant institutions.

220. In addition, the Government of China planned to use remaining balances of US $250,000 for an ODS on-line management system, and US $750,000 for capacity-building with the Customs Authority.

221. At the 84th meeting, the Secretariat noted the following:

(a) The ODS on-line management system will enable all enterprises that use ODS to apply and register as an ODS user, and to report data. While the Secretariat supported the proposal it was not familiar with the details of the on-line management system and was unable to assess the level of funding for this activity. Moreover, funding from other projects, including methyl bromide (MB) production, the industrial and commercial refrigeration and the room air-conditioning sector plans under the HCFC phase-out management plan (HPMP), and the HCFC production phase-out management plan (HPPMP), had been used to strengthen the ODS on-line management system; such pooling of funding is likely an efficient use of resources, but makes monitoring the financial and implementation progress challenging;

(b) Funding is similarly proposed under the MB production sector for capacity-building with the Customs Authority. The Foreign Environmental Cooperation Center (FECO) clarified that the contract under the MB production sector is focused on MB used for quarantine and pre-shipment applications, while the capacity-building under the process agent II sector plan would be focused on anti-smuggling efforts;

(c) While the six proposed activities will be useful, the Secretariat was unclear who much funding would be allocated to each activity. In addition, the Secretariat considered that additional reporting on the outcome of some of the activities would be useful. For example, the activity related to market supervision could provide a better understanding of how facilities that produced CFC-11 were able to purchase CTC. The Secretariat suggested that the market supervision activity would continue to be helpful after the completion of the project, and that a budget within MEE be allocated for that purpose. The construction and upgrade of the on-line monitoring system on CTC production would enable such market supervision. The Secretariat suggested that the Government of China, through the World Bank, provide additional information on the proposed activities, their budget, and a progress report on their implementation, to the 85th meeting; and that the Executive Committee may also wish to provide additional guidance on the US $1 million allocated to the ODS on-line management system and capacity-building with the Customs Authority.

222. Following bilateral discussions, the Executive Committee requested the Government of China, through the World Bank, to provide additional information on the proposed activities to be undertaken under the process agent II sector plan, their budget and a progress report on their implementation at the 85th meeting (decision 84/39(d)).

<u>Additional information provided to the 85th meeting</u>

223. The budget for the ODS on-line management system was increased to US $280,000; a consulting firm was selected and awarded a contract for US$272,238. During the implementation of stage I of the HPPMP, an on-line system has been set up through which enterprises were requested to apply for HCFC production and consumption quota, sales registration and feedstock use registration, and to report the relevant data on-line. The purpose of this activity is to develop a system that extends the data reporting and management mechanism of HCFCs to all ODS.

224. For the capacity building for customs, regular trainings for custom officers from both central and local customs bureaus have been conducting by FECO and the Customs Authority. The budget for this activity remained at US $750,000.

225. Regarding the remaining six activities, given fluctuations in the exchange rate, the budget was increased to US $1.26 million for the following four activities:

(a) *Construction and upgrade the on-line monitoring system on CTC production*: The project, with a budget of US $450,000, will improve the data transmission method used by the system to monitor and manage CTC, including by using the internet for transmitting data; expand the existing CTC on-line monitoring system software and hardware capacity; and establish a webpage version of the system. The central monitoring platform is a data monitoring platform for all aspects of the production and use of CTC, including sales, disposal, and inventory, allowing dynamic control of production data, data analysis and other functions. The consultant was selected and has started preparing the technical concept, framework, software interface and data transfer protocol that are compatible with CTC producers' database systems;

(b) *Capacity-building for Customs on supervision and management of ODS*: This capacity-building activity, with a budget of US $650,000, includes continuing the implementation of overseas training programmes for customs personnel, promoting China's import and export management capabilities and cross-border law enforcement cooperation; assisting the Customs Authority to establish an illegal trade data information research and judgment system, establishing a multi-sectoral information and intelligence sharing mechanism and strengthening joint law enforcement capabilities, which can combat ODS import and export violations, and trace sources of domestic illegal production and sales. FECO and the Customs Authority have prepared a work plan, and the terms of reference for the establishment of an illegal trade data information research and judgment system has been developed;

(c) *Investigations of CTC production and feedstock uses, support to enterprises on development and supply the necessary reagent (substitute of CTC) that is applied by the amended national standard*: This activity, with a budget of US $120,000, aims to continue monitoring the production and feedstock use of CTC; it includes an on-site survey and verification of CTC production and feedstock uses, and support to reagent manufacturers to set up the necessary purifying facilities of PCE. The consultant has been selected and desk reviews of CTC production and feedstock consumption have been initiated; however, the onsite survey has not begun due to travel restrictions due to the COVID-19 pandemic. The activity to support the supply of laboratory grade PCE is being discussed with the industry association; and

(d) *Technical, policy and law support on ODS management, inspection, supervision, enforcement, as well as ODS disposal*: Technical, policy and law support on ODS management, inspection, supervision, enforcement, as well as ODS disposal. The budget for this activity is US $40,000. Terms of reference are being finalized by MEE, and experts will be selected and contracted by end of June 2020; the activity will be completed by the end of 2020.

Secretariat's comments

226. In contrast to the MB production sector, where there were delays in finalizing the cooperation modality between FECO and the Customs Authority, the World Bank explained that the robust cooperation mechanism that exists between MEE, the Customs Authority and the Ministry of Commerce since the Import/Export Office was established, will continue to be used, and that no delays in finalizing the ongoing activities related to the process agent II sector plan with the Customs Authority are foreseen.

227. The market supervision and information collection on ODS sales that had been proposed at the 84th meeting, will be carried out under the monitoring, reporting and verification programme implemented by MEE, in line with decision 83/41(c)(v). An officer has been assigned to liaise with the industry to

monitor sales of ODS and ODS-based products. This task was therefore removed from the process agent work programme.

228. Regarding the nexus between the ODS on-line management system (US $280,000) and the on-line monitoring system on CTC production (US $450,000), the World Bank clarified that the existing ODS on-line management system was designed for monitoring HCFC production and sales only; producers are required to report monthly production and sales on a quarterly basis; that data is compiled by FECO and used as a basis for the annual independent HCFC production and consumption verification exercise conducted by the World Bank. FECO commissioned consultants to expand the existing HCFC on-line system to cover other ODS, including CTC; this activity will be completed by end 2020. The on-line monitoring system on CTC production is to ensure the real-time transfer of CTC production data (measured by the flow meters and stored at the enterprises' process control systems) from each CTC producer to Government authorities; the information collected will be used to cross-check monthly production and sales records, which will be submitted by enterprises every quarter in the separate, expanded ODS on-line management system.

229. Regarding the distinction between the capacity-building with the Customs Authority (US $750,000) and capacity-building for Customs on supervision and management of ODS (US $650,000), the World Bank explained that the former was for the regular training of Custom officers from both central and local Customs bureaus that have been conducted by FECO and the Customs Authority, while the latter is to assist the Customs Authority to establish an illegal trade data information research and judgement system, establish a multi-sectoral information and intelligence sharing mechanism, and strengthen joint law enforcement capabilities.

230. The Secretariat supports the proposed activities to be implemented under the process agent II sector plan; however, with the additional information provided by the Government of China it was unable to assess the costs of the proposed activities.

Recommendation

231. The Executive Committee may wish to note the additional information on the proposed activities to be undertaken under the process agent II sector plan for China, their budget and the progress report on their implementation (decision 84/39(d)) contained in document UNEP/OzL.Pro/ExCom/85/9.

Requests for extension of enabling activities (UNDP, UNEP and UNIDO)

232. In line with decision 81/32(a),[51] on behalf of nine Article 5 countries, the bilateral and implementing agencies have submitted official requests for extension of enabling activities for the phase-down of HFCs, as shown in Table 10.

Table 10: Requests for extension of enabling activities for HFC phase-down submitted to 85th meeting

Country	Lead agency	Completion date	Extension date
Bahamas (the)	UNEP	30 June 2020	30 June 2021
Bolivia (Plurinational State of)	UNEP	30 June 2020	30 June 2021
Brunei Darussalam	UNEP	30 June 2020	30 June 2021
Cape Verde	UNEP	30 June 2020	30 June 2021
Cook Islands (the)	UNEP	30 June 2020	30 June 2021
Jordan	UNIDO	30 June 2020	30 June 2021
Mauritius	UNEP	30 June 2020	30 June 2021
Qatar*	UNIDO	30 June 2020	30 June 2021
Timor-Leste	UNEP	30 June 2020	30 June 2021

*UNEP as cooperating implementing agency

[51] The Committee decided to maintain the 18-month implementation period for enabling activities and, if needed, to extend that period by no more than 12 months (totalling 30 months from project approval), when an official request for extension was received by the Secretariat.

Secretariat's comments

233. The reason for the requests for the extension of the enabling activities includes *inter alia*, additional time required to start implementation than originally expected, coordination between the national ozone units (NOUs), stakeholders and UNEP, and the need to complete all planned activities. The Secretariat noted that all the issues that had delayed the start of implementation have been addressed and progress has been achieved. The Governments of the countries concerned are aware that the enabling activities should be completed no later than 30 June 2021, and balances should be returned once the activities have been completed.

Recommendation

234. The Executive Committee may wish:

(a) To note the requests for extension of enabling activities for HFC phase-down submitted by the respective implementing agencies for the nine Article 5 countries listed in Table 10 of document UNEP/OzL.Pro/ExCom/85/9; and

(b) To extend the completion date for the enabling activities for HFC phase-down to 30 June 2021, for the Bahamas, Bolivia (Plurinational State of), Brunei Darussalam, Cape Verde, the Cook Islands, Jordan, Mauritius, Qatar, and Timor-Leste, on the understanding that no further extension would be requested and that implementing agencies would submit, within six months of the project completion date, a final report of the enabling activities completed in line with decision 81/32(b).

SECTION III: REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS FOR INDIVIDUAL CONSIDERATION

Reports related to HPMPs

Democratic People's Republic of Korea: HCFC phase-out management plan (stage I – progress report on implementation of activities) (UNIDO)

Background

235. At its 73rd meeting, the Executive Committee approved, in principle, stage I of the HPMP for the Democratic People's Republic of Korea, with UNIDO as lead implementing agency and UNEP as cooperating implementing agency, to achieve a reduction of HCFC consumption to a sustained level of 66.30 ODP tonnes by 1 January 2018 (i.e., 15 per cent below the HCFC baseline for compliance of 78.00 ODP tonnes). The approval took place upon confirmation by the implementing agencies that stage I of the HPMP could be implemented in compliance with the resolutions of the UNSC[52] on the Democratic People's Republic of Korea.

236. Since the approval of stage I, the Executive Committee has approved three out of four funding tranches at a total level of US $808,550 (i.e., 95.3 per cent of the total funds of US $848,550 approved in principle), as well as the transfer to UNIDO of all phase-out activities to be implemented by UNEP. In line with the Agreement between the Government and the Executive Committee, the last tranche of stage I of the HPMP, in the amount of US $40,000, was scheduled to be submitted at the 81st meeting. As of the 84th meeting, UNIDO had been unable to submit the tranche request, due to the UNSC resolutions.

[52] The UN Security Council Committee established pursuant to Resolution 1718 was consulted before submission of stage I of the HPMP to establish whether the equipment or any other services under the HPMP could be provided to the country.

Progress report

237. UNIDO has submitted to the 85th meeting a progress report on the implementation of stage I of the HPMP, listing the activities implemented so far, the level of disbursement achieved, the challenges encountered to continue the implementation of activities in compliance with the UNSC resolutions, and a request for guidance from the Executive Committee.

238. The report indicates that despite difficulties resulting from the UNSC resolutions, the main activities performed during the first and second tranches included:

(a) Procurement of three refrigerant identifiers for the country's customs office;

(b) Purchase of one spray foaming machine for the Puhung Building Material factory upon clearance from the UNSC Committee in 2015 and preparation of a contract for and shipment of auxiliary equipment to enable the installation/commissioning of spray foaming equipment;

(c) Procurement of PU foam equipment (methyl formate) cleared by the UNSC Committee in line with the procedures established in the UNSC Resolution 2270 (2016); a purchase contract to the equipment suppliers was issued; the equipment was shipped through China, as it could not be shipped directly to the Democratic People's Republic of Korea, but was rejected by the Customs authorities in China and returned to the supplier;

(d) Procurement of training equipment for refrigeration and air-conditioning (RAC) servicing technicians upon clearance by the UNSC Committee, shipped and distributed to refrigeration service technicians in June 2016;

(e) Organization of a train-the-trainers workshop for 35 RAC servicing technicians conducted in August and September 2016;

(f) Completion of an additional training session for five trainers in best practices in RAC servicing, conducted in India in December 2016; and

(g) Conducting the first train-the-trainers workshop for 40 customs officers in May 2017.

Level of fund disbursement

239. As at 30 March 2020, of the total amount of US $808,550 of funds approved, US $303,313 (36 per cent) had been disbursed, as shown in Table 11.

Table 11: Financial report of stage I of the HPMP for the Democratic People's Republic of Korea (US $)

Tranche	Approved	Disbursed	Disbursement rate (%)
First	134,003	87,386	65.2
Second	506,680	211,110	41.7
Third	167,867	1,817	1.1
Total	**808,550**	**300,313**	**36.0**

Update on the implementation plan for stage I of the HPMP

240. The activities that have not yet implemented include:

(a) Follow-up on the training workshops for RAC servicing technicians and customs officers;

(b) Mapping of existing reclaim and recovery centres and procurement of additional equipment; and

(c) Establishing the project management unit once the funding transfer channel has been approved and made operational.

241. In addition, the PU foam equipment that was returned to the supplier by the Customs authorities in China, could not be re-imported as an additional resolution 2397 issued in 2017 specifically prohibits "all industrial machinery (HS codes 84 and 85), transportation vehicles (HS codes 86 through 89), and iron, steel, and other metals (HS codes 72 through 83)". Subsequent to this resolution, UNIDO was advised to submit to the UNSC a new exemption request, together with an updated list of the equipment to be imported into the country. UNIDO submitted an official exemption request on 8 May 2019 and the UNSC Committee denied the exemption on 18 June 2019. In view of the above, UNIDO has not been able to proceed with the delivery of equipment.

242. Non-investment activities have also been impacted due to the inability to transfer funds within the country, made even more difficult by the introduction of stricter sanctions following the adoption of resolution 2397 (2017).

243. In view of the above, UNIDO indicated in its report that it is not in a position to continue the implementation of the HPMP for the Democratic People's Republic of Korea and is requesting guidance from the Executive Committee.

Secretariat's comments

244. The Secretariat notes that UNIDO has continued exercising due diligence and monitoring throughout the implementation of the project. Upon the adoption of an additional UNSC resolution in 2017, it has submitted to the UNSC Committee pursuant to resolution 1718 an exemption request, together with an updated list of the equipment to be imported into the country, and has remained in close cooperation with relevant UN member states regarding the procurement and export of equipment designed to phase out the use of controlled substances in the country.

Recommendation

245. The Executive Committee may wish to consider the information on the implementation of activities under stage I of the HCFC phase-out management plan (HPMP) for the Democratic People's Republic of Korea, submitted by UNIDO.

Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors in China

China: Financial audit reports for the CFC production, halon, polyurethane foam, process agent II, refrigeration servicing and solvent sectors (UNDP, UNIDO and World Bank)

Background

246. At its 84th meeting, the Executive Committee considered the financial audit reports for the CFC production, halon, polyurethane (PU) foam, process agent II, refrigeration servicing and solvent sectors, in which an update of activities implemented in each sector plan was also provided.[53] Subsequently, the Executive Committee *inter alia* requested the Government of China, through the relevant implementing agency, to submit at the 85th meeting the financial audit reports as at 31 December 2019 for the CFC production, halon, PU foam, process agent II, refrigeration servicing, and solvent sector plans, and the

[53] Paragraphs 6-105 of UNEP/OzL.Pro/ExCom/84/22/Add.1

project completion reports (PCRs) for the CFC production, PU foam, refrigeration servicing and solvent sector plans; and to return to the Multilateral Fund at the 85th meeting the funding balances available as at 31 December 2019 associated with the CFC production, PU foam, refrigeration servicing and solvent sector plans (decision 84/39(c)(i) and (c)(ii)).

247. In line with decision 84/39(c)(i), relevant implementing agencies, on behalf of the Government of China, submitted the financial audit reports as at 31 December 2019 and PCRs for the CFC production, PU foam, refrigeration servicing and solvent sectors. Supplemental final reports were submitted for the refrigeration servicing and solvent sectors. An update on progress in the process agent II sector is provided in paragraphs 218 to 230 of the present document.

248. The financial data in the present report is based on the audit report submitted by the Government of China as of 31 December 2019, reflecting remaining balances of US $11,309,628 (Table 12). The remaining balances from completed sector plans (i.e., CFC production, PU foam, refrigeration servicing and solvent) amount to US $792,215 (i.e., US $311,653 from balances US $480,561 from cumulative interest). In line with decision 84/39(c)(ii), the balances being returned to the 85th meeting therefore amount to US $792,215.

Table 12: Remaining balances and interest for CFC production, halon, PU foam, process agent II, refrigeration servicing, and solvent sector plans (US $)

Activity	Balance as at 30 June 2019	Balance as at 31 December 2019	Cumulative interest	Completion date
CFC production (World Bank)	179,878	33,907	22,119	Dec-19
Halon sector (World Bank)	9,154,827	8,913,167		Dec-20
Process agent II (World Bank)	3,076,109	2,084,808		Dec-20
PU foam (World Bank)	897,009	280,108		Dec-19
Servicing (Japan, UNEP, UNIDO)	735,791	752	99,178	Dec-19
Solvent (UNDP)	708,822	*-3,114	*359,265	Dec-19
Total	**14,752,436**	**11,309,628**	**480,561**	

*The total balance to be returned by UNDP is calculated as US $356,151.

Secretariat comments

249. The CFC production, PU foam, refrigeration servicing, and solvent sector plans have been completed. While preliminary PCRs have been submitted, the financial data does not yet reflect the final disbursements to beneficiaries, nor the returns to the 85th meeting. The Senior Monitoring and Evaluation Officer is working with the relevant implementing agencies to ensure the financial data is included in the respective PCRs.

250. As agreed at the 84th meeting, the halon and process agent II sector plans will be completed by 31 December 2020, and any remaining balances as at that date would be returned to the 87th meeting, in line with decision 84/39(b).

Recommendation

251. The Executive Committee may wish:

(a) To note:

(i) The financial audit reports for the CFC production, halon, polyurethane (PU) foam, process agent II, solvent and servicing sectors in China, contained in document UNEP/OzL.Pro/ExCom/85/9;

(ii) That the World Bank had returned the remaining balances in the CFC production and PU foam sectors of US $314,015, and accumulated interest of US $22,119, to the 85th meeting;

(iii) That UNIDO had returned the remaining balances in the refrigeration servicing sector plan of US $752, plus accumulated interest of US $99,178 to the 85th meeting;

(iv) That UNDP had returned US $356,151, the accumulated interest from the solvent sector plan to the 85th meeting;

(b) To request the World Bank to submit the financial audit reports for the halon and process agent II sector plans that would be completed by 31 December 2020, in line with decision 84/39(b) to the 87th meeting together with the corresponding project completion reports (PCRs) and any remaining balances as at 31 December 2020; and

(c) To request the Senior Monitoring and Evaluation Officer to work with the relevant implementing agency to ensure that the PCRs submitted for the CFC production, PU foam, refrigeration servicing, and solvent sector plans reflect disbursements to final beneficiaries, consistent with the information provided in the financial audit reports submitted to the 85th meeting.

SECTION IV: LIST OF ENTERPRISES FUNDED UNDER HPMPS WITH DELAYS AND/OR SUBJECT TO CHANGES IN THE IMPLEMENTATION PLAN AND ENTERPRISES FOR CONVERSION TO LOW-GWP TECHNOLOGIES WITH DELAYS DUE TO ISSUES RELATED TO THEIR AVAILABILITY IN THE LOCAL MARKET AND/OR HIGHER COSTS (decisions 84/27 and 84/42)

Background

252. At its 84th meeting, the Executive Committee considered the reports on projects with specific reporting requirements.[54] During the discussion, members raised the importance to consider the reasons for delays in the introduction of approved low-global-warming potential (GWP) alternatives. Subsequently the Executive Committee requested the Secretariat to prepare, for the 85th meeting, a list of enterprises that had been funded under HCFC phase-out management plans (HPMPs) for conversion to low-GWP technologies, and that had experienced implementation delays due to issues related to availability in the local market and/or higher costs (decision 84/27).

253. In order to have access to regularly updated information on the reasons for project changes and cancellations, at its 84th meeting, the Committee also requested the Secretariat to prepare, for the 85th meeting, a simple table, using information extracted from the related progress reports, on the situations of enterprises funded under HPMPs that were experiencing delays and/or subject to changes in the implementation plan (decision 84/42).

<u>Actions taken by the Secretariat and the agencies</u>

254. In order to address the requests in decisions 84/27 and 84/42, the Secretariat requested an update from the bilateral and implementing agencies on projects experiencing delays, and reviewed progress reports on implementation of HPMPs submitted by bilateral and implementing agencies to supplement the information provided by the agencies. Annex VIII to the present document lists all the enterprises with issues related to decision 84/27 and/or decision 84/42.

[54] UNEP/OzL.Pro/ExCom/84/22, Add.1, Add.2 and Add.3

255. The Government of Germany informed that seven projects in the foam sector experienced delays in relation to decisions 84/27 and 84/42. One project experienced delays due to lack of availability in the local market of the selected technology, and six projects experienced delays due to changes in the implementation plan due to *inter alia* obtaining counterpart funding, or addressing UN sanctions.

256. UNDP informed that 78 projects faced delays in relation to decisions 84/27 and 84/42; of these, 22 projects were in the foam sector, 52 projects were in the refrigeration and air-conditioning (RAC) sector and four projects were in the solvent sector. Sixty projects experienced delays due to issues related to the lack of and/or higher costs of the low-GWP technology selected in the local markets; in several cases enterprises withdrew from projects due to higher costs and/or non-availability of components of the alternative technology selected. Eighteen projects experienced delays due to other factors (e.g., administrative approval process, signing relevant document by the Government, delays in signing agreements with enterprises on project implementation process, and longer time required for testing alternatives and safety certification).

257. UNIDO informed that 70 projects faced delays in relation to decisions 84/27 and 84/42; of these, 51 projects were in the foam sector and 19 projects were in the RAC sector. Ten projects experienced delays due to issues related to availability in the local market and/or higher costs of the alternative technology selected; and 60 projects experienced delays due to other factors (e.g., administrative approval process by the Government, signing agreement with enterprises, additional time required to implement regulations related to the projects, political/security situation and UN sanctions).

258. The World Bank did not identify projects that would require reporting in relation to decisions 84/27 and 84/42.

Secretariat's comments

259. The Secretariat notes with appreciation the information provided by the Government of Germany, UNDP, UNIDO and the World Bank, in addressing the requirements of decisions 84/27 and 84/42.

260. Of the 155 enterprise-level projects with delays 80 were in the foam sector, 71 were in the RAC sector, and four were in the solvent sector; 71 projects were delayed due to non-availability and/or higher cost of the alternative technology that was selected, and 84 projects were facing delays due to other factors. In addition, there could be other projects that were experiencing delays during the project implementation process due to specific project-related issues; these implementation issues were addressed by the agencies in consultation with the enterprises and national stakeholders.

261. The information provided by the agencies showed that the main reasons for delays in project implementation related to the lower market acceptance of low-GWP refrigerant technology against high-GWP refrigerant technologies in air-conditioning applications available at lower costs and with higher energy efficiency; and the lack of cost-effective HFO-based foam blowing formulations[55] compared with HCFC-141b/high-GWP alternatives despite the important role that systems houses had played in testing and adapting alternative formulations.

262. The Secretariat also noted that in progress reports on implementation of HPMPs for some projects, delay was reported in project implementation due to changes in implementation plan but not reported relating to this decision (e.g. change of technology during implementation of the conversion of residential air-conditioner project and in four foam sector projects; or higher cost of installation and maintenance of room air-conditioners using R-290). The agencies in their responses mentioned that as per their assessment,

[55] In projects where pentane-based blowing agents were adopted, the projects did not experience delays as the technology was proven and adopted in different countries since CFC phase-out era.

the delay in implementation of those projects was not related to issues raised in decisions 84/27 and 84/42, and had been addressed as a part of the regular project management and review process.

263. A comprehensive assessment of the enterprise-level project implementation delays, impact of such delays on achieving HPMP targets and actions proposed to be implemented to resolve the implementation issues are addressed during the review process of HPMP tranche request and under reports on projects with specific reporting requirements. Agencies mentioned that this process not only helps the agencies in addressing delays keeping in view country-specific and project-specific conditions, but also helps the Executive Committee in providing necessary guidance for expediting project implementation. The focus of bilateral and implementing agencies is on ensuring that the overall implementation of the HPMPs is achieved in a timely manner and achieving national consumption targets, and ensuring the sustainability of the phase-out that has been achieved.

Recommendation

264. The Executive Committee may wish to note the reports submitted by the Government of Germany, UNDP, UNIDO and the World Bank in line with decisions 84/27 and 84/42 as contained in document UNEP/OzL.Pro/ExCom/85/9.

SECTION V: HFC-RELATED INVESTMENT PROJECTS AND ENABLING ACTIVITIES FUNDED USING THE ADDITIONAL CONTRIBUTIONS BY A GROUP OF 17 NON-ARTICLE 5 PARTIES (DECISION 84/12(b))

Background

265. At its 84th meeting in considering the consolidated progress report of the Multilateral Fund as at 31 December 2018, the Executive Committee requested the Secretariat to submit, at the 85th meeting, an additional report on the HFC-related investment projects and enabling activities funded using the additional contributions by a group of 17 non-Article 5 Parties, identifying the countries for which the projects had been approved and providing an overview of the objectives, status of implementation, key findings and lessons learned, the amounts of HFC phased out where applicable, the level of funds approved and disbursed and potential challenges in completing the projects and activities, on the understanding that that information would be provided on an individual basis for the HFC-related investment projects and on an aggregated basis for the HFC enabling activities (decision 84/12(b)).

266. The Secretariat developed a format to facilitate the collection of information[56] and presented it to bilateral and implementing agencies at the Inter-agency coordination meeting.[57]

267. In response to decision 84/12(b), the Secretariat has submitted to the 85th meeting the additional report on the HFC-related investment projects and enabling activities using the updated format after incorporating relevant suggestions by the agencies.

Report on the HFC-related investment projects

268. The implementing agencies provided detailed status reports on the implementation of HFC-related investment projects for Argentina, Bangladesh, China, Lebanon, Mexico, and Thailand. Table 13 provides a summary of the projects while Annex IX to the present document provides more detailed information.

[56] Annex IV of document MLF/IACM.2020/1/7
[57] Montreal, 25-27 February 2020.

Table 13. Summary of HFC-related investment projects

Country	Agency	Products	HFC used (mt)	Alternative used	Mt CO_2 eq	Approved (US $)	Disbursed (US $)
Argentina	UNIDO	Domestic and commercial refrigerators	HFC-134a (96.60 mt)	R-600a/R-290	137,993	1,840,755	1,065,380
Bangladesh	UNDP	Domestic refrigerators and compressors	HFC-134a (230.63 mt)	R-600a	329,372	3,131,610	3,126,415
China	UNDP	Domestic refrigerator insulation foam	Cyclopentane + HFC-245fa (250.00 mt)	Cyclopentane + HFO-1233zd(E)	256,750	1,275,000	380,000
Lebanon	UNIDO	Domestic and commercial refrigerators	HFC-134a/ R-404A (112.58 mt)	R-600a/R-290	137,993	1,053,858	842,975
Mexico	UNIDO	Commercial refrigerators	HFC-134a/ R-404A (56.04 mt)	R-600a/R-290	90,793	1,018,123	41
Thailand	World Bank	Commercial refrigerators	HFC-134a (8.78 mt)	R-600a	12,543	183,514	0
Total			**754.64**		**965,444**	**8,502,860**	**5,414,811**

269. One project (Bangladesh) has been completed and a detailed project report has been provided by UNDP. While the remaining five projects are progressing satisfactorily, the COVID-19 situation may cause some delays in their completion.

Report on enabling activities for HFC phase-down

270. The list of countries that received funding for enabling activities for HFC phase-down are listed in Annex X to the present document. The main objectives of the requests for funding enabling activities included *inter alia* support for early ratification of the Kigali Amendment; implementation of activities identified in paragraph 20 of decision XXVIII/2 aimed at initiating supporting institutional arrangements, the review of licensing systems, data reporting on HFC consumption and production, and demonstration of non-investment activities such as training and information outreach. Table 14 presents an overview of the status of implementation of key components of the enabling activities under current implementation.

Table 14. Overview of key activities implemented under enabling activities for HFC phase-down

Agency	Number of countries	Ratification of Kigali Amendment(*)		Licensing and quota system		Data collection and monitoring system		Demonstration non-investment activities	
Agency		**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
UNDP	11	5	6	2	9	5	6	2	9
UNEP	79	30	49	21	58	18	61	15	64
UNIDO	28	13	15	12	16	11	17	7	21
World Bank	3	0	3	0	3	1	2	1	2
Germany	3	1	2	1	2	3	0	0	3
Italy	4	3	1	3	1	3	1	3	1
Total	**128**	**52**	**76**	**39**	**89**	**41**	**87**	**28**	**100**

(*) Information would change with time.

Overview of project implementation progress

271. Enabling activities are progressing well in almost all countries. So far, UNEP[58] and UNIDO[59] have completed enabling activities in three countries each.

272. A summary of the activities reported is given below:

(a) Ratification of the Kigali Amendment: Activities under implementation include stakeholder consultations; drafting legal documents with consultant support in some cases; coordination and information outreach to different stakeholders; country assessment report on HFC consumption trends and impact of Kigali Amendment on different stakeholders; training needs assessment for the servicing sector on the introduction of HFC-free technologies; and participation in regional workshop on Kigali Amendment ratification;

(b) Development and enforcement of licensing and quota system: Activities under implementation include reviewing and/or revising legislations and regulations to include Kigali Amendment provisions in the licensing and quota system; consultative workshops on development of licensing and quota system; and consultations on mechanisms for monitoring HFC supply and use in cooperation with customs and other stakeholders;

(c) Support for enforcement of data collection and monitoring system: Activities under implementation includes development of data collection system for HFCs; stakeholder consultations with importers, traders and other stakeholders on HFC and HFC-blends data collection; reporting and monitoring requirements; updating the Harmonized System (HS) Codes for monitoring HFCs and HFC blends; procurement of equipment for identification of HFC refrigerants;

(d) Implementation of other activities including demonstration and training: Activities under implementation include training programme for low-GWP alternatives including flammable refrigerants with technical expert support; outreach programmes for public awareness on the Kigali Amendment, HFCs and HFC-free alternatives used in different applications, adoption of low-GWP alternatives; regulatory controls and monitoring for the manufacturing and/or refrigeration servicing sector, Government and technical institutions and the public; and differential taxation based on GWP of refrigerants; and

(e) Energy efficiency (EE) related activities: Activities under implementation include coordinating with EE institutions to include Kigali Amendment provisions while implementing EE measures (e.g., minimum energy performance standards (MEPS), labelling programmes, EE improvement for refrigeration and air-conditioning (RAC) equipment, participation in cooling plans development to promote low-GWP energy efficient technologies, inputs during regional standards development on adopting EE technologies[60]); encouraging participation of EE stakeholders in Kigali Amendment related meetings; promoting EE relating to cooling in sectoral EE promotion measures; training on energy efficient RAC technologies; demonstrating savings to the users through adoption of EE equipment; and design of energy efficient RAC equipment and measures to enhance adoption of EE technologies.

[58] Cambodia, Kyrgyzstan and Tonga.
[59] Albania, Montenegro and Viet Nam.
[60] There are many new activities on EE improvement implemented in countries; thus, the information on types of project is illustrative and not exhaustive.

Key finding and lessons learned

273. During implementation of enabling activities, countries gained experience on the Kigali Amendment ratification process and implementation of HFC phase-down enabling activities as summarized below:

(a) Country assessment report for understanding HFC consumption trends helps stakeholders identify actions to be taken and their responsibilities in implementing these actions; guidelines on data collection methodologies and structured survey questionnaires/report templates were prepared and communicated to all stakeholders involved; and interfaces with existing and planned HCFC phase-out management plans activities were internalized through analysis of the levels of consumption of HCFCs and HFCs, and consultations with industry stakeholders;

(b) Strengthening licensing and quota system to include HFCs and HFC-blends is a priority action for monitoring and reporting, which requires detailed consultations with relevant institutions; implementation of online systems are appreciated by customs officers and importers, as it saves them time, costs and efforts; additional capacity building and training of officials handling data collection and monitoring is also a priority action; and customs and enforcement training and strengthening border control points with identification equipment is essential for preventing illegal trade of HFCs;

(c) Continuous follow-up by national ozone unit (NOU) with authorities responsible for the drafting, finalization and approval of HFC policies and regulations;

(d) Significant efforts required for approval of regulations for adopting low-GWP refrigerants especially relating to safety aspects; capacity building including training and technical information outreach is essential for sustainable adoption of low-GWP refrigerants that are flammable, toxic and operate under high-pressure; and capacity building of training and technical institutions, certification of service technicians for handling low-GWP refrigerants and training for technicians programmes are essential;

(e) Introduction of MEPS, and a progressive tax/duty system based on the EE of non-HFC-based RAC equipment creates incentives for the industry to move towards low-GWP and better EE equipment; and import of second-hand RAC equipment that have lower EE levels affects implementing EE improvement measures;

(f) Identification of local expertise for undertaking activities requires the continuous support from NOU and for capacity building; and

(g) Awareness and outreach activities through regular consultations and communications, are essential for ensuring that stakeholders understand the implications of the Kigali Amendment.

Potential challenges

274. There are a few project-specific challenges (e.g., changes in the institutional structure in the Government result in delays in approval and project implementation of certain components, political situation that affects implementation) that can delay certain projects; these will be separately addressed in the progress reports that would be submitted to the 86th meeting and included in the final reports on enabling activities.

<u>Funds approved and disbursed</u>

275. As of March 2020, the total funds approved for HFC investment projects and enabling activities under the additional contributions by a group of 17 donor countries amounted to US $23,687,811, with a total disbursement of US $13,114,664.

Secretariat's comments

276. The Secretariat noted that the HFC-related investment projects and enabling activities for HFC phase-down are progressing; one HFC-related investment project and enabling activities for six countries are completed. The COVID-19 situation is likely to affect timely completion of some of these projects.

Recommendation

277. The Executive Committee may wish to note the information on HFC-related investment projects and enabling activities, submitted by bilateral and implementing agencies in line with decision 84/12(b), contained in document UNEP/OzL.Pro/ExCom/85/9.

Annex I

PROJECTS THAT ARE CLASSIFIED AS "SOME PROGRESS" AND ARE RECOMMENDED FOR CONTINUED MONITORING

Country	Code	Project title	Agency
China	CPR/ARS/56/INV/473	Sector plan for phase-out of CFCs consumption in MDI sector	UNIDO
Egypt	EGY/ARS/50/INV/92	Phase-out of CFC consumption in the manufacture of aerosol metered dose inhalers (MDIs)	UNIDO
Iraq	IRQ/REF/57/INV/07	Replacement of refrigerant CFC-12 with isobutane and foam blowing agent CFC-11 with cyclopentane in the manufacture of domestic refrigerators and chest freezers at Light Industries Company	UNIDO
Saint Vincent and the Grenadines	STV/PHA/77/TAS/24	Verification report on the implementation of the HCFC phase-out management plan	UNEP
Syrian Arab Republic	SYR/REF/62/INV/103	Phase-out of HCFC-22 and HCFC-141b from the manufacture of unitary air-conditioning equipment and rigid polyurethane insulation panels at Al Hafez Group	UNIDO

Annex II

PROJECTS FOR WHICH ADDITIONAL STATUS REPORTS ARE REQUESTED

Country	Code	Project title	Agency	Recommendations
Algeria	ALG/SEV/73/INS/81	Extension of the institutional strengthening project (phase VI: 12/2014-11/2016)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement
Botswana	BOT/SEV/76/INS/19	Extension of institutional strengthening project (phase V: 6/2016-7/2018)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the small-scale funding agreement (SSFA)
Central African Republic	CAF/SEV/68/INS/23	Extension of the institutional strengthening project (phase VI: 1/2013-12/2014)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement, signing of the SSFA, and on progress in implementation
Democratic Republic of the Congo	DRC/PHA/79/PRP/42	Preparation of a HCFC phase-out management plan (stage II)	UNDP	To request a status report to the 86th meeting on the level of funds disbursement and the status of submission of stage II of the HPMP
Democratic Republic of the Congo	DRC/PHA/79/PRP/43	Preparation of a HCFC phase-out management plan (stage II)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and on the submission of stage II of the HPMP
Dominica	DMI/SEV/80/INS/23	Additional emergency assistance for institutional strengthening	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA
Dominica	DMI/SEV/80/TAS/01+	Enabling activities for HFC phase-down	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and on progress in implementation
Dominica	DMI/SEV/81/INS/24	Extension of the institutional strengthening project (phase VII: 6/2018-5/2020)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA
Haiti	HAI/PHA/76/TAS/21	HCFC phase-out management plan (stage I, second tranche)	UNEP	To request a status report to the 86th meeting on the progress in implementation
Haiti	HAI/SEV/75/INS/20	Extension of the institutional strengthening project (phase IV: 11/2015-10/2017)	UNEP	To request a status report to the 86th meeting on progress in implementation

Country	Code	Project title	Agency	Recommendations
Lebanon	LEB/DES/73/DEM/83	Pilot demonstration project on ODS waste management and disposal	UNIDO	To urge UNIDO to submit the project completion report in line with decision 82/15(c)
Libya	LIB/FOA/82/PRP/41	Preparation for HCFC phase-out investment activities (stage II) (foam sector)	UNIDO	To request a status report to the 86th meeting on progress in the preparation of stage II of the HPMP
Libya	LIB/PHA/82/PRP/43	Preparation of a HCFC phase-out management plan (stage II)	UNIDO	To request a status report to the 86th meeting on progress in the preparation of stage II of the HPMP
Peru	PER/SEV/80/INS/56	Renewal of institutional strengthening project (phase V: 1/2018-12/2019)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and on progress in implementation
Qatar	QAT/PHA/65/TAS/17	HCFC phase-out management plan (stage I, first tranche) (refrigeration servicing sector)	UNEP	To request an update to the 86th meeting on the status of the return of balances
Qatar	QAT/PHA/73/PRP/20	Preparation of a HCFC phase-out management plan (stage II)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and on the submission of stage II
Qatar	QAT/PHA/73/PRP/21	Preparation of a HCFC phase-out management plan (stage II)	UNIDO	To request a status report to the 86th meeting on progress in preparation and submission of stage II
Saudi Arabia	SAU/FOA/62/INV/13	Phase-out of HCFC-22 and HCFC-142b from the manufacture of extruded polystyrene panel at Al-Watania Plastics	UNIDO	To request a status report to the 86th meeting on the conclusion of auction process
Saudi Arabia	SAU/SEV/67/INS/15	Extension of the institutional strengthening project (phase II: 7/2012-6/2014)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA
South Sudan	SSD/PHA/77/TAS/04	HCFC phase-out management plan (stage I, first tranche)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA
South Sudan	SSD/SEV/76/INS/03	Institutional strengthening project (phase I: 5/2016-4/2018)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA
Suriname	SUR/PHA/81/TAS/26	HCFC phase-out management plan (stage I, third tranche)	UNEP	To request a status report to the 86th meeting on the level of funds disbursement and signing of the SSFA

Country	Code	Project title	Agency	Recommendations
Syrian Arab Republic	SYR/FOA/61/PRP/102	Preparation for HCFC phase-out investment activities (foam sector)	UNIDO	To request a status report to the 86th meeting on project preparation and proposed date for submission of the HPMP
Syrian Arab Republic	SYR/PHA/55/PRP/97	Preparation of a HCFC phase-out management plan	UNIDO	To request a status report to the 86th meeting on project preparation and proposed date for submission of the HPMP
Syrian Arab Republic	SYR/SEV/73/INS/104	Extension of institutional strengthening (phase V: 1/2015-12/2016)	UNIDO	To request a status report to the 86th meeting on progress in implementation and the level of funds disbursement
Yemen	YEM/SEV/73/INS/43	Extension of the institutional strengthening project (phase VIII: 1/2015-12/2016)	UNEP	To request a status report to the 86th meeting on progress in implementation

FINAL REPORT

PROJECT TITLE: Demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets (Argentina and Tunisia)

PROJECT NUMBER: GLO/REF/76/DEM/335

Table of Contents

BACKGROUND

On its 76th Meeting, the Executive Committee decided:

(a) To approve the demonstration project in Argentina and Tunisia for the introduction of trans-critical CO_2 refrigeration technology for supermarkets, in the amount of US $846,300, plus agency support costs of US $59,241 for UNIDO, in line with decision 72/40; and

(b) To request the Governments of Argentina and Tunisia, and UNIDO, to complete the projects within 30 months of its approval, and to submit a comprehensive final report soon after project completion. **(Decision 76/27)**

The subproject designed for Tunisia was not implemented due to lack of interest. The project funds approved for Tunisia amounts to **USD 319,131**. The remaining funds available will be returned as per decision.

The project funds approved for Argentina amounts to **USD 527,169** plus agency support cost.

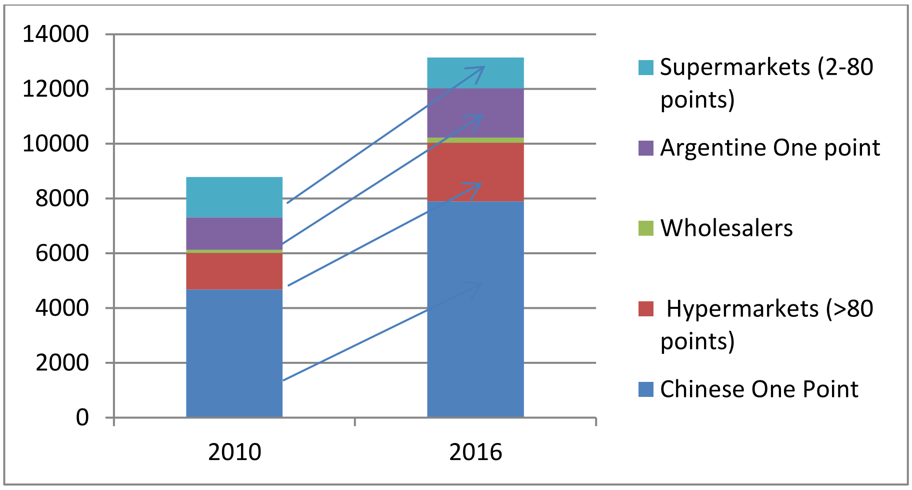
This document is prepared for the information of the members of the Executive Committee and takes account of the background, the implementation process and the results achieved as well as the experience gathered through the subject demonstration project.

The supermarket sector in Argentina

Between 2010 to 2016, the five largest Argentine supermarket chains had grown by 63%. The total estimated points of sale were of 8,672 in 2010[1], reaching around 13,000 in 2016[2] and a future growth[3] had been expected.

The growth was boosted by the opening of proximity small self-service markets by the big players of the sector.

[1] Informe Relevamiento sobre Supermercados en Argentina. 2011. Federación Argentina de Empleados de Comercio y Servicios.
[2] Informe de Actualización: Evolución del Sector Supermercadista. 2016 Federación Argentina de Empleados de Comercio y Servicios.
[3] Encuesta de Supermercados. Informes Técnicos vol. 1 nº 65, Comercio vol. 1 nº 9. INDEC, Febrero de 2017.



Refrigerants used in the food chain

Synthetic refrigerants have been typically used in retail food refrigeration. At the beginning CFCs were used; later they were replaced by HCFCs.

HCFC-22 has been the most popular refrigerant over the past decades for retail food refrigeration systems and it is still widely used in the supermarket sector. Therefore, consumption of HCFC-22 in this sector is still very relevant in Argentina; it is estimated at around 750-800 MT. Leakage rates are very high ranging from 35% for big and medium size installations to above 70% for small installations. This is caused by inadequate maintenance and sometimes bad quality installations.

When HCFCs phase-out gathered momentum, it became a priority to replace HCFC refrigerants used in the supermarkets. As a result, HFCs have started replacing HCFCs. Natural refrigerant technologies had not been commonly used in this sector in Argentina.

The Kigali amendment is imposing limitations on the use of HFCs refrigerants with high GWP. As a result, the refrigerant manufacturing chemical industry as well as the end users of their products have been compelled to find new low GWP alternatives. In view of the growing concern about climate change, new technologies with very low GWP alternatives have been developed, matured and put into the market. These are spreading fast in many A2[4] countries. Among these low GWP refrigerants CO_2 is gaining popularity.

Environmental impact of supermarket systems

The environmental impact of the supermarket sector is caused by its

i. High energy consumption, and
ii. Significant consumption of ozone depleting refrigerants, and

[4] Article 2 countries under Montreal Protocol

iii. Increased use of high GWP refrigerants.

Among the commercial outlets, supermarkets have the highest specific energy consumption, typically in the range of 400-600 kWh/m^2 annually. The largest energy consumers in a supermarket are the refrigeration equipment (30%-50%), which is followed by ventilation, heating and cooling of the store and its lighting.

The generation of electricity used by the supermarkets is associated with CO_2 emission in various degree depending on the energy mix. The effect of this type of CO_2 emission is called indirect impact.

THE DEMONSTRATION PROJECT

Objective

The primary objective of the project was to evaluate the performance and energy efficiency of trans-critical CO_2 technology in a real case scenario: a carefully selected representative supermarket located in moderately warm climatic conditions

The other objective was to identify incentives and barriers related to an upgraded to trans-critical CO_2 technology, by phasing out HCFCs and leapfrogging the HFC conversion step.

When successful, the project is expected to be replicated in countries of the region thereby promoting the use of low-GWP refrigerants in the sector.

Project Budget

The project was approved by the Executive Committee of the MLF in May 2016 with a budget of U$527,169, with UNIDO as implementing agency and an implementing period of 30 months.

The details of the budget are shown in the table below:

TABLE 1. PROJECT COST

Item	USD
Refrigeration plant	
Transcritical plant	117,497
Condenser / gas cooler	19,299
Subcooler (Option 2 R-290 refrigerant)	41,060
8 x evaporators	12,675
Refrigeration installation and materials	115,632
Electrical installation	54,828
Electrical panels and electronics	28,875

Total refrigeration system	**389,866**
Food display cabinets	
8 fresh food cabinets with doors and led model	66,754
5 frozen food islands	35,722
2 semi-cabinets for frozen food	25,630
6 Fresh food cabinets	34,197
Less cost sharing	-60,000
Total cabinets	**102,303**
Subtotal equipment cost (incl. installation)	**492,169**
Engineering and transport	
Engineering	10,000
Transportation, 3%	11,451
Cost sharing	-6,451
Total services	**15,000**
Total cost of equipment and services	**507,169**
Demonstration project for 20 participants	20,000
TOTAL COST OF SUB-PROJECT 1: ARGENTINA	**527,169**

Methodology used in the project

The main barrier for introducing low GWP alternatives, especially CO_2 in the supermarket sector in Article 5 countries is the lack of knowledge and experience as well as the limited availability of equipment components and know-how related to the new technology as well as the still high initial cost implication.

For these reasons, even when the end users decide to phase out HCFCs in their installations, the likelihood that they would opt for an HFC well-known technology is rather high. Furthermore, such conversions require less modifications and thus it will be the less costly solution.

At the time the project was formulated, there was only one supermarket in Argentina using a transcritical CO_2 centralized refrigeration system. This is operated in the south of Argentina (Patagonia region) - a location with a very cold climate condition.

Therefore, Argentina decided to implement a project to address the issues and barriers related to as well as the feasibility of CO_2 technology in warmer climatic conditions where the CO_2 transcritical technology had not yet been used.

Determination of baseline data

In the past, the electricity consumption of the refrigeration equipment was neither measured, nor monitored. Thus, in order to quantify the impact of the project on the energy consumption of the technological equipment La Anonima separated the electrical supply of the refrigeration systems from the air conditioning and lighting. They also installed separate power meters with data loggers.

The electricity consumption of refrigeration equipment had been meticulously measured during the first year of the project, when only the bidding, manufacturing and delivery of equipment took place. The data collected in the pre-startup year was used to determine the baseline electrical consumption level.

Temperatures, as well as, general climate condition information were taken for all the measuring period from the nearest meteorological station.

The consumption of refrigerants was not strictly monitored by the supermarket. After approval of the project the supermarket started strict monitoring of the actual use of refrigerants and the causes of leaks.

Post project data

During the one-year post conversion period the measurements of electricity consumption of the refrigeration equipment as well as refrigerant continued, and the data were compiled.

Thus, we were able to compare the pre- and post-conversion energy consumption based on real data.

Sustainability and barriers

To identify potential barriers, the long-term sustainability, as well as the impact of this demonstration project, we assessed various aspects, such as:

- Technical viability,
- Investment and relevant operating costs,
- Environmental benefits,
- Impact of energy consumption
- Availability of components,
- Installation and servicing skill requirements,
- Other possible advantages and disadvantages.

These factors are also important to assess the opportunities for replication at country level, regionally and/or globally.

During the project we organized several meetings with the supermarket's maintenance management and staff, as well as with the vendor of the equipment and technology, in order to investigate and collect cost data, maintenance requirements and other financial and technical matters.

Location and Baseline Situation

OPROZ contacted several nationally owned supermarket chains to select the supermarket ready and capable to implement the demonstration project in a timely manner. In order to enhance the demonstration value of the project it was important to find a supermarket located in one of the warmest locations of the country, which could serve as a model for other supermarkets in moderately hot A5 countries. It was also important to find a company with appropriate financial means and technical expertise required to complement the resources and technical inputs granted through the project.

The selection was narrowed down to a supermarket in the town of Lincoln, Buenos Aires Province. It is part of a large Argentine supermarket chain, which belongs to Sociedad Anónima Importadora y Exportadora de la Patagonia, in short La Anónima. This supermarket is located in a moderately warm climatic zone (GPS coordinates: Latitude: -34.8637778 (34º 51' 49.6" S), Longitude: -61.528350 (61º 31' 42.062" W). The chain had been in healthy financial situation, possess highly trained technical and maintenance staff and has been eager to participate in the demonstration project. So, it had complied with all criteria of the demonstration project.

Figure 1 La Anonima, Lincoln Branch

Ű

TABLE 2. AREA OF THE SUPERMARKET

Area	m^2
Total sales area	1,258
a. Cold food cabinets	49
b. Frozen food cabinets	6
c. Frozen food aisles	16
Total storage area	449
a. Cold storage	108
b. Walk-in freezers	14

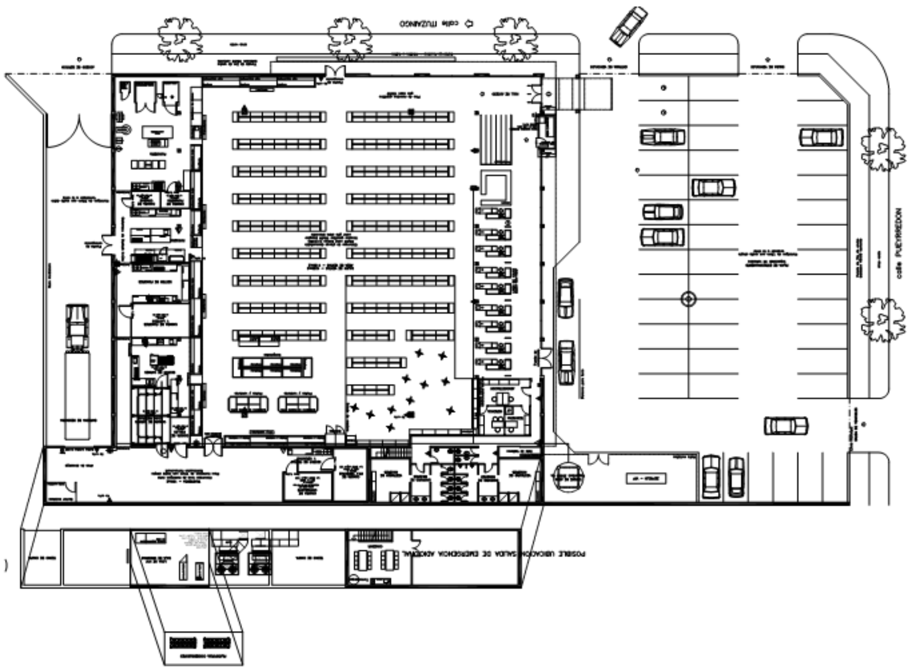


Figure 2 Layout of the LaAnonima Supermarket in Lincoln

Figure 2 depicts the layout of the supermarket with the location of the refrigerated and frozen food sections and the roof with the machine room.

In the baseline, the supermarket had two central refrigeration systems, one for low and another for medium temperature.

Figure 3 Baseline machine room

The refrigerant used in the central systems was **HCFC-22**.

Furthermore, there were a number of self-contained freezer units (islands and upright reach-in cabinets) working with **HFC-404A**.

Figure 4 Baseline Cabinets and Freezer Aisles

Figure 5 Baseline Dairy Cold room

Selection of CO_2 commercial refrigeration technology

In the last 15 years, as environmental considerations gradually came to the forefront, CO_2 technology was "reinvented" as an environmentally friendly solution in commercial refrigeration, based on the low Global Warming Potential (GWP) of CO_2 resulting in lower Total Equivalent Warming Impact (TEWI) compared with HFC refrigerants. Today, in A2 countries there is no difficulty in sourcing all the necessary equipment for CO_2 technology. However, in A5 countries this technology is still new and rarely used in areas of warm climate.

Booster systems have been the preferred option due to their relative simplicity and lower initial cost compared to cascade systems. At the time of the preparation of the project there were already some

4,000 systems, mainly in supermarkets, which use the traditional booster system shown below. According to Danfoss there is a 100% market growth on year on year basis for these systems and it seems that in moderate climate countries booster system is now the market standard. The trend is now to move the market towards warmer regions.

However, at higher ambient temperatures the inherent properties of R-744 lead to loss of efficiency and elevated equipment costs. The efficiency of systems with CO_2 depends more on the application and the climate conditions prevailing on the site of installation than in the case of other refrigerants. For all refrigerants there is a decline in system efficiency with increasing condensing temperatures, and CO_2 is among the refrigerants with the steepest drop. The good thermo-physical properties of CO_2 can compensate to some extent, but there is a limit.

The problem with transcritical CO_2 systems in warm climate is not that they will not work, but more that there is a significant loss of capacity and efficiency.

In cold climates like the Nordic climate we see 10% lower energy consumption, but going to warm climates like Asia, South Europe, Southern part of North America, Latin America and Africa is a challenge for CO_2 systems. The extra cost of compressors and loss of efficiency could make the technology less attractive.

The traditional booster system is illustrated on Figure 6.

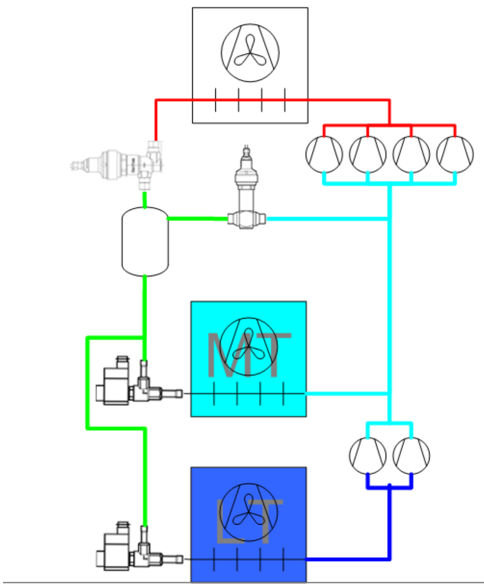


Figure 6 Traditional Booster System

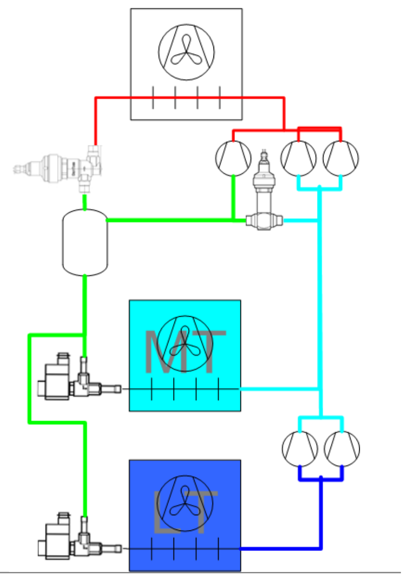


Figure 7 Booster System with Parallel Compression

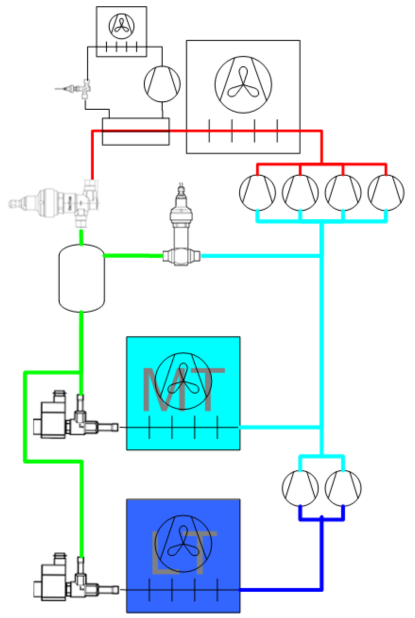


Figure 8 Booster System with Parallel Compression and Subcooling

Figure 7. shows that the traditional booster system is complemented with a compressor, which compresses the flash gas from the refrigerant valve that regulates the pressure in the liquid receiver (flash tank) and associated pipe work. The advantages of this solution are:

a. Solution is mature and well proven,
b. 5-10% energy improvement in warm climates,
c. Approximately 25% saving on installed capacity,
d. Can be combined with other features to enhance the system.

The system shown on Figure 8 includes an additional heat exchanger – so called subcooler. The advantages of this solution are:

a. Solution is ready
b. 5-10% energy improvement in warm climates
c. Up to 50% saving on compressor capacity, but the capacity is needed on the auxiliary cooling unit.

In warm climates, when the system works in transcritical cycle the amount of flash gas inside the liquid receiver increases.

In a transcritical system the receiver pressure is controlled by expanding the vapor released through connection of a by-pass Flash Valve to the medium temperature suction header.

The parallel compressor in the system the result is a better performance due to a reduction in the compression work between the intermediate pressure in the receiver and the common discharge pressure.

For example, under external temperature of 40 ºC, the system develops increased amount of flash gas. Medium temperature compressors will work with a COP of 1.34 and the parallel compressor will have a COP=2. Without parallel compressor all the flash gas will pass through the medium temperature compressors.

Other component added to the system to save energy is an external subcooler installed before the transcritical valve. It is a plate heat exchanger, which works with a dedicated chiller. This subcooler reduces the gas's enthalpy and reduces the amount of flash gas.

Figure 9 shows the actually installed system and provides additional explanations.

With the aim of increasing energy efficiency during the warm periods of the year when there are excessive room temperatures in the supermarket, a Subcooler was installed.

UNIDO and the counterpart decided to reduce the climate impact of the new system by using only natural low GWP refrigerants. We succeeded to convince the supplier to design a subcooler with a refrigeration system using R-290 refrigerant. R-290 is refrigerant grade propane, a natural refrigerant widely used in a wide range of refrigeration and air conditioning applications with smaller charge size. The use of R-290 in various applications is increasing due to its low environmental impact and excellent thermodynamic performance. It is non-toxic with zero ODP (Ozone Depletion Potential) and very low GWP (Global Warming Potential).

However, R-290 is a flammable refrigerant so it is vital to take appropriate safety measures at the installation site. R-290 may react violently with oxidants, air, oxidizers. It was necessary to study carefully the national safety rules and designate a suitable outside location for the machine. In view of the charge size. It is important to demarcate the area around the subcooler, where heat, sparks, open flames, hot surfaces, and no smoking is allowed. In our case the sub-cooler was installed on the roof where good natural ventilation is prevailing, so there was no need to install special sensors

The subcooler includes an inertia module with CO_2 - Glycol plate heat exchanger.

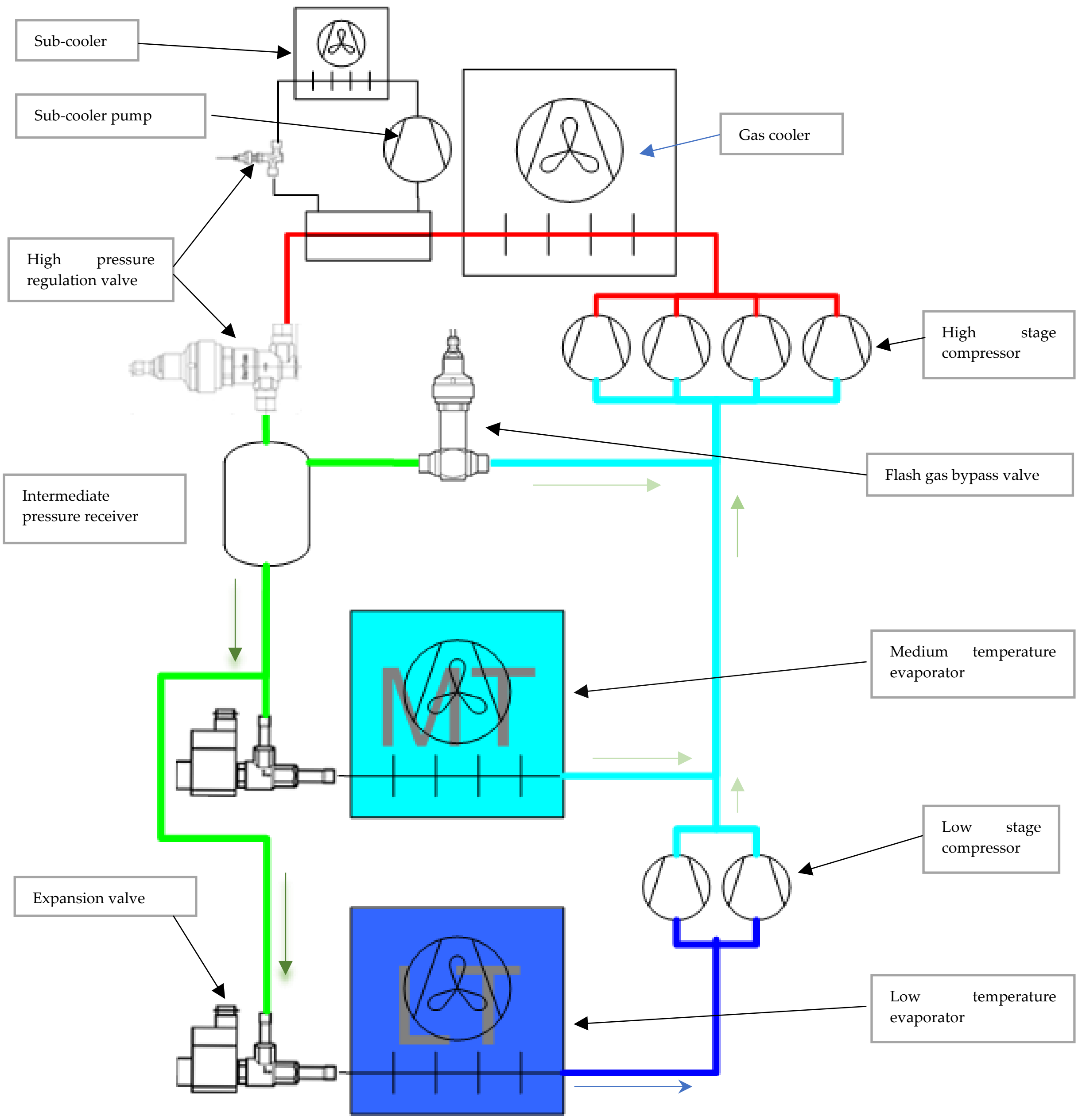


Figure 9 Booster System with Parallel Compression and Subcooling

The latest development is the so-called Ejector Compression System. At the time of the development of the project, this technology had been still under development and had not yet come out on the market.

Further energy savings could have been be achieved by utilization of waste heat developed in the refrigeration system. Such integrated systems combining the energy requirements of cooling, heating and air-conditioning are extremely attractive under cool or moderate climate condition but could bring benefits also in warmer countries e.g. to produce hot water. The applicability is to be evaluated based on the cost-benefit ratio. This combination was not considered in the subject demonstration project.

Thus, after thorough review of the available technological options in 2015 suitable for supermarkets located in warm climate conditions, it was decided to introduce a transcritical CO_2 booster system with parallel compression and subcooling. In order to use natural refrigerants for all the system it was decided to incorporate a R290 subcooler.

PROJECT IMPLEMENTATION

Timeframe

After the approval of the project in May 2016 the implementation was organized by OPROZ and UNIDO in close cooperation with the beneficiary company.

The Terms of Reference was prepared, and the bidding was initiated by the end of 2016. After the contract award, the equipment was manufactured in Argentina by EPTA and in Italy by EPTA's mother company and delivered to the site in 2017. The installation was completed in December 2017. The supermarket has been operated with the new technology as of January 2018 and the monitoring of energy consumption was undertaken throughout all the year of 2018.

Thus, the actual implementation took about 1.5 years, the remaining time of the project duration was spent to study and monitor the post-conversion situation and to assess the project performance.

According to the Project Document the duration of the physical implementation (bidding, purchase, delivery of equipment, its installation and start up) of the project was projected for 2 years.

To gain a true picture of the long-term reliability of operation, maintenance requirement, leakage rate and also of the energy efficiency the originally planned 6-month project evaluation was extended to 12 months. It was necessary, because the energy consumption is fluctuating during the year depending, inter alia, on the climate/temperature fconditions. Thus, it was decided to measure the energy consumption for an entire year prior conversion and also an entire year after conversion and compare the results. Thus, the project was not delayed, but more information has been obtained than expected.

Installation and start-up of the new equipment

The CO_2 transcritical system design was developed in Argentina by EPTA with the assistance from their design headquarters in Italy and UK following UNIDO and OPROZ national and international consultants' technical requirements.

A critical point was the design, calculation and manufacturing of the R290 subcooler. This work was undertaken by the equipment manufacturer. The refrigeration system was built by EPTA using a subcooler of an Italian manufacturer. All piping calculations were adjusted locally

The conversion did not affect the layout of the supermarket.

The arrangement, number, configuration and temperature set points of the new display cases, cold rooms and walk-in coolers are nearly identical to the baseline too.

The stand-alone R404A units of the baseline installation were replaced and the new ones were integrated into the CO_2 centralized system.

The refrigeration capacity of the medium temperature circuit is 68,79 kW and the same of the low-temperature side 9,53 kW. This is smaller than in the baseline: 72,09 kW for the HCFC-22 positive temperature cabinets and cold room, and 10,05 kW for the HFC-404A low-temperature cabinets and cold rooms.

In order to supply the refrigeration needs of all supermarket's refrigeration equipment a multi compressor refrigeration central has been installed. A parallel compressor was incorporated into the refrigeration plant and mounted on the refrigeration plant's frame.

Figure 10 The CO_2 Transcritical Refrigeration Machinery

Figure 11 Walk-in Vegetable Cooler and its CO_2 Evaporator

The installation`s condensation is achieved by using a Condenser/Gas Cooler designed to withstand a pressure of 120 bar pressure. To avoid accidents the installation is protected by safety pressure valves, which release the refrigerant pressure in the event of exceeding the said 120 bar.

In a CO_2 transcritical installation, it is necessary to use a correctly dimensioned Condenser/Gas Cooler to ensure that the heat dissipation requirements of the discharge of the compressors are met even in extreme heat conditions.

The cold rooms remained unchanged; however, their evaporators had to be replaced. All evaporators for the positive temperature cold rooms, the working rooms and the negative temperature cold rooms are compact and equipped with integrated ventilators and electronic expansion valves.

Figure 12 New CO_2 Freezer Cabinets and Aisles

With the aim of increasing the energy efficiency during the warm periods of the year, a R290 subcooler was installed. The subcooler is a R290 (Propane) chiller and propilenglycol is the recirculated fluid. The R290 charge size (1,7 kilograms) is small and the device is located in the open air. Anyway, it is important to demarcate the area around the subcooler where heat, sparks, open flames, hot surfaces, and smoking are not allowed.

The application of CO_2 in the loop required the change of the pipes to harmonize the system to the lower charge and also to withstand the very high operating pressures.

A system for continuous display of the refrigeration parameters in both the cold rooms and display cabinets was installed. This display system allows easy observation of the working parameters on a screen incorporated into the electronics module.

Other important safety devices are the leak detectors and alarms installed in the cold rooms. In the case of excessive refrigerant gas (R-744) leak this detector closes the electronic valves of the CO_2 supply side of the circuit to avoid suffocation hazard through build-up of CO_2 concentration.

During the implementation of the conversion process the smooth operation of the supermarket was maintained, thus the operation of the baseline machinery had been in operation until the new took over their role. The old machinery was dismantled only after successful start-up and trial runs of the new system.

Figure 13 CO2 Leak Detector

Figure 14 Display of the Electronic Control System

LESSONS LEARNT

The project was approved for the introduction of transcritical CO_2 system to replace the medium and low temperature refrigeration system of a supermarket working with HCFC-22 and HFC-404A refrigerant, respectively. No funds were approved to convert a similar supermarket to HFC (R-404A or R-134a) refrigerants. Thus, we could only compare the performance of base-line pre-project and the post-project scenarios (transcritical CO_2 equipment).

Equipment related issues

1. Since HCFC-22 is being phased out, the most important competitor of transcritical CO_2 equipment in Latin America is HFC-404A. In view of lack of direct information on the cost of conversion to HFC of a similar supermarket, we estimated the difference between the investment cost of the traditional HFC 404A and the transcritical system using indirect investment cost information collected from the industry and the technical literature.

   The initial cost of a CO_2 transcritical system used to be substantially higher than a conventional HFC 404A system. A study prepared for the US Department of Energy[5] in 2015 stated: "Given the nascence of transcritical CO_2 technology in the US market, these systems currently have an upfront cost that is 40-50% higher than that of conventional systems at the time of this study". Lately the price difference has been decreasing due to the standardization of several components. Today, according the information received from a large equipment manufacturer the price of an HFC-404A

5

installation is about 20% lower the equivalent CO_2 one in case of a direct cooling system and around 10-13% lower in case of an HFC/glycol system in the Latin American Region depending on the size and characteristics of the systems. The reason of this price difference is related to the substantially higher pressure used in the CO_2 installations. Thus, they require the use of stronger piping, better welding of the circuit and also several controls and monitoring devices that are normally not part of an HFC systems.

2. Cost of installation of CO_2 system due to the high-pressure requirements is still very high in Argentina. TIG brazing is made by specialized companies so the price is much higher than standard brazing. Availability of specialized brazing companies is lacking in some locations of the country. Two of such specialized brazing companies have been employed during Lincoln installation.

3. The installed CO_2 transcritical system did not leak from the start up until now and, if leaks would occur in the future, the recharge would be done at a low price due to the much lower price of CO_2 compared to the current prices of synthetic refrigerants.

4. The refrigeration systems are optimized for the designed refrigerant charge. Leaks would lead to suboptimal conditions loss of refrigeration capacity, increased energy consumption. Such systems will cause damages to the perishable goods, so losses could be quite significant. Thus, low leakage rates of the new system is advantageous from several points of view.

5. The first charge of CO_2 was supplied by EPTA. Industrial gas vendors like Praxair and Air Liquide are located in Argentina and offer CO_2 with 20 ppm humidity and since it is used for sparkling beverages, it is easily available. This CO_2 is also used for some other refrigeration systems in Argentina.

6. R290 has been supplied to EPTA by a local refrigerant importer and EPTA maintains a stock for emergencies.

7. Frequency of preventive maintenance is similar to HCFC/HFC systems and the only is the adequate training of the service staff. The equipment of La Anonima Lincoln is maintained by its own staff, they have been properly trained by EPTA, as part of the project.

8. The selected vendor had the necessary expertise to provide assistance during installation and start up as well as after sales maintenance. During the procurement process this was a condition required from the bidders. Vendor was also required to train the maintenance staff of the Lincoln supermarket on the following:

   - Procedures to intervene on a CO_2 system under pressure
   - Maintenance procedures like filters and oil replacement, sight glass control.

- Management of electronic controls of the refrigeration rack and system
- Operation of monitoring system

9. OPROZ also offered during 2017 and 2018 all over the country trainings for more than 700 technicians on Good Practices in Handling Low GWP refrigerants which included CO_2.

10. Parts to be replaced most frequently are manometers and valves. These devices are now available in Argentina. As previously stated, several components, like valves, are standardized today for several refrigerants and their working pressures are adequate even for CO_2.

11. Availability of CO_2 transcritical system vendors in the local market is low. CO2 central refrigeration systems as well as the evaporators and subcooler were manufactured in Italy by EPTA Italy. The size of the market is still not sufficient for manufacturing it locally.

12. Compressors in this case were manufactured by Bitzer and the service center for these compressors is located in Brazil, so the project vendor has a reduced stock for emergency. Because of this, the capacity of the CO_2 central was calculated with a slight reserve so it could work even if one of the compressors fails.

13. Display cabinets are manufactured by EPTA Argentina locally at their Rosario manufacturing plant but some of the components are imported.

14. Most electrical components are available locally but some cables as well as special connectors are imported.

15. The Control system is manufactured by Carel, which is based in Brazil and has distributors in Argentina. Carel control systems for CO_2 transcritical installations are manufactured in Italy so the project vendor maintains a complete control system in stock as well as pressure transducers to be able to assist in case of emergency.

Electricity consumption

As expected with any refrigeration system, the electricity consumption of the CO_2 transcritical booster refrigeration system showed correlation with the ambient temperatures. In the summer period from December to March the average maximum temperature was 32 °C, and most of the time over 30°C, as shown in the following figure.

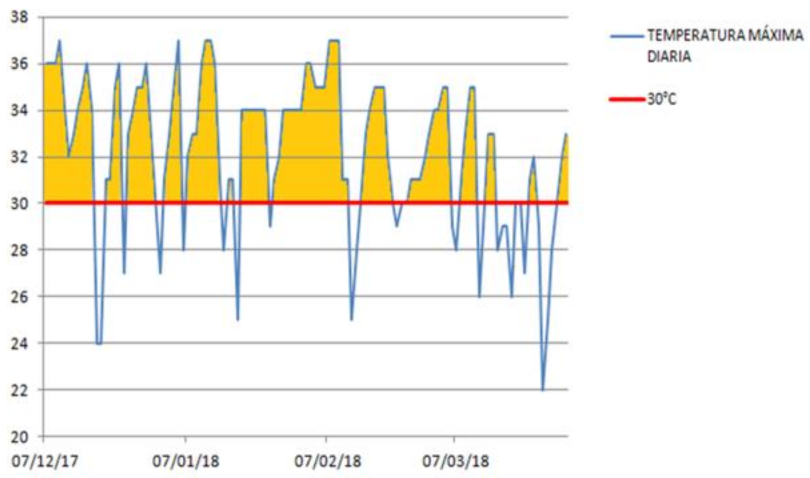


Figure 15 Average maximum temperature between December 2017 and March 2018

Year 2018[6] showed more extreme temperatures than the baseline year 2017[7], with an increase of almost 2 Celsius degrees in the maximum temperatures during several days.

Prior to the project the supermarket had only one meter to measure all electrical consumption of the shop. Thus, the supermarket did not have any information on the consumption of the refrigeration equipment. In order to be able to assess the impact of the project, the first thing was to install of a separate meter to delineate the measurement of the electrical power consumption of the cooling equipment only. In the following figure and table, the monthly electricity consumption of the new CO_2 transcritical system is presented versus the baseline registered during the test period from January to November.

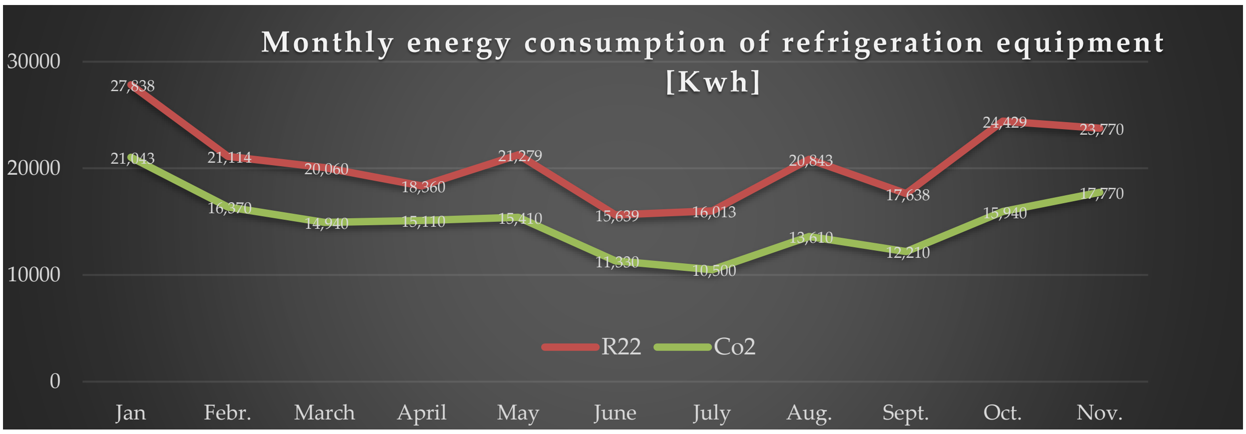


Figure 16 Energy consumption of refrigeration equipment

[6] Monitoreo Regional de la Temperatura 2018. Servicio Meteorológico Nacional
[7] Monitoreo Regional de la Temperatura 2017. Servicio Meteorológico Nacional

During the first 11 month of the trial period, the cumulative electric consumption of the CO_2 transcritical system in the first year of its operation was 27.64% lower compared to the pre-project annual electric consumption of the baseline equipment. The annual energy consumption was extrapolated based on the power-meter measurements of the first 11 months and the results are shown on the following graph.

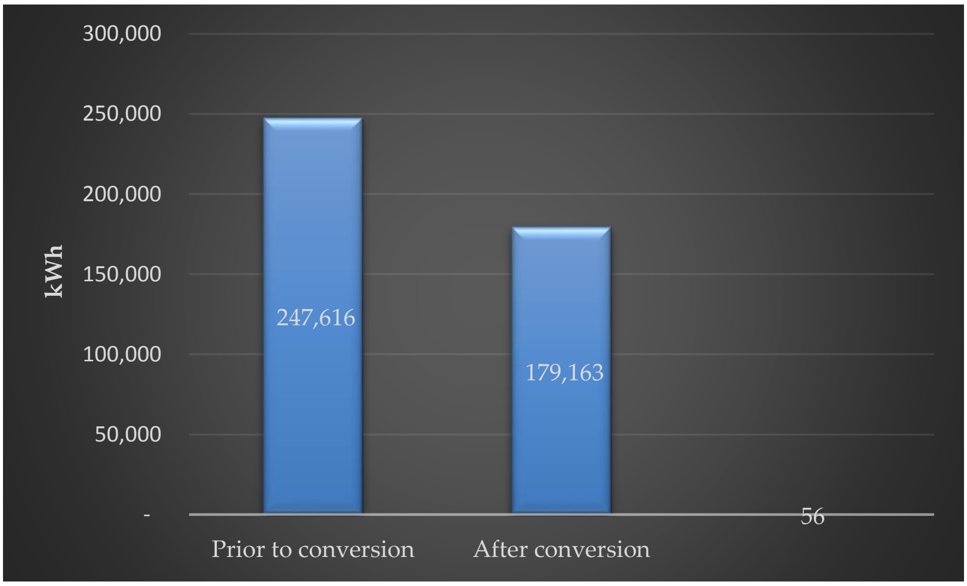


Figure 17 Annual electrical energy consumption of refrigeration equipment

The annual electricity bills (including non-technological energy use) showed a 27% year saving of pesos $343,673 (U$S 9,200).

The following graph shows energy cost comparison based on electricity bills of 2017 and 2018.

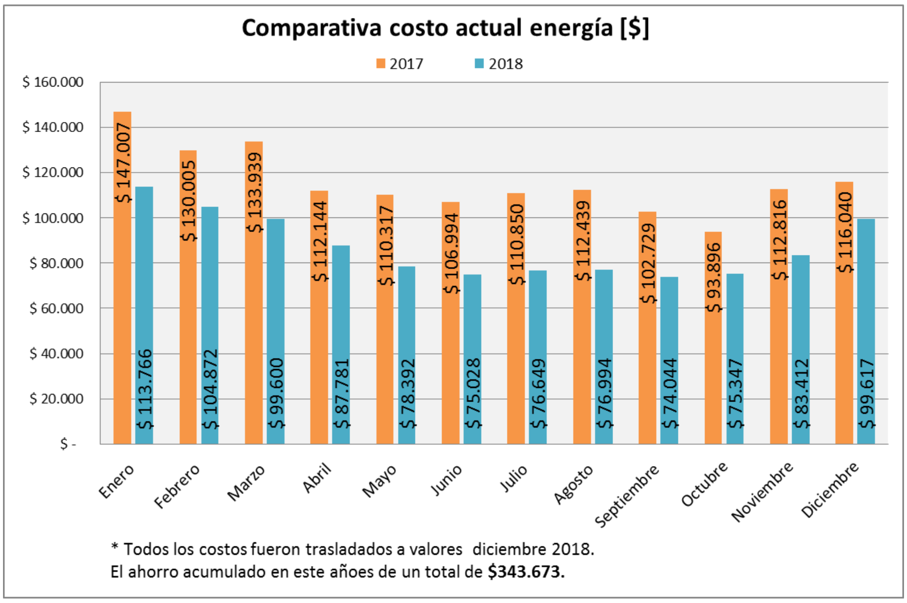


Figure 18 Electricity cost of the supermarket

Refrigerant leaks

The refrigerant charge amounts and leakage data are shown in Table 3.

TABLE 3. REFRIGERANT CHARGES AND LEAKS, SUPERMARKET IN LINCOLN

Year	HCFC-22 (kg)			HFC-404A		
	Charge [kg]	**Leak**	**%**	**Charge [kg]**	**Leak**	**%**
2011	400	244	61%		N/A	-
2012	400	593	148%		N/A	-
2013	400	312	78%		N/A	-
2014	400	517	129%	10.6	27.2	**257%**
2015	400	272	68%	10.6	40.8	**385%**
Average	**400**	**387.6**	**97%**	**10.6**	**34.0**	**321%**

The baseline annual consumption of refrigerants at the Lincoln La Anónima supermarket amounted to 398.2 kg. The associated refrigerant cost amounted to 5,700 USD.

The new system is filled with 300 kg CO_2.

In view of the high pressure of the CO_2, high quality pipes are used. Special attention and qualified/certified technicians and welders were employed for the connections and installation of the circuits and equipment. Rigorous testing of all joints and of the entire circuit was carried out prior commissioning and start-up. In view of the high quality of the equipment and installation work, almost no leaks occurred during the first year of operation. Thus, the cost of the refrigerants is now saved and also the labour cost of replacements and repairs associated with it. The loss of perishable goods was not quantified.

Environmental impact

The following table shows the impact of direct and indirect green-house gas emissions during the monitoring period. As shown in Table 4 the direct green-house gas emission reduction is 834.9 T_{CO2eq} due to the high GWP of R-22 refrigerant as well as the extensive baseline annual leakage average amounting to 97% of the total charge compared to the GWP and leakage of R744 and R290 of the new system.

In 2019, during the generation of 1 kWh electrical energy in Argentina 310 g of $CO_{2\ eq}$ greenhouse gas was emitted[8]. Even if this figure is not too excessive compared to other countries (e.g. EU- 269 g_{CO2eq}/kWh[9], USA – 401 g_{CO2eq}/kWh[10], China 555g_{CO2eq}/kWh[11]) the energy saving results in substantial greenhouse gas savings amounting to 21.43 t_{CO2eq}. Even though this is quite low compared to the direct emission saving, but it is recurring annually during the entire lifetime of the machinery.

TABLE 4 CALCULATION OF CLIMATE IMPACT OF THE PROJECT

DIRECT EMISSION			
Chemicals	Average leakage (kg)	GWP	Direct emission (tCO2eq)
Prior to conversion			
R-404A	34	3,922	133.35
HCFC-22	387.6	1,810	701.56
Total			834.90
After conversion			
R-290	0	5	0
CO_2	0	1	0
Saving			**834.90**
INDIRECT EMISSION			
	Electricity consumption	Intensity of power generation (g_{CO2eq}/kWh)	Indirect emission (t_{CO2eq})
Prior to conversion	247,616	313	77.50
After conversion	179,163	313	56.08
Saving			**21.43**
CLIMATE IMPACT			
Total emission saving			**856.33**

The climate impact is illustrated on the following graphs.

[8] https://www.climate-transparency.org/wp-content/uploads/2019/11/B2G_2019_Argentina.pdf
[9] https://www.climate-transparency.org/wp-content/uploads/2019/11/B2G_2019_EU.pdf
[10] https://www.climate-transparency.org/wp-content/uploads/2019/11/B2G_2019_USA.pdf
[11] https://www.climate-transparency.org/wp-content/uploads/2019/11/B2G_2019_China.pdf

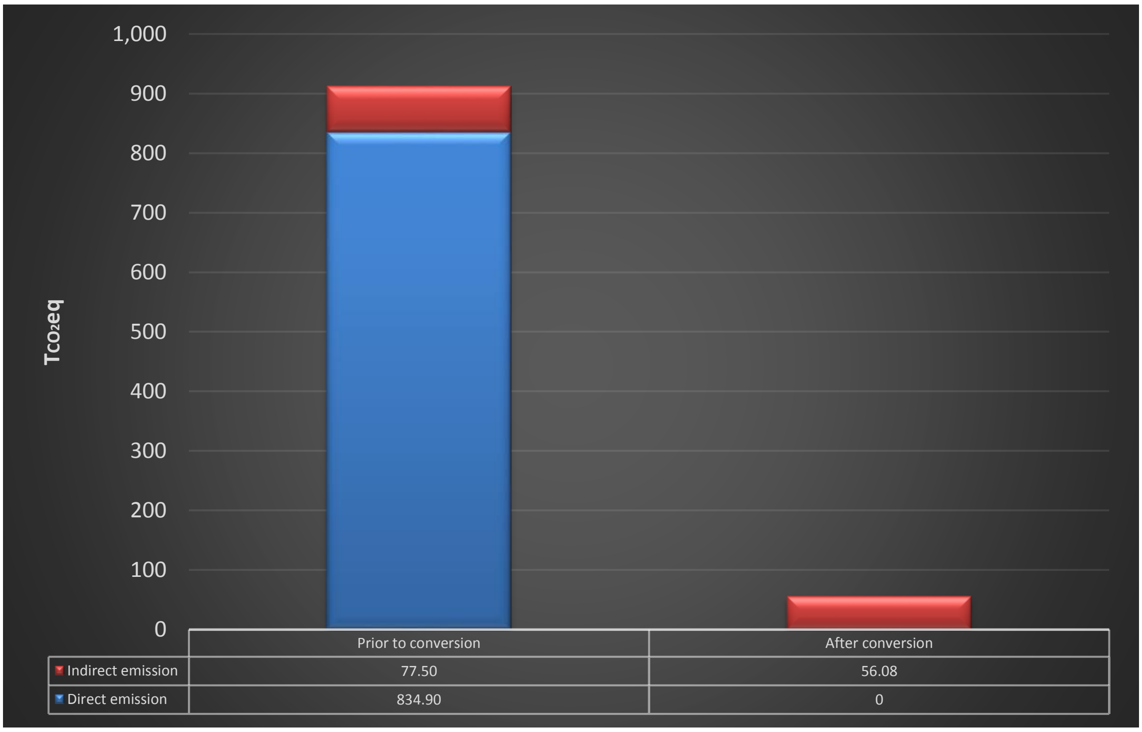


Figure 19 Overall climate impact of the project

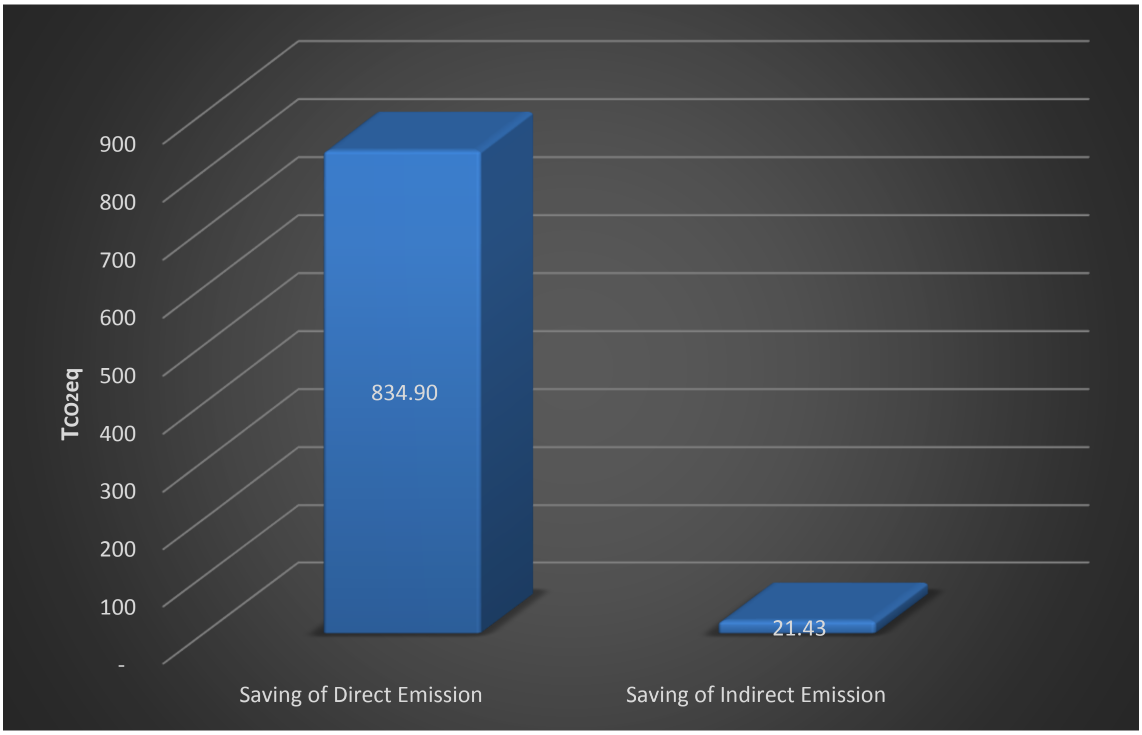


Figure 20 Climate impact of the project by emission types

The total annual reduction of climate impact in the year after the conversion amounted to approximately 856 metric tons CO_2 equivalent. For illustration, this number is equivalent to the annual CO_2 release of approx. 420 passenger cars running 15,000 km in a year! (A currently used mid-size car releases 110 - 160 g CO2 per km.)

The strong commitment of the recipient company as well as of OPROZ, the vendor and of the skills and hard work of the national and international consultants' of UNIDO contributed to the successful completion of the project and laid the foundation for its long-term sustainability and replicability in the country.

Based on the good results obtained in the project, the recipient company La Anónima, has adopted transcritical CO_2 as the default technology for its new branches as well as for updating or refurbishing of current ones, whenever it is feasible.

The project helped to create confidence in the technology. It demonstrated its feasibility, removed many barriers and accelerated the adoption of this technology even for warmer climate zones of this country (e.g. Córdoba, Santa Fe, Salta and Tucuman). As of the date of this report, the number of supermarkets using CO_2 transcritical systems in Argentina increased to a total of 20, belonging to eight different supermarket chains.

At regional level, the same vendor has installed 3 more systems in Chile, 1 in Colombia and 12 in Ecuador from 2017 up to now.

SUSTAINABILITY

The strong commitment of the recipient company as well as of OPROZ, the vendor and of the skills and hard work of the national and international consultants of UNIDO contributed to the successful completion of the project and laid the foundation for its long-term sustainability and replicability in the country.

Based on the good results obtained in the project, the recipient company La Anónima, has adopted transcritical CO_2 as the default technology for its new branches as well as for updating or refurbishing of current ones, whenever it is feasible.

The project helped to create confidence in the technology. It demonstrated its feasibility, removed many barriers and accelerated the adoption of this technology even for warmer climate zones of this country (e.g. Córdoba, Santa Fe, Salta and Tucuman). The number of supermarkets using CO_2 transcritical systems in Argentina increased to a total of 13 belonging to seven different supermarket chains.

At regional level, the same vendor has installed 3 more systems in Chile and 9 in Ecuador from 2017 up to now.

The following e-mail represents a true testimony of the success of the project:

> ***De:*** *Gil Nestor - Epta Argentina <Nestor.Gil@epta-argentina.com>*
> ***Enviado el:*** *miércoles, 26 de febrero de 2020 04:03 p.m.*
> ***Para:*** *Laura Estela Berón <lberon@ambiente.gob.ar>*
> ***Asunto:*** *Buenas nuevas*

Hola Laura, tenemos buenas noticias !

A partir de los resultados de Lincoln, La Anonima y Epta firmamos un acuerdo estratégico para comenzar a reemplazar gases sintéticos por CO2 en sus tiendas existentes. Es una excelente noticia ya que fue anunciada en el marco de EuroShop en Alemania.

Pensábamos que estaría bueno distinguir a La Anonima como primera cadena en instalar Trancritico y también en tomar una decisión de esta característica.

Que opinas ?

Translation:

Hi Laura, we have good news!

Based on the results of Lincoln, La Anonima and Epta, we signed a strategic agreement to begin replacing synthetic gases with CO2 in their existing stores. This is excellent news as it was announced within the framework of EuroShop in Germany.

We thought it would be good to distinguish La Anonima as the first chain to install transcritical equipment and also of having taken a decision accordingly. What do you think ?

Thank you and regards,

Nestor

SUB-PROJECT: TUNISIA

The project funds approved for the Tunisia component amounts to **USD 319,131**.

UNIDO has been working closely with the NOU on the introduction of trans-critical CO_2 refrigeration technology at Monoprix supermarket within the framework of the contract "Demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets in Tunisia". Technical experts were mobilized and the needed ToRs have been prepared and approved by all partners. Unfortunately, the beneficiary decided to withdraw and the project was on hold.

In June 2019, a meeting was held with the NOU and it was decided to look for an alternative beneficiary that can participate in the project. Carrefour was identified as a potential partner. UNIDO mobilized an international expert and a meeting was held with the representative of Carrefour and the Manager of the Technical Department. Carrefour confirmed the plan to build a new supermarket by February 2020 that will be opened by March 2020. No delay on these dates will be allowed given to profitability reasons. The company is present in Tunisia as a franchise of the French firm. This means that the ownership is from Tunisia; there are no French capitals.

The planned cooling capacity is 53,188 W for the positive temperature and 4,700 W for negative temperature. The original plan was to install a system based on R404A. Carrefour representatives committed their agreement to installing a CO_2 trans-critical system in the new supermarket.

After further consultations with the MLF Secretariat, it was decided not to proceed with the installation as the initial intention was to replace an existing technology with the CO_2 trans-critical system rather than performing a new installation. The NOU and the beneficiary have been notified accordingly.

The remaining funds after financial completion will be returned as per decision.

BUDGET AND EXPENDITURES

The financial status of the Project is summarized in Table 3 overleaf.

Item as per Approved Proposal	Budget as per Approved Proposal (US$)	Disbursements So Far (US$)	Remaining Obligations (US$)	Balance (US$)	Comments
Argentina					
New refrigerating equipment	389,866	484,372 (*)			
Food display cabinets	102,303	Included in (*)			
Engineering and transport	15,000	Included in (*)			
Workshops to disseminate results of the project	20,000	23,763			
Subtotal Argentina	**527,169**	**508,135**			
Tunisia					
New refrigerating equipment	245,347	0			
Food display cabinets	43,784	0			
Engineering and transport	10,000	0			
Workshops to disseminate results of the project (intern. consultant, meetings, traveling**)	20,000	20,000 **			
Subtotal Tunisia	**319,131**	**20,000**			
Totals (Argentina + Tunisia)	**846,300**	**528,135**		**318,165**	The remaining funds from the project will be returned to the MLF upon financial closure.

Annex IV

DEMONSTRATION PROJECT ON REFRIGERANT QUALITY, CONTAINMENT AND INTRODUCTION OF LOW-GLOBAL-WARMING POTENTIAL (GWP) ALTERNATIVES

Final Report

85th meeting of the Executive Committee for the Implementation of the Montreal Protocol

March 2020

CARIBBEAN SUB-COMPONENT

Countries:	the Bahamas, Grenada, Saint Lucia, Saint Vincent and the Grenadines, Suriname
Title:	Safe handling of low-GWP flammable refrigerants
Project Budget:	USD 234,584
Implementing Agency:	UNIDO
National Counterparts:	National Ozone Units, National Refrigerant Associations, Vocational Schools

Table of content

I. Background

The phase-out of hydrochlorofluorocarbons (HCFCs), specifically in the refrigeration and air-conditioning sector, brought about a broader discussion on suitable long-term alternatives. Readily available refrigerant alternatives, which are hydrofluorocarbons (HFCs), have however high global warming potentials (GWPs) and contribute to global warming. The refrigeration and air-conditioning manufacturing sectors worldwide, are thus gearing towards the use of low-GWP alternatives, such as hydrocarbons (HCs) and novel refrigerant formulations of HFO and HFC blends, which are designed to have short atmospheric lifetimes.

It has been established that refrigeration service technicians in countries with large service sectors need to be well trained and equipped to cope with the installation and maintenance demands of next-generation appliances. HCs and HFOs have zero-ODP and low-GWP properties, but are flammable. HCs, such as propane, are classed as "A3 - highly flammable". HFOs and HFC blends are classified with "A2L – mild flammability" with slow propagation. Countries are steadily beginning to take up hydrocarbons as an alternative to HCFCs in air-conditioning although few technicians are trained to handle the alternatives effectively. It is anticipated that as old installations near decommissioning, more end-users will opt for hydrocarbon-based appliances.

However, specialised training for technicians on flammability needs to be done to ensure that only well-trained technicians service hydrocarbon-based equipment. Hydrocarbons such as propane, LPG and hydrocarbon mixtures have been used during service operations, where the risks associated with the flammability and the thermodynamically properties of the refrigerants has not always been taken into account. Hence it is important to increase the know-how and confidence of technicians with regard to using flammable low-GWP refrigerants when installing new units or servicing old units.

To address these barriers, the Executive Committee for the Implementation of the Montreal Protocol approved at its 76th in May 2016 a demonstration project on refrigerant quality, containment and introduction of low-global-warming potential (GWP) alternatives. The project was implemented through two components, one in the Caribbean, and one in Eastern African, by UNIDO (lead implementing agency) and UNEP (co-operating implementing agency).

The Caribbean component was implemented by UNIDO in the Bahamas, Grenada, Saint Lucia, Saint Vincent and the Grenadines, and Suriname for a total funding of USD 234,584.

II. Project objectives

In order to facilitate the introduction of low-GWP refrigerants in the servicing sector, the demonstration project aimed to:

- Enhance the expertise of technicians and train specialized trainers;
- Upgrade the training curricula at vocational centers;
- Augment the equipment at the regional training center;
- Expose stakeholders to the latest HC-based equipment and components on the market.

The activities planned under the project were linked to the countries' respective HPMPs. The use of flammable refrigerant alternatives is covered to varying extents in the HPMPs. However, the funding levels of the HPMPs could not adequately cover the issue of flammability. Therefore, regional, as well as country-specific activities were required to bring about a more comprehensive approach that would enable the countries to transition to flammable low-GWP refrigerants in a safe manner, as proposed in the project and described in more details below. Moreover, it was vital that these activities were carried out as soon as possible, so that current HC service practices are conducted safely, in light of the concerns pointed out under decision 72/17 of the Executive Committee.

III. Implementation plan

Activities	**Budget (USD)**	**Countries**
1. Design of training curriculum preparation and monitoring of training	30,000	All
2. Upgrading training centre	72,417	Grenada
3. Train the trainers regional workshop	42,792	All
4. Training sessions for technicians	49,375	All
5. Workshop and exhibition	5,000	Grenada
6. Regional expert group meeting and dissemination of results	35,000	All
Total	**234,584**	

IV. Implementation report

Activity 1: Design of training curriculum preparation and monitoring of training

A regional workshop for policy makers and curriculum developers was held in May 2017, where representatives from national ozone units and training providers were trained on preparing a training course and operational and organisational activities featuring the essential aspects of the training organisation. In addition, various types of certification schemes from different regions were introduced and discussed to serve as a platform to selecting the right components for a scheme for the Caribbean region.

The National Ozone Officers, their alternates, national consultants and training provider during the regional workshop

A regional training curriculum was designed to ensure that only qualified technicians are handling and servicing equipment and flammable fluids. This curriculum encompasses theoretical knowledge as well as specifies practical expertise that must be achieved to get the necessary skills to safely handle low-GWP alternatives and flammable refrigerants. It includes a list of the appropriate equipment and materials for training of technicians. In addition, the competence and requirements for an adequate assessor and venue requirements are also provided. This curriculum should be adapted by each country for their respective schemes, but it is already in use at the regional training center in Grenada, together with a training programme developed by the GIZ. The complete curriculum is provided in annex 1.

Activity 2: Upgrading Training Centre

In order to facilitate the introduction and the safe use of low-GWP refrigerants, the regional training centre in Grenada at the T.A. Marryshow Community College (TAMCC), St. George's was upgraded in 2017 with equipment, tools and materials suitable for low-GWP flammable refrigerants.

The list of items was established in consultation with the National Ozone Officer of Grenada, and other National Ozone Officers of the region, based on needs identified at the regional level and following the recommendations contained in the training and certification curriculum on flammable refrigerants developed as part of the project and the "Guidelines for the safe use of hydrocarbon refrigerants" developed by the GTZ Proklima in 2010.

Items delivered included manifolds with gauge for hydrocarbons, electronic leak detectors for flammable refrigerants, portable charging stations for hydrocarbons, propane and butane gas cylinders, and other tools and material for use of low-GWP refrigerants in air-conditioning. The complete list of equipment, tools and materials delivered is provided in annex 2.

In 2019, the regional training center was operating fully for the RAC technicians of Grenada, and will open to technicians of other countries of the region in 2020. The training center has the capacity to train up to 20 technicians per session, and it is envisaged that once open to other neighbouring and participating countries, up to 10 technicians could come from outside Grenada at each session. Participation of technicians from all countries in the training remains subject to availability of financing. Countries are therefore invited to consider possible source of funding such as the national HPMPs or other ozone or climate related projects.

Activity 3: Train the trainers Regional Workshop

A regional train-the-trainers workshop was organised in Grenada on 22-25 August 2017. 20 RAC technicians, four from each of the participating countries, were trained as trainers on theoretical and practical aspects of refrigeration servicing, in particular on the safe handling of refrigerants and alternatives. Technicians who participated in the workshop already possessed consistent knowledge and practical skills on HFCs and other traditional refrigerants. The full list of technicians who attended the workshop is provided in annex 3.

The objectives of the workshop were more specifically to:

- Disseminate technical knowledge on the flammable refrigerants necessary to operate with these types of refrigerants;
- Showcase the reduction of direct and indirect global warming emissions that it is possible to obtain with systems using flammable refrigerants thanks to their better energy efficiency;
- Present the safety aspects, as mandatory knowledge required when dealing with the flammable refrigerants;
- Provide practical and technical skills, which would allow technicians to maintain andrepair flammable refrigerant-systems in safe conditions;
- Provide a consistent theoretical and practical knowledge (train-the-trainers) for future training of other technicians in their area;
- Activate a l knowledge process, which students could further develop for a life project of continuous learning.

The workshop consisted of both theory and practice sessions, preparing for the final assessment. The training took place at the TAMCC, recently upgraded with equipment, tools and materials suitable for low-GWP flammable refrigerants. Part of the theoretical lessons were prepared based on the REAL alternatives learning material, and on guidelines on F-gas refrigerants. Furthermore, additional material was prepared specifically by the trainer, based on European laws.

The theoretical topics presented during the workshop included:

- Information on HCFC-free technologies available or HCFC alternative substances in servicing including training on the safe handling of refrigerants and alternatives, mainly those with high toxicity, flammability or pressure;
- Refrigeration principles and fundamentals, refrigerants, temperature-pressure relation and diagrams, refrigerant properties;
- Thermodynamic principles, basic components of the refrigeration cycle;
- Applications with a choice of components, compressors, evaporators, condensers, calculations and sizing;
- Refrigerating plant: efficiency and refrigerating capacity, maintenance, disadvantages, correct installation, component functionality control (compressor, condenser, evaporator, valves), main electrical problems, different types of refrigerants, lubricants and problems connected with their utilisation, faulty functioning of refrigerating plants;
- Presentations of hydrocarbon applications in window and split type air-conditioners, chiller, etc.;
- Methodology for conducting risk assessments for systems and equipment using

hydrocarbon/flammable refrigerants, e.g. electrical components.

Participants during the theoretical session

The practical session covered the following aspects:

- Introduce good practices to avoid the refrigerant emissions during servicing, troubleshooting and maintenance, including refrigerant containment;
- Vacuum, charge. regulation, tools, recovery, retrofit, drop-in, manometer reading, pressure gauge;
- Research and damage detection, leak detection, valves, filters, oil and liquid separators;
- Practical applications of hydrocarbons in the refrigeration-servicing sector;
- Safe handling of flammable refrigerants.

At the end of the training course, an assessment was carried out and successful participants received the F-gas and the REAL alternatives certifications. These certifications are recognised worldwide and certify the competence level of technicians for handling refrigerant gases- in this case, F-gases and flammable refrigerants. An example of the REAL alternatives certificate is provided as annex 4.

Activity 4: Training sessions for technicians

Two hydrocarbon-based air-conditioning units were delivered to each country (apart from Grenada, which received units earlier for the regional training centre) to organise their in-country training sessions. This activity met with difficulties as manufacturers of hydrocarbon-based air-conditioners are still reluctant to sell small quantities commercially. Based on consultations with National Ozone Officers, additional purchases of materials were made in all countries but Grenada to ensure that each country is well equipped for their in-country training. The complete lists are provided as annex 5.

As of March 2020, 85 air-conditioning technicians have already been trained during the country training sessions organised since the train-the-trainers regional workshop which took place in August 2017 in Grenada. An additional 40 to 70 technicians will be trained before August 2020. When possible, the trainers trained during the workshop have been carrying out the country training sessions. The detail of the training sessions by country is provided hereafter.

The Bahamas:

A three-evening training course was organised on 20-22 August 2019 for 9 technicians. One local RAC trainer and the National Ozone Officer conducted the training. The full list of participants to the training is provided in annex 6.

The topics covered included: properties of hydrocarbons, toxicity, flammability restrictions on use of hydrocarbons, availability of hydrocarbons, design characteristics of appliances using hydrocarbons, leakage issues and leak detection, maintenance and repairs of appliances using hydrocarbons.

Grenada:

A two-day training course was organised on 8-9 May 2019 for 32 technicians. Two local RAC trainers and the National Ozone Officer (NOO) conducted the training. The technicians were required to have at least three years working experience in the field of RAC to participate in the training. The full list of participants to the training is provided in annex 6.

Major topics covered in the training included but were not limited to: properties of hydrocarbons, risk assessment, legislation, policy and standards, fire and electrical safety, charge limitation and room size calculations, personal protective equipment and specialise tools and equipment required for installation and servicing, leak detection, installation, servicing and maintenance practices, and brazing and pipe connections. The methodology used included a combination of power point presentations, lectures, handouts and multi-media.

Participants during the theoretical session

During the practical training, the participants were required to demonstrate their competence in brazing, flare joint connections, leak and pressure testing, evacuation, venting and charging of refrigerants.

Participants during the practical work

During the evaluation participants were asked to give their overall rating of the training. Out of 27 respondents, 18 rated the training as been excellent, eight as very good and one as good. At the end of the training, certificates of participation were awarded to all the participants.

Participants receiving their certificate

<u>*Saint Lucia:*</u>

A two-day training session was organised on 4-5 February 2020 for 11 air-conditioning technicians. The facilitators of the training were two refrigeration technicians who underwent training in flammable refrigerants and their technology under the "train the trainer" component of the project. The full list of participants to the training is provided in annex 6.

Participants during the theoretical session

The first day was dedicated to theoretical aspects, including a presentation of the Montreal Protocol and of the HPMP for Saint Lucia, descriptions of the most common types of refrigerants, measures for the safe handling of flammable refrigerants and good servicing practices for flammable refrigerants, and a reminder of thermodynamic notions relevant to refrigeration and air-conditioning, At the end of the first day, participants were given an examination to assess their knowledge and understanding on the subjects covered during the theoretical component. The second one consisted of practical sessions and hands-on exercise.

Overall, the technicians found the training to be very useful and informative. The recommendations which were made by participants included the organisation of longer training sessions and the possibility for RAC technicians to purchase HC-based servicing tools to familiarise themselves with the technology.

Saint Vincent and the Grenadines:

A four-day training course was organised on 10-13 February 2020 for 11 technicians on the safe handling of low-global warming potential flammable refrigerants. Two local RAC trainers and the National Ozone Officer conducted the training. The full list of participants to the training is provided in annex 6.

The range of topics selected for the training session were geared towards ensuring that technicians are adequately prepared for the introduction and use of flammable refrigerants. These topics included: refrigeration cooling system, hydrocarbon refrigerants, flammable refrigerant safety, GIZ cool training programme and overview of training, safe design and general criteria for hydrocarbon refrigerants, hydrocarbons vs hydrochloroflourocarbons.

Participants during the theoretical session

The training also included practical work and hands-on exercise on the following topics: brazing project, testing and evaluation, demonstration of brazing with and without nitrogen, fabrication according to best practice, installations of hydrocarbon air conditioner, collection of data and system's analysis, requirements for data recording and labelling of systems, leak testing.

Participants during the practical work

Full day sessions were well attended by all registered participants. Theoretical sessions not only created an opportunity for technicians to have a better understanding of the use of hydrocarbon refrigerants, but also created a forum where participants were able to interact and network with other personnel within the industry to share their experiences. The practical exercises were successfully completed by all technicians. Participants indicated their appreciation for the training workshop and expressed a desire to be involved in similar sessions.

Suriname:

22 technicians were trained following the train-the-trainers workshop in Grenada in August 2017. All the technicians are members of the Air-conditioning, Refrigeration & Ventilation Association Suriname (ARVAS).

This training programme is now being extended, with multiple sessions taking place from March to August 2020, for an additional 40 to 70 technicians, in particular non-ARVAS members technicians and technicians from the informal sector. Each session will last four days, with two days of theory on topics such as basic thermodynamics, the cooling system, refrigerants, alternative refrigerants (hydrocarbons, carbon dioxide), differences between alternative refrigerants and HCFC, safety aspects,and compressor replacement and instalment. The two following days will be dedicated to practical sessions.

Activity 5: Workshop and exhibition

The workshop and exhibition was intended to showcase the offer of appliances using low-GWP alternative and servicing equipment offered by regional and international suppliers. Representatives from these suppliers would have participated to present their offers and answer questions from workshop participants. It was in particular envisaged to organise the exhibition back to back with the regional expert group meeting to create synergies between the discussions with the suppliers' representatives, and those on the success and challenges of the project among shareholders.

As international suppliers expressed the desire to understand better regional market conditions and trends, market surveys for each country have been considered and started, but the lack of data available, both in the countries and from public sources, did not allow to draw any certain and conclusive results. More generally, the lack of data on the market remains a challenge to encourage international suppliers of HC equipment to increase their presence in the region. The geographical distance from markets which are more mature in terms of natural refrigerants is also seen as a barrier to the growth of trade between the region and international suppliers or manufactures. Hence, only documentation and catalogues were collected from international suppliers and no representative participated in the event.

Regarding regional suppliers, a representative from Grenz concept, a reseller of R290 appliances and RAC equipment participated remotely in the regional expert group which took place in Paramaribo, Suriname, on 5 October 2019. The representative gave on this occasion a presentation on its offer and business model, and answered the questions from participants. He indicated in particular that the recent end of the production of the 12,000 BTU units by Godrej is an issue as these models are the most popular in the country. It is supposed that Godrej stopped the production of these units due to the dynamics of its domestic market, India, where the 18,000 and 24,000 BTU units are preferred because of the very high ambient temperature.

The representative of Grenz concept further indicated that warranty is not offered by the company to customers if the appliances are not maintained by trained technicians. The manufacturer on its side guarantee the compressor for 10 years, and five years for the rest of the unit. Grenz concept currently sells in Guyana and Trinidad and Tobago, and estimates that there is a potentially large market in the Caribbean for R290 appliances. Shipping time from India is three months, therefore Grenz concept mostly operates based on stocks. The 12,000 BTU units are sold nationally for USD 900, and the 18,000 BTU for USD 1,300, both excluding transportation. The supplier's representative indicated that it would be ready to supply other countries, as the the representative from Saint Lucia in particular demonstrated strong interest.

Activity 6: Regional expert group meeting and dissemination of results

The regional expert group meeting took place in Paramaribo, Suriname, on 5 October 2019. 11 persons, including National Ozone Officers or their alternate representatives, attended the event. Two additional persons joined the meeting remotely. The attendance per country or organisation is as follows: the Bahamas (1), Grenada (2), Saint Lucia (2), Saint Vincent and the Grenadines (2), Suriname (3), Grenz concept, a supplier of R290 appliances in Grenada (1), and UNIDO (2). The topics discussed during the expert group meeting included among others the barriers to the introduction of low-GWP alternative, the curriculum and national training programs, as well as the

lessons learned of the project. The full list of participants to the regional expert group meeting is provided as annex 7.

Participants during a working session

Persistent Barriers to the introduction of low-GWP alternative:

In Suriname, R290 appliances and maintenance equipment are not present in the country to date. However, R32 equipment are available as well as R600a ones to a lesser extent. There are only two suppliers of refrigerants in the country, but they do not supply R290 gas. The main problem to the uptake of natural refrigerant in the country is the cost of the appliances, which is a complex issue to address due to the low consumption of the country.

In Saint Lucia, R290 appliances, maintenance equipment and gases are also not present in the country to date, except some R290 chillers. For the phase-out of CFCs, the government played an instrumental role in bringing alternative equipment in the country by developing collaboration with suppliers, but similar actions are still to be implemented for natural refrigerants. A majority of technicians still refuse to use R290 as a refrigerant, due to safety concerns, and even ignore that some chillers operating with R290 exist in the country.

In Saint Vincent and the Grenadines**,** R290 appliances, maintenance equipment and gases are as well not present. Further, there is a fatigue with regard to HC training and sensitisation. There are only three RAC maintenance companies in the country. Out of the four trainers trained during the train-the-trainers workshop, only one is ready to train technicians. The lack of availability of trainers locally remains an issue in organising more training sessions. The high number of private islands in the Grenadines is an additional challenge to control the equipment and technologies entering the country.

In Grenada, there is a lack of institutional and technical capacity to deal with natural refrigerants, in particular economic and fiscal barriers. The government could take further appropriate measures in this regard. Regarding availability of equipment, the situation in Grenada is different from the one in other countries. There are two suppliers of R290 appliances, all manufactured by Godrej. There are few suppliers of gases, different from the resellers of equipment. However, R290 specific maintenance equipment are not available in the country. All these suppliers embarked on alternative refrigerants supply following business recommendations and support from the National Ozone Office. There is also a need for additional awareness raising, as HC suffers from bad press and create fears among technicians. Additionally, standards and codes (in particular regarding charging procedures, room. size, brazing methods, venting, etc.) are not yet well known by the whole technician community. This should improve as training sessions are extended to more technicians. Specific technical topics, such as moisture prevention on equipment operating with R290 or R600a, are to be better addressed by the continuous training programme as technicians are not familiar with the specificities of hydrocarbons.

In the Bahamas, most if not all technicians in the country still ignore hydrocarbon use. The main barrier is the lack of equipment in the country since the market is mainly dependent on the US market. The country does not have any supplier of R290 appliances, maintenance equipment or gas.

Curriculum and subsequent training:

The curriculum is not yet officially adopted by individual countries, but it has already integrated the body of reference material available in the region to design training on the safe handling of low-global warming potential flammable refrigerants. At the regional training centre at TAMCC in Grenada, it is used in combination with training material developed as part of a project with the GIZ.

In Suriname, 22 technicians were trained following the train-the-trainers workshop in Grenada in August 2017. In Saint Vincent and the Grenadines, the training of technicians following the train-the-trainers workshop did increase their confidence in alternative technologies.

The group agreed together with UNIDO that the curriculum will be further discussed.

Other discussions:

The group had extensive discussion on the voltage and frequency for the operation of R290 air-conditioners. Currently no equipment are available for countries using 110V/60Hz mains electricity. Technicians from Suriname, Grenada and Saint Lucia further indicated that countries with 60Hz frequency cannot use appliances made for 50Hz. This is a major limitation to the intake of R290 in the Caribbean and elsewhere. Using appliances designed to operate at a frequency of 50Hz in countries having 60Hz was deemed as counterproductive, as it increases energy consumption, reduces appliance lifetime, and leads to early malfunctioning. However, it was noted that technical assessments could be carried out with R290 appliances to examine how they operate under 110V/60Hz mains electricity, and if local alternatives could be developed. Finally, it was indicated that no appliances operating at 110V/60Hz is to be expected to be developed as long as .

The group also exchanged views on the risks associated with brazing and retrofitting appliances for use with R290. Grenada indicated that the GIZ developed a step-by-step guide on retrofitting, and that if correctly done, with all the necessary safety measures to prevent ignition, retrofitting can be consider as a viable option in absence of R290 appliances in the countries. Grenada explained that, in the national training, one full day is dedicated to brazing and safety measures while brazing. Grenada however strongly discouraged against using 290 as a drop-in replacement in appliances designed for the other refrigerants. It was further noted that the MLF and UNIDO strongly advise against the retrofitting of appliances or drop-in replacement, due to the safety risks and lack of awareness on dangers of hydrocarbon use in both scenarios.

Finally, tools available to promote good servicing practices were discussed by the group. Grenada in particular presented how to use the Android application “Good Servicing: Flammable Refrigerants Quick Guide”. Grenada showed for example how to calculate the minimum floor area based on refrigerant charge, and vice versa. Grenada encouraged the group to promote the mobile application among their national technician community.

V. Financial status

Activities	Budget (USD)	Total expenditures (USD)
1. Design of training curriculum preparation and monitoring of training	30,000	28,701
2. Upgrading training centre	72,417	77,874
3. Train the trainers’ regional workshop	42,792	42,769

4. Training sessions for technicians	49,375	62,643
5. Workshop and exhibition	5,000	0
6. Regional expert group meeting and dissemination of results	35,000	21,989
Total	**234,584**	**233,976**

VI. Lessons learned and recommendations for the sustainability of the project

Some of the following recommendations were made during the expert group meeting held in Paramaribo in October 2019 and after observations from project implementation:

- Individual countries to consider legally adopting the curriculum with small adaptations for country specificity where needed;
- Take appropriate measures to ensure that the regional training center in Grenada opens to RAC training technicians of other participating countries in 2020;
- Assess on a regular basis the capacity of the regional training center in Grenada and consider the need for a second regional training center in another country if capacities are not sufficient;
- Develop appropriate mechanisms and partnerships to encourage international suppliers or manufacturers of HC equipment and tools to offer a stronger presence in the region;
- Collect and analyse RAC market data with the view to encourage international suppliers or manufacturers to offer a stronger presence in the region;
- Develop appropriate mechanisms to encourage local suppliers to distribute HC equipment and tools;
- Envisage group purchases at the regional level of HC equipment and tools for distribution to local resellers with the view to limit the impact of transportation costs;
- Consider the opportunity to create a regional refrigeration association;
- Formulate monitoring and incentive mechanisms to encourage trainers and trained technicians to increase their participation in awareness raising and capacity building exercises conducted at the national and regional levels;
- Attract additional financial support from international funding bodies for the introduction of low-GWP alternatives refrigerants, in particular to fund capacity building programmes for technicians in the region (through the regional training center in Grenada or at the national level);
- Consider developing eco-labeling schemes for cooling appliances and/or reward schemes when consumers buy green cooling appliances;
- Increase in public tenders the minimum COP required for RAC appliances so as to encourage other users to switch to more energy efficient and modern equipment such as those using low-GWP refrigerants;
- Consider the opportunity to impose fees on appliances which use high GWP refrigerants;
- Consider compulsory technical requirements for designing, constructing or retrofitting civil

buildings (offices, hotels, hospitals, schools, apartment blocks, or trade and service facilities, etc.) with a floor space above a certain size;

- Carry out technical assessments with R290 appliances to examine how they operate under 110V/60Hz mains electricity (as found in the Bahamas among others);
- Develop platforms in each country (e.g. social media, mobile messaging applications) for information sharing among technicians. Such solutions have been implemented in Grenada, and have been facilitating the dissemination of information (e.g. event, training, technical information) by the National Ozone Office and favored mutual assistance by technicians;
- Reinforce presence of RAC technicians in regional meetings, in particular in the Caribbean Network Meeting of the National Ozone Officers. In the past, RAC technicians used to participate in regional meetings. Their involvement in the Regional Expert group provided valuable technical inputs, and participants expressed the wish to benefit from their expertise on technical issues on a more frequent basis.

Annex 1: training curriculum

See next page.

CURRICULUM TRAINING
ON FLAMMABLE REFRIGERANTS

"Refrigeration and Air conditioning using Flammable Refrigerants"

Summary

Disclaimer: The principles contained in this Guide are not legally binding, and following them gives no legal guarantee. A binding interpretation of legislation is the exclusive competence of the European Court of Justice. CSG also recommends to readers, when using this Guide, to always refer to the national legislation, and guidance if any, of the State they are dealing with.

Curriculum Training on flammable refrigerants

Scope

Design of a regional training curriculum for Refrigeration and A/C technicians working with HC A3 (HydroCarbon - HC) and A2L refrigerants. Training curriculum intends to provide the appropriate and practical knowledge and skills to safely and efficiently install, maintain, repair and dismantle refrigeration systems that utilize HC and to a lesser extend A2L refrigerants.

Training is to be devised with a maximum of practical skills and with the minimum of required theoretical content.

Training curricula and necessary equipment

Course details

1) Major (safety / environmental) differences between non- flammable, HC and " A2L" refrigerants
2) Thermodynamic characteristic of Hydrocarbons as refrigerant - p/h diagram
3) Specific components for Hydrocarbons – difference between conventional components and HC specific components
4) Electronic components suitable for flammable refrigerants
5) Refrigeration and Air conditioning applications with HC refigerants
6) Recovery or Venting of HC refrigerants
7) Recovery of A2L refrigerants
8) Vacuum-Charging procedures for HC refrigerants – accuracy / repercussions for over-undercharging
9) Leak testing
10) Mechanical/compression joint connections – avoid brazing
11) Flammability and safety issues
12) Review of Local (if any) guidelines for HC refrigerants – gases
13) Review of International guidelines for the use of HC refrigerants – practical and basic
14) Transport and storage requirements
15) Documentation

Venue requirements and necessary equipment details

See Annex 1

Learning / assessment components

T – Theoretical P – Practical	HC
BASIC THERMODYNAMICS AND PHYSICS	
Thermodynamic properties of HC refrigerant: temperature, pressure, density, thermal capacity, log p/h diagram	T/P
Differences between HC refrigerants and HFCs	T
Characteristic of flammability of the substances, velocity of propagation, LFL, UFL, occupancy	T
Specific components for HC / A2L refrigerant in the refrigeration cycle	T/P
Oil compatibility, oil safety, requirements and oil return	T
REGULATIONS AND STANDARDS	
If available;review of local guidelines for HC (refrigerants) as well as review of international safety guidelines	T
Storage and transportation of HC refrigerant	T
Instructions to end user / customer	P
GOOD PRACTICE[1]	
State and identify the commonly used refrigerants' designation	P
How to label HC refrigerant RAC systems[6]	P
Identify appropriate tools, equipment and PPE for work on HC RAC systems	P
Recovery of A2L refrigerant (when / when not – precautions)	P
Safely removing (venting) HC refrigerant from Refrigeration or A/C system	P
Calculate the max fill weight for a refrigerant recovery cylinder for (A2L) refrigerants	P
Pressure test check direct assessment using appropriate techniques	P
Vacuming the refrigerant circuit – purpose, process	P
Charging of an HC refrigerant system without refrigerant loss (emission) – accuracy / procedure	P
Make a connection without brazing with alternative connections	P
Check the correct functioning of the safety ventilation system	P
Check the correct functioning of the safety system controls	P
HEALTH AND SAFETY REQUIREMENTS	
Safe system shutdown and isolation [6]	P
Extinguish a fire, identify the appropriate fire extinguisher	P
First aid treatment for frostbite	P
First aid treatment for fire burn	P
First aid treatment for suffocation due to breathing problems	P
Safety issues related to high pressures	T
Calculate LFL (confined space)	T
Calculate confined space risk for asphyxiation (heavier than air)	T
Check that Health and Safety rules in the refrigeration system location are respected (emergency exits, fire alarms, leak detectors…)	T
Correct use of Personal Protective Equipment	P

Assessment Structure

Structure of the Exam, tests multiple choice, written (also oral will be considered) with bank of questions, papers for the practical session, Open Book.

In Annex 2 a bank of questions is listed for flammable refrigerants (Certifications on Real Alternatives flammable refrigerants Category HC)

[1] All practical trainings should include theoretical training

Assessment: practical organization issues

It is recommended that the following guidance is followed for the organization of Assessments:

1) The assessment should last 1 day and the candidate will be informed on the same day if they passed. The certificate will be printed and sent after approximately 2 weeks

Theoretical assessment	60 minutes i.e. 9 am – 10 am
Practical assessment	Start just after the theoretical assessment i.e. starting from 10 am . Each candidate in max 2.5 hours should perform all the activities

Theoretical assessment – examination session

2) The candidate should arrive 30 minutes before the scheduled exam time
3) Each candidate MUST have a photo ID to present to the assessor. No one will be allowed to take the exam without it.
4) All electronic devices should be turned off and left in a safe area designated
5) Maximum 20-25 candidates per class dependent on number of assessors (1 assessor/assistant every 10 candidates)
6) Multiple answers tests, 30 questions for 60 minutes duration
7) The same test among candidates with variation of questions to prevent predictability among candidates
8) Open books and specific technical tools such as calculator and pressure-temperature comparator should be available
9) NO! mobile phones or cameras
10) NO! copying or communication between candidates
11) YES! speaking to the assessor for clarification; many candidates use different words and vocabulary to identify the same concept (eg. Valves)
12) Theoretical assessment: Pass mark above 60% correct answers
13) The test could be performed orally if the candidate has asked prior to the beginning of the exam and the assessor has agreed to this arrangement

Practical Exam and Tasks

Practical assessment:

In Annex 3 there are papers to complete during the Practical session and in Annex 4 there are the Instructions

14) The laboratory should be properly equipped for performing the practical test (see Annex 1 for Venue Requirements). Measuring instruments should be calibrated.
15) There are 3 stages of assessment (1. thermodynamic parameter reading, 2. Pressure test, Vacuum, Charge, Recovery, 3. Brazing) for assessing 3 candidates at time, divided by the practical activities to speed up the process. An alternative is to combine “ thermodynamic exercise” (P/T, Superheat,

Subcool, comments) and pressure test, vacuum, recovery in one exercise and brazing in another. Increase the difficulty on brazing by adding an expansion valve, check valve or rotalock fitting.

16) Pass if candidate proves competence in performing all (100%) main RAC service technicians activities without or with only small hesitations (remember candidates could be knowledgeable but be nervous!):

- **B)** Thermodynamic parameters reading through gauges and devices, temperature, pressure, subcooling, superheating,
- **C)** Parameters interpretation, troubleshooting
- **D)** Perform a pressure/leak test
- **E)** Vacuum, charge, recovery with minimum emissions
- **F)** System Logbook reading, understanding and completing
- **G)** Brazing leak tight joints with proper capillary flow.

Training Material and Real Alternatives

Training material can be found at the following link which is a project financed by EU and to which Centro Studi Galileo, the Italian Association of Refrigeration and the European Association AREA has worked for Blended Learning on Alternative Refrigerants. Free of charge but with Licences to use it for commercial purposes (Enquire Licencing modalities to buoni@centrogalileo.it).

www.realalternatives.eu

Assessor Qualification and competence

Assessors and Trainers should be sufficiently skilled in the curriculum

Assessors should be unbiassed in trainees' evaluation

Annex 1 Venue requirements for training and assessment

A Venue is required both for the training and assessment sessions. It is of paramount importance that safety of teacher, students and staff is warranted.

For the theoretical section, technical teaching aids such as beamer/LCD screen, PC/Laptop and white or chalkboard are required. Adequate seating arrangements as well as air conditioning / heating and sufficient light must be provided.

As for the practical section; the venue must be well ventilated, lit and have sturdy workbenches.

Necessary equipment and components (minimum)

1) Training model HC a/c and refrigerator unit
2) Nitrogen Regulator - Cylinder of High Purity Nitrogen
3) Electronic Weighing Platform (accuracy 1 gram)
4) Electronic Vacuum gauge
5) Manifold set - Hoses with ball valves
6) Vacuum Pumps and Hose
7) Recovery Unit
8) Recovery Cylinder
9) Electronic Leak Detector
10) Proprietary Leak Spray
11) Temperature meter
12) Ammeter
13) Tools, Pipe Cutters, Pipe Deburring Tool, Pipework Expanders, Hacksaws, Brazing Rods
14) Flaring Tool
15) Personal protective equipment PPE

Annex 2 Bank of questions (#40)

Question 1 A2L

Mod 3 Eff leak test	Which system is not as suitable for a fluorescent additive leak detection system	One with a coalescing oil separator
		A trans critical system
		A cascade system
		A two stage system

Question 2 A2L

Mod 3 Eff leak test	How frequently should a hand-held electronic leak detector used for R32 be checked?	At least once per year
		There is no requirement for leak detection of R32
		The frequency depends on the charge size
		After every 100 hours of operation

Question 3 A2L

Mod 3 Press testing	What is the benefit of using hydrogen as a trace gas with nitrogen for pressure testing	It has a small molecule and diffuses more readily
		It is easily detectable
		It has an odour
		It is non flammable

Question 4 A2L

Mod 3 Leak test regime	Under the revised F Gas regulation (from 01.01.2015) how frequently would a system containing a charge of 60 tonnes CO2-equivalent of	Twice per year
		Once per year
		Four times per year
		Leak testing is not required

	refrigerant need to be leak tested?	

Question 5 A2L

Mod 3 Indirect leak testing	What is the effect on the high pressure side of a system (with no head pressure control) if it is short of refrigerant?	The discharge pressure will be lower and the degree of subcooling will be lower
		The discharge pressure will be higher and the degree of subcooling will be lower
		The discharge pressure will be higher and the degree of subcooling will be higher
		The discharge pressure will be lower and the degree of subcooling will be higher

Question 6 A2L

Mod 4 Flam refs	Why should you not use an HFC recovery machine on R1234ze?	It contains sources of ignition
		The recovery machine oil is not miscible with R1234ze
		The recovery machine will not withstand the operating pressure of R1234ze
		The low pressure switch setting will not be suitable for R600a because of its lower operating pressure

Question 7 A2L

Mod 4 Flam refs	How do you make sure it is safe to switch on a vacuum pump to evacuate an R32 system?	Use an R32 gas detector to ensure there is no Flammable refrigerant in the area
		Recover the system down onto a slight vacuum before fully evacuating the system with the vacuum pump
		Flush the area with nitrogen before switching on the pump
		Fit a long hose on the outlet of the vacuum pump to discharge the R32 away from the work area

Question 8 A2L

Mod 4 Flam refs	How do you remove as much refrigerant as possible from a condensing unit system with a charge of 800 g R1234ze?	Recover the R1234ze so the system is on a vacuum, break the vacuum with oxygen free nitrogen to pressure of 0.1 bar g
		Recover the R1234ze so the system is on a vacuum
		Vent the R1234ze outside and evacuate the system
		Vent the R1234ze outside; fill the system with oxygen free nitrogen to a positive pressure, vent and evacuate twice, fill the system with nitrogen for a third time and vent

Question 9 A2L

Mod 2 R32	What is the typical PS for the low side of an R32 system with an air cooled condenser in a 32^{O}C ambient?	19.3 bar g
		14.3 bar g
		34.2 bar g
		65 bar g

Question 10 A2L

Mod 3 Leak Points	Which document provides torque values for manually made flared joints	EN378
		The F Gas regulation
		The Pressure Equipment Directive
		EN60079

Question 11 A2L

Mod 3 Indirect leak testing	What is the effect on the low pressure side of a system (with no suction pressure control) if it is short of refrigerant?	The suction pressure will be lower and the useful superheat will be higher
		The suction pressure will be higher and the useful superheat will be higher
		The suction pressure will be lower and the useful superheat will be lower

		The suction pressure will be higher and the useful superheat will be lower

Question 12 A2L

Mod 2 R32	What is the typical PS for the high side of an R32 system with an air cooled condenser in a 32^{O}C ambient?	34.2 bar g
		24.8 bar g
		19.3 bar g
		120 bar g

Question 13 A2L

Mod 2 R1234ze	What is the typical PS for the high side of an R1234ze system with an air cooled condenser in a 32^{O}C ambient?	10.3 bar g
		19.3 bar g
		24.8 bar g
		120 bar g

Question 14 A2L

Mod 3 Leak Points	Why are flare solder adaptors used	They have a factory machined face
		They are brazed onto the pipe work
		They cannot be disconnected once fitted
		They only need to be hand tight

Question 15 A2L

Mod 3 Press testing	What is the approximate rise in nitrogen pressure if its temperature increases by 5^{O}C?	0.7 bar
		There is no change in pressure
		7 bar
		4.75 bar

Question 16 A2L

Mod 1 Intro, Safety	The hazards of R32 include:	Mild flammability
		High flammability
		High toxicity
		Mild toxicity

Question 17 A2L

Mod 3 Leak test regime	According to the latest F Gas regulation (EU517/2014) how frequently must an R1234ze system with a charge of 300kg and no fixed leak detection system be chacked?.	It does not need to be leak tested
		Once per year
		Twice per year
		Four times per year

Question 18 A2L

Mod 1 Intro, Safety	The hazards of R1234ze include:	Mild flammability
		High flammability
		High toxicity
		Highly corrosive

Question 19 A2L

Mod 1 Intro	R32 is used in systems which traditionally use …	R410A
		R134a
		R404A
		R290

Question 20 A2L

Curriculum Training on flammable refrigerants

Mod 1 Intro	What type of refrigerant is R1234ze?	An HFC which has unsaturated carbon
		A hydrocarbon
		Carbon dioxide
		An HFC which has saturated carbon

HC

Question 1 HC

Mod 1 Restr on use HC	What is the maximum charge of R1270 that can be used on a supermarket shop floor (occupancy category A)	1.5 kg
		150 g
		It cannot be used in this application
		There is no limit

Question 2 HC

Mod 1 Intro HC	What is the predominant application for R600a?	Domestic refrigerators and freezers
		Car air conditioning systems
		Glycol chillers for process cooling
		Central plant retail systems

Question 3 HC

Mod 1 Perf HC	What compressor displacement is required for R1270 compared to that used for R404A?	Similar
		50%
		150%
		600%

Question 4 HC

Mod 2		To disperse the refrigerant safely in the event of a leak

R717 R32 R1234ze HCs	On some systems which use a flammable refrigerant, why does the condenser fan run constantly?	To avoid a build up of contamination on the condenser
		To ensure the head pressure is never excessively high
		To reduce energy consumption

Question 5 HC

Mod 4 Intro HC	Why is the charge weight accuracy more important on critically charged R1270 systems compared to HFC systems?	Because the density is less so the charge weight is less compared to a similar HFC system
		Because these systems never have liquid receivers
		Because R1270 is only used in systems with less than 150 g charge weight
		Because of the lower operating pressures

Question 6 HC

Mod 4 Flam refs HC	What is the safe R290 fill weight for a recovery cylinder which has a safe fill weight of 10 kg for R404A?	4.5 kg
		10 kg
		15.4 kg
		22 kg

Question 7 HC

Mod 4 Flam refs HC	Why should you not use an HFC recovery machine on R600a?	It contains sources of ignition
		The recovery machine oil is not miscible with R600a
		The recovery machine will not withstand the operating pressure of R600a
		The low pressure switch setting will not be suitable for R600a because of its lower operating pressure

Question 8 HC

Mod 4 Flam Refs HC	How do you avoid the risk associated with the on/off switch on a standard vacuum pump when evacuating an HC system?	Use the vacuum pump in a well ventilated area and switch on at least 3 m away from the pump
		Fit a long hose to the pump's outlet to discharge the HC away from the system
		Position the vacuum pump 3 m above the floor
		Position the pump outside

Question 9 HC

Mod 4 Flam refs HC	How do you make sure it is safe to light a brazing torch to un braze a joint on a system which operates on a flammable refrigerant?	Ensure the area is well ventilated and use a flammable gas detector to check the area
		You must not un braze connections on a flammable refrigerant system, they should be cut using a pipe cutter
		Work outside
		Purge with oxygen free nitrogen

Question 10 HC

Mod 1 Safety HC	A refrigerant which is classified in refrigerant safety group A3 has which hazards?	High flammability, lower toxicity
		Mild flammability, lower toxicity
		High toxicity, no flame propagation
		Lower toxicity, no flame propagation

Question 11 HC

Mod 1 Intro HC	What is the GWP of R600a (according to EN378)?	3
		550
		0
		6

Question 12 HC

Curriculum Training on flammable refrigerants

Mod 1 Intro R290	R290 is	Propane
		Propene
		Propylene
		Iso butane

Question 13 HC

Mod 1 Restr on use HC	Which factors are used to determine the maximum charge in a comfort cooling / heating application? HC	Lower flammability level, height of the indoor unit, floor area
		Practical limit, height of the indoor unit, floor area
		Practical limit, room volume
		Lower flammability level, room volume

Question 14 HC

Mod 2 HCs	What is the approximate cooling capacity of R1270 compared to R404A?	100%
		50%
		200%
		7 times

Question 15 HC

Mod 2 R717 R32 R1234ze HCs	What is area classification (with regard to the application of flammable refrigerants)	Testing which determines the extent of a flammable zone in the event of a leak of flammable refrigerant
		Zoning of an area where invasive work on a system containing a flammable gas is to be carried out
		Determining where flammable warning diamonds should be located
		Erection of safety barriers while working on systems which use a flammable refrigerant

Question 16 HC

Mod 2 R717 R32 R1234ze HCs	Which of these devices will not ignite a leak of flammable refrigerant?	An EX "n" rated device
		An EC evaporator fan motor
		A high pressure switch
		A thermostat

Question 17 HC

Mod 4 Intro HC	What implication does the density difference between HC and HFC have?	The HC refrigerant charge weight is lower
		The system must be evacuated for longer
		The HC system must be charged with gas not liquid
		The system must be charged very slowly to prevent damage to the compressor

Question 18 HC

Mod 4 Flam refs HC	How do you make sure it is safe to light a brazing torch when working on an HC system?	Ensure the area is well ventilated and use a flammable gas detector to check the area
		You must not un braze connections on an HC system, they should be cut using a pipe cutter
		Work outside
		Purge with oxygen free nitrogen

Question 19 HC

Mod 2 HCs	What is the typical PS for the high side of an R600a system with an air cooled condenser in a $32^{O}C$ ambient?	6.8 bar g
		10.3 bar g
		19.3 bar g
		24.8 bar g

Question 20 HC

Mod 2 R717 R32 R1234ze HCs	What is ATEX?	A European directive which covers equipment intended for use in a potentially explosive atmosphere
		A type of enclosure which can be safely used on a system which operates with a flammable refrigerant
		An electrical device which can be safely used on a system which operates with a flammable refrigerant
		A type of system which uses a flammable refrigerant

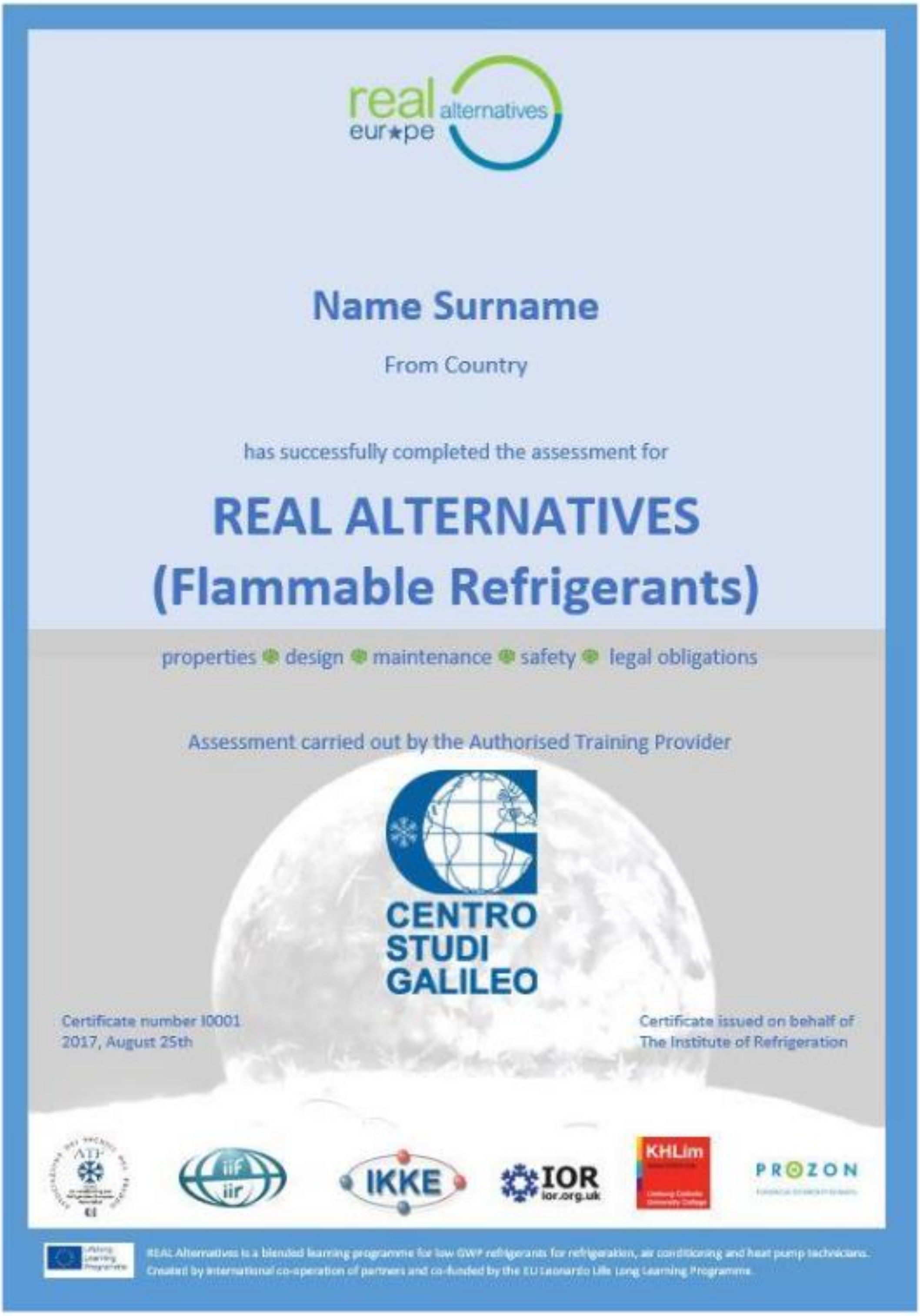
Annex 2: list of equipment, tools and material provided to the regional training centre in Grenada

Item	Quantity	Item	Quantity
4 way manifold gauge set	20	Steel brush	20
Electronic leak detector for halogenated refrigerants and blends	5	Wire stripper	20
Electronic leak detector for HC refrigerants	20	Mains tester with LED	20
Double stage vacuum pump	10	Oxy/Acetylene brazing unit	5
Digital scale	10	Metallic tool box	20
Portable charging station for R600a and HC blends	5	Cylinder with HC refrigerant R290	20
Refrigerant reclaim unit	2	HC refrigerant R600a	20
Advanced refrigerant identifier ID Pro	2	Cans HC blend refrigerant	20
Split air conditioning unit (R-22)	2	Refillable refrigerant recovery cylinders	20
Precise Electronic Thermometer	4	Set of copper tube rolls	10
Nitrogen cylinder with valve and cap	5	Packet of brazing rods	40
Nitrogen cylinder pressure regulator	5	Box of Flux	20
Set of 7 screw drivers	20	Set of filter drier for HC refrigerant	40
Set of 4 pliers	20	Set of adapters, fitting, flare nuts	20
Piercing pliers	20	Portable CO2 Fire extinguishers	5
Set of tubing tools	20	Portable Dry powder extinguishers	5
Cable reel	10	Refrigerant recovery unit with external recycling module	10
Combination wrenches set	20	Gallon of compressor mineral lubricant	10
Adjustable wrench	20	Gallon of compressor synthetic lubricant	10
Ratchet wrench	20	Pair of safety gloves refrigerant handling	20
Safety goggle	20	Pair of safety gloves for mechanical work	20
Cable knife	20	Pipe wrench 35 mm.	20
Hack saw and extra blades	20	Folding rule 2 m	20
Hammer	20		

Annex 3: list of participants to the train the trainer workshop

Name	Surname
Giltan	Baptiste
Frederick Perceival Philip	Beausoleil
Michael	Cadore
Alexander	Darville Jr
Ells	Breuno
Lance	Simpson
Henry	Frederick
Wayne	Grant
Earl Michael	Harte
Vincent	Lorde
Andrew	Miller
Alfred Tyrone	Paul
Gary	Peters
David	Ramsey
Satiesh	Sardjoe
Curtis	James
Stanley	Sovan
Milton	Spier
William	Sturrup
Jerry	Van Ommeren

Annex 4: REAL alternatives certificate



Annex 5: list of tools and material provided to National Ozone Units, National Refrigerant Associations, Vocational Schools to support the in-country training sessions

The Bahamas

Item	Quantity
Leak Detector D-400 (UN)	2
Manifold Set 4 valve UNIDO	2
Refrigerant Control Valve 1/4" flare	2
1⁄4" Charging Hose Gasket 10 pcs	2
3/8" hose gasket K10	2
Gauge HD R-600a,R-290, R22, B/PSI, C/F 80mm T-line	4
Gauge LD R-600a,R-290, R22, B/PSI, C/F 80mm T-line	4
Gauge HP R-134a,404A,410A,407C B/PSI, C/F 80mm T-line	4
Gauge HP R-134a,404A,410A,407C B/PSI, C/F 80mm T-line	4
Fieldpiece dual input thermometer ST4	2
Fieldpiece K-Type thermocoupler Bead Tip ATB1	4
Compact Clamp Meter w/Temp SC240 Fieldpiece	2
Filter copper capillair SM-20M Metric	5
Cylinder refrigerant 12.5 ltr.	2
Pair of safety gloves	10
Portable Charging unit HC, K-PGTB-A3	1
Charging Scale 0-5000 gr P&M	2
Oil 1 liter ISO32 (3GS)	5
Label Flammable Gas 100 x 100 (roll 1,000 pcs)	5

Saint Lucia

Item	Quantity
Leak Detector D-400 (UN)	2
Manifold Set 4 valve UNIDO	2
Refrigerant Control Valve 1/4" flare	2
1⁄4" Charging Hose Gasket 10 pcs	2
3/8" hose gasket K10	2
Gauge HD R-600a,R-290, R22, B/PSI, C/F 80mm T-line	2
Gauge LD R-600a,R-290, R22, B/PSI, C/F 80mm T-line	2
Gauge HP R-134a,404A,410A,407C B/PSI, C/F 80mm T-line	2
Gauge HP R-134a,404A,410A,407C B/PSI, C/F 80mm T-line	2
Fieldpiece dual input thermometer ST4	2
Fieldpiece K-Type thermocoupler Bead Tip ATB1	4
Compact Clamp Meter w/Temp SC240 Fieldpiece	2
Filter copper capillair SM-20M Metric	4
Cylinder refrigerant 12.5 ltr.	6
Pair of safety gloves	10

Portable Charging unit HC, K-PGTB-A3	1
Charging Scale 0-5000 gr P&M	2
Oil 1 liter ISO32 (3GS)	2
Label Flammable Gas 100 x 100 (roll 1,000 pcs)	5

Saint Vincent and the Grenadines

Item	**Quantity**
Manifold Set four way	10
Portable Charging unit for HC, K-PGTB-A3	5
Leak Detector for HC's D-400	10
Fieldpiece dual input thermometer ST4 including: 2 x Fieldpiece K-Type thermoc. Bead Tip ATB1	10
Compact Clamp Meter w/Temp SC240 Fieldpiece	10
Filter copper capillair SM-20M Metric	20
Flammable Gas Label	2500
Pair of safety gloves	20
Charging Scale 0-5000 gr P&M	10
Oil 1 liter ISO32 (3GS)	10

Suriname

Item	**Quantity**
Fridges (R600a)	2
Flammable Gas Label (set of 30)	2

Annex 6: lists of participants to training sessions for technicians

The Bahamas (20-22 August 2019)

The names of the technicians that paticipated in the training exercise are;

- Mr. Jerry Josey
- Mr. Deon Ferguson
- Mr. Keno Munroe
- Mr. Maurice Knowles
- Mr. Robert McKinney Jr.
- Mr. Dwight Forbes
- Mr. Refshinko Stubbs
- Mr. Kevin Gibbs
- Mr. Kashmir Colebrooke

Grenada (8-9 May 2019)

List of participants

Natural Refrigerants Workshop

T A Marryshow Community College (TAMMCC)

May 8th and 9th, 2019

ATTENDANCE REGISTER

#	Name	Company	Gender	Tel #	email
1	Amanaki Millette	Phillip's AC & Refrigeration	M	4101454	amanakimillette123@gmail.com
2	Allen Rick Lyons	Rapid Cool	M	4109620	rapdcoolgda@gmmail.com
3	Nicholas Joseph	BL International	M	4072531	
4	Chad Walcott	Total Engineering Co. Ltd	M	4560413	cwalcott@totalengineeringgd.com
5	Razzum Baptiste	Viking Engineering Co ltd	M	4222849	
6	Everton Connor	ELCICS	M	4065068	evertonconnor3113@gmail.com
7	Ian Benoit	ELCICS	M	4160616	
8	Glendon Regis	ELCICS	M	5340331	
9	Javid Mitchell	Modern Electrical Solutions	M	4232364	javidmitchell@techie.com
10	Shane Roberts	Modern Electrical Solutions	M	4141931	shane.roberts01@gmail.com
11	Arnold Fraser	Grenada Airports Authority	M	4155555160	arnoldfraser1@gmail.com
12	Kwesi Hamlet	LA Purcell/ Courts	M	5383431	ultrakool82@gmail.com
13	Devon Fraser	Courts	M	5373971	ultrakool82@gmail.com
14	Godfrey Debellotte	General Hospital	M	4495250	desmondg1691@hotmail.com
15	Ronald Mark	General Hospital	M		
16	Levon Philbert	General Hospital	M	4220975	
17	Kelly Ann Telesford	Self Employed	F	4178838	kellyanntelesford@gmail.com
18	Kenneth Stephen	STE-TECH	M	4590150	propertygrenada@gmail.com
19	David Ganpot	Ganpot's Technical Services	M	4202823	davidganpot@hotmail.com
20	Vonnet John	NEWLO	F	5342455 4236154	vonnetjohn24@gmail.com
21	Jade Pursue	NEWLO	M	4207966	jpersue@gmail.com
22	Trevor Andrew	Spice Island Beach Resort	M	4060507	
23	Karvin Johnson	Spice Island Beach Resort	M	5367077	
24	Ramesh Patrick	Grenada Elctrical/Franks Refrigeration	M	4578758	rameshpatrick917@hotmail.com
25	Jordan Paredes	Cool Breeze	M	4102192	oldwester28@outlook.com
26	Presley Thomas	Cool Breeze	M	4195246	presleythomas@hotmail.com
27	Jerry Coutain	Self Employed	M	5358284	jerrycoutain@hotmail.com
28	Aldrin Cox	James Refrigeration Services	M	4208769	aldrincox90@gmail.com
29	Britnay Frank	Grenada Electrical/ Franks Refrigeration	F	4584297	
30	Dondre Sandy	Ultra Kool	M	4199293	dondre473@gmail.com
31	Meril Fraser	Courts	F		
32	John Campbell	SGU (Observer)		4052718	jcampbell@sgu.edu
36					
37					
38					
39					
40					

List of Facilitators

Name	Company/Institution	Telephone	email
Mr. Lance Simpson	Cooling Tech Limited	534 6423	lsimpson@coolingtech.gd
Mr. Henry Frederick	Maurice Bishop International Airport	415 1198	hfrederick@mbiagrenada.com
Mr. Leslie Smith	National Ozone Unit	409 8128	Smithld31@gmail.com

Saint Lucia (4-5 February 2020)

Name of participants
Lambert Calixte
Brandon Mathurin
Keisha Lansiquot
Clemence Charlemagne
Archibald Anderson
Rudolph Felix
Sherwin Joseph
Collin Mondesir
David Charles
Daniel Jn Baptiste
Aaron Doxilly
Facilitators
Michael harte
Percival Beausoliel
National Ozone Unit
Kasha Jn Baptiste
Shanna Scott

Saint Vincent and the Grenadines (10-13 February 2020)

ATTENDANCE SHEET

1) Ronald Jessop	East Caribbean Metal Industry	Technician	wayneip@yahoo.com	593-2855
2) Cameron Julian Conliffe	AIW Fish Market	Technician	cameron.conliffe@gmail.com	530-8228
3) Lou-Anne Dover	Thompson Cooling & Electrical	Office manager	louloupeng@gmail.com	497-3060
4) Vondon Herbert	Thompson Cooling & Electrical	Technician	vondonherbert@live.com	434-9327
5) Bernard Celestine	Mustique Company	Technician	Juiceberryxs60@gmail.com	530-0138
6) Jason Raguette	AIW Fish Market	Technician	Jason24783@hotmail.com	530-4555
7) Kenny Campbell	Self Employed	Technician	Jjken21@hotmail.com	532-2181
8) Clyde Gurley	JAD	Technician	Docgurley32@gmail.com	531-3222
9) Damien Hinds	JAD	Technician	dodley@gmail.com	531-6946
10) Arthur A. Matthews Jr.	Self Employed	Technician	Mathur1318@gmail.com	431-6980
11) Zoanie Bailey	OSV	Technician	doaniebailey@gmail.com	492-7920

Annex 7: list of participants to the regional expert group meeting (Paramaribo, Suriname, on October 5, 2019)

Participant name	**Participant function**	**Country**
Ryan PERPALL	National Ozone Officer	the Bahamas
Leslie SMITH	National Ozone Officer	Grenada
Henry FREDERICK	Technician, consultant with National Ozone Office	Grenada
Kelly CYRUS (remote)	CEO from Grenz concept, RAC and R290 appliances supplier	Grenada
Shanna SCOTT	Alternate to the National Ozone Officer	Saint Lucia
Frederick BEAUSOLEIL	Technician and national supplier, consultant with National Ozone Office	Saint Lucia
Janeel MILLER	National Ozone Officer	Saint Vincent and the Grenadines
Brentin QUAMMIE	Alternate to the National Ozone Officer	Saint Vincent and the Grenadines
Cedric NELOM	National Ozone Officer	Suriname
Jerry VAN OMMEREN	Technician, consultant with National Ozone Office	Suriname
Satiesh SARDJOE	Technician, consultant with National Ozone Office	Suriname
Ozunimi ITI (remote)	Project manager, Industrial development officer	UNIDO
Guillaume CAZOR	Consultant	UNIDO

EASTERN AFRICA SUB-COMPONENT

Contents

Executive Summary

The project “Demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives (Eastern Africa and Caribbean regions)” was planned to be implemented by UNIDO, as lead agency, and UNEP on behalf of the Governments of Eritrea, Kenya, Tanzania, Uganda, and Zambia. The demonstration project was approved at a funding level of USD 369,150 including PSC for UNIDO and USD 56,500 plus PSC for UNEP – in total USD 425,650.

It was approved in May 2016 at the 76^{th} Meeting of the Executive Committee (ExCom) of the Multilateral Fund of the Montreal Protocol, at the funding level of USD 345,000 for UNIDO, and USD 50,000 for UNEP (excluding Project Support Cost (PSC)). For the refrigerant quality component, UNIDO allocate USD < 110,415 > and for the Caribbean component USD < 234,584 >. Preliminary project expenditures are USD < 110,181 > related to UNIDO, and USD < 0 > related to UNEP. Thus, the overall expenditure of the project is USD < 110,181 >.

The project aimed to demonstrate the availability of fake refrigerant; the lack of awareness of stakeholders; gaps in customs and legislation; and propose ways to ensure refrigerant quality in the market in Eritrea, Kenya, Uganda, Tanzania, and Zambia. The United Republic of Tanzania was selected as the lead pilot country for leading the implementation of the project due to its geographical location and the biggest by size and population among target countries.

The project included a series of activities:
i) carrying out surveys on refrigerant availability in the markets; ii) conducting a regional train-the-trainer workshop for refrigeration technicians; iii) training national for customs officers, environmental inspectors, importers, and staff from the Tanzanian Bureau of Standards in Tanzania and Eritrea; iv) equipping project stakeholders; v) establishing testing centres and; vi) supporting awareness raising among refrigeration technicians and all stakeholders.
Results of the activities are described within the report.

The project achieved all the goals as follows:

1) Availability: Through the surveys, it was clear that counterfake refrigerant is available in the majority of shops in project countries. Even there are shops were there are two prices for the same refrigerant, meaning better or lower quality. Also that for National Ozone Units, it is complete unknown fact, ‘in this country there is no fake refrigerant’.
2) Availability mimetic: Refrigerant packed as R-22 were found containing several non-standard blends, expanded refrigerants, recovered refrigerant and more. The same for HFC, blends of refrigerants, hydrocarbons etc. The main source were cans and small cylinders. In general the counterfake refrigerants can be detected due to misleading information in the labels, colours of cylinder, trade names, mistakes in nomenclature, etc.
3) Lack of awareness: It is clear the fact that stakeholders e.g. technicians, importers, custom officers, government officers (including NOU) were not aware of counterfake refrigerant, consequences, extra costs generated – refrigerant consumption, more energy, potential compressor damage, reduce efficiency etc.
4) Gaps in policy: No legislation regarding refrigerant quality is available. Customs ensure that control substances are regulated, there is lack of awareness on counterfake. Since stakeholders are not aware, there is no legislation or standards for refrigerants.
5) Quality assurance: To ensure refrigerant quality, demonstration on the opposite was the first step. A workshop for trainers to demonstrate fake refrigerant and consequences; workshop for stakeholders, customs, bureau of standards, etc. Establishment of testing centers through the provision of tools and equipment including Ultima ID – HVAC Refrigerant Identifiers.

6) Quality assurance awareness: The project raised awareness on counterfeit refrigerants taking into account mislabelling, consequences of using fake refrigerants, potential safety risks and dangers including tips for indentifying fake refrigerants. Brochurs were developed and distributed to the technicians and other stakeholders.

Recommendations

16) The counterfake refrigerant are not only present in countries included in this Demo Project. UNIDO staff member has surveyed the situation and found the same cases in many countries. In general the same situation, lack of awareness, cheap prices offered, gaps in customs and legislation. The subject should be included in the HPMP and Enabling Activities since the consequences – more refrigerant leaking, more consumption, extra energy, etc – were demonstrated.
17) This issue needs to be tackled because refrigerant being phase out from some countries, ends in other countries under the label 'new'. This became excellent business, just collecting recovered refrigerant, bottling and deliver. In some cases, the blends tested shows the right composition but not percentages, blends recovered and repacked in original cylinders.
18) It is required to establish testing centres, work in standards and public awareness. The counterfake refrigerant will likely be vented and more refrigerant consumed since, due to lack of awareness, the technicians blame the equipment.
19) It is important also to work with the importers and create awareness, it is clear that some of them are not aware of fake refrigerants.

I. Context and background

Context

Refrigerant supply is growing in line with the demand due to the increasing number of comfort, industrial and commercial equipment. However, low quality refrigerants of various sources and origins are finding their ways to the domestic market. This negatively affects not only the whole refrigerant market, but it also has become one of the major concerns and a serious obstacle to the development of the refrigeration-servicing sector. Contaminated, mixed or recovered refrigerants can lead to decreased cooling capacity and energy efficiency, reduced lifetime, increased servicing needs, they can damage the compressor of the equipment and end up being vented to the atmosphere.

All of the target countries are Low-Volume Consuming Article 5 countries, where the refrigerant market is small with loose standards, so low-quality substances can easily and quickly spread. Moreover, since the countries of the region have strong economic and commercial connections, refrigerants can easily cross borders. It is particularly true for Kenya, Tanzania and Uganda.

The predominant HCFC consumed in the region is HCFC-22 which is solely used in the refrigeration and air-conditioning servicing sector. The complex issue of low-quality refrigerants (contaminated, recovered, mixed) should be addressed in the first place in order to enhance the technical level of the servicing sector. For this, it is necessary to use policy instruments, monitoring mechanisms and raising awareness of dealers, technicians and end-users.

The root of the problem is that the purity of virgin refrigerant is questioned neither by the importers nor by the end-users. Most technicians assume that the refrigerant in the cylinder is "good enough" until the RAC system develops failures or cooling problems. Furthermore, even if a technician suspects the refrigerant is somehow contaminated, there is no proper mechanism/strategy to detect or avoid low-quality refrigerants.

The present proposal fits into the concept of the ongoing HPMPs: it would benefit from the established network of stakeholders and the experience gained so far. At the same time, it would give new impetus to improve efficiency and impact of the HPMP by extending its scope of activities and widening the group of stakeholders.

It should be noted that the project has an enormous relevance not only for the phase out of HCFCs but also for the phase down of HFCs. It is clear that counterfake refrigerant are available for all kind of refrigerants, including hydrocarbons. The presence of counterfake in article V countries is directly linked with the increase of consumption due to failure in the refrigeration systems and consequent recharge.

The lack of awareness at all levels, - service technicians, importers, trainers, custom officers – standards, policies and testing options are increasing the potential for more availability of fake. As mentioned before, fake refrigerant includes also ‘refrigerant phased out’ in other countries, recovered and mixed or expanded. In all cases, the refrigerant will end vented generating more ozone depletion, global warming and consumption.

Background

The quality of refrigerants available on the market in many developing countries is of major concern in relation to the development of the refrigeration servicing sector and the proper adoption of best practices. The main problems and challenges identified are mixed refrigerants on the market, fake refrigerants, i.e. substances sold as refrigerant but not in conformity with the requirements and specification related to any classified standard refrigerant, improper drop-ins i.e. some refrigerants sold as drop-ins but incapable of fulfilling the technical requirements and performing the task required, and incorrect labelling i.e. by mistake or on purpose. These discrepancies are driven by economic interests, deficiencies of the regulatory framework, insufficient and inefficient control mechanisms, and lack of technical knowledge.

The objective of the project was to demonstrate: i) the availability of fake refrigerant; ii) the lack of awareness of stakeholders; iii) gaps in customs and legislation; and iv) propose ways to ensure refrigerant quality in the domestic market in Eritrea, Kenya, Uganda, Tanzania and Zambia.

For this purpose, the project begin with surveys of refrigerant available in project countries. It was clear that the counterfake refrigerants are available in different forms. It was also clear that stakeholders were not aware of the fact.

Among other activities: surveys on quality of refrigerant; train-the-trainer workshop; training for customs officers, environmental inspectors, importers, etc; establishing testing centres; gap analysis; and awareness raising.

All the activities were completed, but more public awareness and workshops for stakeholders were missing and should be carried out in line with other projects activities.

Approval and cancellation

The project was approved for 'Demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives (Eastern Africa and Caribbean regions)'. Despite that, the two components are related to refrigeration service and HPMP the implementation activities were split due to regional execution and different activities and therefore the funds were also divided internally in UNIDO.

The project "Demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives (Eastern Africa and Caribbean regions)" was submitted jointly by UNIDO, as lead agency, and UNEP on behalf of the Governments of Eritrea, Kenya, Uganda, Tanzania and Zambia. It was approved at the 76th Meeting of the ExCom of the Multilateral Fund in May 2016 (UNEP/OzL.Pro/ExCom/76/66, Decision 76/36).

UNIDO's component (GLO/REF/76/DEM/336) was approved at USD 369,150 including PSC. From this amount, US$ 110,415 were destined for 'Demonstration project on refrigerant quality, containment' to be implemented in Eastern Africa region. UNEP's component (GLO/REF/76/DEM/334) was approved at USD 56,500 including PSC. Since UNEP was not able to implement their component of the project, this was cancelled and funds returned at 82nd ExCom Meeting held in Montreal in December 2018.

> "*UNEP/OzL.Pro/ExCom/82/72*
> *115. Concerning the cancellation of the UNEP component of the global demonstration project in the Eastern Africa and Caribbean regions, the representative of the Secretariat said that, despite the best efforts of UNEP, the project had not yet been initiated, although the part being implemented by UNIDO was in its final stages. After consultations with UNEP, the*

recommendation to the Committee was to cancel the part of the project being implemented by UNEP.

(c) Regarding the global demonstration project on refrigerant quality, containment and introduction of low-GWP refrigerants in the Eastern Africa and Caribbean regions implemented by UNEP and UNIDO:

(i) To cancel the component implemented by UNEP (GLO/REF/76/DEM/334), and to note that US $50,000, plus agency support costs of US $6,500 for UNEP had already been returned at the 82nd meeting;
(ii) To extend to 31 July 2019 the project completion date for the component implemented by UNIDO (GLO/REF/76/DEM/333), on the understanding that no further extension would be requested, and to request UNIDO to submit the final report no later than the 84th meeting;"

Project components and implementation strategy

The demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives was divided into three components:

Component 1: Policy review including detailed assessment of the current national policy frameworks. Certifying the presence of fake, mixed and/or recovered refrigerants. Detailed gap analysis on control mechanisms at the local and regional level and provision of technical advice.

Component 2: Technical assistance through provision of tools and equipment. Training of stakeholders on the importance of refrigerant quality and establishing testing centres to provide free service of identification to ensure quality and providing information on potential fake based on labelling.

Component 3: Awareness raising among stakeholders regarding the importance of refrigerant quality, related costs of using fake (operational, energy consumption, redo jobs, etc) and its relationship with the efficiency of equipment.

Strategy

The project concept included the following strategy and implementation plan. In the report it can be found that in general the project was well planned, due to different circumstances some activities were replaced.

Due to the nature of the demonstration project and the common characteristics of the target countries, Tanzania was selected as lead pilot country. While most of the activities targeted all beneficiary countries, many of the activities were implemented in the pilot country. This allowed the demonstration and monitoring of the project results at the country level, while ensuring that the experience and lessons learned are shared at a regional level offering the potential for regional replications.

II. Project objective

The objective of the project is to facilitate safer and more efficient operation of equipment in the RAC sector through the improved availability of appropriate quality refrigerants.

The objectives were slightly adapted to the needs of the project during the project implementation it may differ with those planned in the Project Concept.

- Demonstrate that fake refrigerant is widely available in the markets and the lack of awareness on the stakeholders including NOUs, service technicians, importers;
- Increase the awareness among technicians and end-users of the benefits to the RAC performances from the use of high-quality refrigerants;
- Identify the gaps in customs and legislation.
- Establish strategy to reduce the availability of fake refrigerant and provide means to test refrigerant quality;
- Foster the market availability of high-quality refrigerant;

III. Activities and Achievements

General approach

The project was planned with Tanzania as main country for the implementation activities due to the geographical location (borders with three countries included in the project), the port in Dar es Salam, the results of HPMP implementation in the country at the time. Based on that, a Tanzanian coordinator, Mr. Japhet Nidja, former Ozone Officer was selected and the project launched.

Having selected the project coordinator the implementation plan was decided and a brief mission to Kenya, Tanzania and Zambia undertaken. For the other two countries in the project, the project manager was informed and coordinated the activities. A copy of the project implementation plan can be found attached in Annex I.

The first activity was visiting the respective National Ozone Units of Kenya, Uganda, Tanzania, and Zambia. The project activities, approach and goals were defined during the visits. In addition, some refrigerant dealers were visited and a first approach for the market situation was obtained. In general, fake refrigerant, based on the packing, labels, codes and names, among others, is widely available. In some cases, they have a different price level. A copy of the mission report can be found attached in the Annex II.

Component 1: Policy incl. actual National Policy Frameworks and Gap Analysis

The project implementing activities includes the three components, the report will be focussed on the activities related to each component rather than chronological or logical order.

Context

This component was focused on the non-investment component. The planned activities were achieved with some changes but the results are considered satisfactory. The following paragraphs include the activities, the results and reports can be found in the annexes.

Activities

1. Assessments of the actual situation of the refrigerant supply chain including the quality of refrigerants available on the domestic market. Assessments of national policy frameworks were carried out for Kenya, Uganda, Tanzania, and Zambia.

2. National experts were hired in each country and survey assessments of the actual situation of the refrigerant supply chain, including the quality of refrigerants available on the domestic market were carried out. All reports were received and information shared with respective NOUs. The activity was coordinated by Mr. Japhet Kanizius, project coordinator and the report is attached as Annex III. The annex also includes a special report and country program from Kenya.

3. Samples of R-22, R-134a were randomly picked from refrigerant selling shops and tested for their qualities using refrigerant identifiers. Consequently, a general impression of the quality reliability of the supplied refrigerants in the local market was obtained. The results showed that counterfake refrigerants are available especially for HCFC-22 and HFC-134a. Detailed information on the standards and market availability of quality refrigerants is included in the mentioned report Annex III.

4. For the gap analysis, it was planned to contract Tanzanian Bureau of Standards - TBS. Some visits were paid to Ms. Agnes NJAU and the aim of the project agreed. UNIDO requested the services through the Terms of Reference, copy attached in Annex IV. The offer was received by UNIDO with budget beyond the available funding.

5. At the time of negotiation, UNIDO found out that UNEP was cancelling their participation in the project and decided to cancel the proposal. Since the gap analysis was a pillar for the project implementation, it was decided to contract national experts in Kenya and Uganda. The most relevant and accurate information had been received before from both countries.

6. The activity was carried out by Ms. Selelah OKOTH in Nairobi; Mr. Reuben LANGART in Mombasa and Mr. Paulo ODU in Kampala. A sample of the Terms of Reference for the consultant is attached in Annex IV.

7. The reports from the three experts were received and analysed. So far, the information was only shared with the respective National Ozone Units of the countries under the Demonstration Project. The socialization of the information was a component of the activities to be implemented by the cooperation agency UNEP.

8. The most relevant findings, comments and conclusions are summarized below. Table includes Gap Analysis, after proposed counter measures, conclusion and recommendations applicable to all countries under the demo project and other not only in the region.

Summary of Gap Analysis

No	Thematic Area	Gap(s) Identified
1	Policy and Legal Framework	The existing policy has inadequate statements relating to the RAC sector. This therefore fails in providing a strong guiding framework towards the growth of the sector The Controlled Substances Regulations has no provisions on use of spectrophotometer analyzer which would be essential in quality assurance The Regulations have no stringent punitive measures upon ODS/RAC gases importers in the event of shipment of fake refrigerants The Regulations have no framework for tracking movement of RAC gases once cleared at the port of entry. This makes it difficult to ascertain the end point for RAC gases declared as on transit.

2	Licensing and Licensing Conditions	While the accessed licenses show that all refrigerants are regulated, the aspect of quality control is not emphasized beyond the provision that only licensed refrigerants are allowed. There is no provision instructing the importer to ensure that certificate of conformance (CoC) is obtained prior to shipment. The use of the licensing system that has no linkage with the upcoming Integrated Customs Management System (ICMS) raises a gap in quality control as some refrigerants may easily pass the border point if due diligence is not undertaken by the Customs officials.
3	Standards	There are no easily accessible standards relating to the quality of refrigerants.
4	Enforcement	Inadequate presence of e*nvironmental inspectors* at the border points.
5	Interagency coordination	No clearly documented framework is in place regarding working relationship among the various stakeholders more specifically the regulators in the RAC sector

Proposed counter measures to prevent counterfeit/contaminated refrigerants from entry to local market

The counter measures that can be put in place include:

i. Encouraging collaboration between all the stakeholders involved thus; Anti-Counterfeit Agency, Customs, Bureau of Standards, NOUs and RAC importers Association to come up with the strategy to counter and minimize the influx of the contaminated/ counterfeit refrigerants into the local market.

ii. Encourage all importers who have not been using the Electronic Single Window Licensing System (or equivalent) to procure their goods through the system for transparency and accountability.

iii. As for lack of awareness on newly manufactured equipment containing fake / contaminated refrigerant, public awareness creation campaign to be conducted on use of quality refrigerants, on reviewed cylinder general appearance in terms of colour, labels and specifications according to UN numbers including testing of the refrigerants.

iv. Entry through illegal routes and diversion of transit counterfeits should be controlled by the sharing of intelligence information by all the relevant enforcement authorities by tracking the illegal routes and prosecuting those involved in diversion of goods on transit.

v. The dishonest importers/traders who request repackaging/refilling of contaminated refrigerants from the exporting countries should be prosecuted upon conviction. This can be done through government to government collaboration/agreement on the enforcement of the policies, standards and laws relating to prevention of contaminated refrigerants getting into the market. Both Governments could arrange meetings for the importers and exporters from the two countries to strategize on how to minimize circulation of the contaminated refrigerants in the local market. This effort will address the loopholes due to refilling /repackaging of contaminated refrigerants from country of origin by dishonest traders, as a result of requests made by importers.

vi. The NOUs to review their database of compliant RAC Importers from time to time and blacklist those that sneak contaminated refrigerants into the country.

Conclusion

Countries should put strategies in place to prevent or minimize the importation of contaminated /counterfeit refrigerants which include the enforcement of use of the *Electronic Single Window Licensing System* by all validated RAC importers.

However, there is a challenge in enforcement due to the activities of traders who import contaminated refrigerants through illegal entry ports and hence are not easy to prosecute. RAC importers reported that Contaminated / counterfeit refrigerants are popular to some traders because they are cheap, require low investment and guarantee them maximum profits.

During the process of survey, some RAC importers disclosed that some travel abroad to the source of refrigerants and influence them to refill/ repackage the contaminated/counterfeit in genuine popular branded cylinders and import them through either illegal routes/ entry points to avoid paying taxes or comprise by means of negligence/deceit of the control points and legally import.

In order to control this, there should be a Government to Government agreement /policy on standards of the export refrigerants meant for export by enforcing quality. Further this framework should explore convening of regular meetings of all RAC importers and Exporters of the countries concerned. This will call for training of the customs officers, and other inspectors involved in law enforcement. The customs officials should immediately alert the NOUs inspectors on imports of counterfeit refrigerants through illegal ports of entry.

Adequate human capacity and analyser equipment to be available in all entry points for use to test for any contamination of the refrigerants. These efforts require that any illegal entry points must be monitored through collaboration of all the regulatory agencies by deploying more personnel to man them.

To further strengthen compliance and enforcement there is a need to raise awareness among the stakeholders, the RAC Sector, Customs, NOUs, ACA, including the public on the relevant regulatory requirements on quality refrigerants.

A combination of all these efforts of regulatory, capacity building, awareness campaigns will minimize consumption of the contaminated refrigerants because the equipment owners and end users will be aware of the risk that can cause damage to their equipment.

These strategies will eventually reduce demand for these refrigerants in the local market.

Recommendations

This report was prepared by the consultants with the input of the relevant stakeholders through one to one interviews, telephone calls interviews and review of the existing legislation in coming up with the following recommendations:

i. The National Ozone Office (NOU) should ensure that it is always in touch with refrigerant importers so that trust could be developed, and hence transparency is seen to prevail and sharing of information on how to identify counterfeits refrigerants.
ii. There is need for continuous capacity building programmes for customs officers and NOUs officers. This should be well mapped out to include new officers based at border points. There is a need to include the Anti-counterfeit agency as currently their role in the RAC sector is not clear.

iii. NOUs and Customs must strengthen enforcement of refrigerants on transit. One possible solution is to consider a tracking system that must be endorsed by the importer and NOUs as well as Customs upon entry and exit of the refrigerants on transit.
iv. The inter agency Collaboration between NOU, Standard offices, Customs Department, Ports Authority and other enforcement officials needs to be strengthened in order to eliminate or minimize influx of illegal imports of contaminated/counterfeit refrigerants.
v. The NOU should ensure that refrigerant identifiers are functional, distributed and regularly provide trainings to customs officers at all entry points to increase efficiency in the identification of counterfeit refrigerants.
vi. The Anti-Counterfeit Authority should build human capacity through training among all the counterfeit inspectors.
vii. A harmonized Coding system should be embraced by Customs including use of UN number, chemical formula and ASHRAE number among others.
viii. ODS regulations should be reviewed to include all refrigerants and ensure that counterfeits refrigerants are not imported.
ix. The refrigeration and air conditioning sectors importers Association and technicians should be more involved in awareness campaign to minimize counterfeit refrigerants being imported into the local market.
x. NOU or Environment Authorities must ensure that the refrigerants are specified before endorsing the importing permits. This could be done by creating awareness of possibilities of repackaging of refrigerants, brand identification, labelling and colour codes.
xi. Provide enforcement officers with the necessary skills and equipment to identify, monitor and control imports of contaminated refrigerants. Incentives/awards to customs officers who manage to seize counterfeit refrigerants should be given incentives by way of rewards for their seriousness in work
xii. Develop brochures and flyers that should be displayed at all border points that can guide Customs and NOUs on chemical composition of the various refrigerants during analysis.
xiii. Strengthen the network for RAC technicians that would make it possible to avail information on quality of refrigerants to the regulators since they have direct contact with these refrigerants during servicing and maintenance works.
xiv.

Please note that the reports were shared with NOUs from Eritrea, Kenya, Uganda, Tanzania and Zambia. Since project funds were reduced and this activity was intended by the Cooperating Agency, UNIDO could only share the reports and advice to find the best way to implement in their own countries.

Training on refrigerant quality

Component 2: Technical assistance through provision of tools and equipment.

This component was focused on the investment component. The results reached mainly the trainers in project countries and, in some cases, refrigeration technicians. The planned activities were achieved with interesting results and an innovative approach. The results are satisfactory for UNIDO and, based on received comments, for the involved NOUs. The following paragraphs include the activities, the results and reports can be found in the Annex V.

Context

1. There are two main reasons for the wide availability of counterfeit refrigerants in the market, not only in those countries under the present project. The first is the absence of awareness among stakeholders on the availability of fake refrigerants in the market and, the second, the lack of testing methods for the technicians.

2. Lack of awareness is an asset for *fake refrigerant dealers* and the consequences were demonstrated during project implementing activities. Good refrigeration practices and procedures with the best available tools can be applied, however, the fake refrigerant spoil the efforts. At the end, more refrigerant is released, efficiency is reduced and energy consumption increased, among other potential consequences. Refrigeration technicians, in general, consider that the refrigerant is 'good enough' even if they have paid for 'cheap gases'.

3. In line with the absence of awareness, once the issue is addressed, it is required to deal with the lack of testing facilities or tools. This is a challenge since refrigerant identifiers are expensive and delicate tools and to establish a testing centre is also difficult.

4. Prior to the project approval, a testing centre had been established in Asmara, Eritrea. At the time, one of the main issues in the country was the availability of contaminated refrigerant in the country and lack of testing centre. As HPMP component, the service for testing refrigerant was offered in the National Ozone Unit office. The results at the time were remarkable and fake refrigerant was drastically reduced.

5. Once the testing centre was operating, before purchasing refrigerants the condition of previous testing in some cases was established. Since this is an LVC country and the number of stakeholders is manageable, the refrigerant tested as contaminated was returned to the supplier.

6. As a consequence, after some meetings, the importers in Eritrea decided to request 'certificate of origin' and some quality assurance documents for the refrigerant.

Activities

1. The first activity was to provide all countries with Refrigerant Identifiers Ultima id. Pro. The quantity of identifiers were decided based on the size of the country and the needs as per agreement with respective NOUs. The table below was used for the supplier at the delivery time.

Component 2. Table 1. Distribution of refrigerant identifiers.

Country	# of Units	Contact person	Email	Address	Telephone
Eritrea	1	Kibrom WELDEGEBRIEL National Ozone Officer	kibromaw@gmail.com	Ministry of Land, Water & Environment Asmara Eritrea	290.0049525
Kenya	2	*To be delivered to UNIDO office in Kenya.* Emmanuel KALENZI (UNIDO Representative)	E.Kalenzi@unido.org	P.O. Box 41609 United Nations Avenue Nairobi KENYA	+254 207624369
Tanzania	2	Zainabu KUHANWA National Ozone Officer	zaikuhanwa@yahoo.com	Vice President's Office P.O. Box 5380, Dar-es-Salaam Tanzania	+ 255 222113857
Uganda	1	Margaret AANYU National Ozone Officer	maanyu@nemaug.org	National Environment Management Authority (NEMA), NEMA-House, Kampala. Uganda.	256 (0)414 251064 /5 /8
Zambia	2	Mathias BANDA National Ozone Officer	mbanda@zema.org.zm	Environmental Management Agency, Corner Suez and Church Road, Lusaka 10101, ZAMBIA.	260 211254023 /59

2. Following the success case in Eritrea, it was agreed with all NOUs involved in the project that a testing centre was required. In each country the conditions differ and based on that, centres were created in Training Centres, NOU offices, Refrigeration Technicians Associations or even refrigeration dealers. The testing service was agreed to be provided for free. In some countries like Kenya and Tanzania, two testing centres were established.

3. A workshop for training of trainers and government officials in refrigerant quality was held in Tanzania in February 2017. For this training, 20 participants, in the main trainers from seven countries attended. The participants from non-demo project countries were financed by the respective HPMPs. A list of participants, including the trainers can be found below.

	Name	Country	Comment
1	Kamthunzi Marvin	Malawi	Trainer
2	Peter Kiarie Nyagah	Kenya	
3	Joseph Kibet Rugut	Kenya	
4	Stephen Kanyoni K	Kenya	
5	Raymond Sichembe	Zambia	
6	Kelvin Kwila	Zambia	
7	Stephen Ngoma	Zambia	
8	Paulo Odu	Uganda	Associate trainer
9	Mohammed Kanyike	Uganda	
10	Basile Sebulikoko	Rwanda	
11	Alphonse Dushimimana	Rwanda	
12	Wabi Marcos	Benin	

13	Codjo Dedji	Benin	
14	Robinson Swai	Tanzania	
15	Scholastica Mbena	Tanzania	
16	Daudi Kadinda	Tanzania	
17	Said Mziwanda	Tanzania	
18	Haji Maalim Sinani	Tanzania	Local participant (Kibaha)
19	Victor A. Ngowi	Tanzania	Local participant (Kibaha)
20	Japhet Kanizius	Tanzania	UNIDO national expert

4. The aim of the training was to demonstrate the availability and consequences of contaminated or fake refrigerant in the system. For this purpose, the training started with the concept of good practices, good refrigerant management and introduction of alternatives. A copy of the Agenda and certificate can be found in the annex V.

5. Since the core of the workshop was to demonstrate the consequences of the fake refrigerant, three kinds of refrigerant were used in three HCFC based brand new mini spilt air conditioners of 12,000 BTU. For this First HCFC-22 original from the system, which was tested and approved. The second was charged with R-290 after recovery of HCFC-22 and the third was charged with contaminated HCFC-22 purchased locally, as pure HCFC-22, for the training. *(It should be noted that as a component of the training of trainers, the safety use and introduction of hydrocarbon as refrigerant was also included. The activity included good refrigeration practices, demonstration of HC as refrigerant using HC based equipment and fake refrigerant and its consequences). (It was also cleared that retrofit from HCFC-22 to HC is not recommended, and if the case, it will be under the responsibility of the user).*

6. Based on the refrigerant identifier, the contaminated HCFC-22 contained 80% HCFC-409A (R-22/R-124/R-142b) with (60%/25%/15%) and 10% air and 10% other gases. As it can be seen in the table below, taken from Honeywell refrigerants, the liquid density and boiling point of R-22 and R-409A are quite similar, therefore it can be easily mimetized. It is to be noted that the lubricant type differs, for HCFC-22 mineral oil is recommended and for HCFC-409A Alkylbenzene.

Genetron® Product	ASHRAE Number	Refrigerant Type	Refrigerant Class	Typical Lubricant Used*	Liquid Density (lbs/ft³)** 0 °F	80 °F	Boiling Point °F
Genetron 11†	11	Single Component	CFC	MO	98.2	91.9	74.7
Genetron 12†	12	Single Component	CFC	MO	90.6	81.5	-21.6
Genetron 13†	13	Single Component	CFC	MO	76.9	49.0	-114.7
Genetron 22	22	Single Component	HCFC	MO	83.6	73.9	-41.5
Genetron 23	23	Single Component	HFC	POE	72.0	–	-115.6
Genetron 123	123	Single Component	HCFC	AB	97.9	91.1	82.1
Genetron 134a	134a	Single Component	HFC	POE	84.4	74.9	-14.9
Genetron 422D	422D	Blend	HFC	MO	82.2	70.9	-45.7
Genetron MP39	401A	Blend	HCFC	AB	82.8	73.9	-27.3
Genetron MP66	401B	Blend	HCFC	AB	82.8	73.8	-30.2
Genetron HP80	402A	Blend	HCFC	AB	82.7	71.0	-56.1
Genetron HP81	402B	Blend	HCFC	AB	82.1	71.3	-52.6
Genetron 404A	404A	Blend	HFC	POE	75.8	64.7	-51.2
Genetron 407C	407C	Blend	HFC	POE	81.0	70.6	-46.5
Genetron LT	407F	Blend	HFC	POE	79.9	69.2	-50.9
Genetron 409A	409A	Blend	HCFC	AB	84.3	75.4	-30.0
Genetron AZ-20®	410A	Azeotropic Mixture	HFC	POE	77.2	65.6	-60.6
Genetron 500†	500	Azeotrope	CFC	MO	79.6	70.9	-28.5
Genetron 502†	502	Azeotrope	CFC	MO	86.9	75.4	-49.3
Genetron 503†	503	Azeotrope	CFC	MO	73.6	–	-126.0
Genetron AZ-50®	507	Azeotrope	HFC	POE	76.3	64.9	-52.1
Genetron 508B	508B	Azeotrope	HFC/PFC	POE	72.1	–	-125.3

7. The parameters were verified once the units were commissioned and several times, as can be seen in the report for trainers and some experts in the Annex V. After ca. 2 hours working, the conditions of the first and second units were stable as expected. The performance with HC-290 can be stated as little better and in this case was just to demonstrate how to operate this kind of refrigerant.

8. The third unit was consuming ca. 35% more energy based on the design, the efficiency of the system drop ca. 30%. Most importantly, the compressor became so hot that it was decided to stop the system and recover the refrigerant. After the procedure, the system was cleaned without using HCFC-141b, in this case with high efficient filters.

9. From the report of the main trainer, Mr. Marvin Kamthunzi, the conclusions and some technical comments were extracted for the present report:

> ***Practical session:*** *Practical covered three days of the workshop interspaced with theory presentations. There were 3 new min-split units designed for use with R22. The participants were then divided in 3 groups.*
>
> - *Group 1: install and operate pure R22*
> - *Group 2: use unknown and assumed R22 (fake)*
> - *Group 3: replace R22 with R290 (refrigerant grade)*
>
> *Refrigerant charging:*
>
> - *Unit design and pre-charged R22 – 583 gm;*
> - *Fake refrigerant unit – as R22 – 583 gm;*
> - *Unit for R290 (42% of R22 charge) 203 gm.*
>
> *Outcome: After several readings of various parameters, results were as follow:*
>
> - *Unit charged with fake refrigerant depicted highest temperature (82°C)*
> - *R22 unit registered 62°C*
> - *R290 unit had discharge temp of only 41°C*

It was also observed that:

- *R290 unit had lowest evaporator off coil temp of 14.3°C followed by R22 unit at 15°C and fake at 18°C.*
- *Overall power consumption was lowest for R290 unit at 974 watts followed by R22 at 1339 watts and fake at 1935 watts.*
- *The capacity (output) of the units was 12000 Btu/hr. this shows that on Energy Efficiency Ratio:*

R22 gives 8.96, Fake gives 6.20 while R290 is at 12.32 BTU per H per watt input.

The fake refrigerant was later identified to contain about 80% R409A, 10% air and 10% some unknown trace gases. Air in a system is considered a contaminant and results in high compressor head pressure resulting in high power consumption. Running for a long time on this refrigerant would eventually damage the system. Besides, R409A is HFC and could not work with mineral oil (lubricant) that is used in HCFC systems like the one with R22.

Conclusion

At the end of the 'Train-the-Trainer workshop (4 days for technicians and 2 days for non-technical (back to back)) the participants assured UNIDO, Demo Project coordinator that they would use the knowledge gained and would also share with those they work with in order to positively and effectively contribute to their respective countries' efforts to phase out HCFCs and promote environmentally friendly technologies including Carbon Dioxide, Hydrocarbons, Ammonia etc.

On fake refrigerants, the participants found it very useful and informative as a few countries in the region reported to have experienced unexplained equipment failures that were never thought to have been caused by use of fake and or contaminated refrigerants. In this regard, the Refrigerant Identifier has become an invaluable tool to counter fake refrigerants. There are also a number of falsely labelled refrigerants in order to conceal the real type of chemical contained.

Participants further reiterated their desire to build capacity within their respective fields through training so as to keep pace with the changing technologies.

The two day Non-technical group also requested training to last at least three days. After using the refrigerant identifier they felt UNIDO should assist Tanzania Bureau of Standards and Customs with similar equipment for use in strategic locations to effectively control fake refrigerants as a means of refrigerant quality control.

10. In addition, a training for Customs Officers, Border Police, Ministry of Environment staff, Tanzania Bureau of Standards, importers and other relevant staff was held back to back with the training of trainers. The report from Mr. Kamthunzi includes the results of this workshop.

11. The same activity, training of trainers including test of fake refrigerants was carried out in Eritrea in June 2019. The results do not differ much from those from the demonstration in Tanzania. The report from the trainer, Mr. Kamthunzi, is attached in the annex V. Some comments and conclusion extracted from the report are below:

Practical session: Practical was for one day of the workshop period in each location interspaced with theory presentations. There were 2 new min-split units designed for use with R22. The participants were then divided in 2 groups.

- *Group 1: install and operate pure R22*
- *Group 2: install and operate with unknown and assumed R22 (fake)*

Refrigerant charging:

- *Unit design and pre-charged R22 – 910 gm;*
- *Fake refrigerant unit – (as R22) – 910 gm;*

Comments:

- *Unit charged with fake refrigerant depicted highest compressor temperature (109 and 95°C)*
- *R22 unit registered compressor temperature of 84 to 92°C*
- *R22 split unit was run for a longer period than the one with assumed fake. This was due to the fact that group 2 had to recover original refrigerant, weigh and recharge with deferent refrigerant.*
- *The assumed contaminated/fake refrigerant was actually mixture of R22, R134a and 409a (50%, 45%, and 5%) since the available cylinders had pure refrigerant composition, though contaminated/fake refrigerants are available in certain places in the country.*
- *HFC 134a, 409a are not compatible with mineral oil used with HCFC 22. This may explain the rise in compressor casing temperature. Running this system for longer period, say full day, would have resulted in oil degradation and compressor failure.*
- *R 134a, though not suitable as retrofit alternative to R 22, is a low pressure refrigerant and therefore the other recorded parameters cannot be used for comparison. Fake refrigerant would have showed the high pressures and temperatures associated with characteristics and therefore corresponding higher energy consumption.*
- *Availability of suitable alternative to R22, for example R 290 would have shown favourable (lower) pressures/temperatures and therefore lower energy use.*

Conclusion

At the end of workshop in both Asmara and Massawa, Stakeholders and technicians, the participants assured NOU that they would use the knowledge gained and would also share with those they work with in order to positively and effectively contribute to efforts to phase out HCFCs and where available and cost effective, promote environmentally friendly technologies including Carbon Dioxide, Hydrocarbons, Ammonia and other L-GWP alternatives.

*On fake refrigerants, the participants found it very useful and informative. Some reported unexplained equipment failures that could not have been linked to use of fake and or contaminated refrigerants. The pamphlet provided by UNIDO**, ‘REFRIGERANT CAN BE COUNTERFEIT!’** came at the right time as well.*

In this regard, the Refrigerant Identifier has become an invaluable tool to counter fake refrigerants. There are also a number of falsely labelled refrigerants in order to conceal the real type of chemical contained. However, for Eritrea, they only have two working units and therefore more would be required.

Follow up action

For continuation of the training objectives the NOU should ensure that trainers have access to equipment and specialized tools, so as to provide meaningful and effective training in a professional manner. It is encouraging though, to UNIDO to note, that those trained last year, *have been able to conduct training workshops, to train others, at least twice locally to date already.*

Measures are to be taken for effective public awareness involving government agencies, importers, end users and technicians on influx of counterfeits. It is through government involvement that suitable registration and regulations can be enacted and implemented in order for those with lawful authority to enforce compliance.

Some of the participants deliver reports with lessons learned and recommendation. The following summarized of some of the reports:

Peter Nyagah - Kenya

I wish to express my appreciation for the chance to take part in the regional training in Tanzania starting on the 20-2-2017 to 24 -2-2017. The training was very helpful. We learnt several things such as:-
-how to detect fake refrigerants
-measuring performance parameters using pure and fake refrigerants
-how to use the refrigerant analyzer
exchange of experiences from various countries.
I look forward to participating in more of such trainings in the future
Too I would request that one of those analyzers be stationed at NITA Mombasa because it is more strategic and has the most interaction with the refrigeration industry.
Regards

Mr. Rugut – Kenya

1. The demonstration through practical means for the use of fake/wrong type of refrigerant in a designated system affect the sector adversely.
2. Awareness of the presence of impure gases in the market.
3. We need to pass this knowledge as fast as possible.
4. Availability of testing and proving equipment is paramount.
5. A follow up in how to place control systems especially views from the RAC techs is the way to speed this up.

RECOMMENDATION
I take this opportunity firstly to give my sincere thanks to Vice President's Office and UNIDO for my nomination to attend this workshop; I have acquired new knowledge and skills towards my career. It is therefore, this workshop has prepared me to share acquired knowledge, skills and experience with my fellow RAC Technicians and Artisans.
Secondly, the workshop duration was not enough for the participants to cover the materials given; therefore, I am laying a special request that the preparations of this kind of workshop(s) should consider the adequate time to meet the planned contents.

Prepared By: Said Mziwanda, Tanzania

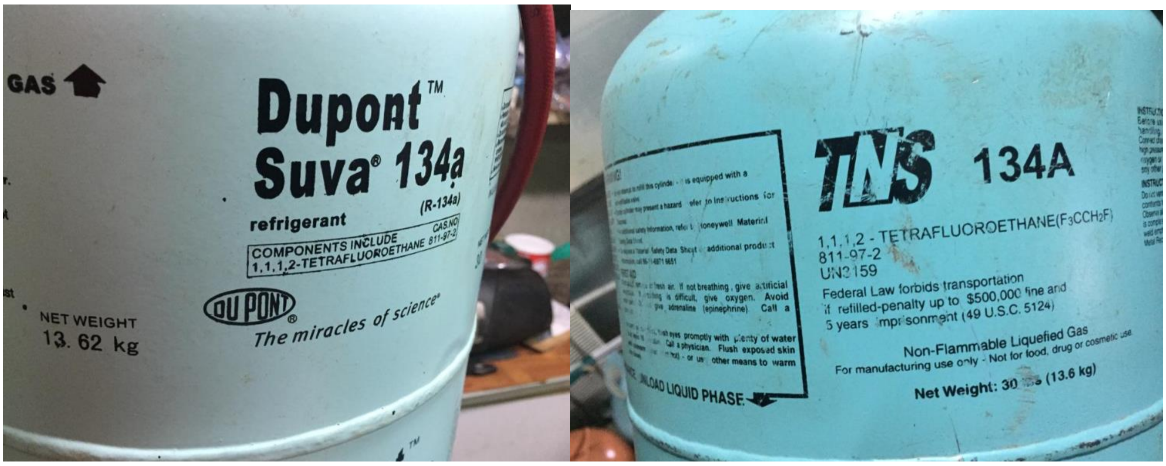
RECOMMENDATIONS
To be in a good position the authority concerned should be provided:
- *standby generator before*
- *adequate time of training which is relevant with the materials provided*

- *adequate tools and equipment for recovery, recycling, reclamation, and refrigerant handling containment etc*
- *several workshops be completed within a short time*

IMPLEMENTATION PLAN IN MY DAILY WORK
The phase-out of unwanted refrigerant like R22 and introduces (in the market) new refrigerant, like R290, is a global strategies and the aim is to protect the ozone layer. The following is the implementation plan which I thought will work

(i) *to inform or educate the Centre Management to be aware of the refrigerant quality*
(ii) *to prepare / purchase new refrigerants*
(iii) *to involve other staff and trainees concerning protection of ozone layer*
(iv) *to prepare schedule of removing unwanted refrigerant and charging new refrigerant*

Mr. Kadinda, Tanzania



'Dupont' Suva and R-134A

Component 3: Awareness Raising including Information Dissemination

This component was planned to be implemented by the Cooperating Agency. Unfortunately, it was not possible to carry out the activities and UNIDO took over and redistribute the funds and activities to complete the project in the best possible way.

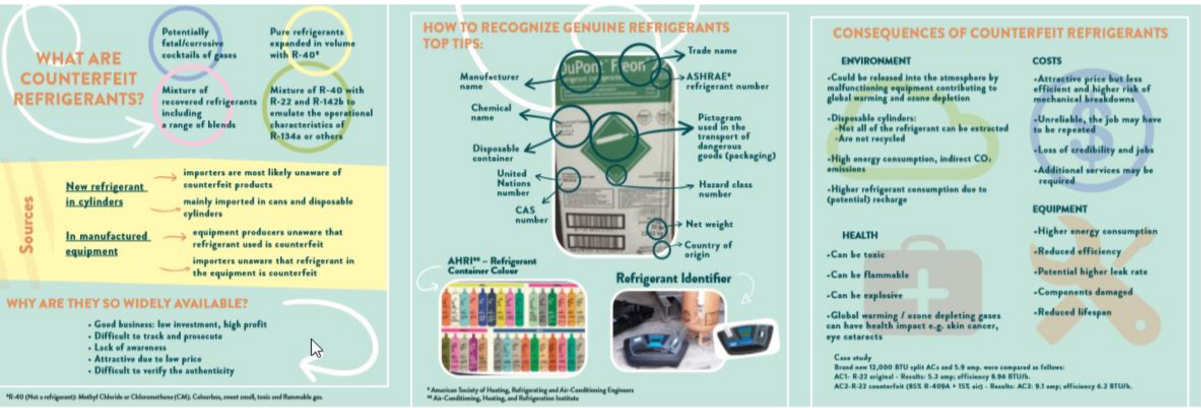
Context

The awareness and information dissemination is as relevant as the previous components. One of the main conclusions of the present report is the need of public awareness for the stakeholders. A second important final step is sharing information with not only the National Ozone Units but other institutions and policy makers. The report includes only the activities undertaken by UNIDO which unfortunately could not fulfil the plan.

Activities

1. The main activity carried out for public awareness was the design and print a brochure with information related to Counterfeit Refrigerants. The design was shared with some of the Ozone Officers, trainers and stakeholders involved in Demo Project and other.

2. Below the English version of the brochure, a Spanish version was also completed. In the Annex VI copies of the brochures can be find.



3. Copies were delivered to the respective NOUs Eritrea, Kenia, Tanzania, Uganda and Zambia for distribution. More than 200 copies and file to be reprinted if required were sent. Each country has the right to distribute the brochures as per they own criteria.

4. The complementary activities related to this component are included in the report of trainings held in Tanzania and Eritrea. Unfortunately, this component could not be completed.

Replace for R-134a and R-600

IV. Financial report

The demonstration project was approved at a funding level of USD 369,150 including PSC for UNIDO and USD 56,500 plus PSC for UNEP – in total USD 425,650.

The project "Demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives (Eastern Africa and Caribbean regions)" was approved as Global including two regions. Based on that, the funds received by UNIDO were divided as follows:

1. Demonstration project on refrigerant quality and containment - Eastern Africa region. US$ 110,415
2. Demonstration project on introduction of low-global warming potential alternatives Caribbean region US$ 134,585

The present report includes only information related to the first component related

Upon project completion, the estimated project expenditures are USD <110,181> related to UNIDO's component, it is to be noted that UNEP's component was returned with balance of expenditures equal cero USD <0>. Thus, the overall cost estimate of the project is USD <110,181>. Any balances will be returned to the Multilateral Fund after financial completion.

At the time of presenting this report almost 100% of the funds approved for UNIDO - East Africa component have been committed and spent and 98% delivered. The table below shows the budget and actual expenses.

Activity	Planned Expenditures (US $)	Actual Expenditures As of Sep 2019 (US $)	Disbursement As of Sep 2019 (US $)	Funds available As of Sep 2019 (US$)

a. International experts	12,000	12,289	12,289	-289
b. Project management	5,000	2,031	2,031	2,969
c. National experts	25,000	24,886	24,620	114
c. Workshops	30,000	30,947	28,919	-947
d. Equipment	35,000	37,633	37,633	-2,633
e. Subcontract public awareness	3,000	2,395	2,395	605
f. Contingencies	415			415
TOTAL	**110,415**	**110,181**	**107,888**	**234**

The funds spent in equipment were used to purchase the refrigerant identifiers and room air conditioners used for the workshops as indicated in component 2 of the present report. A total of 8 identifiers Ultima Id Pro were purchased and delivered as per table 1 in Component 2. It also includes 5 mini-split units of 12,000 BTU, fake refrigerant and other materials and tools purchased for workshops.

V. Conclusions and recommendations

This paragraph does not include the conclusions already inserted above from the national and international experts. The present conclusions are from the project findings and implementation activities.

Conclusions

1. The first conclusion is that lack of knowledge from all stakeholders, even Implementing Agencies, on the fact that Counterfake or contaminated refrigerant is widely available in the market. It cannot be stated that ‘all over the world’ but it is more and more available.

2. Nowadays, the web commercial pages increased the availability of this kind of refrigerant. It is possible to find and purchase many kind of refrigerants at different prices without any restriction.

3. The project was implemented in direct cooperation with the experts in the countries, the involvement of NOU and local technicians was the main factor for the success. In cooperation with the project manager, many local refrigeration dealers were visited and different kind of refrigerants with misleading labeling and packing were found.

4. The demonstration carried out during workshops was one of the most important activities. With this, the technicians understood the consequences they can expect using the counterfake refrigerant. It was clear that the good refrigeration practices and proper use of tools are useless if the refrigerant has not standard quality.

5. Among the consequences of fake refrigerant can be listed the following:

   a) More energy consumption, indirect CO_2 emissions.
   b) Damage of components, compressor burnout, equipment to be cleaned.
   c) Reduce of equipment life spam.
   d) Lost of efficiency in the system.
   e) Can be flammable or toxic.

f) Cannot be recycled or reclaimed.
g) Potential increase in refrigerant consumption due to recharge.
h) Potential increase of leaks, if higher pressure refrigerant charged.
i) Unreliable, the job may have to be repeated. Loss of credibility for the technicians.
j) Counterfake refrigerant will end vented releasing ODS and GWP gases.

6. The couterfake refrigerant are widely available among other due to the following reasons.

    a) It is a profitable business.
    - In some cases it is matter just of bottling recovered refrigerant. This include all kind of pure of blend refrigerants that can be contaminated by particles, other gases, acidity etc. or unbalanced blends.
    - It is also possible to expand pure refrigerants with no-standard gases like R-40.
    - Just recovered phase-out gases bottled and reselled.
    - More and more examples can be found in the market.
    b) Difficult to track and prosecute.
    - As per the results of surveys included in the present report. In some cases, customs allow refrigerants which are not banned. For customs, the quality is not a requirement.
    - Refrigerant are not entering the countries through the regular ways.
    - Refrigerant are not properly declared in customs
    - No country of origin, no proper import licences.
    - More and more examples
    c) Lack of awareness
    - This can be the most important conclusion. In general, the concept is that there is only one quality, even if refrigerant of the same denomination is available at quite different prices in the same market.
    - Even importers, seems to be, are not aware on the refrigerant quality.
    - Stakeholders are unaware of quality and consequences.
    - Good refrigeration practices and, in general, training does not include the refrigerant quality as subject.
    d) Attractive due to low price
    - Price drive market.
    - It is repacked in some countries and distributed in low quantities
    e) Difficult and expensive to verify authenticity
    - One of the first activities implemented in the project.
    - Refrigerant identifiers should be also provided to training centres

7. The refrigerant identifiers are very expensive but delicate tools. So many units have been distributed all over the article 5 countries and are damaged. The refrigerant identifiers are designed to be used for gas and includes a device to be used for liquid. One of the issues is that if couterfake refrigerant is being tested, the identifier can be used with liquid refrigerant and the consequences are well known after some uses. It is recommended to emphasize the uses to use always the identifier with the liquid testing device and also with the small 'capillary valve' included and seldom used.

8. As per the brochure prepared by UNIDO, there are some tips on how to identify counterfake refrigerants:

    a) Lower or upper case: E.g. R-134a is different to R-134A or R-141b to R-141B, and R-410A to R-410a, inclusive R-600 is not R-600a and R-600A does not exist.
    b) Small letter is used for single refrigerant to indicate change in chemical composition. R-134 is different than R-134a.

c) Capital letter is use to indicate the composition of the blend R-410A, R-508B or R-401C. Eg. R-409A (60% R-22/25% R-124/15%R-142b) and R-409B (65% R-22/25% R-124/10%R-142b)
d) Brand names: Dupont can be found in some cylinders and it is DuPont. Genatron is used instead of Genetron.
e) General appearance of the cylinders: Some cylinders or cans are scrapped, repainted, soiled or damaged. Some are out of dimension or even renamed.
f) AHRI colour code: The colour code is a good guidance, sometimes same refrigerant is available in cylinders of two different colours.
g) Misleading advertising: from R-600a or R-290 non-flammable to 'replace for' can be found in the market.
h) The brochure include some tips on how to recognize genuine refrigerants. It is to be noted that not all should be included, but it can be used as guidance. Some tips are: manufacturers name; trade name; ASHRAE refrigerant number; chemical name; UN number; CS number; country of origin; net weight.

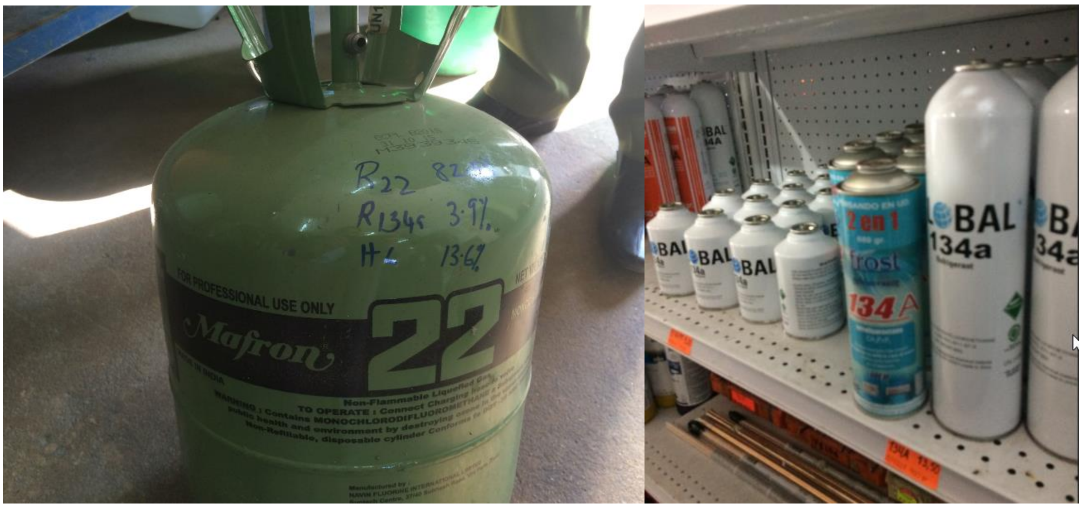
9. The lack of knowledge on the refrigerant quality is also found in the custom officers. In general, the training is focused in the substances and licensing systems but the general aspects of the packing and labeling is not included.
10. The best way to stop the counterfeit refrigerants is through the training of technicians and public awareness. The brochure also includes some tips on this issue: - Check the packing or cylinder based on described; if possible, test the refrigerant; report counterfeit refrigerant to enforcement agencies, refrigeration service technicians association, relevant authorities; do not accept counterfeit (it is for your own safety); no demand, no offer; public awareness, spread the word; low enforcement, policy and standards.
11. Project manager have found counterfake refrigerant in many countries beyond those included in the present demonstration project. Even, in some countries, the refrigerant available in the training centres was first externally verified and then tested, the results showed that there is clear relation between packing and containment. In many cases contaminated refrigerant was found and good examples to teach on ways to identify potential fake refrigerants based on the label.
12. Conclusion of the project implementation:
    a) Due to geographical distribution, the project was indirectly implemented in two parts. The main was for the neighbor countries Kenia, Uganda, Tanzania and Zambia and the second for Eritrea. In both cases the same activities were implemented and the results are summarized in the present report.
    b) The support received from the National Ozone Units from Kenia and Uganda was very valuable for the project implementation.
    c) The lack of funds for public awareness and information dissemination jeopardize the project implementation plan. Since the activities from UNIDO side were well advanced, the project was redirected and completed in the best possible way.

Recommendations

The recommendations given are intended to be applicable and not a wish list which would require big investment and impossible activities.

1. In the training activities for trainers and technicians, is should be included the subject of fake refrigerants. The basic tips for identification, the testing options with or without identifiers and the demonstration with refrigeration units, hopefully new refrigerant identifiers should be included.

2. Wherever possible, a testing centre should be established. It should provide the service for free and have statistic information on counterfake refrigerant available in the country. At least one testing centre should be located in the main city and second in a port city if the case. Training centre is a good option, however, every country can find the best venue for this purpose.
3. Public awareness at all levels is the most important tool to combat the counterfake refrigerants. Since so many environmental treats are included in the fact that counterfake refrigerant is entering the markets, it is a good opportunity to join national public awareness campaigns to protect the environment.
4. It is required to include the basic information and provide brochures, like the one designed by UNIDO, to the custom officers. It will be necessary to include the requirements in the check lists.
5. The brochures were design in English and Spanish language. Some copies have been delivered to countries were UNIDO is implementing projects. It can be distributed in other countries or at least copied and adapted to the local requirements.
6. It is time to work on standards for refrigeration, as already included in the Enabling Activities for the Kigali Amendment. The standard should not be only for HFC but for all kind of refrigerant, labeling and packing.



Composition for R-22 and R-134A and R-134a

ANNEXES

Final Report

Demonstration project on refrigerant quality, containment and introduction of low-global warming potential alternatives (Eastern Africa and Caribbean regions)

Annex I. Agreed Work Plan for the project implementation.

Tanzania_Workplan _UNIDO Assignment

Annex II. Report of joint mission Project Manager and Project leader.

Mission report Zam-Kan-Tan JN Sep

Annex III. Reports of:

Standards and Market Availability of Quality Refrigerants in Tanzania, Kenya, Uganda and Zambia)

Tanzania_UNIDO Assignment_DEMO

Standards and market availability of Quality Refrigerants in Kenya

Standards and Market Availability o

Country program Kenya

Country program Kenya Oct 16 -.docx

Annex IV. Reports on gap analysis

Reports on gap analysis

UNIDO FINAL SURVEY REPORT.doc

ODU's Survey June 19.docx

Refrigerant Survey_Gap Analysis

REFRIGERANTS SURVEY IN NAIROBI

Annex V. UNIDO Brochures

Refrigerant can be Counterfeit! English version

Brochure_Gas_En.pdf

!Los refrigerantes también los falsifican! Spanish version

Brochure_Gas_Sp.pdf

Annex V

Final Report on the Project

Decision 76/35 of THE EXECUTIVE COMMITTEE OF THE

MULTILATERAL FUND FOR THE IMPLEMENTATION OF THE MONTREAL PROTOCOL

Development of Regional center of excellence for training and certification and demonstration of low-global warming potential alternative refrigerants in Eastern Europe and Central Asia

Submitted by the Russian Federation

As of December 2019

CONTENT

Introduction

EXECUTIVE COMMITTEE OF THE MULTILATERAL FUND FOR IMPLEMENTATION OF MONTREAL PROTOCOL at its Seventy-sixth Meeting (Montreal, 9-13 May 2016) approved (Decision 76/35) the demonstration project for the Eastern Europe and Central Asia region on development of a Regional center of excellence for training and certification and demonstration of alternative refrigerants with low-global warming potential (hereinafter referred to as Regional Center), with allocation of funds in amount of US $591,600, plus agency support costs of US $75,076 (total amount US $666,676.00).

In line with Decision 72/40 the allocated funds came from the annual contribution of the Government of the Russian Federation to MLF for 2016 (against the MLF invoice in amount of US $5,290,344.00). The Executive Committee of MLF requested the Government of the Russian Federation to complete the Project within 36 months of its approval (May 2016) and accordingly submit the final report. As a matter of fact the money was wired by MLF to the Implementing agency in July 2017.

According to the Trust Fund agreement between the United Nations Industrial Development Organization (UNIDO) and the Government of the Russian Federation dated 31 August 2017 UNIDO has been implementing the Project in 2017 – 2019.

Objectives of the Project and deliverables

The overall objective of the project is to improve the technical capacity of the refrigeration and air-conditioning sectors in the countries of the Region (Eastern Europe and Central Asia) and consequently facilitate:

- overcoming the barriers on the way to introduction of low-GWP refrigerants;
- improving service practices used on the national level, and
- reducing the level of F-gas emission from the existing refrigeration and air-conditioning equipment.

As result the trained national technicians and designers will enhance their awareness, understanding and promoting introduction of new approaches to energy efficient design and operation on their national market in domestic, commercial and industrial refrigeration and air-conditioning systems.

This project sets up the training and assessment facilities at the Regional Center for the benefit of the countries of the Region, on the basis of using of curriculum document and certification program for the national level corporate employees performing maintenance, servicing or manufacturing of products and equipment relying on or containing F-gases and/or low-GWP refrigerants in line with the requirements of article 10 of (EU) № 517/2014, Directive 2006/40/EC; Regulations (EC) № 303/2008, (EC) № 306/2008 and Regulation (EC) № 307/2008. The Regional Center acts also as a demonstration hub and knowledge base for alternative refrigerant technology especially for safe handling, application and related systems design using low-GWP refrigerants.

The main deliverables of the Project are as follows:

1. Center of Excellence is established and put into operation with fully equipped training and assessment facilities.

2. Training and certification programs and technical advisory services of the Regional Center are developed and accredited under Real Alternatives certification system.

3. A common draft F-gas regulation harmonized with (EU) No. 517/2014 was developed and published as e-version in Russian and English languages for dissemination among partner countries of the Region.

4. Demonstration Project showing utilization of low-GWP refrigerants and energy efficient design is in place and accessible for conducting study tours and analysis.

5. Common curriculum was developed for providing vocational and academic studies covering refrigeration and air-conditioning service practices.

By collocating the practical training and job certification with the development of expertise in design and systems operation, the Regional Center will be able to provide excellent opportunities for private and public organizations to demonstrate new and innovative technology and the latest refrigeration and air-conditioning systems, components, controls and operating practices. The operating model is therefore based on public-private partnerships where mutual benefit can be derived to achieve the common objectives of improving current practices, performance, energy efficiency and climate impact of refrigeration and air-conditioning systems.

Financial statement as of December 2019

	Component	Funds approved, USD	Disbursement, USD
1	Infrastructure of the Regional Center	128,500	138,697
2	Operation of the Center	39,600	45,347
3	Adaptation and Printing of UNIDO Programmes and Manuals (English and Russian)	51,500	55,500
4	Development of Online Interactive Courses (English and Russian)	58,500	62,500
5	Pilot Refrigeration Plant Based on Natural Refrigerants	214,000	188,261
6	PR Activities	8,500	8,500
7	Internet-portal of the Project (in Russian and English)	28,500	30,295
8	Management, Office	62,500	62,500
	Total:	**591,600**	**591,600**

Main activities and key outcomes

Planning Activity (as per initial project document)	Outputs or service delivered	Outcomes observed
Deliverable 1: Center of Excellence is established and put into operation with fully equipped training and assessment facilities	– With support from the Russian Federation the host side (Ministry of Nature Protection of the Republic of Armenia) nominated the beneficiary for location and establishment of the Regional center of excellence; – Bidding procedures implemented to choose the Contractor/ Service Provider; – The instructors of the Regional center of excellence received training in Moscow on stands operation; – Works completed on production,	Regional center of excellence with training and assessment facilities was put into operation.

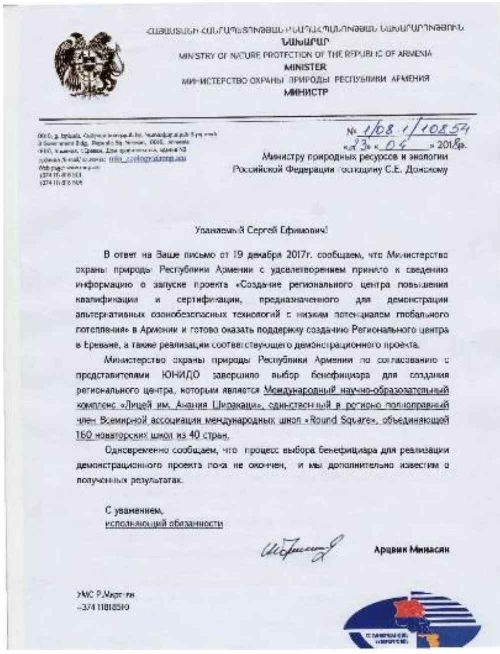
Planning Activity (as per initial project document)	Outputs or service delivered	Outcomes observed
	delivery and installation of equipment at the Regional Center of excellence; – The launching ceremony was held on September 18, 2019. It was a part of the session of the Interstate Ecological Council of the Commonwealth of Independent States (CIS) which was attended by representatives of Environmental ministries, UNIDO, RAC associations and NOUs representatives, technical experts communities and Lyceum students; – 5 trainings were conducted; a new contract was signed to conduct trainings in the Regional Center for 45 technicians representing the Eastern Europe and Central Asia countries.	
Deliverable 2: Training and certification programs and technical advisory services of the Regional Center are developed and accredited under Real Alternatives certification system.	– Bidding procedures implemented to choose the Contractor; – Major part of work on developing training programs and technical advisory services were carried out before December 31, 2018; – Website http://hvaccenter.am/ was created for remote online learning; – 5 trainers were certified (F-gas + Real Alternatives); – The Regional Center was accredited under the Real Alternatives certification system.	Training Center is accredited under the internationally recognized EU certification system of Real Alternatives.
Deliverable 3: A common draft F-gas regulation harmonized with (EU) № 517/2014 was developed and published as e-version in Russian and English languages for dissemination among partner countries of the Region.	– A set of documents on F-gas regulation was translated into Russian (working language in the Regional Center); – Proposal based on F-gas regulation for simplification of certification reasonable for the countries of the Region was developed; – Each country of the Region is expected to consider national regulations harmonization after ratification of the Kigali Amendment.	A set of useful documents was compiled and then translated into Russian language to facilitate development of national regulation and certification systems in the countries of the Region.
Deliverable 4: Demonstration Project showing utilization of low-GWP refrigerants and energy efficient design is in place and accessible for conducting study tours and analysis.	– – The host side (Ministry of Nature Protection of the Republic of Armenia) defined the beneficiary for development of demonstration project; – UNIDO carried out tender procedures to choose the Contractor/ Service Provider; – Works on production, supply and installation were carried out; – The Regional Center launching	Implementation of this Demonstration Project resulted in presenting real benefits from using hydrocarbon refrigeration system to enhance safety

Planning Activity (as per initial project document)	Outputs or service delivered	Outcomes observed
	ceremony was held on September 18, 2019; – Demo-project "Hydrocarbon refrigeration system for typical fruits and vegetables storages" is aimed at improvements in the field of safety, energy efficiency (by 34% on the demo-project site). – The information events were held in September 2019 for Armenian HVAC&R representatives and government officials and in December 2019 for technicians from Turkmenistan.	and energy efficiency with aim to spread replication widely.
Deliverable 5: Common curriculum is developed for providing vocational and academic studies covering refrigeration and air-conditioning service practices.	– Bidding procedures implemented to choose the Contractor/ Service Provider; – All procedures and works under the Contract were completed.	Common curriculum of the Regional Center is developed for providing vocational and academic studies.

Description of outcomes

OUTCOME 1: Center of Excellence is established and put into operation with fully equipped training and assessment facilities.

The Ministry of Nature Protection of the Republic of Armenia nominated the International Scientific-Educational Complex of "Shirakatsy Lyceum" for location and functioning of the Regional center of Excellence.


MINISTRY OF NATURE PROTECTION OF THE REPUBLIC OF ARMENIA
MINISTER
МИНИСТЕРСТВО ОХРАНЫ ПРИРОДЫ РЕСПУБЛИКИ АРМЕНИЯ
МИНИСТР

№ 1/08.1/10854
«23» «04» 2018г.

Министру природных ресурсов и экологии
Российской Федерации господину С.Е. Донскому

Уважаемый Сергей Ефимович!

В ответ на Ваше письмо от 19 декабря 2017г. сообщаем, что Министерство охраны природы Республики Армения с удовлетворением приняло к сведению информацию о запуске проекта «Создание регионального центра повышения квалификации и сертификации, предназначенного для демонстрации альтернативных озонобезопасных технологий с низким потенциалом глобального потепления» в Армении и готово оказать поддержку созданию Регионального центра в Ереване, а также реализации соответствующего демонстрационного проекта.

Министерство охраны природы Республики Армения по согласованию с представителями ЮНИДО завершило выбор бенефициара для создания регионального центра, которым является Международный научно-образовательный комплекс «Лицей им. Анания Ширакаци», единственный в регионе полноправный член Всемирной ассоциации международных школ «Round Square», объединяющей 160 новаторских школ из 40 стран.

Одновременно сообщаем, что процесс выбора бенефициара для реализации демонстрационного проекта пока не окончен, и мы дополнительно известим о полученных результатах.

С уважением,
исполняющий обязанности

Арцвик Минасян

"Shirakatsy Lyceum" was founded in 1990 to reveal gifted children, manage their education and study their gift problems. Since October 2009 the "Shirakatsy Lyceum" has been officially recognized as a regional one, and since 2010, it has been a sound member of the World Association of International Schools «Round Square» (network of 150 innovative schools located in 40 countries on five continents). More than 300 graduates from "Shirakatsy Lyceum" continued their studies at leading world universities such as Harvard, Cambridge, Sorbonne, Oxford, Stanford, Lomonosov, Massachusetts, Tokyo, Beijing, and London universities.

The Regional center of Excellence is equipped with the following training simulators and equipment:

- CO_2-based refrigeration machine;
- HC-based refrigeration machine ("HC-based refrigeration machine" and "Retrofit to HC refrigerants");
- Training simulator "Welding and soldering. Supply and exhaust ventilation";
- Training simulator "Principles of refrigeration machine operation. Azeotropic refrigerants";
- Training simulator "Principles of refrigeration machine operation. Zeotropic refrigerants";
- Training simulator "Refrigerants. Types. Identification. Recovery and regeneration";
- Training simulator "Refrigeration machine. VRF";
- Training simulator «Refrigeration machine. Chiller & fan coil unit»;
- The furniture and office equipment have been supplied in the following scope: desks for students and a trainer, chairs for students and a trainer, desk for a trainer, lap tops, interactive whiteboard, racks for the back office, safety and warning signs, first-aid kits, consumables and tools;
- Training courses and software installed on the laptops to enable simultaneous training of 15 HVAC system specialists.

Fig. 1 Main class-room equipped with the state-of-the art training simulators

The Regional Center was launched in September 18, 2019. The launching ceremony was a part of the session of the Interstate Ecological Council of the Commonwealth of Independent States (CIS) countries. It was attended by more than 50 participants: ministers and deputy ministers of CIS countries, representatives of UNIDO, HVAC&R associations and companies, technical experts and students.

Fig. 2 Participants of the launching ceremony

Fig. 3 A ribbon-cutting ceremony

(from left: Erik Grigoryan, Minister of Environment of the Republic of Armenia, and Sergey Yastrebov, Deputy Minister of Natural Resources and Environment of the Russian Federation)

OUTCOME 2: Training and certification programs and technical advisory services of the Regional Center are developed and accredited under Real Alternatives certification system.

The Regional Center was accredited under the internationally recognized certification schemes (Real Alternatives) and accessed to the learning programs for technicians working in the refrigeration, air conditioning and heat pump sector, designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants in English and Russian languages.

Fig. 4-6 Training process and handing of certificates

The accreditation scope of supply includes the following:

- learning booklets for individual self-study delivered as pdf downloads;

- e-learning modules that mirror the learning booklets;

- practical training course design;

- assessments and certification for individuals;

- a train the trainer programme and licensing of training providers;

- programme website.

5 trainers were trained and certified under F-gas and Real Alternatives certification systems.

The National Lead agreement was signed. The Regional Center as a National Lead will provide learners with access to the Real Alternatives materials, conduct trainings and assessment exams.

The level of equipment in the Regional Center was highly praised by the Centro Studi Galileo (Italy), which conducted the accreditation assessments with following remarks:

- The HVACR training center is very well equipped with several RAC didactical units (e.g. AC split, unit with f-gases, equipment with CO_2 and with HCs, etc). The technological relevance of the equipment is high. The disposition of the training equipment in the center allows the best task performance. There is also a vast, up-to-date and useful stock of reserve equipment, tools, and consumables.
- The five participants were motivated, very well prepared and highly skilled. They possess a remarkable theoretical knowledge and the motivation to perform the practical tasks; this allowed carrying out the training and assessments smoothly and rapidly. Many questions and comments raised by the participants allowed for a stimulating debate at the end of each session. The younger participants demonstrated a promising attitude and interest for the activity. All participants passed the three assessments with remarkable grades, higher than average.

Additionally, the Regional Center signed a special agreement on cooperation with the related Moscow training Center. So now the Regional Center can provide additional training courses for learners and grant them with safety and skills certificates (such as electrical safety, works at heights, pressure receptacles and soldering skills) valid on the territory of Russia and Eurasian Economic Union states.

OUTCOME 3: A common draft F-gas regulation harmonized with (EU) №517/2014 was developed and published as e-version in Russian and English languages for dissemination among partner countries of the Region.

The set of F-gas documents directly related to the training and certification issues were translated into Russian:

- Regulation (EU) № 517/2014 of the European Parliament and of the Council dated 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) № 842/2006 Text with EEA relevance;
- Commission Regulation (EC) № 1516/2007 dated 19 December 2007 establishing, pursuant to Regulation (EC) № 842/2006 of the European Parliament and of the Council, standard leakage checking requirements for stationary refrigeration, air conditioning and heat pump equipment containing certain fluorinated greenhouse gases (Text with EEA relevance);
- Commission Implementing Regulation (EU) 2015/2067 dated 17 November 2015 establishing, pursuant to Regulation (EU) № 517/2014 of the European Parliament and of the Council, minimum requirements and the conditions for mutual recognition for the certification of natural persons as regards stationary refrigeration, air conditioning and heat pump equipment, and refrigeration units of refrigerated trucks and trailers, containing fluorinated greenhouse gases and for the certification of companies as regards stationary refrigeration, air conditioning and heat pump equipment, containing fluorinated greenhouse gases (Text with EEA relevance);

These documents were taken into account when certification training courses had been developed and introduced.

The countries of the Region will consider the process of harmonization of national legislation and regulation after their ratification of the Kigali Amendment. The Regional Center is now ready to provide advisory services and technical assistance regarding implementation of needed harmonization of legislation and regulation on a request of any country of the Region. The Interstate Technical Council of National Refrigeration Associations has been established to accelerate this process.

OUTCOME 4: Demonstration Project showing utilization of low-GWP refrigerants and energy efficient design is in place and accessible for conducting study tours and analysis.

Demo-project «Hydrocarbon refrigeration system for typical fruits and vegetables storages» was implemented in Province of Kotayk, Armenia. Old-fashioned cooling system using CFC-12 as refrigerant was replaced with secondary refrigeration system using R290 (propane).

Fig. 7 Hydrocarbon refrigeration system installed in Province of Kotayk, Armenia

The new cooling system installation provided benefits in terms of safety, energy efficiency, reduction of life-cycle costs and opportunity for wide spreading replication.

Description of benefits considered while conducting study tours are as follows.

Safety

Refrigerant charge is 6 kg. Considering the fact that R290 is a highly flammable matter, the following fire safety measures have to be taken:

- all spark-hazardous electrical components are located beyond protecting casing and are installed in a separate control switchboard;
- all components installed in a protecting casing are explosion-proof;
- a protecting case has an internal alarm system with R290 leakage detector, which in case of refrigerant leakage isolates the refrigeration plant;
- new unit is installed outdoor as specified by fire safety requirements.

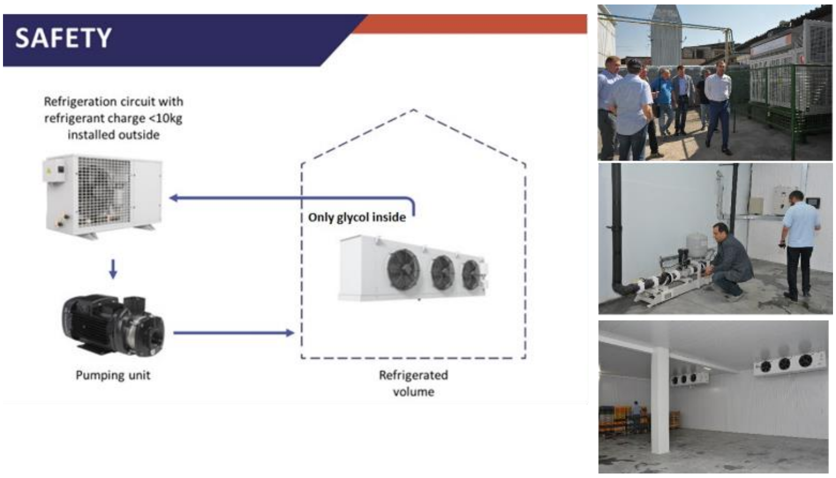


Fig. 8 Example of safety location of equipment

Energy efficiency

High energy efficiency is ensured by lower refrigeration load through enhanced heat insulation, condenser of larger size and automation system maintaining minimum condensing pressure. As result energy efficiency has improved by 34%.

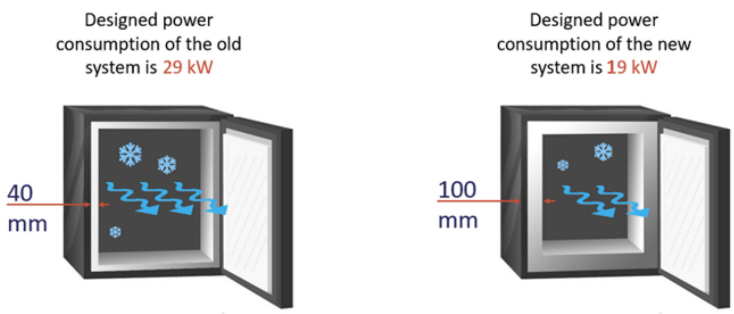


Fig. 9 Comparison of energy efficiency between new and old-fashioned systems

Reduction of life-cycle costs

The life-cycle costs include initial (capital) expenditures, cost of electrical energy and repair and maintenance costs. Average operation time before overhaul is taken as 10 years.

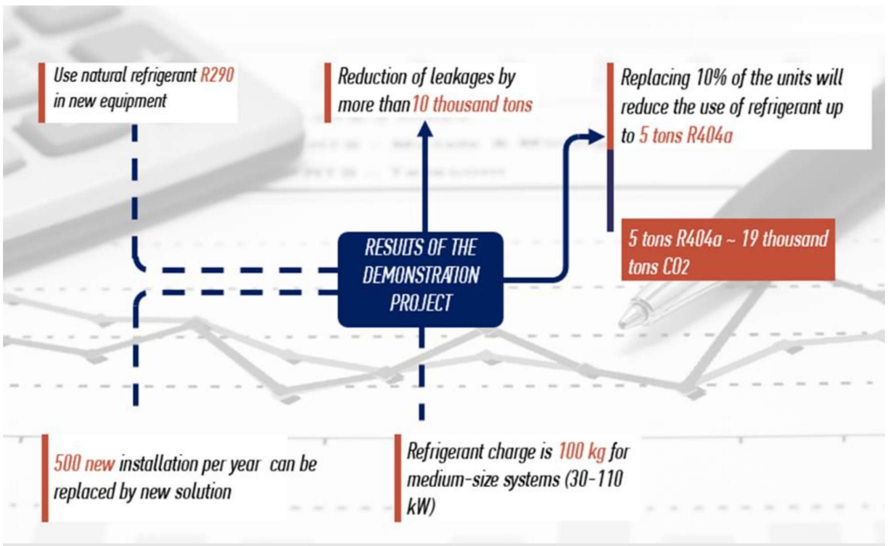
Solution	Initial expenditures, USD	Electrical energy		Repair and maintenance cost, USD/y	Total in 10 years, USD
		kWh/y	USD/y		
Old equipment*	0	52 000	9 360	112 000	213 600
R404a central system	105 000	43 545	7 838	3 000	213 381
Proposed solution	125 000	34 525	6 215	500	192 145

*Cost of operation of old equipment includes overhaul with possible purchase of R12 in future.

Fig. 10 Sample calculations and comparison of life-cycle cost

10 years later the proposed solution will enable to save USD 21,236 as compared to R404a central system and USD 21,445 as compared to the "old-fashioned" equipment.

Opportunities for wide spreading replication



This demo-project has some technological advantages: factory assembly, easy for installation, parameters are maintained without service personnel, materials are available and maintenance costs are low.
Up to 500 new installations per year can be replaced by using this solution in the countries of the Region (Eastern Europe and Central Asia).

Fig. 11 Opportunities for replication of this solution

All visitors of the Regional Center and potentially interested parties in the countries of the Region are invited to undertake site visit and see an example of successfully implemented project showing safety and energy efficiency of the proposed solution on the basis of natural refrigerants.

The system operation parameters are transmitted in real time and recorded for further analysis and studies. Thus, the Demonstration Project serves as a platform for promoting natural refrigerants solutions in the countries of the Region.

OUTCOME 5: Common curriculum was developed for providing vocational and academic studies covering refrigeration and air-conditioning service practices.

The common curriculum for vocational and academic studies covering refrigeration and air-conditioning practices is based on use of internationally recognized programs.

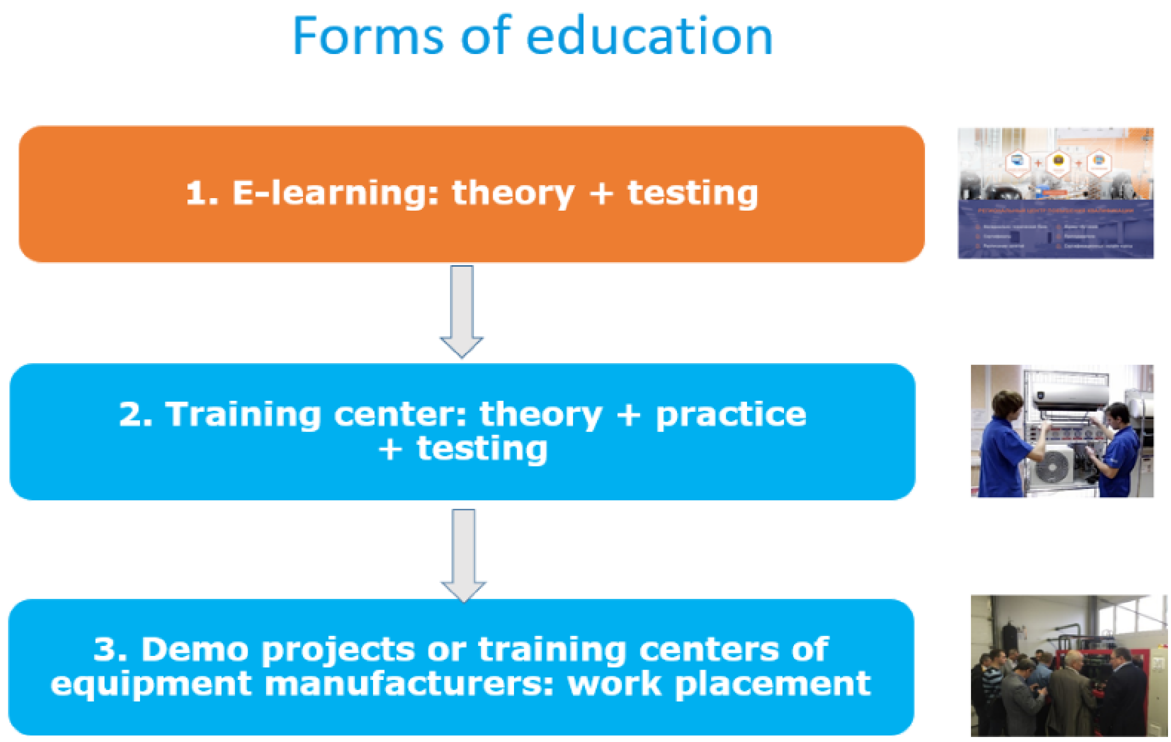


Fig. 12 A scheme used in the Regional Center for development of common curriculum

The forms of education include first e-learning: theory + testing, then coming to Armenia and in-depth study of theory, practice and testing at the Regional Center. The final process of consolidation of knowledge includes undertaking practice on site of demo-project or/and at the training centers of equipment manufacturers and partners facilities.

The Regional Center provides a wide range of training programs for different target audience given in the table below:

Title of program	Forms of education	Target audience	Trainers	Certificate
Real Alternatives learning program	E-learning on https://www.realalternatives.eu, theory, practice, assessments and certification for individuals	HVAC&R specialists	Certified Regional Center Trainers	Real Alternatives
F-gas certification course (4 category)	E-learning on hvaccenter.am, theory, practice, assessments	Technicians and other	Certified Regional	European F-gas, if

	and certification for individuals	HVAC&R specialists	Center Trainers + independent assessment procedure	necessary
Use of natural refrigerants in various sectors	E-learning on hvaccenter.am, theory, practice and advisory services	Customers and HVAC&R specialists	Certified Regional Center Trainers, Regional Center partners	Not applicable
Safe use of ammonia refrigeration systems	E-learning on hvaccenter.am, theory, practice at Regional Center and advisory services	Customers and HVAC&R specialists	Certified Regional Center Trainers, Regional Center partners	Not applicable
Safe use of hydrocarbon refrigeration systems	E-learning on hvaccenter.am, theory, practice at Regional Center and demo-project and advisory services	Customers and HVAC&R specialists	Certified Regional Center Trainers, Regional Center partners	Not applicable
Safe use of carbon dioxide (CO_2) refrigeration systems	E-learning on hvaccenter.am, theory, practice at Regional Center and demo-project and advisory services	Customers and HVAC&R specialists	Certified Regional Center Trainers, Regional Center partners	Not applicable
Ozone layer protection and climate change legislation	E-learning on hvaccenter.am, theory, practice at Regional Center	Customers, government officials and HVAC&R specialists	Certified Regional Center Trainers, NOU experts	Not applicable
Design and operation of carbon dioxide (CO_2) refrigeration systems	Theory and practice at Regional Center	Customers and HVAC&R specialists	Regional Center partners	Not applicable
Danfoss training courses: 1) Refrigeration fundamentals 2) Danfoss compressors 3) Danfoss automation systems 4) Industrial refrigeration 5) Commercial refrigeration	Theory and practice at Regional Center	HVAC&R specialists	Regional Center partners	Danfoss certificates

The training package includes:

- Curriculum of training courses;
- Online training course;
- Training manual;

- Training presentations for theoretical classes of the course;
- Practical training course design;
- Assessments and certification for individuals (where applicable).

Gender issues

The equal rights of women and men were provided through the whole project cycle.

A key role in the project implementation was played by UNIDO Country Representative and Head of Ozone office, National Ozone Focal Point for Armenia.

The percentage of women-managers in the beneficiary institution has increased to 50% and it is higher than in average in an ordinary organization in Armenia.

The Regional Center ensures equal rights and equal access to its services for women and men. It encourages women's participation in trainings by popularizing women in Trades and Technology together with the Regional Ozone Network for A 5 Countries in the Region of Eastern Europe and Central Asia.

PR activities and cooperation with other projects

The PR activities of the project included arrangement of special events, participation in relevant meetings and information dissemination.

The Project participants repeatedly discussed issues related to development of the Regional Center of excellence at the meetings of Ozone Officers Network for the region of Eastern Europe, Caucasus and Central Asia and community events held in Moldova, Georgia, Belorussia and Turkey in 2017-2018. The issues related to the Regional center of excellence vision and training programs under development, as well as the unified concept of the regional certification system were under discussion.

Representatives of refrigeration associations and working groups also met in Moscow (more information can be found on website: http://www.ozoneprogram.ru/eng/news/refrigeration_associations_in_moscow/) to discuss among other issues the development of a regional certification structure and certification concept.

The Project participants held numerous meetings with representatives of the Ministry of Nature Protection of the Republic of Armenia, project`s beneficiaries, local stakeholders and Armenian RAC Association.

The Interim Project report was submitted for consideration at a workshop on activities of the Russian Federation in area of International Development held at the Russian Embassy in Yerevan on January 30, 2019.

The launching ceremony was a very important PR-event and organized as a part of the session of the Interstate Ecological Council of the Commonwealth of Independent States (CIS). It was the important event for Armenia, Russia and other CIS countries and was widely covered by mass media including TV and governmental and HVAC association websites, e.g.:

- http://www.mnr.gov.ru/press/news/v_armenii_po_initsiative_i_pri_finansovoy_podderzhke_rf_otkrylsya_regionalnyy_tsentr_povysheniya_kva/
- http://www.mnp.am/en/post/4185
- https://www.youtube.com/watch?t=4s&v=3lE3M1tEfdY&app=desktop
- http://www.rshp.ru/index.php?option=com_content&view=article&id=673:2019-09-25-04-15-51&catid=62:2009-08-28-05-54-21&Itemid=2
- https://armenpress.am/arm/amp/988505
- https://news.am/arm/news/534091.html
- https://168.am/2019/09/18/1175278.html
- https://enews.am/news/5d821d110a975a6f105e8c84
- https://www.tert.am/am/news/2019/09/18/mnp/3096706
- https://assets.danfoss.com/documents/DOC320841040091/DOC320841040091.pdf (page 10)

The Regional Center was also presented at Europe and Central Asia (ECA) network meeting held in Kiev on 24-25 September, 2019.

Project implementation delays

The project was approved in May 2016. The implementation period was expected to be 36 months after the project approval therefore it should have been completed by June 2019. But funds were allocated to the Implementing Agency (UNIDO) in September 2017. So actually financing of the Project activity was commenced with delay of one year. Therefore December 2019 can be considered as early estimated completion of the Project (36 months will expire in September 2020). It means the project is completed faster than planned.

Other factors causing minor delays of the Project commencement and accomplishment are as follows: delays in defining beneficiaries for the Regional Center of Excellence (till 23.04.2018) and in implementation of the Demonstration project (till 18.07.2018) were caused on the host side (Ministry of Nature Protection of the Republic of Armenia), mostly due to replacement of beneficiary for the Demonstration project (till 02.11.2018), resulting in rescheduling of bidding procedures terms and bidding tasks adjustment.

Long-lasted repair works in the premises of the Regional Center were carried out by the beneficiary to prepare the required classrooms and make installation of training stands (all works were competed only in February 2019). These delays were caused mostly due to some political reforms and decision maker replacements in the Republic of Armenia.

Project sustainability evidence

Development concept

The Development concept for the Regional Center provides its management with important information on the educational market in the countries of the Region, the promising directions of development of the Regional Center, its partners, training programs, potential customers, pricing, staff and other important issues. The development concept was under discussion as one of key issues with the Regional Center management.

Governmental support and official partners

The Regional Center is supported by the Ministry of Environment of the Republic of Armenia and the National Ozone Unit of the Republic of Armenia. The Regional Center has five partners and cooperation with them on the basis of signed partnership agreements as follows:

- The Danfoss Group manufactures products and provides services used in cooling food, air conditioning, heating buildings, variable frequency drives, gas compressors and powering mobile machinery.

- NORD is a Russian manufacturer of CO_2 and Hydrocarbons systems.

- Rossoyuzkholodprom is a Russian HVAC association working closely with the Russian government.

- Vercont-service is a Russian HVAC training-center, established with technical assistance of UNIDO. It works successfully without governmental support, that is important for success in exchange of experience.

- IMEI helps the Regional Center to get safety certificates valid on the territory of Russia and other Eurasian Economic Union states.

The Center provides an open platform for potential partners to contribute to operation of the Regional Center in return to fair exposure of their goods and services and testing and demonstration of products and systems. They are also interested in supporting the HVAC sector globally and fostering research activities, including practical application of testing results (environmentally-safe techniques of handling refrigerants), energy-efficiency performance, and many other issues incorporated into certified academic programs.

Trainings held in the Regional Center

A few trainings have been conducted since the establishment of the Regional Center.

The first training event for trainers started immediately after the launching ceremony. Five trainers were trained and certified under F-gas and Real Alternatives (CO_2, HC) program.

Fig. 13 Training process

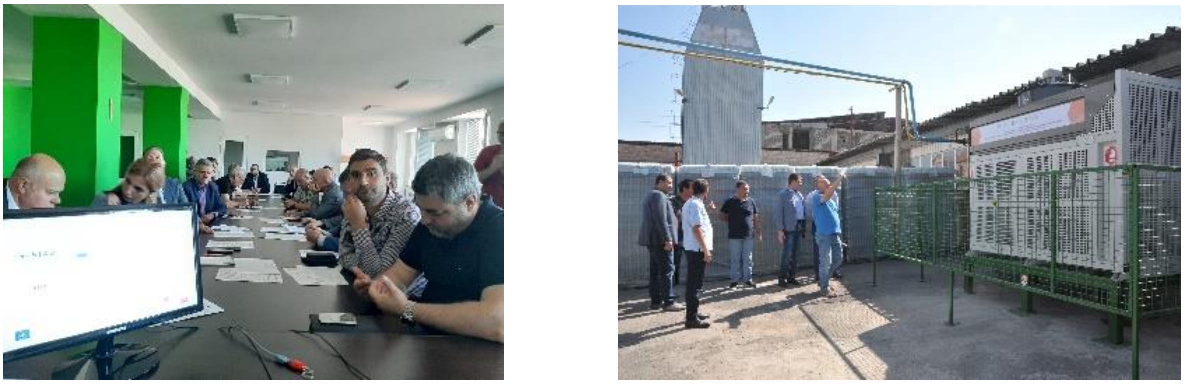


Fig. 14 Training course in class and on site

The second training course was held with the partners of the Center. It was dedicated to its development and the demo-project key features. More than 30 participants, including partners of the Regional Center, HVAC specialists and Regional Center representatives attended the second training event.

The third training event was carried out in October 2019 immediately after the Prom Expo exhibition held in Yerevan, with assistance of Danfoss company (official partner of the Regional Center). A group of 17 participants represented HVAC&R specialists and trainers from Armenian technical colleges and universities.

Fig. 15 Course leavers with certificates handed

The fourth training course was held in November and December 2019 for technicians from Turkmenistan in amount of 15 participants. They received Regional Centre certificates and safety certificates valid on the territory of CIS countries (electrical safety, work at heights, pressure receptacles, soldering).

Fig. 16 A group of course leavers from Turkmenistan with certificates handed

The fifth training course was carried out in December 2019 for Armenian technicians in amount of 15 participants representing Armenian RAC. All of them received Real Alternatives certificates.

Fig. 17 Training process in a classroom

As result of the Regional Centre activity it was contracted in the end of 2019 to conduct training courses in early 2020 for minimum 45 technicians representing the countries of the Region of Eastern Europe and Central Asia.

Initiation of F-gas certification for participants from the countries of the Region

The Interstate Ecological Council of the Commonwealth of Independent States (CIS) addressed this issue of F-gas certification for the countries of the Region at its session in Yerevan in September 2019. The states of the Region which are not yet a Party of the Kigali amendment to the Montreal Protocol including the Russian Federation will initiate F-gas certification after ratification of the Kigali Amendment.

Recommendations

- Additional funds to be allocated to continue and develop the Project success and enable the countries of the Region to direct their technicians to the Regional center in Yerevan for certified training

The original Project budget was proposed by the Russian Federation in amount of USD 852,600 excluding 13 % of Agency Support Costs. The budget was expected to cover expenses for both development of the Regional center and further conducting training and certification of expected and considerable number of technicians from the countries of the Region.

The originally proposed budget of the Project was reduced more than by 30 % and the budget approved amounted to USD 591,600 excluding 13% Agency Support Costs. Nevertheless the main tasks of the Project have been performed but substantial reducing of the budget resulted in considerable cutting-down of total number of trained technicians representing the countries of the Region.

Therefore the Russian Federation suggests that some needed additional funds to be allocated to complete the Project component related to enabling the countries of the Region to direct their technicians to the Regional center in Yerevan. The funds can be allocated as Phase 2 of the Project and covered from the Russian Federation contribution to MLF for 2020 paid and wired in full amount of USD 7,782,333.00 in December 2019.

- Customers training is a key target

The refrigeration systems owners and potential customers are real decision-makers on the local markets. They make a final decision what to "buy" and "which system to install". It is strongly recommended to concentrate efforts on customers training in similar future projects implementation.

- Commencing Project implementation shall be provided by timely allocation of funding in order to avoid any delays

The Project implementation period should be determined from a moment of receiving sufficient funds by Implementing Agency.

- Country situation assessment shall be a subject of proper investigation

There is a need in more proper assessment of the country situation. For example, a lack of vocational schools and universities, qualified specialists, co-financing sources as well as temporary political instability in Armenia at the period of implementation of the Project (obviously this factor cannot be predicted or expected) can result in delays in the schedule of implementation.

Final Report

DEMONSTRATION PROJECT FOR THE PHASE-OUT OF HCFCS BY USING HFO AS FOAM BLOWING AGENT IN THE SPRAY FOAM APPLICATIONS IN HIGH AMBIENT TEMPERATURES SAU/REF/76/DEM/27

2020

Table of contents

1. Objective

Demonstrate benefits from the use of the HFO-1233zd(E) and HFO-1336mzz(Z), which have very low GWP in replacement of HCFC-141b with water, in terms of lower GWP and CO2 release and insulation properties in the PU spray foam insulation sector;
Demonstrate the easy applicability of the technology and, consequently, the replicability of the results;
Demonstrate that lower cost structure as compared to other alternatives can be obtained by means of lower foam density and lower thermal conductivity;
Objectively analyze, if the incremental operating cost could be reduced overall in similar future projects by means of using optimized water / physical foam blowing agent applied in the foaming process;
Objectively analyze, if the incremental capital cost at the System Houses can be utilized by means of lesser focus on the flammable gas detection and ventilation. In particular, the extensive exhaust ventilation in the countries with hot climate may result in unexpected costs in the air-conditioning production area during the hot summer periods.

Table 1-1 – HFO Foaming agent

Common Name	**HCFC-141b**	**Formacel® 1100**	**Solstice Liquid BA™**	**Forane® 1233zd**
		1336mzz(Z)	1233zd(E)	1233zd(E)
Chemical Formula	CH_3CFCl_3	Cis-CF_3-CH=CH-CF_3	Trans-ClCH=CH-CF_3	Trans-ClCH=CH-CF_3
Molecular Weight	117	164	130.5	130.5
Boling Point (°C)	31.9	33	19	19
Gas thermal conductivity (W/mk)	8.8	10.7	9.52	9
Foam Properties	Good	Very good	Very good	Very good
Flammable Limits in air (Vol %)	5.6-17.7 (Effectively none-flammable)	None	None	None
GWP (100 years ITH)	725	2	1	1
TLV (ppm)	500	500	800	Not disclosed

Price (US$/kg)	2.0 – 4.0	?	USD 9 - 13	?
Manufacturer		Chemours (Formerly DuPont and Dow)	Honeywell	Arkema

2. Companies selected (background/application)

HCFC-141b is used by Sham Najd International in in-situ formed sprayed rigid polyurethane (PUR) and polyisocyanurate foam (PIR) for insulating and water proofing walls, ceilings, roofs, suspended ceilings and floors at the construction sites and industrial sites in the Kingdom of Saudi Arabia. Thus, Sham Najd was solely selected to phase-out HCFC-141b within this demonstration project by converting to HFO foaming agent technology due to its willingness and availability to act simultaneously as a demonstration project. The chosen technology is a non-ozone depleting and low GWP foaming agent. This HFO technology, which is a definitive alternative under the Montreal Protocol and additionally has a positive impact on climate, is in compliance with Decision XIX/6.

Replacing HCFC-141b in spray foam in the Kingdom of Saudi Arabia (KSA) presents an opportunity and technical challenge, making it worthy of a demonstration project. The preliminary 2014 HCFC consumption estimates show that 600 MT of HCFC-141b or 66 ODP tonnes were consumed in 2014 for spray foam in the Kingdom of Saudi-Arabia (these figures include import of pre-blended polyurethane systems). Also, in 2014, the Ministry of Municipal and Rural Affairs of KSA has made thermal insulation compulsory for all new buildings in the 24 districts of the country covering 80% of the populations. The addition of thermal insulation in new building is expected to reduce 40% of energy use in air conditioning. Today, air conditioners account for 70% of electricity consumption in the region and with 1.5 Million new homes needed to keep up with the population growth, energy demand is anticipated to double by 2030 if energy conservation measures are not put in place.

3. Technologies Considered and selected

3.1. Alternative technologies considered

In accordance with the 2014 report of the rigid and flexible foams technical options committee, there are numbers of alternatives that are available to replace the use of HCFC 141b in rigid polyurethane foam. Several foaming technologies, including the following, are used as alternate technology:

- Cyclopentane
- HFC-245fa
- HFC-365mfc/227ea

- HFC-134a
- Methyl formate
- CO2 (Water)
- u-HFC
- Liquid unsaturated HFC/HCFC (HFOs) as emerging technology (subject for this demonstration project)

3.2. Commercially Available Options

Option	Pros	Cons	Comments
Cyclopentane & n-Pentane	Low GWP	Highly flammable	High incremental capital cost, may be uneconomic for SMEs
	Low operating costs		
	Good foam properties		
HFC-245fa, HFC-365mfc/227ea, HFC-134a	Non-flammable	High GWP	Low incremental Capital Cost
	Good foam properties	High Operating Cost	Improved insulation (cf. HC)
CO2 (water)	Low GWP	Moderate foam properties -high thermal conductivity-	Low incremental Capital Cost
	Non-flammable		
Methyl Formate/Methylal	Low GWP	Moderate foam properties -high thermal conductivity-	Moderate incremental capital cost (corrosion protection recommended)
	Flammable although blends with polyols may not be flammable		

3.3. Emerging Options

Option	Pros	Cons	Comments
Liquid Unsaturated HFC/HCFC (HFOs)	Low GWP	High operating costs	First expected commercialization in 2013
	Non-flammable	Moderate operating costs	Trials in progress
			Low incremental capital cost

The Indicative assessment of criteria for commercially available options as well as emerging alternatives in PU foam is provided in the table below:

3.4. Assessment of criteria for commercially available options

	c-pentane	i-pentane n-pentane	HFC-245fa	HFC365mfc/ 227ea	CO_2 (water)	Methyl Formate
Proof of performance	+	++	++	++	++	+
Flammability	---	---	++	+(+)	+++	--
Other Health & Safety	0	0	+	+	-	0
Global Warming	+++	+++	--	---	++	++
Other Environmental	-	-	0	0	++	-
Cost Effectiveness (C)	--	---	++	++	++	0
Cost Effectiveness (O)	++	+++	--	--	+	+
Process Versatility	++	++	+	++	+	+

Assessment of criteria for Emerging Technology options

	HFO-1234ze(E)	HFO-1336mzzm(Z)	HFO-1233zd(E)
	Gaseous	liquid	Liquid
Proof of performance	0	+	+
Flammability	++	+++	+++
Other Health & Safety	+	+	+
Global Warming	+++	+++	+++
Other Environmental	+	+	+
Cost Effectiveness (C)	++	++	++
Cost Effectiveness (O)	--	--	--
Process Versatility	+	+	+

3.5. IOC comparison between major alternatives during demonstration project formulation

IOC	HCFC-141b			HFO-1233zd			Methyl Formate			Water-blown / Formic Acid		
	Formula	%	Cost/kg	Formula	%	Cost/kg	Formula	%	Cost/kg	Formula	%	Cost/kg
Polyol	100	44,29%	2,70	100	46,08%	2,70	100	37,88%	2,70	100	37,95%	2,70
B.A	15,8	7,00%	2,70	7	3,23%	11,00	9	3,41%	2,70	3,5	1,33%	2,70
MDI	110	48,72%	2,70	110	50,69%	2,70	155	58,71%	2,70	160	60,72%	2,50
Total	**225,8**	**100,00%**	**2,70**	**217**	**100,00%**	**2,97**	**264**	**100,00%**	**2,70**	**263,5**	**100,00%**	**2,58**
Thermal conductivity mW/mK			**21**			**21**			**23**			**31**
Foam density			42			42			42			42
Equivalent cost USD			**2,70**			**2,97**			**2,96**			**3,81**
Total PU consumption 2015	400000	27,99	1080000	400000		1187097	400000		1182857	400000		1522577
IOC / year USD						**107097**			**102857**			**442577**

3.6. Selection of alternative technology for the Demonstration project

The technology chosen has been HFOs due to the following:

Spray foam is used to insulate, provide air sealing and improve structural strength in buildings. The insulation potential of spray foam is dependent upon the insulating gas in the cells of the polyurethane foam. In addition to the insulation performance, polyurethane foams used for the insulation purpose require inherently superior dimensional stability and resistance to fire.

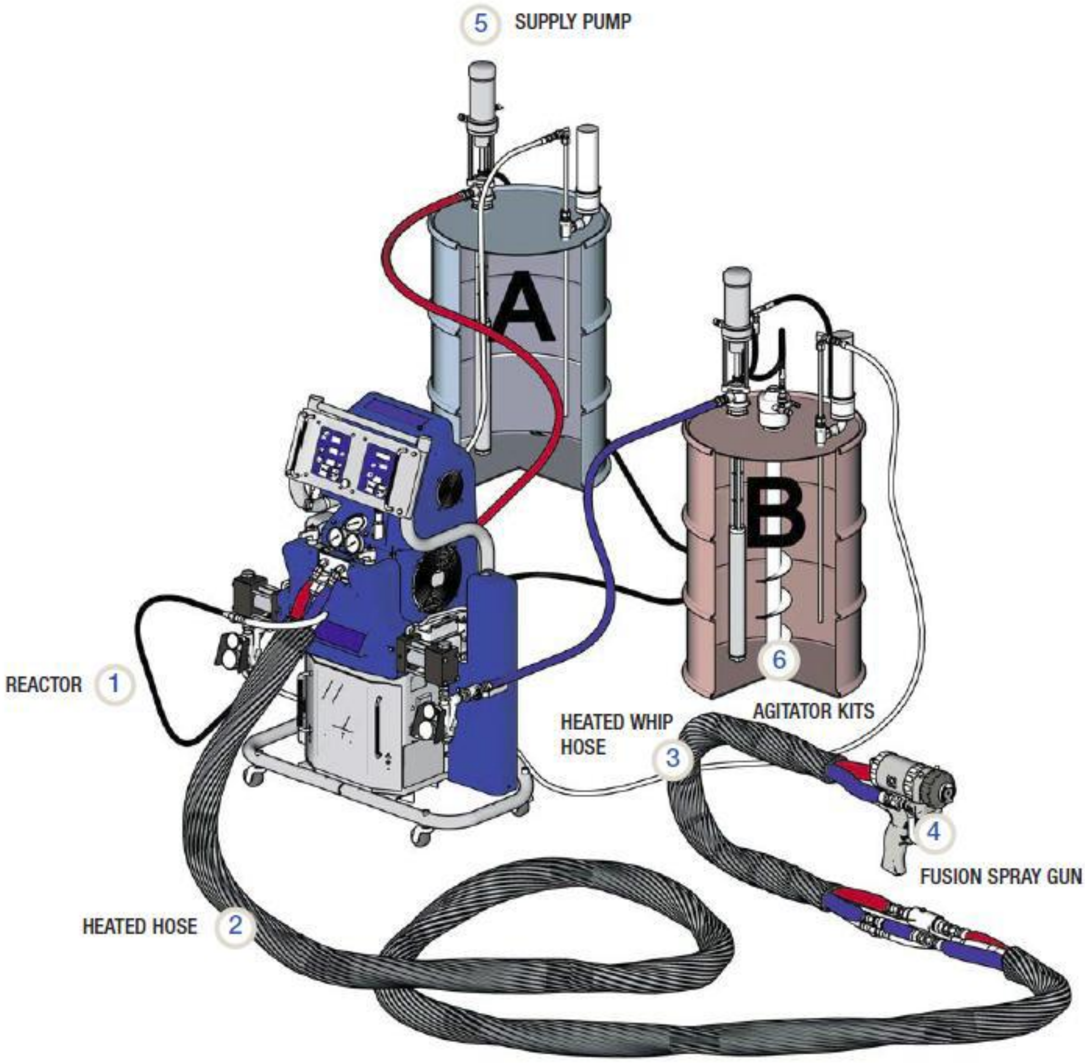
The current zero ODP options for replacement of HCFC-141b in foam applications include hydrofluorocarbons (HFCs) and hydrocarbons. Both HFCs and hydrocarbons are characterized by increased thermal conductivities compared to the HCFC, resulting in inferior insulation performance.

Few alternatives exist for replacing 141b in spray foam. Hydrocarbons are not a viable alternative for spray foam, and HFC-245fa and HFC-365, while viable, have high global warming potential (GWP). Also, the low boiling point of HFC-245fa and the flammability of hydrocarbons and HFC-365mfc present significant challenges to refrigerants processing and handling that are critically important in spray foam applications. On the other hand, foam blowing agents HFO-1233zd(E) and HFO-1336mzz(Z) have very low GWP, both less than 5, and HFO-1233zd (E) is claimed to be even less than 1. These molecules are also non-flammable and stable liquids at ambient temperatures. The HFO-1233zd(E) is already commercialized and HFO-1336mzz(Z) was expected to be commercially available from the year 2016. However, during the project implementation it was found out impossible to obtain it in such quantities which would have facilitated full-scale demonstration project. Thus, only blowing agent HFO-1233zd(E) has been tested in this demonstration project.

4. Modification of production

The foaming agent technology did not require new foaming equipment. All testing was performed with Sham Najd existing equipment (Graco E-XP1 Applicator).

Graco E-XP1 Applicator



5. Technical evaluation

Testing of the spray foam system SHPU 45 FSSL-50 from Covestro, UAE. The testing took place at Sham Najd's Labor camp & Warehouse area on 13 through 15 March 2017.

The spray foam testing operation was conducted by means of Sham Najd's existing Graco Reactor E-XP1 spray foaming machine and using the Fusion Air Purge Plural-Component Spray Gun.

The testing started on 13 March 2017 by means of spraying the standard non-fire rated spray foam system PS 105 H 40 Winter from KSA local system house SUCCO. The test results are provided in the table 1 and 2.

Testing was continued on 14 March 2017 with Covestro's HFO-1233zd blown SHPU 45 FSSL-50 fire retarded foam system. The test results are provided in table 1 and 2. All tests were conducted as follows:

Table 5-1. Test Results from the first samples in March 2017

Density	Approx. 43-47	ASTM D1622
Compressive strength	> 0.1 MPa	ASTM D 1621
Fire rating (DIN4102-1)	B2	DIN 4102
Fire rating Butler Chimney	Above 50%	ASTM 3014
Thermal Conductivity	≤0.024 W/m°K (10°C) ≤0.029 W/m°K (35°C)	ASTM C518
Dimensional Stability -20°C/+70°C, 48 hrs	Max 1%	ASTM D2126

Table 5-2. Thermal conductivity at 10°C

System	Density kg/m3	Compressive strength MPa	Dim. Stability % Max allowable 1%	Thermal conductivity W/mK @ 10°C	Aged thermal conductivity 21 days @70°C W/mK	Butler Chimney test ASTM 3014
SHPU45FSSL-50 (HFO-1233zd)	40.8	0,298	0.85	0.0210	0.0267	81.9%
PS 105 H 40 (HCFC-141b)	57.8	0,406	0.81	0.0248	0.0296	52.0%

Table 5-3. Thermal conductivity at 35°C measured two weeks after production

System	Density kg/m3	Compressive strength MPa	Dim. Stability % Max allowable 1%	Thermal conductivity W/mK @ 10°C	Aged thermal conductivity 21 days @70°C W/mK	Butler Chimney test ASTM 3014
SHPU45FSSL-50 (HFO-1233zd)	44.5	0,350	0.85	0.0246	0.0273	81.9%
PS 105 H 40 (HCFC-141b)	57.8	0,406	0.81	0.0275	0.0298	52.0%

Table 5- 4. Physical properties measured after 18 months from applying the foam on the roof. The samples were stored next to the test roof for easier testing purpose

Property		Unit	Average	Typical	Assessment of 18 months foam
Foam Density	EN 1602	kg/m^3	48,7	47	Typical value for roof insulation
Thermal Conductivity λ_{10} (+10°C)	EN 13165	mW/mk	26,1	26	Increased from 21 to 26.1, but understandable due to 18 months ageing at the construction site
Aged Thermal Conductivity (21days +70°C) λ_{10} (+10°C)	EN 13165	mW/mK	26,8	27	Shows that foam has kept insulation well
Thermal Conductivity λ_{35}(+35°C)	EN 13165	mW/mk	28,2	28	Increased from 24.6 to 28.2, but understandable due to 18 months ageing at the construction site
Aged Thermal Conductivity (21days +70°C) λ_{10} (+35°C)	EN 13165	mW/MK	28,9	29	Shows that foam has kept insulation well
Compression Behavior	EN 826	kPa	352	300	Similar to original 298 kPa -> 352 kPa (improved), which is typical that physical foam properties improve during the first months, upon all foam has after polymerized. The compression strength of PUR/PIR products remains constant with time if there is no air diffusing into the cells (ageing). If air diffusion is characteristic of the product then the compression strength will increase with time. The level of this increase will increase with the level of closed cells present, i.e. this increase will be the highest with level CCC4 (>90%) and least with level CCC1 (<20%).
Tensile Strength	EN 1602	kPa	183	150-200	This is typical for sprayfoam
Dimensional stability (3 days +70°C)	EN 1605	%	+0,66	±1	Excellent
Dimensional stability (10 days +70°C)	EN 1605	%	+0,69	±1	Excellent
Reaction to Fire Butler Chimney Test	ASTM 3014	%	91,1	80-90	Very good, practically IMPROVED FROM 81.9% to 91.1%
Reaction to Fire B2 Test	DIN 4102	cm	10,5	10-11	Has kept the fire rating well (15 cm max)
Water Vapor Resistance	ISO 12572	(m^2 s Pa/kg)	10,5*10^9	8-12*10^9	This is a typical value, and means that about 10 g water vapor goes through the 2 cm thick foam within 24 hrs, when there is 50 RH% humidity difference at 20 deg centigrade
Closed Cell Content	ISO 4590	%	93,3	90	Similar to HCFC-141b based foams
Closed Cell Content Corrected	ISO 4590	%	97,4	95	Similar to HCFC-141b based foams

Table 5-5. Following characteristics were studied due to high ambient temperature

Characteristic	Observations
The maximum concentration of HFO in the polyol to be used without pressurization of polyol vessel	12%
Impact to surfactants and catalysts	It was noticed that special package was to be introduced. Honeywell, the foaming agent supplier, was able to provide necessary package.
Pre-mixed polyol storage at the System House or Enduser's own storage	Five months during November 2016 to March 2017 did not cause any reactivity changes
Surface of the polyurethane as a product	The surface had somewhat more of pinholes compared to baseline foam formulation. However, it is meeting the customer expectations
Dimensional stability of sprayed foam	The tested foam system's dimensional stability in regard to baseline was somewhat reduced, however acceptable and meeting the spray foam standards. In regard to the most important direction against rise, the stability was good
Evaluate the correct timing for laying the protective coating for surface	The protective layer was sprayed on the foam just like on the baseline case (1.5 cm per pass)
Evaluate the performance of existing standard coating spray materials' applicability for the new product	Performance is the same

6. Commercial Evaluation

Commercial evaluation has been prepared basing on actual foaming results. If considering the thermal conductivity remains the same with HCFC-141b and HFO-1233zd the phase-out cost of HCFC-141b with present foaming agent prices the phase-out of HCFC-141b will cost USD 3.18/kg HCFC-141b. The actual laboratory tests displayed better results for HFO-1233zd based foam and in such case the phase-out cost of HCFC-141b were USD 0.52/kg.

Table 6-1 – Commercial Evaluation / IOC

Commercial Evaluation / IOC	HCFC-141b			HFO-1233zd			Water-blown / Formic Acid		
	Formula	%	Cost/kg	Formula	%	Cost/kg	Formula	%	Cost/kg
Polyol	100	38,46 %	2,46	100	38,17 %	2,70	100	37,95 %	2,80
B.A	20	7,69 %	4,00	12	4,58 %	9,50	3,50	1,33 %	2,46
MDI	140	53,85 %	3,50	150	57,25 %	3,50	160	60,72 %	3,50
Total	260	100,00 %	3,14	262	100,00 %	3,47	263,50	100,00 %	3,22
Aged Thermal conductivity mW/mK	29.8			28.2			31		
Required foam density			45			45			52
Equivalent cost USD			3.14			3.47			3.87
IOC (USD/kg HCFC 141b)						4,30			1,07
IOC (USD/kg HCFC 141b) considering change in thermal conductivity and foam density						0.33			9,53

7. Environmental impact

The project impact on the environment was studied for both chemicals i.e. HCFC-141b and HFOs. The CO_2 emission before conversion (using HCFC-141b as blowing agent with Global Warming Potential of 725) is expected as 20,282.68 metric ton per year whereas after conversion to HFO with GWP 1, it is estimated 17.32 metric ton per year. The net impact on the environment is positive. The CO_2 emission is expected to be reduced by 20,282.68 MT after implementing the new technology at Sham Najd. In whole KSA respectively the impact will be 434,643.00 CO2 MT/ year. The ODP phase-out at Sham Najd is 3.08 ODP tonnes and respectively in KSA 66 ODP tonnes. The net effect calculation is provided in the table below:

Table 7-1 – Environmental impact

Name of Industry Sham Najd	Substance	GWP	Phase out amount MT/ year	Total equivalent warming impact CO2 eq. MT/ year	ODP HCFC-141b	Total ODP
Before Conversion						
Total CO_2 emission in M tonnes	HCFC-141b	725	28	20,300.00	0.11	3.08
After Conversion						
Total CO_2 emission in M tonnes	HFO-1233zd	1	17,32	17.32	0	0
Net Impact				20,282.68		3.08
Before conversion Kingdom of Saudi Arabia						
Total CO_2 emission in M tonnes	HCFC-141b	725	600	435,000.00	0.11	66
After Conversion		1	357	357	0	0
Total CO_2 emission in M tonnes				434,643.00		66

8. Additional information

Table 8-1 – List of chemicals

Product	Supplier	Price USD / Kg
HFO-1233zd - Solistice LBA	Honeywell	9.50-15.00
Dabco 2040	Evonik	27.95
Dabco 203	Evonik	13.75
Tegostab B84711	Evonik	8.70
MDI	Sadara (Dow Chemicals' joint venture in KSA)	6.75 SAR USD 1.80

Since the spray foam systems are now available locally in KSA, there will be further local spray foam system use by Sham Najd and other spray foam applicators like Al-Babtain and customers of SUCCO and Saptex.

The SUCCO's actual field testing was conducted during early 2018 with Al-Babtain spray foam applicator for roofing of Honeywell's store area roofing. This testing was not actually connected to this Demo project but demonstrating the local Foam System Houses availability to provide foam systems, which facilitate phase-out of HCFC-141b.

Workshop with all results was held in June 2019. This workshop provided detailed information from the results in Jeddah, Riaydh and Damman.

Table 8-2 – Demo project results were presented at Foam Sector workshops during 22-25 June 2019 at Jeddah, Riyadh and Damman / Al Khobar

Place of venue	Presentations	Subjects	Audience
Jeddah Riaydh Damman	Saptex System House	Alternative foaming agent for spray and pour-in-place applications	Spray applicators 15 Construction consultants 4 National Ozone Unit UNEP
	Succo System House	Foaming results and challenges experienced in the foam formulations and expectations with PU spray foam	
	Sham Najd - Spray Applicator	Comments on the Demo Project	
	Jundi – System House	Experience in the use of natural and flammable foam blowing agent	

	UNIDO International Consultant	1st: Foaming with HFO foaming agents- Solstice LBA and Opteon 1100 2nd: Foaming results with hydrocarbons and other blowing agents 3rd: Foam cost calculations	
	Momentive	Foam formulations	
	Honeywell	4th Generation Blowing Agents	

9. Conclusion

The phase-out of HCFC-141b in Sham Najd will reduce the total CO_2 emission and ODP emissions by a significant margin. The conversion will facilitate the phase-out cost-effectively. The same approach can be applied to the whole KSA and the surrounding region respectively.

Spray foam for roofing in the KSA where the insulation demand is growing will require superior insulating and water-proofing properties and ability to be monolithically apply to all shapes and types of surfaces.

According to the field testing and resulting laboratory testing, the spray foam formulation with HFO-1233zd foaming agent appears to have a high potential to replace HCFCs and HFCs as it has very similar technical and physical attributes and has a very low GWP and zero ODP factor.

Following conclusive characteristics can be noted:

1. The end spray product is matching HCFC-141b blown spray foam in many aspects, such as adhesion, thermal conductivity, dimensional stability, paint-ability, overall foam density and compression strength;
2. Lesser amount of HFO-1233zd can be mixed due to the boiling point of polyol mix will also be lower than boiling point of HCFC-141b blown foam;
3. Storage of mixed polyol needs to be kept at max 28 degrees of centigrade - > needs upgrade of polyol mix storage room air-conditioning;
4. On construction sites, the drum storing of polyol by the spray foam applicators require shelters;
5. HFO-1233zd needs to be kept in pressure vessels;
6. HFO-1233zd needs to be mixed in the temperature-controlled mixing vessel (reactor), temperature less than 18 °C, or to use in-line pre-mixer unit;
7. HFO-based foam system needs special additives in order to avoid deterioration of ageing performance of the polyol mix, see the chemicals to be purchased.

8. Cost of foam system is presently higher than HCFC-141b blown foam. However, it is expected to be balanced within few years.

Advantages:

1. Better foam performance in the cold weather period season (lower boiling point);
2. HFO-1233zd provides future foam formulation without concern of use limitations;
3. Very low Global Warming Potential (GWP) of 1;
4. Non-ozone depleting;
5. Nonflammable (ASTM E-681), VOC exempt (per U.S. EPA) and
6. Facilitate required improved energy efficiency for the future constructions and buildings and can be used for improving old buildings to meet present insulation requirements.

Budget

Total budget approved 96,250 USD

Expenditures: **94,000 USD** (2019), which contains of:

Consultancy services and travels -	28,000 USD
Equipment/Chemicals –	48,000 USD
Workshop and laboratory test -	18,000 USD

Other notes

Response to MFS comments on Interim Report of HFO demonstration project in PU foam Saudi Arabia

1. At the 80th meeting, the Executive Committee agreed to extend the project completion date to 31 December 2018, on the understanding that no further extension of project implementation would be requested, and to request UNIDO to submit the final report no later than the 83rd meeting (decision 80/26(i)). The Secretariat notes from the present report that substantial progress has been achieved in the implementation of the demonstration, but that some activities (i.e., scale field testing and dissemination workshop) have not taken place yet. We would appreciate the following clarifications on the remaining activities to finalize the project:

(a) Please provide the characteristics of the scale field testing planned (specific tests planned, how many tests in how many enterprises, formulations to be used, duration of these tests and additional information expected);

Response: It is tentatively, and as per the project document intention to conduct the field testing only by the company Sham Najd. Intention is to obtain foam systems from KSA SHs SUCCO and Saptex. In the project document it was foreseen only Saptex, but during implementation of this project and System House projects, SUCCO appears to have the most experience in the foam formulation development. The laboratory formulations are already in place, and those are to be field tested.

(b) Please confirm estimated date of completion of all pending activities;

Response: It is foreseen that testing would be completed and results available by October 2019.

(c) Given that these reports are going to be used by other Article 5 countries as reference when implementing projects, we would appreciate that the final detailed report of the demonstration is presented to the 84th meeting, including the result of the remaining tests, any conclusions or additional information emerging from the workshop, and additional details requested the comments below.

Response: The final report is projected to be available by October 2019.

Formulations

2. Please clarify the origin of the formulation used to test HFO-1233zd(E). Was it developed by Covestro for the demonstration project, or is it a commercially formulation available to any systems house?

Response: All foam formulations details are always System Houses' own developments and secrets and based on their polyols in use. However, the additive suppliers (for instance Evonik and Momentive) and the foaming agent suppliers (Honeywell and Chemours) have R&D support available, and they actively provide their experience to the formulators at System Houses. In the case of the Spray Demo project first phase the formulation was fully developed by Covestro, and not available to any other source.

3. Kindly inform if all the tests were done with a formulation containing pure HFO-1233zd(E) or if there were also tests with formulations reduced with water. If that was the case, please also provide the results and how the foam with reduced formulations compare with pure HFO-1233zd and HCFC-141b-foam?

Response: The HFO-1233zd formulations are always substantially reduced with water. The HFO-1233zd content as foaming agent is from 8 to 12 % in polyol formulation high ambient temperature countries. Due to HFO-1233zd's low boiling point, it is not really possible to formulate cost-effectively polyol mixture, which could keep blowing agent fully soluble. The testing has shown that blowing agent start boiling strongly, and the hot climate conditions preclude this kind of high content HFO-1233zd formulations.

The below tables are providing information from the laboratory test. It is to be noted that the HCFC-141b foam was not most suitable for the comparison. However, it was only available.

System	Density kg/m3	Compressive strength MPa	Dim. Stability % Max allowable 1%	Thermal conductivity W/mK @ 10°C	Aged thermal conductivity 21 days @70°C W/mK	Butler Chimney test ASTM 3014
SHPU45FSSL-50 (HFO-1233zd)	40.8	0,298	0.85	0.0210	0.0267	81.9%
PS 105 H 40 (HCFC-141b)	57.8	0,406	0.81	0.0248	0.0296	52.0%

System	Density kg/m3	Compressive strength MPa	Dim. Stability % Max allowable 1%	Thermal conductivity W/mK @ 35°C	Aged thermal conductivity 21 days @70°C W/mK	Butler Chimney test ASTM 3014
SHPU45FSSL-50 (HFO-1233zd)	44.5	0,350	0.85	0.0246	0.0273	81.9%
PS 105 H 40 (HCFC-141b)	57.8	0,406	0.81	0.0275	0.0298	52.0%

Tests undertaken and results

4. Thank you very much for Table 1 listing the tests undertaken. Kindly inform why other typical tests such as adhesion strength (ASTM D-1623), water absorption or closed cell content (ASTM D-2856) were not included. Could they be included in the next measurements?

Response: These above-mentioned tests were to be conducted, but misunderstanding with the UAE Test laboratory, they were not able to conduct all tests. These tests will be conducted for the next test.

5. Table 2 can be considered a clear summary of the results. However, it does not contain all the information that other Article 5 countries will need as reference. We would appreciate if for the final report you could include for each of the tests listed, a brief description on how the test was done (how many times, at what temperature,

relative humidity and other conditions) and how you interpret the results found. Please feel free to include Annexes for additional tables, where necessary.

Response: The following testing will be included:

- European in-situ formed sprayed PU foam standard EN 14315;
- Thermal resistance and thermal conductivity
- Measurement of lambda values (thermal conductivity W/mK)
- Ageing of lambda value
- Reaction to fire of the products
- The reaction to fire classification of the products shall be determined in accordance with EN-13501-1 and using data obtained from tests carried out according to procedures EN ISO 11925-2 and EN 13823
- Dimensional stability under specified temperature and humidity conditions
- Dimensional stability under specified temperature and humidity conditions shall be determined in accordance with EN 1604
- Reaction profile and free-rise density
- Durability characteristics
- Durability of reaction to fire against ageing/degradation
- Durability of thermal resistance against ageing/degradation
- Durability of compression strength against ageing/degradation
- Closed cell content
- Short-term water absorption by partial immersion
- Compressive stress or compressive strength

All tests above will be conducted according to EN 14315 (Thermal insulating products for buildings — In-situ formed sprayed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products)

6. Kindly inform if the characteristics of the foam were measured again several weeks after, in order to obtain information on aging. It has been observed in several of the demonstration projects that some of the characteristics of the alternative foam may vary over time in a different way than HCFC-141b-foam. If this was measured, please include it in the final report. If this was not done, please explain the reasons and kindly consider undertaken additional measurements.

Response: We understand this need, and it is foreseen.

7. It is understood from the demonstration that no modifications were required to the foam dispenser for the application of HFO-1233zd(E) in spray foam applications. Is there any instance in which a modification to the spray foam equipment would be needed or it can be inferred that in general no changes are needed?

Response: The evaluation was done with relatively new Graco Spray foam unit, which has very good control on the pressure, mixing and heating of hoses. Thus, it can be used as such.

8. The conclusion section indicates that mixed polyols needs to be stored at maximum 28 degrees Celsius. The reasons are not explained in the report.

Response: Boiling point of the HFO-1233zd is so low that it will cause evaporation / boiling of the chemical. It is not azeotropic mixture with polyol.

9. The conclusions also indicate that HFO-1233zd should be mixed in the reactor at a temperature lower than 18 degrees Celsius. The reasons are not explained in the report.

Response: Boiling point of HFO-1233zd is 19.5 °C, and in order to avoid loss of the blowing agent during mixing process, it needs to be mixed preferable at 15°C

10. What have been identified as the main challenges to introduce HFO-1233zd(E) in spray foam application in Saudi Arabia?

Response: Ambient temperature, shelf-life of the polyol mixture, high price and motivation to the SH's due to the availability of HCFC-141b formulations and bulk.

11. Kindly include in the final report an independent technical review.

Response: Will be budgeted and included as requested.

Cost

12. What is the cost of the additional surfactants and catalysts required for the application of HFO-1233zd(E)? Please also provide an explanation on why they are required.

Response: The Evonik catalyst – emulsifier - silicone surfactant package, having the commercial product names;

- Dabco 203
- Dabco 2040 and
- Tegostab B8471

This optimized catalyst package through extensive and multi-year testing is recommended by Evonik and HFO-1223zd supplier Honeywell for spray foam formulators, when using HFO-1233zd as foam blowing agent, and this catalyst package provide self-life for polyol blend for more than 8 months. Thus, UNIDO Demonstration project needs to follow these recommendations.

Name of chemical	kg	USD/ kg	One drum	Description	Other information
Dabco 2040	200	27,50	5 500,00	Dabco 2040 catalyst is a low odor amine used to enhance cure and adhesion to substrate in HFO-blown spray foams.	
Dabco 203	200	13,20	2 640,00	Dabco 204 catalyst can help customers achieve between 6 to 8 months of polyol blend stability when used with HFO-1233zd(E). Dabco 203 catalyst performs similarly to Polycat 204 catalyst, but brings the added advantage of having a low water content, providing additional flexibility to formulators.	Typical uses levels of Dabco 203 catalyst / Dabco 204 catalyst are 2-4% by weight on the polyol side. The product can be used in conjunction with other catalysts to optimize system stability, overall reactivity as well as back-end cure speed. Recommended co-catalysts for HFO based systems include: Dabco® 2039 catalyst, Dabco® 2040 catalyst.
Tegostab B8471	200	8,25	1 650,00	TEGOSTAB® B 8471 acts as a silicone surfactant. Offers foam stabilization. Used in polyurethane rigid foam for construction applications.	Improves stability in formulation.

Momentive package is including following.

- Silicone L5107
- DMEA
- DMCHA
- Catalyst A-1 (Momentive)
- Potassium Octoate from Momentive

13. Is the formulation in Table 5 the one used in the demonstration project (Covestro HFC-1233zd blown SHPU 45 FSSL-50)?

Response: Yes.

14. Is the price of pure HFO-1233zd(E) in Saudi Arabia US $9.50/kg as indicated in Table 5?

Response: Seems to be that price in smaller quantities is USD 15,000 / MT. So, price has not been reduced as expected. In the case of Demo material from Covestro, UNIDO purchased foam as a system, and foam individual chemicall prices were not revealed.

15. Kindly explain how the IOC value of US $0.52/kg was obtained?

Response: From the calculation below, foam cost USD /kg difference is USD 0,04/kg. However, when thermal conductivity is considered, the HFO-1233zd foam USD 0.52/kg lower in cost.

Commercial Evaluation / IOC	HCFC-141b			HFO-1233zd			Water-blown / Formic Acid		
	Formula	%	Cost/kg	Formula	%	Cost/kg	Formula	%	Cost/kg
Polyol	100	38,46 %	2,46	100	38,17 %	2,70	100	37,95 %	2,80
B.A	20	7,69 %	4,00	12	4,58 %	9,50	3,50	1,33 %	2,46
MDI	140	53,85 %	3,50	150	57,25 %	3,50	160	60,72 %	3,50
Total	260	100,00 %	3,14	262	100,00 %	3,47	263,50	100,00 %	3,22
Aged Thermal conductivity mW/mK	29,8			27,3			31		
Required foam density			45			45			52
Equivalent cost USD			3,14			3,18			3,87
IOC (USD/kg HCFC 141b)						4,30			1,07
IOC (USD/kg HCFC 141b) considering change in thermal conductivity and foam density						0,52			9,53

RATES OY

Construction Product Testing Laboratory

August 21^{th} 2019

UNIDO UDITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

Yuri SOROKIN
Industrial Development Officer Montreal
Protocol Division VAGRAMERSTR. 5 VIENNA
AUSTRIA

TEST REPORT

Physical Properties of Sprayed PIR Foam							Typical value
Property		**Unit**	**1.**	**2.**	**3.**	**Average**	
Foam Density	EN 1602	kg/m^3	48,9	48,4	48,9	48,7	47
Thermal Conductivity λ10 (+10ºC)	EN 13165	mW/mk	26,1	26,0	26,1	26,1	26
Aged Thermal Conductivity (21days +70ºC) λ10 (+10ºC)	EN 13165	mW/mK	26,7	26,4	27,3	26,8	27
Thermal Conductivity λ35(+35ºC)	EN 13165	mW/mk	27,3	28,6	28,7	28,2	28
Compression Behaviour	EN 826	kPa	351	345	359	352	300
Tensile Strength	EN 1602	kPa	172	229	149	183	150-200
Dimensional stability (3 days +70ºC)	EN 1605	%	+0,60	+0,63	+0,74	+0,66	±1
Dimensional stability (10 days +70ºC)	EN 1605	%	+0,68	+0,63	+0,76	+0,69	±1
Reaction to Fire Butler Chimney Test	ASTM 3014	%	88,7 93,8	88,5 93,9	93,8 88,1	91,1	80-90
Reaction to Fire B2 Test	DIN 4102	cm	10 11	11 10	11 10	10,5	10-11
Water Vapour Resistance	ISO 12572	(m^2 s Pa/kg)	$10,7*10^9$	$9,8*10^9$	$11,0*10^9$	$10,5*10^9$	$8-12*10^9$
Closed Cell Content	ISO 4590	%	93,6	92,8	93,4	93,3	90
Closed Cell Content Corrected	ISO 4590	%	97,6	97,1	97,5	97,4	95

RATES OY

Heikki Tolonen
Laboratory Manager

+358 40 5322350Rates Oy VAT-CODE

Huvijärventie 3 2535453-4

12100 OITTI
FINLAND

Annex VII

Promoting Low-GWP Refrigerants for Air-Conditioning Sectors in High Ambient temperature Countries Phase II (PRAHA-II)

2019

Project Report

Project supported by the Multilateral Fund of the Montreal Protocol

UNITED NATIONS ENVIRONMENT - UNEP

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGNIZATION - UNIDO

Disclaimer

Acknowledgments

The project team would like to acknowledge the assistance given by the governments and the National Ozone Units of the countries participating in the PRAHA project for their support in the implementation of the project phases and their assistance in facilitating communication with the different stakeholders.

We also acknowledge the independent International Technical Review Team that assist the project team in reviewing the project report. The team includes:

- Dr. Abdelaziz, Omar (Zewail City of Science and Technology, Egypt);
- Eng. Almatouq, Yaqoub (Environment Public Authority - Kuwait);
- Prof. Chakroun, Walid (University of Kuwait);
- Dr. Olama, Alaa (Independent Consultant - Egypt);
- Prof. Peixoto, Roberto (MAUA University - Brazil);
- Mr. Wang, Xudong (Air Conditioning, Heating and Refrigerating Institute - USA); and
- JRAIA team of experts

We acknowledge the contribution of the Air Conditioning, Heating, and Refrigeration technical Institute (AHRTI) and the Japan Refrigeration and Air Conditioning Industry Association (JRAIA) for their cooperation in the conduction of the optimization and risk assessment elements of the project.

Acknowledgement also goes to the “Technology Providers” for providing components and advice

Refrigerant Providers: Chemours, Daikin, and Honeywell.
Compressor providers: Emerson.

We recognize the efforts by Optimized Thermal System (OTS) in the optimization elements and the AHRI members who were part of the optimization project monitoring team. We also recognize the efforts of the JRAIA members in their assistance and especially in conducting teleconferences at late hours.

Special thanks to Prof. Chakroun, Walid who supported PRAHA-II in the designing and evaluating the content of the optimization element of the project.

Project Team

Project Managers:
Mr. Eltalouny, Ayman - Coordinator International Partnerships, OzonAction, Law Division (UNEP)
Mr. Nielsen, Ole - Chief of Montreal Protocol Division (UNIDO)

Project Consultant and Report Lead Author:
Mr. Elassaad, Bassam - P.Eng. – HVAC Expert

Table of Contents

List of Tables

List of Figures

ACRONYMS

AC	Air Conditioning
AHRI	Air Conditioning, Heating, and Refrigeration Institute
AHRTI	Air Conditioning, Heating, and Refrigeration Technical Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BTU/hr	British Thermal Unit per Hour
CHEAA	China Home and Electrical Appliance Association
EGYPRA	Promotion of Low-GWP Refrigerants for the AC Industry in Egypt
ETA	Event Tree Analysis
EVX	Electronic Expansion Device
FMEA	Fault Measurement and Effects Analysis
FOA	First Order Analysis
FTA	Fault Tree Analysis
GWP	Global Warming Potential
HAT	High Ambient temperature
HC	Hydrocarbon
HCFC	Hydro Chloro Fluoro Carbon
HFC	Hydro Fluoro Carbon
HFO	Hydro Fluoro Olefin
HOC	Heat of Combustion
HX	Heat Exchanger
IPR	Intellectual Property Rights
JRAIA	Japan Refrigeration and Air Conditioning Industry Association
kW	Kilowatt
lbs	Pounds
LFL	Lower Flammability Limit
MCHX	Micro Channel Heat Exchanger
MOP	Meeting of the Parties
OEWG	Open-Ended Working Group
RACHP	Refrigeration, Air-Conditioning, and Heat Pumps
TFHX	Tube Fin Heat Exchanger
TXV	Thermal Expansion Valve
UA	Thermal Conductance
UFL	Upper Flammability Level

Executive Summary

PRAHA Has Turned into a Process!

PRAHA-I created an awareness about the challenges faced by high ambient temperature (HAT) countries and offered stakeholders in HAT countries support in building their technical knowledge of the alternatives technologies as well as practical support through the building and testing of several prototypes using lower-GWP refrigerants.

PRAHA-I concept of testing prototypes at high ambient temperatures pioneered other testing and research programs which eventually tested more alternative refrigerants than the few refrigerants that were still in the development stage when PRAHA-I was launched. In Addition, PRAHA-I also helped component manufacturers, especially compressors, to start building and testing dedicated compressors for the new alternative refrigerants that are capable of delivering sustained energy efficiency levels at HAT conditions.

The main result of PRAHA is that it went beyond the level of being an individual project with specific planned outcomes and outputs, PRAHA turned to be a **PROCESS** at different levels: governmental, local industry, institutional as well as for the international technology providers.

PRAHA-II is a continuation of the process with specific goals that are aligned with the findings of PRAHA-I. The two main findings of PRAHA-I are that, 1) there are viable alternatives at HAT conditions which need optimized equipment design to perform and deliver the energy efficiency minimum requirements, and 2) that there is a concern about safety of the mostly flammable alternative refrigerants that calls for a special risk assessment model for the HAT countries.

PRAHA-II Elements

PRAHA-II had three main elements: 1) to build the capacity of the local industry in designing and testing products using efficient lower-GWP flammable refrigerants; 2) to evaluate and optimize the prototype built for PRAHA-I; and 3) To build a risk assessment model for the high ambient temperature countries.

Each element has its components and events and was designed to give maximum exposure to the stakeholders, both the industry as well as research institutions and the government, on the latest technology and the developments that are happening worldwide. All three elements were designed to benefit the maximum number of stakeholders.

PRAHA-II Main Findings

PRAHA-II delivered tangible and beneficial results on all three main elements.

- **Capacity Building**: The capacity building element was successful in providing a platform of cooperation between governments, research institutes, industry associations, and the industry in general and became a process for the sharing of information and results among the different stakeholders. The experience of working on PRAHA-I gave UN Environment and UNIDO the confidence that international stakeholders support the goals of the project and that the outcome will be beneficial to all and beyond economic gains. Simultaneous to the efforts by the PRAHA project to create awareness about HAT challenges and the work done through the different symposia held in the HAT countries that were participating in the PRAHA project, the local industry themselves started to directly evaluate and examine long term alternatives which reflect the level of built awareness and attention gained to the wise selection of alternatives.

- **Design Optimization**: The original scope and schedule were modified during the project as new findings and challenges surfaced. The original baseline test data was used for comparison with tests done on the optimized units built according to the modeling work done even though the latter tests included measurements and metrics not typically performed in energy certification tests of the type done under PRAHA-I.
  A resume of the conclusions:
    - For systems operating in considerably higher temperatures (greater than 46°C), the resultant impact on performance must be considered since performance will degrade as compared to operating under more temperate conditions.
    - The design assessment through modeling provided good insights on adequate component design and/or selection for proper system functioning when using novel refrigerants;
    - Rebuilt and tested units exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This indicates the importance of proper compressor selection.
    - Because of the differences in saturation curves from the simulation analysis, refrigerant with wider saturation curves tend to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed however, that by making appropriate component selection, such as compressors with larger displacement volumes and higher mass flow rate, the cooling capacities and overall performance of the other refrigerants were of the same order of magnitude.
    - Refrigerant fractionation as evidenced by the leak tests, does not appear to be a great concern since less than 2% change in cooling capacity was observed after the system's re-charge.
- **Risk Assessment**: The work on risk assessment required resources beyond the traditional RACHP expertise that is allocated for typical conversion/demo projects. The different usage and servicing practices used in the region needed to be considered in order to assess the risk of using flammable refrigerants. The initial concern about the effect of high ambient temperature on the increased risk of ignition was removed and the main focus is on actual practices. The recommendation is for HAT countries to continue the risk assessment based on actual situations and reduce the risk by implementing various measures that are verified such as minimizing ignition probability. In addition, the risk assessments of other stages matching cultural and lifestyle aspects should be studied.

The Way Forward

In general, PRAHA-II outcomes will be of benefit to all 35 countries defined by the Montreal Protocol Parties at the OEWG-37, 2016 as "High Ambient Temperature Countries". A HAT symposium scheduled for March 2020 will convey these results to representatives from those countries. UN Environment and UNIDO intend to transform the PRAHA initiative into a live process with continuous feedback and support to HAT countries.

1. Background and Project Main Elements

Background

The 69th meeting of ExCom approved PRAHA-I with the aim to support assessing the feasibility of lower-GWP refrigerants suitable for high-ambient temperature countries and in particular for air-conditioning applications. UN Environment and UNIDO worked with local industries, international technology providers and national ozone units in these countries to do such assessment through an agreeable independent process that included in its core component building and testing 18 different prototypes and comparing them with respective baseline units which are available from the local industry using mainly HCFC and high-GWP HFC such as R-410A. The process of building and testing the prototypes was completed in 2015 and the final report was released in January 2016. PRAHA included additional components for assessing the technology transfer barriers, energy efficiency implications and economics of alternatives in addition to assessment of district cooling opportunities to reduce dependency on high-GWP alternatives and technologies.

The key finding of PRAHA-I show the potentials and challenges to promote the use of lower-GWP alternatives. Furthermore, many of the non-testing components under PRAHA, like assessing standards and codes and promoting technology transfer, were not thoroughly completed due to two main reasons; the commercial availability of the lower-GWP alternatives in the high-ambient markets and limited resources available to complete the work needed. The findings also pose important queries about what is left to be done in order to make the deployment of low-GWP alternatives possible at high-ambient temperature countries.

PRAHA-I Key Findings

The non-testing components under PRAHA-I assessed technological, economic and energy efficiency aspects in conjunction with high ambient temperature with the following key findings:

I. There are potential alternative refrigerants that are close, or in some cases better, in performance and efficiency compared to baseline refrigerants (HCFC_22 and R-410A) that are worth further investigation. With further product engineering (design and optimization) those alternatives can be strong candidates for replacement of HCFC-22;

II. There is a need to develop the R&D capacity of the local air-conditioning industry in high ambient temperature countries in terms of the design and optimization of products using lower-GWP alternatives with their specifics characteristics, such as flammability, higher operating pressures, temperature glide, etc.;

III. Economic and technology transfer barriers Intellectual Property Rights (IPR) will continue to be issues for some time before international and regional markets stabilize on a limited group of candidates that are sustainable compared to the current long list of options being examined;

IV. Due to the nature of those alternatives and the consequent safety issues, a comprehensive risk assessment model needs to be tailored to the needs of A5 countries, in particular for high ambient temperature conditions. Such a model needs to address manufacturing, placing into market, servicing and the end-of-life of the equipment;

V. There is a lack of institutional programs that address alternative technologies to reduce the dependency on high-GWP alternatives in high ambient temperature countries. This is clearly reflected by the market directions during the phase-out of HCFCs;

VI. The process of improving energy efficiency (EE) standards for air-conditioning application in high ambient temperature countries is progressing at a much quicker pace compared to the process of assessing and selecting alternative refrigerants. A smart approach is needed to jointly consider addressing EE and lower-GWP alternatives in order to avoid promoting higher-GWP alternatives that are commercially available at this stage of time.

Figure 1 summarizes the main findings from PRAHA-I.

Technical Feasibility of low-GWP Alternatives

- *Comparison to commercially existing options i.e. HCFCs & high-GWP HFCs*
- *Relation to Energy Effeceincy programs Directives*

Safety consideration and and Availbility of Materials

- *Risk assessment of A2L and A3 alternatives in industry and service*
- *Availability and cost of alternatives and components*
- *Technology transfer and IPR considerations*

Research and Development Capacities

- *Knowledge and capacity of industry to design with lower-GWP alternatives*
- *Related research programs at global, regional and national levels*

Contribution of District Cooling

- Size and potentiality of district cooling applications
- Use of lower-GWP refrigerants or not-in-kind technologies in district cooling applications

FIGURE 1: MAIN FINDINGS FROM PRAHA-I

The Project

UN Environment and UNIDO approached the Multilateral Fund seeking support for stage-II of PRAHA which is designed to address the priority areas identified in PRAHA-I. The Executive Committee of the Multilateral Fund of Montreal Protocol approved, in its 76th meeting in May 2016, stage-II of the project which is now called PRAHA-II.

The main objective of the project is to maintain the momentum generated by PRAHA-I and advance the technical capacities of stakeholders to enable the adoption and use of lower-GWP sustainable technologies for high ambient temperature countries by supporting the decision-making process related to the acceptance and promotion of lower-GWP refrigerants and advancing the technological capabilities of the local industry to design with those refrigerants.

In consultation with the project stakeholders, several areas were identified that would require further work in order to ensure putting the process of alternative refrigerants' deployment on the right track and address all technical, technological and economic concerns of both industry and policy makers. The areas identified and envisaged to be part of PRAHA-II fall under two components with three distinct elements as shown in **Error! Reference source not found.**. The three elements of PRAHA-II are detailed b elow.

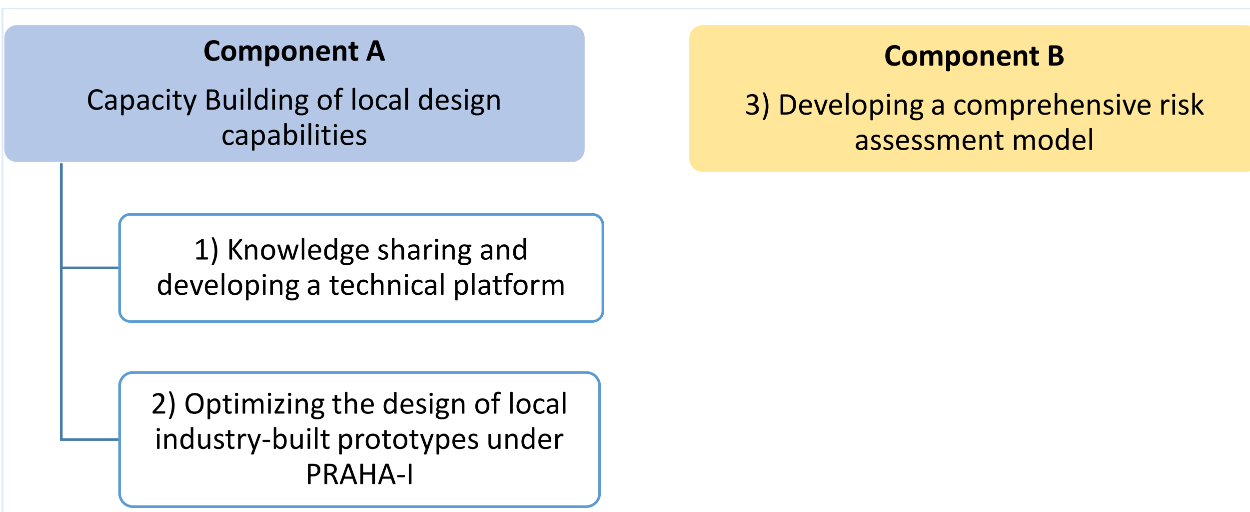


FIGURE 2: OUTLINE OF PRAHA-II

Under Component A, Capacity Building, there are two elements**:**

I. **Building the capacity of R&D sectors in designing with low-GWP alternatives through knowledge sharing and developing a technical platform**
There are three technology schools when it comes to design air-conditioning units, excluding chiller systems, with low-GWP alternatives:

- Designing with HFC-32, which is quite established by the Japanese industry;
- Designing with HC-290, which is at an acceptable level of maturity in China and in other countries;

- Designing with HFO/HFC blends which is just starting to be implemented in different places around the globe.

II. **Optimizing the designs of PRAHA-I prototypes to meet/exceed the baseline designs:** This includes several elements using prototypes of PRAHA-I that had good results and candidate refrigerants that are promising. Prototypes showing unexpectedly poor results will also be evaluated to identify shortcomings.

Component B aims at developing a comprehensive Risk Assessment Model: This includes designing, developing and examining a risk assessment model suitable for use pattern and operating conditions for high ambient conditions and in particular for the GCC region.

2. Capacity Building through Knowledge Sharing and developing a Technical Platform

The concept behind this element is to benefit from the experience of the most advanced industry for each technology in building the capacity of the local R&D in high ambient temperature countries. This includes attending special courses, workshops and conferences discussing these technologies, as well as field visits to manufacturing centers in countries pioneering the technologies.

The three centers of technology for the three main types of lower-GWP refrigerants are Japan, China, and the United States. The Japanese industry is leading in HFC-32 technology for the residential air conditioning sector (apart from Variable Refrigerant Flow -VRF) and is the most proliferated technology in terms of market penetration even though it does not have the lowest GWP. The Japanese market is fully transitioned into using this technology and all Japanese manufacturers are currently producing products using HFC-32. These companies, and other, are building HFC-32 products outside Japan and are marketing them in other markets including some of the HAT countries. The HFC-32 program was conducted in cooperation with Japan Refrigeration and Air Conditioning Industry Association (JRAIA) with input from the Japan Society of Refrigeration and Air Conditioning Engineers (JSRAE) and the industry.

The Chinese industry have an established HC-290 technology and have successfully implemented several conversion projects under UNIDO/UNEP. . Even though the products are not widely available globally, the potential for this technology is very promising due to the many advantages that HC-290 offers in terms of energy efficiency and low-GWP characteristics. The draw-back of high flammability was the main concentration of the capacity building efforts for the stakeholders. The HC-290 program was conducted in cooperation with the Chinese Household and Electrical Appliances Association (CHEAA) and the Chinese industry

The North American industry is leading in the field of unsaturated HFC technology, also referred to a Hydrofluoroolefin (HFO) technology. Although most of the lower-GWP HF0 refrigerants are still not widely available globally, test results have shown some promising alternatives with good performance. The HFO training program which was designed in cooperation with the Air Conditioning, Heating, and Refrigeration Institute (AHRI) which represents the industry in the US with involvement from and the technology providers, i.e., refrigerant and compressor manufacturers.

The capacity building efforts had two tracks: TRACK-I capacity building for the manufacturers of PRAHA-I, and TRACK-II knowledge sharing with different stakeholders at regional and global events

2.1. Track-I: Capacity Building for the Manufacturers of PRAHA-I

The objective of this track is to expose the manufacturers of PRAHA-I to the three technologies through factory visits, study tours, specialized courses, and special events. The purpose is to see firsthand how the technologies have developed in the three centers and how to apply them locally in terms of design, production capabilities, and after sales support.

This track included two study tours, one to Japan and one to China which also included events that were specially designed for PRAHA. In Japan, a risk assessment workshop to explain the Japanese model for A2L refrigerants and the data needed for building the model; and in China a special workshop on A3 refrigerants that attracted input from local and international resources and included participants from other HAT countries.

The HFC-32 study tour objective was to provide participants with a good background about designing and working with lower-GWP refrigerants with A2L low-flammability characteristics. The tour included plants visits, the risk assessment workshop, as well as attending the JRAIA International Symposium on "New Refrigerants and Environmental Technology".

The plant visits took place at Daikin facility in Shiga and the Mitsubishi plant in Shizuoka. Both plants produce HFC-32 based units and have been in production for a couple of years with hundreds of thousands of units installed. The plant visit included explanation of the charging and testing facilities where special precautions are needed. Participants were able to view the special measures taken for the safe handling of flammable refrigerants including storage.

The one-day workshop was conducted by JRAIA at their premises in Tokyo. The subject was risk assessment of A2L refrigerants for residential and commercial equipment. The information provided was detailed and included a review of the risk assessment work conducted by JRAIA; a presentation of key requirements for design; risk assessment for residential & commercial split type air conditioners and VRF during installation and maintenance; and safety guidelines during charging and servicing. Presenters were from Daikin, Panasonic, and Mitsubishi.

The symposium took place in Kobe Dec 1 & 2, 2016: The program provided in-depth information about global efforts to transition to lower-GWP refrigerants including research, regulation, design, safety, components, and energy conservation. The symposium also included a session on new refrigerants and their systems.

The HC-290 study tour objective was to provide in-depth knowledge of HC-290 with visit to a production plant, a building with an HC-290 installation, a special workshop, plus visit to China Refrigeration Expo to attend a one-day roundtable organized by UN Environment and other associations billed as Ozone2Climate Industry Roundtable (O2C).

The visit to AUX factory near Ningbo allowed the participants to view the special measures taken to manufacture equipment working with A3 flammable refrigerants. Factory personnel provided an overview of the R&D work and planning as well as sharing some information on the availability of products and their comparison to those operating with high-GWP refrigerants.

A visit to a facility with more than 1,100 units running on HC-290 was also arranged. The facility is a student dormitory for over 2,000 students in several buildings and all rooms are fitted with mini-splits running on HC-290. The units have been in operation for over two years and no incidents or major problems were reported. Participants were given a presentation by the management and maintenance staff and had the chance to interact with students and gauge their experience living in a facility with units running with an A3 refrigerant.

Workshop on Designing, Production and Installation with HC-290 in the Air Conditioning Industry was organized for PRAHA in collaboration with the Chinese association CHEAA and the Ozone authority of China, FECO. The workshop was enlarged to include other participants from China who joined the expanded PRAHA team. The expanded team included participants from Egypt, Tunisia and Vietnam. The agenda of the two-day workshop included presentations by research facilities, universities, and Refrigeration, Air Conditioning and Heat Pump (RACHP) component and equipment manufacturers.

The workshop focused on risk assessment and other measures related to hydrocarbons and HC-290 in particular. Presentations included a review of international standards and what is needed to enable the new flammable technologies to be adopted by the residential and commercial AC sector; conversion of a production line for the manufacturing of R290-based RAC equipment; and the performance of HC-290 in high ambient conditions. Other presentations discussed the installation and servicing of equipment with flammable refrigerants; reducing charge amount; and a review of R&D work by the manufacturers on A3 refrigerants.

The O2C Roundtable was organized by UN Environment, UNDP, FECO, and CHEAA and covered subjects on policy to promote alternative technologies, global trends, challenges and opportunities for the industry, and solutions for the cold chain and logistics. The PRAHA team presented the challenges in phasing out HCFCs in the countries with higher ambient temperature. Participants had the chance to visit the China Refrigeration Expo in Shanghai, one of the largest for RAC equipment.

The HFO experience in the United States included a course on "*New ASHRAE-Classified Refrigerants to Meet Society's Changing Needs*" by the ASHRAE Leaning Institute (ALI) was offered to several PRAHA stakeholders who were attending the ASHRAE conference and AHR expo. The course discussed the properties of refrigerants and the history of development of synthetic refrigerants and delved into a detailed discussion on flammability and the safe uses of refrigerants. International standards and agreements governing refrigerants and flammability were discussed.

The participants were also invited to a one-day workshop by the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) on *"Sustainable Technologies for Stationary Air Conditioning"* which aimed to familiarize participants with climate-friendly and cost-effective air conditioning technologies which have proven their applicability to replace high-GWP HFCs.

PRAHA-II team presented on "Challenges at High Ambient Temperature" with discussions on the effect of high ambient on the design and operation of air conditioning systems, energy efficiency of refrigerant alternatives, and safety when using flammable refrigerants. The presentation also included highlights from the four research projects testing low-GWP refrigerant alternatives at different temperatures and a comparison of the results. The presentation concluded with a brief description of the work done on PRAHA-II.

The key outcomes from this element of PRAHA-II were in providing information on risk assessment work for both A2L and A3 refrigerants; informing on the availability of new components and new products running with lower-GWP refrigerants; viewing of operating production lines handling A2l and A3 flammable refrigerant; experiencing an actual installation with more than 1,100 HC-290 units installed; and acquiring information form specially designed workshops, seminars, and courses.

2.2. Track-II: Sharing with the different stakeholders at regional and global events

PRAHA-II expanded beyond the original PRAHA-I participants. PRAHA started by inviting members from EGYPRA, the Egyptian Project for Testing Low-GWP Refrigerant Alternatives, to events and study tours. The addition of EGYPRA was a natural one as both projects have similar goals in testing alternative refrigerants on prototypes built by the local industry. EGYPRA participants joined the study tour to Japan in November 2016. The study tour to China in April 2017 was joined by participants from Tunisia and Vietnam; Pakistan was also invited but could not join.

The workshop in Japan was built for the PRAHA and EGYPRA participants. In China, the workshop included, other than EGYPRA, Tunisia, and Vietnam, many participants from China. It also included NGOs, and global researchers. There were close to a hundred participants and the workshop turned into a large forum on the research and development of A3 refrigerants.

Awareness building about HAT and the PRAHA project has been a constant element of PRAHA. The PRAHA-I final report lists the programs and the events which PRAHA launched or participated in. The HAT series of symposia is but one example of the awareness building achievements of PRAHA.

With PRAHA-II, the campaign continued with PRAHA taking advantage of the presence of its managers or consultants to continue the message and update stakeholders, the industry, and the Parties on the developments and the latest technological information related to HAT or to the research at HAT.

PRAHA appears in websites both by UN Environment and UNIDO. Some examples:

https://www.unido.org/our-focus/safeguarding-environment/implementation-multilateral-environmental-agreements/montreal-protocol/finding-climate-friendly-ways-cool-down

PRAHA has truly helped in spreading awareness on HAT challenges and opportunities. The continuous awareness of the challenges and the opportunities of the HAT regions has made HAT a permanent subject to be added to the Decisions of the Parties and is a part of every Task Force study and report. HAT now is a full chapter of the 2018 RTOC Assessment Report.

Table 1 shows events and functions where PRAHA either organized special/program in their margins, joined as keynote presentation or organized a dedicated event about the subject.

TABLE 1: PRAHA PARTICIPATION IN INTERNATIONAL EVENTS

#	Date	Event
1	Jan 2016	Special Session at ASHRAE Winter Conference
2	Mar 2016	Special Session at West Asia/Africa Joint Network Meeting
3	July 2016	Special Session at OEWG-38
4	Aug 2016	Training Course at IIR Gustav Lorentzen Conference
5	Sept 2016	Special Session ASHRAE-AUB Efficient Building Design Conference
6	Dec 2016	Special Workshop on Designing with A2L Refrigerants

#	Date	Event
7	Jan 2017	ASHRAE Winter Conference and AHR expo
8	Jan 2017	CCAC Sustainable Technologies for Stationary AC Workshop
9	April 2017	Special Workshop on Designing with A3 Refrigerants
10	Oct 2017	International Workshop on Risk Assessment for HAT
11	Nov 2017	Special Session at CCAC Workshop at MOP-30 on Opportunities, Challenges, and Experiences with Transitioning to Low-GWP Alternatives
12	Jan 2018	Special Session at OzonAction First Interregional Networks' Meeting
	Oct 2018	Flammable Refrigerant Research and Planning Conference
13	Jan 2019	ASHRAE Winter Conference
14	Feb 2019	Special Session at OzonAction Second Interregional Networks' Meetings
15	March 2020 *(Planned)*	6th International Symposium on Alternative Refrigerants for High Ambient Temperature Countries

2.3. Conclusion from the Capacity Building Element

The experience of working on PRAHA gave UN Environment and UNIDO the confidence that international stakeholders support the goals of the project and that the outcome will be beneficial to all beyond economic gains. On the other hand, and simultaneous to the efforts by the PRAHA project to create awareness about HAT challenges and the work done through the different symposia held in the HAT countries that were participating in the PRAHA project, the HAT countries themselves were bringing up the issues at the different meetings of the Parties whether at the Open-Ended Working Group (OEWG) meetings or the Meeting of the Parties (MOP).

The capacity building element was successful in providing a platform of cooperation between governments, research institutes, industry associations, and the industry in general and became a process for the sharing of information and results among the different stakeholders.

3. Optimization of PRAHA-I Prototypes

This component includes several elements using prototypes of PRAHA-I that had promising results. Prototypes that showed unexpectedly poor results will also be examined to identify shortcomings. The exercise includes mainly three stages of work on the prototypes, plus a leak analysis stage:

a. Analyzing the design of PRAHA-I prototypes: a physical inspection and analysis of prior experimental results, plus a first order assessment of component and refrigerant performance.

b. Design optimization of PRAHA-I prototypes including: acquiring performance maps for components (compressors, fans) that are more suitable for the application; evaluating alternate heat exchanger design configurations; performing detailed engineering optimization to match or exceed the baseline unit performance within an acceptable design space set forth by an expert committee. This may include installing new upgraded compressors, for same refrigerants used in PRAHA-I, and which were not available at the time PRAHA-I prototypes were built; or compressors for refrigerants not tested under PRAHA-I; if so required.

c. Testing new refrigerants emerging since PRAHA-I using prototypes of PRAHA-I with change/upgrade of compressors.

d. Analyzing leak-recharge effect on performance for high glide alternatives.

3.1. Contracting the Activities

PRAHA first contact was with Oak Ridge National Laboratory (ORNL) who had performed their own testing at HAT conditions on two units with two different baseline refrigerants.

Unfortunately, due to legality issues and differences in the contractual practices commonly followed by UNEP, the contract between UNEP and ORNL did not materialize in spite of several attempts to find out solutions.

PRAHA team managed to negotiate and contract with The Air Conditioning, Heating and Refrigeration Technology Institute (AHRTI), the research arm of (AHRI) to take over the task as an internationally independent institute with relevant experience in conducting similar work i.e. AREP project (Alternative Refrigerants Evaluation Programme) and having access to several reputable testing and research centers within North America where the prototypes from PRAHA-I were being stored since end of PRAHA-I project. AHRTI, finally, selected Optimized Thermal Systems (OTS) as the most capable and sound research center for completing the planned work within the required timeline and budget.

3.2. Scope of Work

The scope of work that is covered by AHRTI's contractor OTS includes five activities as follows:

Activity 1: Analyzing the Design of PRAHA-I Prototypes

This task involved the following:

- Physical inspection
- Prior experimental results assessment
- First order assessment of component and refrigerant performance
- Development of validated model
- Detailed assessment of why the performance is "good, i.e. as designed" or "bad, why it did not perform as designed"

Activity 2: Design Optimization

Design optimization study for select units using the heat pump design model for available prototype units. This entailed:

- Acquiring performance maps for components (compressors, fans) that are more suitable for the application
- Evaluating alternate heat exchanger design configurations
- Performing detailed engineering optimization to match or exceed the baseline unit performance within acceptable design space set forth by an expert committee. This may include installing new upgraded compressors, for same refrigerants used in PRAHA-I that were not available at the time PRAHA-I prototypes were built; or compressors for refrigerants not tested under PRAHA-I; if so required.

Activity 3: Prototype Units Fabrication

AHRTI, in coordination with UN Environment, selected a subset of prototype units and modify them as per the design optimization study. This involved heat exchanger modification, compressor replacement, expansion valve fine-tuning, fans and blower replacements, etc. All components were from standard production lines.

Activity 4: Evaluation of the Optimized Prototypes

Optimized prototypes were tested in the multi-zone environmental chamber to evaluate their performance according to ASHRAE Standard 37 at relevant indoor and outdoor conditions (AHRI 210/240 "A" condition, ISO 5151 "T3" condition, hot and extreme conditions)

Activity 5: Analyzing Leak-Recharge Effect for High Glide Alternatives

The impact of leak-recharge effect on the performance of alternative refrigerants with high glide was experimentally evaluated.

Activity 6: Reporting and Data Management

AHRI submitted a peer-reviewed project report prepared by OTS.

3.3. Deliverables

The key deliverables/results to be achieved are:

a) Evaluation of prototypes tested under PRAHA-I
b) Optimized PRAHA-I prototypes: three units chosen
c) Analysis of leak-recharge of high glide alternatives on system performance
d) Report summarizing the project findings.

3.4. Matrix

The work to be done is shown in the matrix Table 2. The work is in five phases:

- Evaluation of the prototypes;
- Optimization of selected prototypes;
- Building some of the units per the optimized design;
- Testing for a number of refrigerants;
- Leakage assessment.

The selection of units for the various activities as well as that of the refrigerants was done the PRAHA team in coordination with the AHRTI based on:

- For Activity 1, all units needed to be evaluated.
- For Activity 2 for the modeling activity of optimization, the team chose one unit from each application, i.e. window, decorative split, and ducted split. An extra decorative split unit running with HC-290 was also added since decorative splits are the most abundant in the market and the team felt it important to have two splits optimized, one with HC-290 and one with alternatives to R-410A. The team also tried to balance the refrigerants choosing both alternatives to HCFC-22 as well as R-410A. At the time of selection, there was no clear trend or indication from the industry as to which refrigerants would be commercialized. One of the refrigerants originally selected had to be dropped at the request of the supplier.
- For Activities 3 & 4, the window unit with HC-290 was chosen to be re-built and tested. These activities for the window unit had to be dropped for reasons mentioned under **Challenges and Modifications**. For the decorative and ducted splits units 6 and 10, the team chose to work with the same refrigerant alternatives as in Activity 2. Activities 3 and 4 finally worked on one decorative split (unit 6) and one ducted split (unit 10).
- For Activity 4, leak analysis, all the zeotropic blends used in activities 3 and 4 were planned to be tested.

For the unit numbering system, units 1 to 3 are window units, units 4 to 9 are decorative splits and units 10 to 12 are ducted splits.

TABLE 2: MATRIX OF ACTIVITIES FOR THE PROTOTYPE OPTIMIZATION ELEMENT OF PRAHA-II

		Activity 1	Activity 2	Activity 3	Activity 4	Activity 5
Unit	**Type**	**Phase I data analysis**	**Optimization**	**Build per optimization**	**Test per build**	**Leak analysis**
1	Window	L-20 (R-444B)	R-444B			
			R-454C			
			R-290	HC-290*	HC-290*	
			R-457A			
6	Decorative Split	HFC-32	HFC-32	HFC-32	HFC-32	
			R-454B	R-454B	R-454B	R-454B
10	Ducted	HCC-32	R-447B	R-447B	R-447B	R-447B
			R-452B	R-452B	R-452B	R-452B
4	Split	HC-290	HC-290			
2	Window	R-444B				
3	Window	DR-3 (R-454C)				
5	Split	HFC-32				
7	Split	L-41 (R-447A)				
8	Split	R-444B				
9	Split	R-454C				
11	Ducted	R-444B				
12	Ducted	R-454C				

* Could not be completed due to 1) not fitting the timeline, and 2) the limitation of testing A3 packaged (window)

3.5. Project Monitoring

AHRTI assembled a project committee made up of AHRI members to help monitor and guide the project and set-up biweekly conference calls with OTS and the PRAHA management team. The calls, which started in November 2018, are normally held on the first and third Thursday of every month. As part of the bi-weekly update, OTS reports both on the progress as well as the technical aspects of the project and solving any possible problems that may arise

On such example is the participation of an additional refrigerant supplier in the project through the supply of information and quantities of refrigerant R-459A to test in one of the optimized and rebuilt prototypes. The problem of receiving response from the supplier was raised in one of the calls and the supplier was contacted by the PRAHA team. The supplier advised of its inability to provide R-459A timely and asked to withdraw from the project. R-459A was replaced by R-454B which has been gaining acceptance by the industry lately.

3.6. Challenges and Modifications

The implementation of this portion of the PRAHA-II project came up with some challenges:

The tests that were carried out for PRAHA-I, while sufficient for the purpose of measuring capacity and energy efficiency for the purposes of PRAHA-I, did not have enough essential data to enable a complete cycle evaluation for optimization purposes.

Some key components and specifications, such as compressors and/or compressor maps for HC-290 and heat exchangers, were not readily available to fit in the project timeline.

The scheduling mechanism of the lab for PRAHA I (fixed test window) and testing logistics was not suited for completing of the project within the budge and required timeline. Therefore equipment performance testing was carried out in-house at OTS facility; however, its lab was not equipped to test the window unit of unit 1 working with A3 flammable refrigerant HC-290 (propane) due to safety concerns and requirements. Testing Unit 1 had to be dropped. Alternatively, the optimization of window unit was carried out using modeling approach.

Overall, the analyses presented by the design assessment through modeling provided good insights on adequate component design and/or selection for proper system functioning when using novel refrigerants. The tests in activities 3-5 partially served as validation for the models developed, and as check for previous test data from PRAHA I.

3.7. Project Implementation and Findings

The full AHRTI report is an annex to this report. The summary of findings per activity are given below

3.7.1. Activity 1 – Analyzing the Design of PRAHA-I Prototypes

Activity 1 was comprised of three major tasks including: a) reception of 12 physical units at the OTS facility followed by visual inspection and parts identification; b) review of performance test reports from PRAHA I tests; and c), analysis of data and identification, for units of interest, opportunities for improvement targeting higher performance and minimal charge.

The twelve units are shown in Table 3 with the PRAHA-I test results and the new refrigerants to be used.

TABLE 3: MATRIX OF UNITS AND NEW REFRIGERANTS TO BE TESTED

Category	Unit #	Ref.	Designed Capacity Btu/h	Measured Cap. Btu/h	Voltage	Ref. (New designs)	Ref. (Tests)
Window	**1**	**L-20 (R-444B)**	**18,000**	**19,104**	**208-230/60/1**	**R-444B, R-454C, HC-290, R-457A**	**HC-290**
	2	L-20 (R-444B)	18,000	16,924	208-230/60/1		
	3	DR-3 (R-454C)	18,000	18,063	208-230/60/1		
Decorative splits	**4**	**HC-290**	**24000 (18,000)**	**19,000**	**208-230/60/1**	**HC-290**	**HC-290**
	5	HFC-32	24000 (18,000)	19,328	208-230/60/1		
	6	**HFC-32**	**24,000**	**25,456**	**208-230/60/1**	**HFC-32, R-454B**	**HFC-32, R-454B**
	7	L-41 (R-447A)	24,000	24,830	208-230/60/1		
	8	L-20 (R-444B)	24,000	22,740	208-230/60/1		
	9	R-454C	24,000	14,638	208-230/60/1		
Ducted splits	**10**	**HFC-32**	**36,000**	**35,500**	**220-240/50/1**	**R-447B, R-452B**	**R-447B, R-452B**
	11	R-444B	36,000	36,553	220-240/50/1		
	12	DR-3 (R-454C)	36,000	33,032	220-240/50/1		

Following is a summary of findings from Activity I

A. Analysis of PRAHA-I Test Results:

- **For the window units:** *Evaporator:* The inlet refrigerant temperature and pressure were not measured. The outlet pressure was estimated from suction pressure, a reasonable assumption given the short distance between the evaporator and compressor. The outlet temperature was measured so the superheat was computed. *Condenser:* The inlet refrigerant temperature and pressure were measured. The outlet pressure was not measured, but the outlet temperature was measured.
- **For the decorative splits:** *Evaporator:* The "Inlet Pressure" is the value measured at the service port at the exit of the outdoor unit, after the expansion device (capillary tubes). So, there is significant, but unmeasured pressure and saturation temperature drop between the measurement location and the actual inlet of the evaporator as abovementioned. The "Outlet Pressure" was measured at the service port before entering the outdoor unit. There was an unmeasured pressure drop in the suction line from the evaporator outlet to that measurement location. The inlet and outlet temperature measurements seem like reasonable numbers for the actual inlet and outlet. *Condenser:* The inlet pressure was not measured, the inlet temperature was measured, and the outlet pressure was only measured for Unit 4. The outlet liquid temperature was not measured, rather, the "OD Liq" temperature measurement was likely taken at the liquid service port, near the pressure

measurement. The temperature was much too low to be the actual condenser outlet, but not cold enough to be the evaporator inlet.

- **For the ducted splits**: *Evaporator:* The "Inlet Liquid" temperatures and pressures were taken before the TXV, so they were not actual measurements of the evaporator inlet condition. The outlet temperature and pressure measurements were available so the superheat could be calculated (lab used the compressor suction temperature rather than evaporator outlet temperature to compute superheat.) *Condenser:* The inlet temperature was measured, but the pressure was not. The outlet temperature and pressure were measured, so the sub-cooling was calculated. The sub-cooling computed by the lab ranged between 17 to 18°F, which doesn't correspond to the measured conditions. The calculated sub-cooling for Unit 11, however, was negative for all three tests; as such, it is possible that there was a two-phase refrigerant at the condenser outlet.

B. Hardware Improvement Assessment

This section defines a first order analysis of the effect of hardware assessment for units 1, 4, 6, and 10. A first order analysis is structural analysis that is performed without taking the unit apart or making any changes to. The analysis is made for the different components.

Unit Component Modification Potential

Table 4 shows the detailed existing components for the units of interest for modification.

TABLE 4: COMPONENTS FOR UNITS 1, 4, 6, AND 10

System	Unit 1	Unit 4	Unit 6	Unit 10
Refrigerant	**R444B**	**R290**	**R32**	**R32**
Compressor	HIGHLY SL260DG-C8EU	HIGHLY PSH356DG-C8DU3	GMCC KSG226N1UMT	Copeland ZP42K5E-PFJ-XXX
Condenser	5mm Louver TFHX	9.5mm Wavy TFHX	7mm Louver TFHX	9.5mm Louver TFHX
Expansion Device	Capillary Tube	Capillary Tube	Capillary Tube	Capillary Tube
Evaporator	9.5mm Louver TFHX	7mm Louver TFHX	7mm Slit TFHX	9.5mm Louver TFHX

- **Heat Exchangers (HX):** OTS put as an objective to improve performance while minimizing charge. One way of addressing both objectives is by reducing the tube/channel diameter since heat transfer coefficients are inversely proportional to tube diameters. Pressure drop is also inversely proportional to tube diameter so smaller tubes result in reduced size and reduced internal volume but higher pressure drop.

  A qualitative analysis using values from literature was carried out to demonstrate the relative impact of diameter over abovementioned metrics, specifically: heat transfer coefficient, compactness and overall thermal conductance (UA). The left-hand side plot in Figure 3 shows three curves inversely proportional to the diameter; a 5mm tube can achieve, in this example, 70% greater UA than a conventional 9.5mm, within the same cabinet.

These are further explored to illustrate the impact on a system level. Systems respond to UA of both condenser and evaporators, but for the purposes of this analysis, the condenser is only considered. UA represents the overall thermal conductance, which will impact the approach temperatures in the system (ΔT_{app}). If the heat of rejection is kept constant, the higher the UA, the smaller are the ΔT_{app}'s, thus allowing the condenser to operate in lower pressure levels, which will consequently increase the system performance. An example using a hypothetical HFC-32 cycle with an EER of 12 as base is shown in the right-hand side plot in Figure 3. Performance improvement is limited by the Second Law, when the approach temperatures near zero. In this illustration, the EER has the potential to increase by over 20% with better condenser design alone.

It is imperative to note that the results presented in this section are first order analysis for illustration purposes only. Further in this report it is presented in more detail a re-design framework, applied to the units of interest in this project, using the metrics outlined in this section.

Unit 1 already had a 5mm condenser, which limits the options for HX re-design. Unit 6 had a 7mm HX on both the indoor and outdoor units, which allows some room for improvement if reducing to 5mm. Lastly, both coils for Unit 10 had 9.5mm tubes, thus there is greater potential for charge reduction and performance improvement for that unit in particular.

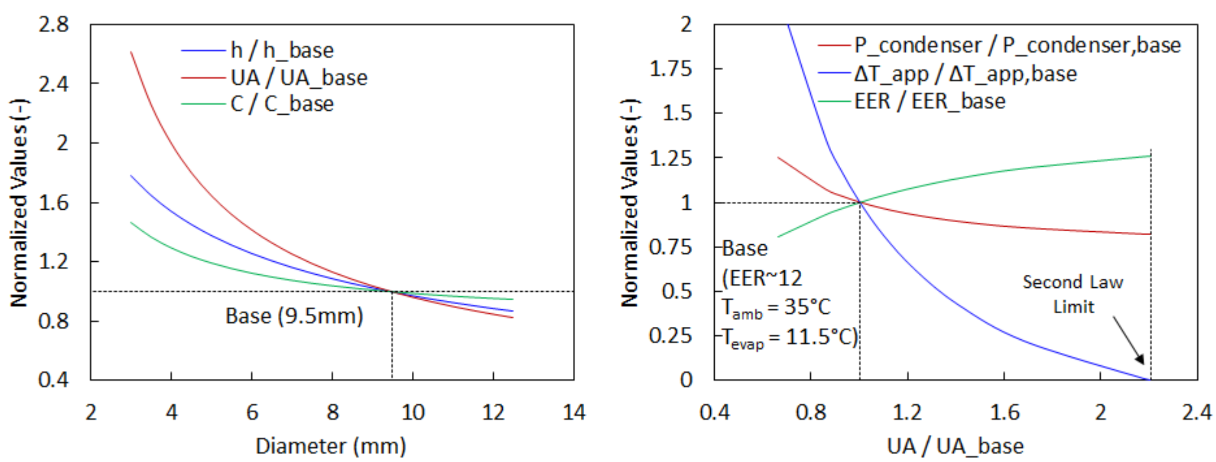


FIGURE 3: HEAT EXCHANGER FIRST ORDER ANALYSIS (FOA)

- **Compressors:** The existing units mostly use compressors sized specifically for R-410A or HCFC-22 and in some cases custom made for the particular application. This presents an opportunity for a better compressor selection when migrating to other refrigerants such as R454B or R447B on Units 6 and 10, respectively. A compressor designed for a particular refrigerant having a higher efficiency rating will result in better energy efficiency performance of the same unit.
- **Expansion Devices:** Expansion devices such as TXV's and EXV's may allow for better control and reduced losses in connecting pipes if located near the evaporator. Some units, such as 6 and 10, have a capillary tube in the outdoor unit, which forces the refrigerant to travel in two-phase

along the connecting pipes, and at lower temperatures, thus increasing pressure drop and heat gain. In some regions, expansion devices are installed in the outdoor units for noise control purposes.

- **Fans and Blowers:** Replacing the fan and blower may be necessary if newly designed HXs offer considerable change in pressure drop over the baseline since the flow rates are kept constant. The lack of test data on pressure drop forces us to rely on predicted values only.

3.7.2. Activity 2 – Design Improvements

OTS developed improved designs for some units, including use with additional refrigerants. The main goals were to maintain capacity while minimizing internal volume (refrigerant charge) and maximizing performance (COP). The exercise in optimizing the improved designs is subject to limitation in component availability from pre-established vendors. The activity involved:

- Developing a cycle simulation model for each of the baseline systems.
- Calibrating the models using the data provided in Activity 1 (relying on the performance test data for the three ambient conditions).
- For each system, evaluating whether the existing compressor and fans are the best fit, or if alternate designs would be preferred.
- Evaluating heat exchanger design options and suppliers for alternative off-the-shelf solutions. As appropriate, conduct a thorough parametric analysis study for the air-to-refrigerant heat exchangers for use with the alternative refrigerants. In addition to heat exchanger type and/or tube diameter and fin pattern, this may include revised circuitry.
- For each of the targeted design cases/refrigerants, evaluating the performance of optimum component selections and quantifying any anticipated performance gains.

Following is a summary of findings from modeling and simulation:

A. Hardware: A first order analysis in Activity 1 showed that moving towards smaller hydraulic diameter tubes can be beneficial from a charge reduction standpoint. Units 4 and 10 use conventional 9.5mm diameter tube condensers making them good candidates for condenser replacement with either a smaller tube diameter or a microchannel heat exchanger (MCHX). The compressors used on Units 1, 4 and 6 do not have available performance maps making it difficult to assess their fitness for the system. The focus of this study is on proper compressor selection and condenser re-design.

B. Refrigerant: HC-290 and HFC-32 have wider saturation regions, as can be seen from Figure 4 and Figure 5 for P/h and T/s, putting them at an advantage since they may operate with smaller superheat and sub-cooling, while benefiting from two-phase heat transfer. Their cycles may get closer to that of the ideal Carnot cycle compared to refrigerants with narrower saturation. Although this appears to be the case, this is not universally true for mixtures since they can exhibit other properties that make them suitable for certain designs.

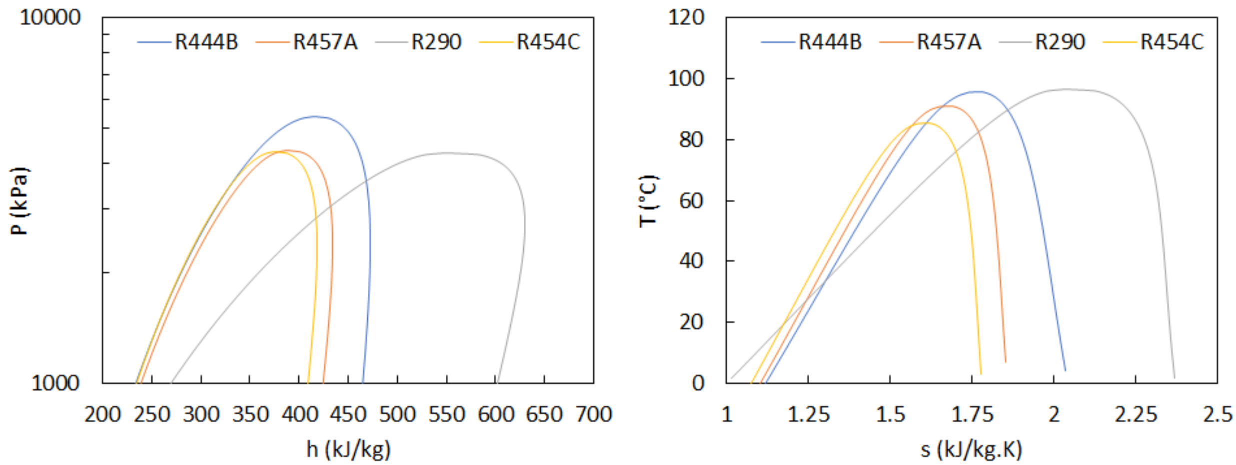


FIGURE 4: P-H AND T-S DIAGRAMS FOR HCFC-22 ALTERNATIVES

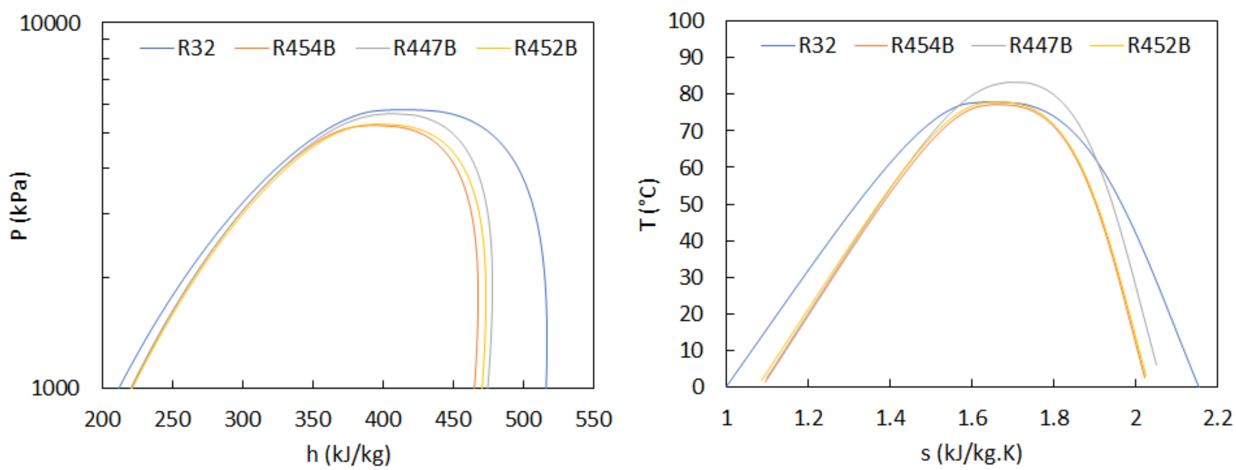


FIGURE 5: P-H AND T-S DIAGRAMS FOR R-410A ALTERNATIVES

Amongst the blends investigated for Unit 1, R-444B has the widest saturation region while also having the highest temperature glide Figure 6 .The latter is typically not beneficial, in particular for evaporators, but it may help the condenser. The glide enables the refrigerant temperature profile to get closer to the air temperature profile without crossing (Figure 6). From a thermodynamic perspective, this means R-444B can have its condensing pressure reduced further, resulting in higher theoretical COP.

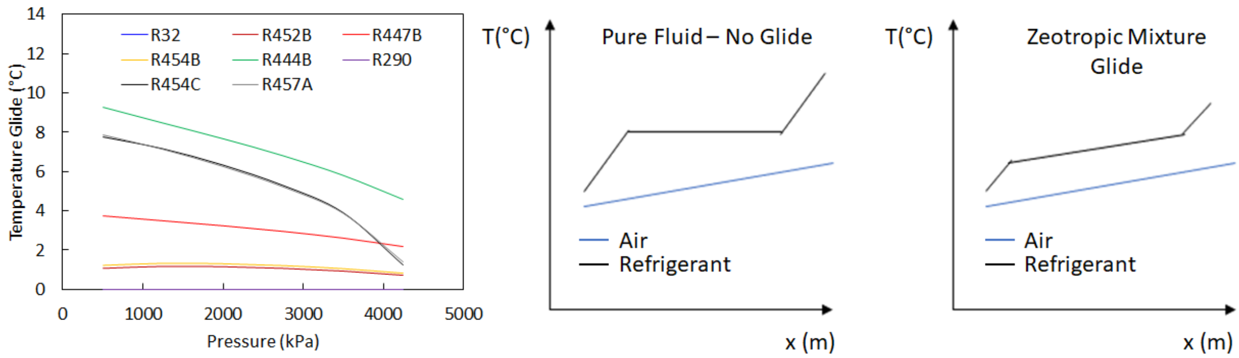


FIGURE 6: PROFILES OF REFRIGERANTS

For Units 6 and 10, the investigated blends, although having narrower saturation than the baseline R32, have similar thermophysical characteristics (Figure 4) with lower temperature glides (Figure 6Figure 7) making them more competitive from a capacity and performance perspective.

C. System Design Optimization / Modification Framework: The framework consists of a retrofit of the existing units by properly designing and selecting components that can be replaced with no modification of the cabinets. In other words, any component replaced must occupy the same envelope as the baseline component. The focus of the re-design is on:

- Compressor
- Condenser, and
- Expansion valve

The evaporator designs were not changed for two main reasons: a) some are custom-made wrap-around the blower units, such as in Unit 6, making it hard to quickly find an off-the-shelf option; and, b) the goal is to deliver the same cooling capacity while improving efficiency. For the latter, there is more room for improvement in the condenser by reducing condensing pressure, assuming the evaporator can already deliver the expected capacity.

The fans and blowers were also not considered for change, in part due to the lack of information on the performance curves from the baseline models, but also due to potential high cost and lead time for replacement with secondary impact on performance since 80-90% of the power consumed comes from the compressor.

The first step to assess the level of performance required for each component is to investigate an improved theoretical cycle, which will indicate how much COP improvement can be expected, as well as refrigerant flow rate needs and HX size (UA). To improve the performance of a vapor compression cycle, the pressure lift between evaporating and condensing pressures must be reduced. Consequently, the approach temperatures between air and refrigerant will be reduced as well (Figure 7), thus the thermal capacitance of the heat exchangers must increase. Furthermore, the closer to the saturation region, the closer the cycle reaches the ideal Carnot efficiency (Figure 8).

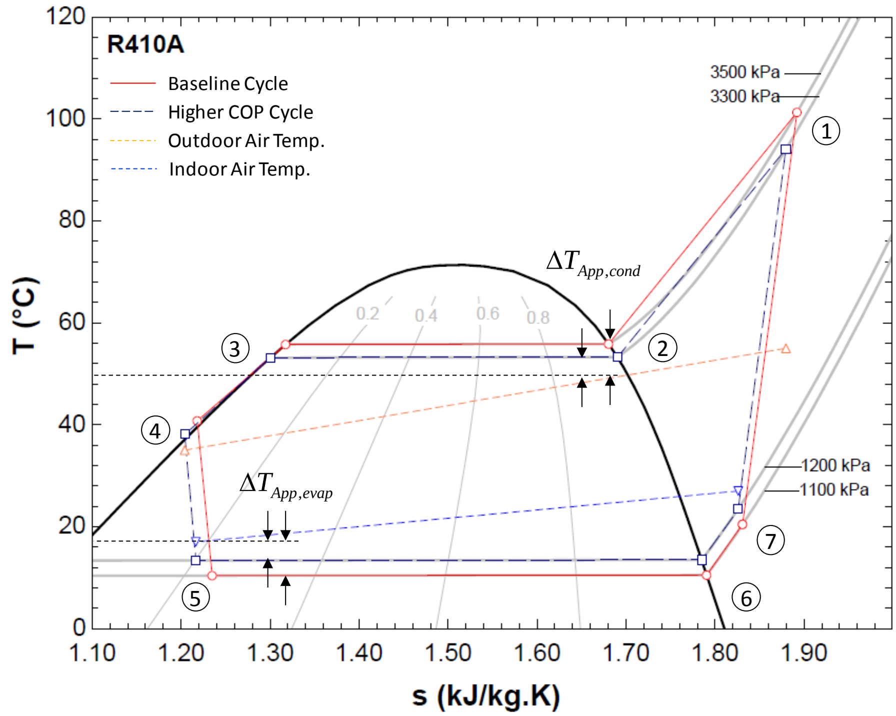


FIGURE 7: ILLUSTRATIVE T-S DIAGRAM FOR BASELINE AND IMPROVED CYCLE

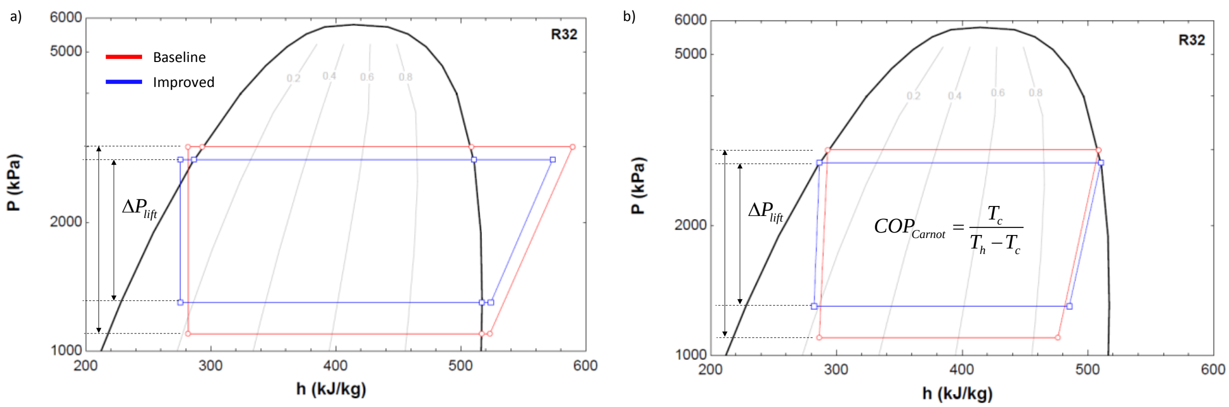


FIGURE 8: DIAGRAM ILLUSTRATING COP IMPROVEMENT A) REAL CYCLE, B) IDEAL CYCLE (CARNOT)

The system design framework is performed according to Figure 9

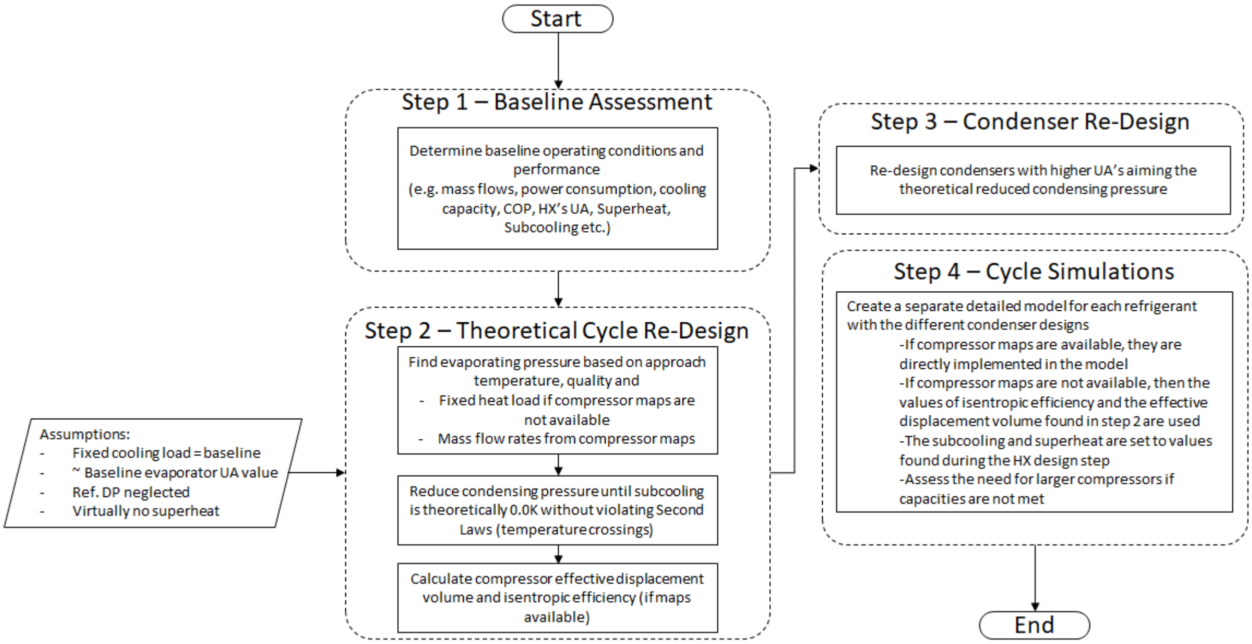


FIGURE 9: SYSTEM DESIGN FRAMEWORK

C. **Compressors**: Modeling compressors are handled in two possible ways, as suggested previously: using performance maps when available or using fixed isentropic efficiency and effective displacement volume. For the larger capacity units (6 and 10), performance maps were provided. Although these compressors were originally designed for R410A refrigerant they may operate – not necessarily optimally – with other refrigerants. Compressor manufacturers supporting this project used proprietary simulation tools, with aid from available empirical data (tests with other refrigerants), to develop theoretical maps for the various refrigerants of interest (Table 5) and made them available to OTS for modeling purposes. It is understood that the predictions are for reference only, and the compressor manufacturer does not guarantee performance for any refrigerants for which the compressors haven't been fully tested.

TABLE 5: COMPRESSOR MODELS

Model	Capacity (BTU/hr)	Frequency (Hz)	Refrigerants
ZP20K5E-PFV	24,000	60	HFC-32, R-454B, R-410A
ZP21K5E-PFV	24,000		
ZP31K6E-PFV	36,000	50/60	R-447B, R-452B, R-454B, R-410A
ZP34K6E-PFV	36,000		

For the smaller units (1 and 4), which were re-designed using HC-290 (Propane), compressor performance maps were not available. The approach for these units then was to set a target isentropic efficiency of 0.7 (baseline data suggests that the compressor efficiencies ranged from 0.55 to 0.65). The required mass flow rate is calculated based on capacity in the theoretical cycle model described above. From there, the effective displacement volume can be determined by the equation below[1]. The latter serves to determine whether a system can use the same compressors for different refrigerants.

$$V_{eff} = \eta_{vol} \cdot V_{disp} = \frac{\dot{m}_{required}}{f \cdot \rho_{suction}}$$

D. **Heat Exchangers:** The condensers design procedure takes into consideration the following:

- **Face area**: baseline face area must be preserved or at most reduced. Furthermore, the aspect ratio must also match that of the baseline so the HX can be drop-in replaced in the same cabinet.
  - o Find the number of tube rows and tube length to match as closely as possible to tube face area and aspect ratio

- **Airside pressure drop and flow rate**: the test data from reports contain only air flow rate measurements, while no information on pressure drop is provided. Additionally, the fan performance curves are also not available, which limits the ability to find the exact operating condition. The baseline models provide an estimate prediction for the pressure drop, which is used as reference.

- **Thermal performance**: this step must be iteratively conducted with the previous step, as such for each design change the air flow rate and capacity are evaluated under the new conditions found in the theoretical cycle re-design.
  - o Gradually increment the condensing pressure until attainable performance is achieved. This process is done iteratively using the theoretical cycle model, to find new expected operating conditions for evaporating pressure, superheat, sub-cooling and refrigerant flow rate.

- **HX Form**: as indicated previously, the HX design is constrained by cabinet dimensions as well as form. In the case of units 1 and 4, the condensers are flat coils placed 90° inside the cabinet (Figure 10), which makes it simpler for drop-in replacement as long as new designs have the same overall dimensions. For units 6 and 10, however, the condensers are L-shaped inside the cabinet (Figure 10). Forming coils is widely done, however, for custom coils it may be a challenge, in particular for MCHX. For this reason, the MCHX designs for units 6 and 10 are sized for a full-face area, assuming the coil can be formed, and a second design that is a single flat slab placed in longer side of the "L" shape (Figure 11).

[1] See Nomenclature at the end of this chapter

FIGURE 10. CONDENSER FORMS: UNIT 1 (LEFT), UNIT 10 (CENTER), UNIT 6 CABINET (RIGHT).

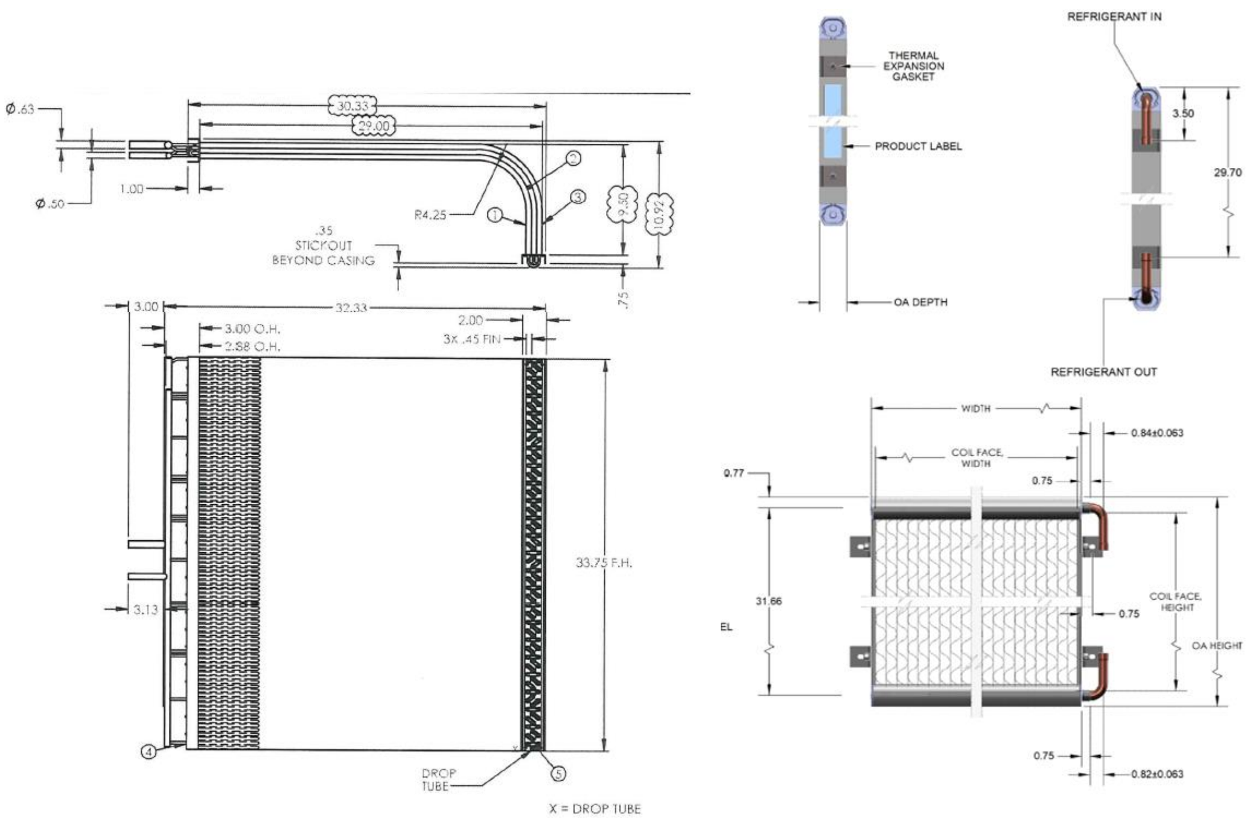


FIGURE 11. HX FORM EXAMPLES: L-SHAPE (LEFT), FLAT (RIGHT).

Summary of Results for Activity 2

Table 6 shows the summary from the design simulation activity

Table 6: Activity 2 Results.

	General Information			Hardware					Performance	
System	Rated Capacity (@35°C)	System Configuration	Refrigerant	Compressor		Condenser		Exp Device	CC @ 46°C	EER @ 46°C
-	BTU/hr	-	-	Effective Disp. Vol. (cm³)*	Efficiency (-)	Type	Effectiveness (-)	Type	%	%
Unit 1	18000	**Baseline**	**R-444B**	**19.8**	**0.66**	**Tube-Fin (5mm Tube)**	**0.20**	**Passive**	**0.00%**	**0.00%**
		Alternate 1	HC-290	25.9	0.70	Same as Baseline	0.35	Active (EXV)	1.40%	8.20%
		Alternate 2	R-454C	24.8	0.69		0.26		4.00%	-1.30%
		Alternate 3	R-444B	19.6	0.70		0.23		4.20%	9.90%
		Alternate 4	R-457A	25.3	0.68	MCHX	0.24		2.00%	3.10%
Unit 4	24000	**Baseline**	**HC-290**	**26.4**	**0.61**	**Tube-Fin (9.5mm Tube)**	**0.24**	**Passive**	**0.00%**	**0.00%**
		Alternate 1	HC-290	26.3	0.70	Tube-Fin (5mm Tube)	0.26	Active (EXV)	1.20%	21.40%
		Alternate 2	HC-290	37.9	0.70		0.20		34.40%	-10.60%
Unit 6	24000	**Baseline**	**HFC-32**	**16.0**	**0.60**	**Tube-Fin (7mm Tube)**	**0.12**	**Passive**	**0.00%**	**0.00%**
		Alternate 1	HFC-32	16.9	0.65	Tube-Fin (5mm Tube)	0.15	Active (EXV)	3.00%	11.20%
		Alternate 2	R-454B	18.4	0.67		0.19		-1.00%	14.80%
		Alternate 3	R-452B	19.0	0.70		0.17		2.50%	13.50%
Unit 10	36000	**Baseline**	**HFC-32**	**19.6**	**0.44**	**Tube-Fin (9.5mm Tube)**	**0.13**	**Passive**	**0.00%**	**0.00%**
		Alternate 1	R-447B	22.3	0.65	Tube-Fin (5mm Tube)	0.25	Active (EXV)	5.10%	47.50%
		Alternate 2	R-452B	23.0	0.67		0.25		6.20%	60.70%
		Alternate 3	R-454B	23.3	0.67		0.25		6.20%	56.50%

** Product of displacement volume and volumetric efficiency*

The General Information describes the baseline unit with the alternate refrigerants used, while the Hardware describes the Compressor, Condenser and the Exp. (expansion) Device for each alternative.

The performance at 46°C is given as a percentage of the baseline performance for the cooling capacity (CC) and Efficiency (EER).

For unit 1 (window unit), the optimized design with the same refrigerant as the baseline can improve EER by 9.9% and using HC-290 can lead to an improvement in the EER by up to 8%.

For unit 4 (decorative split with HC-290), the baseline unit which was supposed to be a true 24,000 Btuh unit had an 18,000 Btuh (26.4 cm^3 effective displacement) compressor with a 24,000 Btuh coils. Optimizing the unit with an 18,000 Btuh compressor would lead to 21.4% improvement in EER, while if a 24,000 Btuh compressor (37.9 cm^3 effective displacement) is used, the EER drops by 10.6%.

The other decorative split (unit 6) running with HFC-32 shows an improvement in EER for all alternative refrigerants.

The unusual results for unit 10 (ducted split) showing a 50% increase in EER is due to using bigger condensers (0.25 effectiveness vs 0.13 for the baseline.

3.7.3. Activities 3, 4, and 5

A. Scope and Implementation of activities

Activity 3: Prototype Units Fabrication

Using design decisions made in Activity 2, OTS constructed two prototypes out of the three that were targeted (see section 4.6 Challenges and Changes). The two units are outlined in Table 7.

TABLE 7: PROTOTYPE UNITS FOR COMPONENT MODIFICATION AND FURTHER TESTING

Category	Unit	Refrigerant(s) for Prototype Development
Decorative Split	6	HFC-32 R-454B
Ducted Split	10	R-447B R-452B

This activity involves modifying the existing prototypes to include the new components while making additional changes, such as adding valves, to enable leak testing in Activity 5.

Activity 4: Evaluation of the Optimized Prototypes

This activity involves physically testing performance of the modified units for at least two ambient conditions:

- ❖ Measurement points include:
  - a. Refrigerant Side
    - i. Compressor suction – temperature, pressure
    - ii. Compressor discharge – temperature, pressure
    - iii. Expansion valve inlet – temperature, pressure
    - iv. Evaporator Inlet – temperature, pressure
    - v. Evaporator Outlet – temperature
  - b. Air Side
    - i. Environmental chamber ambient temperature, relative humidity
    - ii. Condenser incoming air temperature

iii. Condenser exhaust air temperature
iv. Evaporator incoming air temperature
v. Evaporator exhaust air temperature
vi. Evaporator pressure drop
vii. Indoor air flow rate

c. Power

i. Compressor
ii. Fans
iii. Any additional controls or electrical components

- Conduct troubleshooting measures, as needed, to confirm operation prior to start of testing.
- Charging the unit was conducted at 35°C (95°F) in the outdoor unit environmental chamber. Conduct a charge optimization to assess the most appropriate refrigerant charge given the test set-up. This will include testing the unit at three different charge amounts to determine the charge that produces the best possible result (COP) at the rating condition. Conducting this step ensures appropriate charge levels and good measurement values.
- Tests repeated at the high ambient condition T3 (46°C outdoor).
- Test data analyzed and compared against the modeling predictions from Activity 2. Any system modifications that have potential to improve performance, including further adjustments to the refrigerant charge, were identified.

Activity 5: Analyzing Leaks of Alternatives

In addition to addressing the performance of the individual systems, analysis on refrigerant leakage is needed to meet Project Objective #3. Additional testing were conducted following the performance tests

Results

The detailed outcomes and test data can be found in the OTS report which is attached to this report. The following is a summary of the results:

Unit 6

Some modifications were made to Unit 6 to improve its efficiency. The baseline compressor was replaced with alternate models to account for the change in refrigerant and to improve efficiency. The compressor used with R-454B had a higher displacement volume than the one used with HFC-32. Furthermore, the capillary tubes were replaced with a manual throttling valve simulating the TXV that was installed directly at the evaporator inlet to increase the cooling capacity of the evaporator. A summary of the design modifications evaluated for Unit 6 is listed in Table 8.

Tables 9 and 10 show the performance of Unit 6 for baseline and modifications at 35°C and 46°C ambient, respectively. There is a discrepancy in the measurements from condenser outlet to expansion inlet in the baseline case, since the capillary tube (removed in the modified systems) was located in the outdoor unit. The expansion causes the refrigerant to flash in the liquid line thus compromising the readings at the expansion device. For calculation purposes, the condenser outlet enthalpy was used instead of the expansion inlet.

TABLE 8: UNIT 6 MODIFICATIONS FOR TESTING.

System	Unit 6		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R32	R454B
Compressor	GMCC KSG226N1UMT	Copeland ZP20K5E	Copeland ZP21K5E
Expansion Device	Capillary Tube (outdoor unit)	Manual valve[2] (indoor unit)	Manual valve (indoor unit)

Cooling capacity for the modified unit with either refrigerant was consistently lower by 6-12% than the baseline. The modified HFC-32 system reportedly showed lower mass flow rate than expected, likely the main cause for the lower-than-expected thermal performance. The R4-54B system resulted in a lower performance but was less sensitive to ambient temperature than its R32 counterpart - i.e. cooling capacity was near the same at both 35°C and 46°C, while for HFC-32 there was a ~2,000 BTU/hr reduction with the temperature increase. It is also possible that there is a mismatch between thermophysical property library and actual refrigerant properties for R454B which can happen with newer fluids. The libraries need periodic update as more test data become available.

TABLE 9: UNIT 6 - PERFORMANCE TEST SUMMARY FOR R32 BASELINE (OTS) @ 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	HFC-32	HFC-32	R-454B	-	-
Charge	lbs.	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	25,192	23,585	21,966	-6.4%	-12.8%
Energy Balance	%	-2.28%	-4.66%	-3.06%	-	-
Compressor Power	kW	2.11	1.79	1.77	-15.1%	-16.2%
Fan Power	kW	0.32	0.33	0.33	2.2%	2.2%
Total Power	kW	2.43	2.12	2.10	-12.8%	-13.5%
EER	BTU/hr. W	10.37	11.12	10.44	7.2%	0.68%

TABLE 10: UNIT 6 - PERFORMANCE TEST SUMMARY FOR R32 BASELINE (OTS) @ 46°C.

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	HFC-32	HFC-32	R-454B	-	-
Charge	lbs.	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	23,390	21,450	21,821	-8.3%	-6.7%
Energy Balance	%	-1.78%	-4.42%	-7.61%	-	-
Compressor Power	kW	2.71	2.32	2.25	-14.2%	-16.6%
Fan Power	kW	0.40	0.42	0.42	5.3%	5.3%
Total Power	kW	3.10	2.74	2.67	-11.7%	-13.8%
EER	BTU/hr. W	7.55	7.84	8.17	3.8%	8.2%

[2] A manual valve was used to mimic a TXV or EXV; recommended as component modification in these systems.

Unit 10

Applying what was learned in the initial modifications to Unit 6, modifications to Unit 10 were limited to include the compressor and expansion device only. Unlike Unit 6, however, the re-test of the baseline system was not successful; refer Appendix D of the OTS report for additional information. However since Unit 6 baseline re-test showed good reproducibility from original data, it is assumed that the Unit 10 original baseline will act similarly. A summary of the design modifications evaluated for Unit 10 is listed in Table 11. The detailed test data is presented in Appendix E of the OTS report.

TABLE 11: UNIT 10 MODIFICATION FOR TETSING

System	Unit 10		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R447B	R452B
Compressor	Copeland ZP42K6E	Copeland ZP34K5E	Copeland ZP31K5E
Expansion Device	Orifice	Manual Valve	Manual Valve

At 35°C the modified units exhibited almost 20% less cooling capacity with 10% less power consumption, resulting in up to 11% less EER (Table 12). These results were not unexpected since the modified units were re-designed using the 46°C temperature, when the baseline system's performance showed a great degradation of performance. At 46°C condition, the tests confirmed exhibited 2-5% greater cooling capacity with up to 12% less power consumption compared to the baseline, which was equivalent to 13-17% greater system performance.

In Activity 2 the compressor power consumptions were underestimated, as well as the total fan power consumption, leaving the impression the overall performance improvement would considerably be greater than the observed. The cooling capacity, on the other hand, was predicted with less than 2% deviation from test data, validating at least the models created.

TABLE 12: UNIT 10 - PERFORMANCE TEST SUMMARY AT 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	HFC-32	R-447B	R-452B	-	-
Charge	lbs.	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	35,543	32,195	28,128	-9.42%	-20.86%
Energy Balance	%	---	7.52%	-3.29%	-	-
Compressor Power	kW	-	2.67	2.4	-	-
Fan Power	kW	-	0.95	0.98	-	-
Total Power	kW	3.761	3.62	3.38	-3.75%	-10.13%
EER	BTU/hr. W	9.451	8.894	8.322	-5.89%	-11.94%

TABLE 13 : UNIT 10 -PERFORMANCE TEST SUMMARY AT 46°C

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**HFC-32**	**R-447B**	**R-452B**	**-**	**-**
Charge	lbs.	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	29,633	31,073	30,292	4.86%	2.22%
Energy Balance	%	---	4.21%	1.21%	-	-
Compressor Power	kW	---	3.18	2.93	-	-
Fan Power	kW	---	0.95	0.97	-	-
Total Power	kW	4.466	4.13	3.9	-7.52%	-12.67%
EER	BTU/hr. W	6.64	7.52	7.76	13.33%	16.95%

Leak Tests

In the interest of time the leak tests were conducted only on Unit 10 for R447B. The choice of refrigerant was based on temperature glide, where R447B exhibits the highest glide amongst the refrigerants evaluated between Unit 6 and Unit 10 (refer to Figure 6). The leak tests were conducted to closely represent field operation. The procedure applied include the following steps:

1- Run unit until steady-state is achieved (repeat 46°C performance test), monitoring capacity and sub-cooling
2- Gradually remove refrigerant from vapor line until capacity is reduced to approximately 50%, if possible
3- Store and weigh removed refrigerant
4- Re-charge with new refrigerant until same sub-cooling is achieved
5- Compare cooling capacities; if more than 5% deviation is observed, repeat steps 1-4, however in step 2, reduce capacity to 25% only
6- Repeat steps 1-5 for the liquid line

The comparison herein presented refers to a leakage of approximately 30% of charge, while reducing capacity in approximately 50% based on airside only. The leak tests showed less than 2% deviation in cooling capacity after re-charge from both vapor and liquid lines (Table 14). Since the capacity deviation was less than 5%, no further testing for 25% capacity reduction was conducted. The results suggest little impact due to fractionation.

TABLE 14: UNIT 10 – R447B LEAK TEST SUMMARY RESULTS.

System			*Liquid Line Leak*		*Vapor Line Leak*	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	-	**R-447B**	**R-447B**	**R-447B**	**R-447B**	**R-447B**
Charge	lbs.	6.625	4.27	6.625	4.23	6.77
Cooling Capacity	BTU/hr	31,073	14,216	30,865	15,171	30,587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	*
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	*
EER	BTU/hr. W	7.52	3.64	7.42	3.87	*

*Compressor power consumption was not properly recorded for this test; the error was identified after the fact and the team was unable to retrieve that information. While that compromises the assessment of the overall system performance, the deviations are expected to be marginal. The leak test on liquid line suggest minimal impact on power consumption after re-charge, while cooling capacity was reportedly fully recovered after recharge on both leak tests.

3.8. Conclusion and Recommendations from the Optimization Element

The original scope and schedule were modified during the project as new findings and challenges surfaced. The data analysis and processing from the tests conducted in the PRAHA-I project showed that more testing parameters and instrumentation would have been needed to support the optimization and/or redesign process within the scope of PRAHA-II since PRAHA-I was designed to conduct testing and comparison of cooling capacity vs. EER for the prototypes against the baseline units from same manufacturers. This affected the evaluation of the units' performance and consequently in building the baseline models.

The Conclusion from **Activity 1** is that for systems operating in considerably higher temperatures (greater than 46°C), the resultant impact on performance must be considered since performance will degrade compared to operating under more temperate conditions. Furthermore, the discharge temperature should be considered when selecting alternative refrigerants.

The key components for performance improvement identified were the compressor, condenser and expansion device.

- At higher temperatures, the saturation temperatures and refrigerant density at the compressor suction port can be very different than that from the rated conditions. Larger displacement volumes and efficiency curves optimized for higher pressure lifts might be required. Therefore, the proper selection of the compressor is paramount.

- A better performance condenser will reduce the approach temperature between refrigerant and air, reducing discharge pressure.

At high ambient conditions, the system is forced to operate in higher pressure lift than at rated conditions, but still requires a certain refrigerant mass flow rate. Passive devices such as capillary tubes and orifices may not be able to provide enough expansion to allow the system to operate in higher temperature conditions. An active expansion device such as Electronic expansive valve (EXV) can adequately control operating conditions and maintain design superheat.

The analyses presented in **Activity 2** (design evaluation through modeling) provided good insights on adequate component design and/or selection for proper system functioning when using alternative refrigerants. The tests in activities 3-5 partially served as validation for the models developed, and as check for previous test data from PRAHA I. The key conclusions and recommendations are:

I. HC-290 and HFC32 have wider saturation regions allowing the system to operate with smaller superheat and sub-cooling, while benefiting from two-phase heat transfer.
II. Refrigerants with high temperature glide may require new heat exchanger (HX) designs, namely condensers. The original designs proved to be sufficiently effective to allow for most systems to operate with the different refrigerants; however, better designs would allow for higher system efficiency and potentially less charge. HX designs are severely constrained by allowed envelope dimensions. A complete system re-design would provide an opportunity for designing HX's with even higher efficiency.
III. The results of this analysis suggest that for an effective use of alternate low-GWP refrigerant, a proper compressor selection must be done. Higher isentropic efficiencies are desired for higher temperatures, but most importantly, the displacement volume requirements can vary from one refrigerant to another.
IV. It is also imperative that having an active expansion device (preferably an EXV) to not only allow for more controlled superheat, but also to enable the unit to run with different refrigerants with very different thermophysical properties.

For **Activities 3, 4, and 5**

I. Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing. It should be stressed that the baseline unit by design had its capillary tube located in the outdoor unit. This would cause liquid refrigerant leaving the outdoor unit to flash. The refrigerant enthalpy at the condenser outlet state was used to calculate the refrigerant-side capacity assuming an isenthalpic expansion without heat loss in connecting pipe. This is different from the modified systems of which the capillary tube was removed, and a manual expansion valve was placed at the inlet of the indoor unit. For modified systems, the enthalpy at the expansion valve inlet was used to calculate the refrigerant-side capacity.
II. The Unit 6 modified systems had lower performance than expected from the Activity 2 models. The R32 system configuration exhibited more than 10% less flow rate than anticipated due to performance maps over prediction, which corresponded to 10% lower capacity. The R454B configuration exhibited a deviation of 5% between model and test due also in part to a 3% flow rate over prediction in the model.
III. Unit 10, on the other hand, exhibited an excellent agreement to the models with less than 2% deviation in cooling capacity.

IV. Unit 10 exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This also indicates the importance of proper compressor selection.

V. The higher-than-expected power consumption in the Unit 10 baseline tests is also evidenced by the fact that even with zeotropic mixtures (R-447B and R-452B), Unit 10 had higher cooling capacity and efficiency than the baseline for the 46°C test condition, as projected in activity 2.

VI. Because of the differences in saturation curves from the Activity 2 analysis, HFC-32 tends to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed however, that making appropriate component selection, such as compressors with larger displacement volumes for the other refrigerants, cooling capacities and overall performance were of the same order of magnitude.

VII. Refrigerant fractionation as evidenced by the leak tests, does not appear to be a great concern since less than 2% in cooling capacity was observed after the system's re-charge.

VIII. The model validation adds confidence in the numerical simulation findings and recommendations provided in activity 2.

The **recommendations** for future development are:

- Establish a baseline system by conducting comprehensive testing including measurements and metrics not typically performed in energy certification tests.
- Replacing refrigerants is viable and can be competitive to presently used refrigerants but doing so requires proper component design and selection; compressor and expansion device particularly. Drop-in replacement without hardware change is never recommended.
- It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses that will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.
- Always test the modified systems in the same test setup as the baseline, with the same instrumentation.

Nomenclature

COP	Coefficient of Performance	-
D_o	Tube Outer Diameter	mm
f	Frequency	Hz
FPI	Fins per Inch	1/in
h	Enthalpy	kJ/kg
h_t	Tube Height	mm
HX	Heat Exchanger	-
$\dot{m}$	Mass Flow Rate	kg/s
MCHX	Microchannel Heat Exchanger	-
P	Pressure	kPa
P_l	Tube Longitudinal Pitch	mm
P_t	Tube Transverse Pitch	mm
s	Entropy	kJ/kg.K
T	Temperature	°C
TFHX	Tube-Fin Heat Exchanger	-

UA	Thermal Conductance	kW/K
V	Volume	m^3
w_t	Tube Width	mm
η_{vol}	Volumetric Efficiency	-
ρ	Density	kg/m^3

4. Risk Assessment

This component includes designing, developing and examining a risk assessment model suitable for the use pattern and operating conditions at high ambient conditions and in particular for the Gulf Cooperation Council (GCC) region. The plan was to coordinate with local institutes and experts in HAT countries to build a special risk assessment model that suits the countries' local needs and operating conditions. This process was to be conducted through the following elements:

I. Developing comprehensive terms of reference for building the local risk assessment model;
II. Analyzing the needs of local technical and research institutes to implement the risk assessment model including the technical capacities of personnel and laboratories;
III. Examining the risk assessment model and validating its applicability at levels of manufacturing, installations, operation and servicing.

Each of the above elements was to be led by a local research institute in consultation and cooperation with international associations partnering in this project. This chapter explains what was achieved given the large scope of this component of PRAHA-II.

4.1. Background on Risk Assessment

The concept of risk assessment in RACHP applications is fairly new as it was introduced with the advent of flammable refrigerants. A brief background is presented in this section to explain the concept and the different terms.

4.1.1. Flammability Definition and Classes

Flammability

For a fire to happen there needs to be three elements: a rapid leak of the flammable gas, a concentration higher than the lower flammability level, and a source of ignition as shown in figure below. Figure 12 shows the probability of ignition as the resultant of these three elements. Lower Flammability Limit (LFL), usually expressed in volume per cent, is the lower end of the concentration range over which a flammable gas can be ignited at a given temperature and pressure.

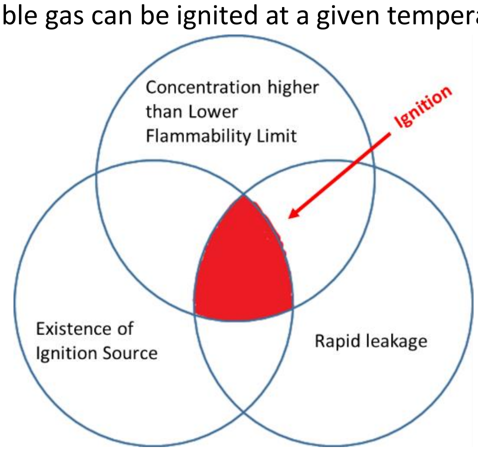


FIGURE 12: FACTORS AND PROBABILITY OF IGNITION

Probability = [rapid Leakage] x [High Concentration] x [Ignition Source]

This report does not aim to cover all aspects of flammability such as the ignition source energy and speed of propagation etc.

Flammability Classification for Refrigerants: Table 15 shows the classes of flammability as defined in ISO 847 and ASHRAE 34.

TABLE 15: FLAMMABILITY CLASSIFICATION FOR REFRIGERANTS

Class	
1	No flame propagation when tested at 60°C and 101.3 kPa
2	Flame propagation and LFL > 0.1 kg/m3 and HOC < 19,000 kJ/kg
2L	Same as 2 except Burning Velocity < 10 cm/s
3	Flame propagation and LFL <= 0.1 kg/m3 and HOC >= 19,000 kJ/kg

Refer to Annex II for a discussion on safety and standards.

4.1.2. Concept of Risk Assessment

The concept behind risk assessment is to define what is an acceptable risk given the conditions for ignition in a particular location. To begin with, a definition of risk is agreed upon and a matrix of probability vs. severity is built. For this purpose, this report adopts the work done by JRAIA in Japan.

Definition of Risk

Risk is a combination of the probability of concurrence of harm and the severity of that harm. Tolerable risk is the level of risk that is accepted in a given context based on the current acceptable values by a community. Residual risk is the risk remaining after reduction measures have been implemented. Safety is freedom from risk which is not tolerable.

The risk levels depend on the severity of injury, the amount of damage to the environment, the frequency at which people are exposed to the danger and the duration of exposure.

Tolerable risk is determined by the search for an optimal balance between the ideal absolute safety and the demands to be met by a product. The factors influencing risk are the practicality and means to reduce risk, the benefit to users, cost effectiveness, and social conventions.

The concept of tolerable vs. unacceptable risk was introduced based on the probability of harm and the severity of harm as per Figure 13.

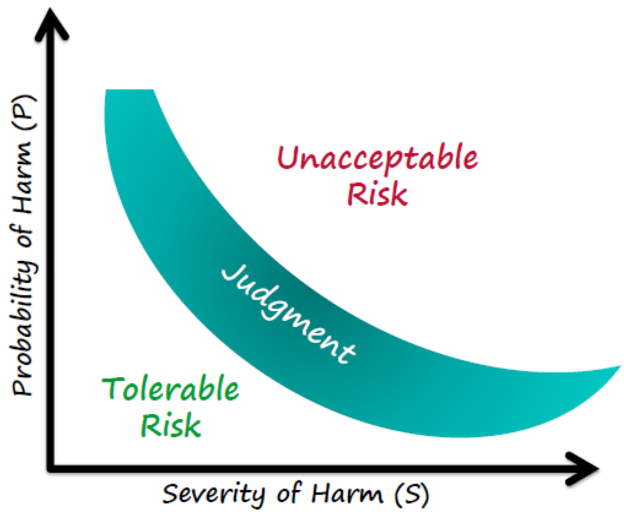


FIGURE 13: TOLERABLE VS. ACCEPTABLE RISK (SOURCE: UL)

The sources of risk start with manufacturing all the way to the end of life of the refrigerant and the equipment. It includes transport and storage, installation and service, operation, as well as removal and dismantling.

4.1.3. Approach of a Risk Assessment Model

The following is part of the process to build a model:

- An outline of the methodology and the components that are the basis for the risk assessment model;
- A model of what data can be collected;
- Information on the regulatory regime and the enforcement mechanisms;
- International standards play a role in the next step of risk assessment in the form of recommendations for local standards; however, the intention is to build a model, not convert it into regulation. Rigorous regulations as those adopted in other regions must be adapted to HAT countries.
- Stakeholders: governments and local research institutions, industry and private sector, and UN Environment & UNIDO;

To determine the outline of the risk assessment model, PRAHA organized a roundtable meeting in cooperation with The Japanese Refrigeration and Air Conditioning Industry Association (JRAIA), and the Air Conditioning, Heating, and Refrigeration Institute (AHRI) as international partners.

The roundtable briefly reviewed the research and testing projects on lower-GWP alternatives for HAT countries as well as the research projects conducted in the United States on A2L refrigerants such as ASHRAE and AHRTI research on flammable refrigerants. Underwriters Laboratory (UL) presented the work that is being done on safety standards and KISR presented a glimpse of their research projects. The industry was also represented in the proceedings and presented their own research and R&D on flammable refrigerants.

A review of the adoptability of flammable refrigerants globally shows the four regions where refrigerants are accepted to varying degrees. Work still needs to be done on HAT regions.

4.1.4. Outline of a Risk Assessment Model

A special expert meeting was held in Cairo in August 2018 focused on the first step of building a risk assessment model through collecting local data and assumptions needed for drafting the model. The meeting aimed to discuss, review and comment on the data collection methodology designed. The meeting was attended by selected experts from the air-conditioning servicing and firefighting sectors, including participation of two members from the Montreal Protocol Refrigeration Technical Options Committee and members of the Halons Technical Options Committee, as well as research institutes' experts, servicing sector expert and National Ozone Officers from Egypt and Kuwait.

JRAIA experts joined the meeting through web-conferencing during the two days. The meeting built clarity and better understanding about the model suggested by JRIAA and included the following:

- Quick Overview of PRAHA-II and First Roundtable Meeting
- JRAIA Risk Assessment Model (Via Web-Meeting) - Brief Introduction to Risk Assessment Concept - Risk Scenarios for installation, use and service of split A/Cs - Explanation of field data/assumptions needed for building the model
- Discussion on Risk Assessment Datasheet and Compilation of Enquiries and Clarification needed from JRAIA - JRAIA Risk Assessment Model - Risk Scenarios for installation, use and service of split A/Cs - Field data/assumptions needed for building the model - Work plan for Data Collection, Review and Validation

The process that will be used is outlined in Figure 14.

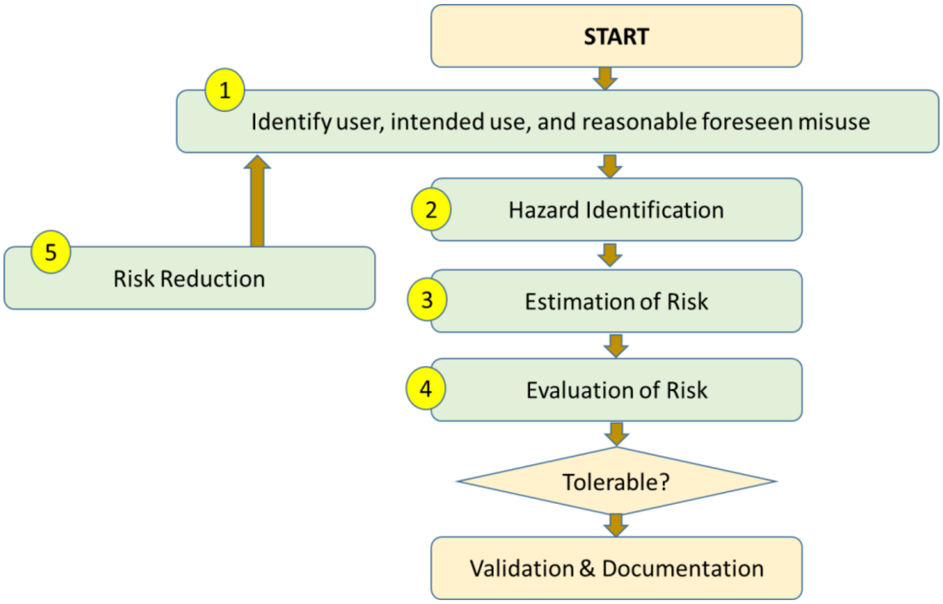


FIGURE 14: PROCEDURE OF RISK EVALUATION ACCORDING TO ISO/IEC 51 (SOURCE: JRAIA)

The experts also discussed the application for the model for which data and information which will be collected. Several applications were suggested with size and use of the room and the sources of ignition. One application will be chosen.
An example of the data tables to be filled before the workshop is shown in **Annex I**.

For more info about the Cairo meeting, please refer to:
https://www.unenvironment.org/ozonaction/news/editorial/un-environment-and-unido-help-countries-high-ambient-temperatures-assess-risk

4.1.5. Global Risk Assessment Efforts

The purpose of this section is not to present a comprehensive background on all the work that has been done globally, but to review those efforts that were presented or shared during the different PRAHA-II events. The PRAHA team is aware of risk assessment efforts done in Columbia and India, among others, some done with the help of implementing or bilateral agencies. Similarly, Chinese associations and industry built their own local risk assessment for the use of A3 refrigerants in unitary air-conditioning applications.

The following is a brief review of research projects that were reviewed both at the International Workshop on Risk Assessment for HAT in Kuwait in Oct 2017 and the Flammable Refrigerant Research and Planning Conference in Chicago in Oct 2018:

Note: AHRTI is the research arm of AHRI in the United States, ASHRAE is the Association of engineers and NFPA is the National Fire Protection Association:

- AHRTI-9007 to conduct refrigerant leak and ignition testing and investigate the control limits and safety factors proposed for IEC 603325-2-40 for air conditioners and 60223-2-89 for refrigeration;
- AHRTI-9009 refrigerant leak detector long-term reliability assessment, to conduct a thorough review of sensor technologies that can detect A2L refrigerants;
- AHRTI-9008 investigation of hot surface ignition temperatures for A2L refrigerants in order to establish a standard;
- ASHRAE-1806 to determine the severity of ignition events using computer modeling;
- ASHRAE-1808 to determine leak rates through mechanical joints;
- NFPA evaluation of fire hazard of A3 refrigerants

AS an example of the work done on A3 refrigerants, the project "Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing of A3 Refrigerants" conducted by AHRTI conducted leak and ignition testing for HC-290 (propane) under whole room scale conditions to develop data and insight into the risks associated with the use of Class A3 refrigerants. This included parametric testing to investigate how key variables (refrigerant charge amount, release rate and height etc.) influence the 'ignition event' under whole room scale scenarios. It involved releasing liquid HC-290 refrigerant into spaces with a variety of viable ignition sources present. The testing scenario simulated a Packaged Terminal Air Conditioner (PTAC) and a mini-split air conditioner (AC) in a typical motel room plus a single door reach-in cooler and a three-door reach-in cooler in a convenience store. The testing scenario was according to the existing requirements or proposed requirements in the IEC Standards 60335-2-40 (for air-conditioning products) and IEC 60335-2-89 (for commercial refrigeration products), and their equivalent North American version published by Underwriters Laboratory (UL).

UL in the US has done work in developing requirements for flammable refrigerants applicable to both air conditioning and refrigeration equipment, as well as the requirements for testing and evaluation of flammable refrigerants including A2L refrigerants. As a result of the work, Standards were published for air conditioners recommending three times the Lower Flammability Limit (3xLFL) under UL 484. For refrigeration, Standard UL 250 for household refrigerators published a 57 gram limit, while UL 60335-2-24 published a 150 gram limit for commercial refrigerators. The transitioning to IEC standards 60335-2-40; 60335-2-24; and 60335-2-89 is now complete.

JRAIA developed a comprehensive risk assessment model for A2L refrigerants. The JRAIA model was used by the PRAHA-II team in the risk assessment work and studied in detail in this chapter. PRAHA-II collaborated with JRAIA to build a model that suits the HAT countries usage and servicing practices.

Initially, it was hoped to cover models for both A3 and A2L. UN Environment and UNIDO were planning to build another parallel model for HAT countries addressing flammable (A3) refrigerants in cooperation with China, given China's expertise and knowledge about hydrocarbon refrigerants, HC-290 in particular. The work which was planned to be with the Chinese association CHEAA.

4.2. Process of a Risk Assessment Model

The following is a step-by-step outline of a Risk Assessment model based on the workshop that was held in japan in April 2019. Experts from Kuwait and Egypt were invited along with the representative of the national Ozone unit of Kuwait to a two and a half days of workshop and lab visit in Tokyo. The agenda covered a reintroduction of the risk assessment model of Japan with focus on minis-splits as well as the introduction of Japan's experience in data collections methodology. The rest of the workshop was dedicated to the study of a risk scenario prepared by the PRAHA team.

A Step-by-step approach to the case study by the PRAHA team is outlined below:

I. **Selection of equipment type and application**: From residential to refrigeration as per figure below identified by JRAIA. The work on VRF and refrigeration assessment by JRAIA is completed. The PRAHA-II team chose residential air conditioning as it is the most used type in number of units and where the risk might be greatest. The team also identified servicing of the indoor unit as the most relevant for the model.

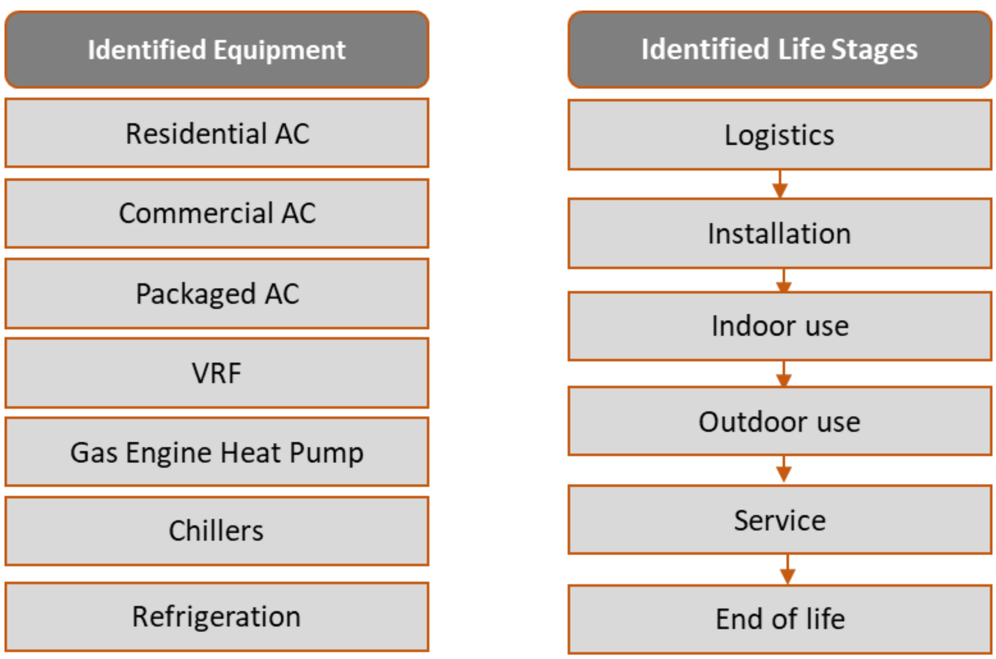


FIGURE 15: SELECTION OF EQUIPMENT AND LIFE STAGE FOR THE RISK ASSESSMENT MODEL

II. **Identify Acceptable and tolerable risk:** Tolerable risk depends on the number of units in the market of the product identified. Tolerable risk depends on the frequency and severity of the accident.

JRAIA defines risk in terms of probability and frequency vs. severity. A low risk is where the probability of an accident is lower and the severity is least. An extreme risk is where the probability is high and the severity is also high.

Table 16 shows the frequency of accidents vs. severity. Frequent accidents leading to catastrophic events are the least acceptable; while improbable of incredible (as in incredibly low frequency) with the least severity are socially acceptable.

TABLE 16 RISK MATRIX - FREQUENCY VS. SEVERITY (SOURCE JRAIA)

	None	**Negligible** (slight injury)	**Marginal** (need for outpatient treatment)	**Critical** (serious injury or need to be hospitalized)	**Catastrophic** (death)
Frequent	C	B3	A1	A2	A3
Probable	C	B2	B3	A1	A2
Occasional	C	B1	B2	B3	A1
Remote	C	C	B1	B2	B3
Improbable	C	C	C	B1	B2
Incredible	C	C	C	C	C
A = Unacceptable risk levels: 1=least, 3= highest		B= Risk levels should be reduced 1= least, 3= highest		C= Socially acceptable risk levels	

III. Analyze Product Cycle

It is necessary to classify the air conditioners into groups and assess the individual risk of each group. If the classification is very narrow, the risk assessment becomes complicated, and data common to different groups cannot be collected because the risk assessment needs to be performed on an individual basis.

The most important considerations for HAT relate primarily to the installation and servicing issue and technicians' skill levels. The temperature has no direct effect on the risk, it is the practice that matters. The question of whether to build a model from scratch or adopt an international model is moot since there is a need to know the status of doing things in the countries that built similar models in order to plug into the locally built model, i.e. level of service, frequency of service, types of installation etc. The team decided to build a model from scratch.

The life cycle range for assessment is shown in Figure 16. Each stage has to be assessed separately and added together to get to the total risk.

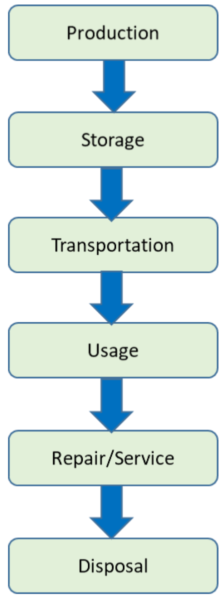


FIGURE 16: LIFE CYCLE RANGE FOR ASSESSMENT

The determination of tolerable risk depends on the population of products in the country. The example from Japan is in Table 17:

TABLE 17: DETERMINATION OF TOLERABLE RISK LEVELS

Product/System	Unit Population	Tolerable risk Usage stage	Tolerable risk Service stage
Residential AC	1×10^{8}	1×10^{-10}	1×10^{-9}
Commercial AC	7.8×10^{6}	1.3×10^{-9}	1.3×10^{-8}
VRF	1×10^{7}	1×10^{-9}	1×10^{-8}
Chillers	1.34×10^{5}	7.5×10^{-7}	7.5×10^{-7}
Condensing units	1.46×10^{5}	6.9×10^{-8}	6.9×10^{-7}

The PRAHA team used the JRAIA approach to set the tolerable risk for residential units at the following levels:
For the usage stage = 1 / 100 x unit population
For the service stage = 1 / 10 x unit population

And the risk map becomes as in Figure 17:

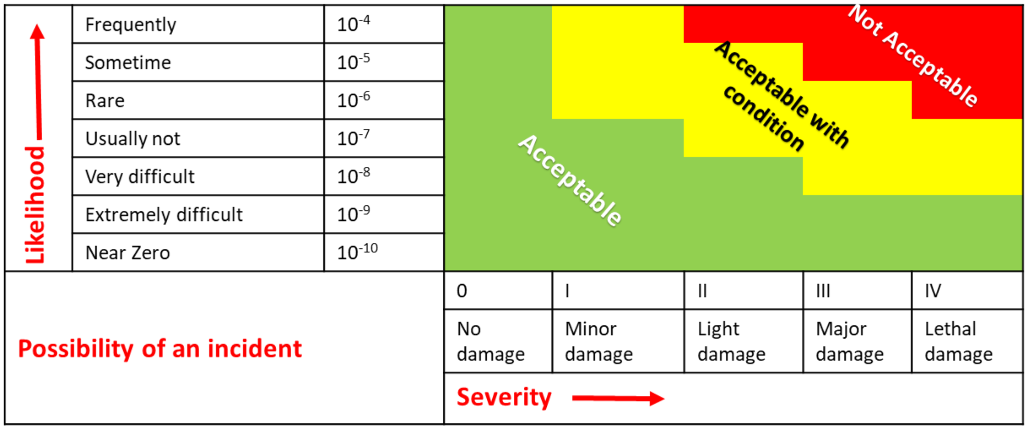


FIGURE 17: RISK MAP

IV. Risk Scenarios

A critical stage of the risk assessment is to identify those scenarios in which an ignition source is present in conjunction with a flammable concentration of leaked refrigerant. To better understand these scenarios, one must consider the various triggering events which could cause refrigerant to be released, the location of the release, and the specific type of person that might be present (*i.e.*, a worker, repair person or customer) at the time of the release. It is important to note that, during normal operations, the refrigerant will be contained within the system, and thus there is no risk of adverse events associated with these refrigerants during regular use. However, if refrigerant leaks from the equipment and is not dispersed prior to accumulating to a flammable concentration and a sufficient energy source is present, refrigerant ignition could occur (AHRTI 8009)

The first step in a risk analysis is to select a risk assessment method. There are three known methods used: Event Tree Analysis (ETA), and Failure Modes and Effects Analysis (FMEA), and Fault Tree Analysis (FTA). ETA is based on binary logic, in which an event either has or has not happened or a component has or has not failed. FMEA is a structured approach to discovering potential failures that may exist within the design of a product or process. Failure modes are the ways in which a process can fail. Effects are the ways that these failures can lead to harmful outcomes for the user. The goal of FTA is to provide an order of magnitude estimate of the likelihood that the outcome in question will occur (US NRC, 1981).

The team chose the fault tree analysis in line with JRAIA. Refer to item VII for FTA description.

The risk assessment of flammable refrigerants considers two individual phenomena: the presence of an ignition source and the generation of a flammable volume. The risk scenarios that were considered were:

A. Refrigerant leak during maintenance work on the indoor unit during brazing and due to pipe breakage by corrosion with an ignition source caused by live wire, static electricity, or electric tool such as screw drivers;

B. Refrigerant leak during brazing of outdoor unit with leakage caused by prior maintenance work or during maintenance work and an ignition source from the brazing torch;
C. Refrigerant leakage during normal home use caused by pipe breakage through corrosion, external pressure or natural causes such as earthquakes with an ignition source of an open flame, electric spark or static electricity.

V. Select Risk Analysis Sources

The input into the model is taken from data tables for the type of application and usage of the equipment that are being studied. Source for input into the volume of the flammable cloud can be taken from research done for the type of gas. Data for source and time of ignition can sometimes be available from the fire department.

VI. Data Collection

Data collection takes into consideration the following:

a) Select the stages of the life cycle of the air conditioners. Choose the manner of classification of manufacturing, transportation, use, service, and disposal of an air conditioner into separate stages for evaluation. The evaluation of the manufacturing stages of each product is normally the responsibility of the manufacturer;
b) Investigate the conditions of installation of the selected air conditioner to determine the conditions to be evaluated during the risk assessment;
c) Determine the severity of the hazard focusing on the damage caused by flammability;
d) Set tolerance levels. Set socially acceptable probability of harm for the air conditioner;
e) Investigate refrigerant leakage rate, speed, and amount based on surveys conducted with air conditioning service companies. The initial leakage location and leakage concentration should also be determined;
f) Determine flammable time volume through CFD or calculations. For the conditions set as per point (b), the flammable time volume can be calculated by CFD simulation based on the leakage amount, speed, and concentration of the refrigerant as per point (e).
g) Consider ignition sources. Distinguish the ignition properties depending on whether the ignition source is a spark (for example, electrical contacts, lighter, and/or static electricity), or an open flame (for example, candles, matches, and/or combustion equipment).

VII. Fault Tree Analysis (FTA)

It utilizes a "top-down" approach, starting with the undesired effect as the top event of a tree of logic. Fault trees (FTs) consist of various event boxes, which reflect the probability or frequency of key events leading up to a system failure. The event boxes are linked by connectors (gates), which describe how the contributing events may combine to produce the system failure. Events may be combined in different ways: in cases where a series of events must all occur to produce an outcome (e.g., ignition source and sufficient oxygen to support combustion), the probabilities or frequencies of the individual contributing events are multiplied via an "AND" gate; in cases where only one of a series of events is needed to produce an outcome (e.g., a strong spark, open flame, or a hot surface all possibly leading to refrigerant ignition), the probabilities are usually added via an "OR" gate. (AHRTI 8009, 2015).

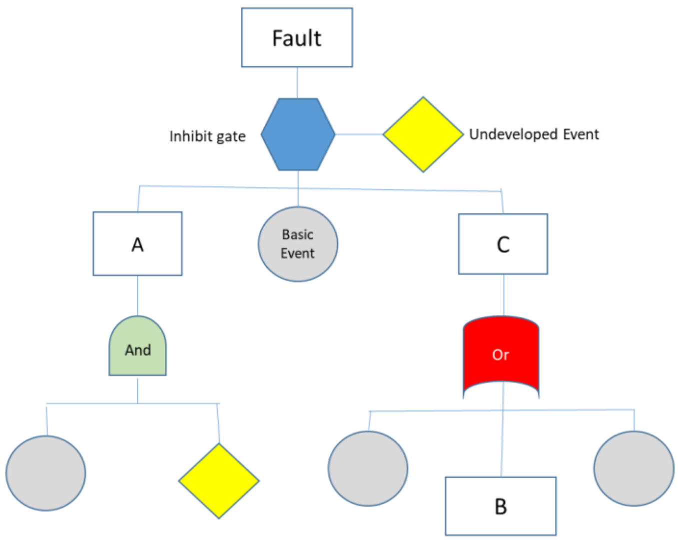


FIGURE 18: FAULT TREE ANALYSIS (FTA) MODEL

In the case of flammability, the probability of leakage is combined with ("and" gate) the possibility that the length of time that flammable cloud exits covered area would lead to ignition in case of the existence of an ignition source (another "and" gate).

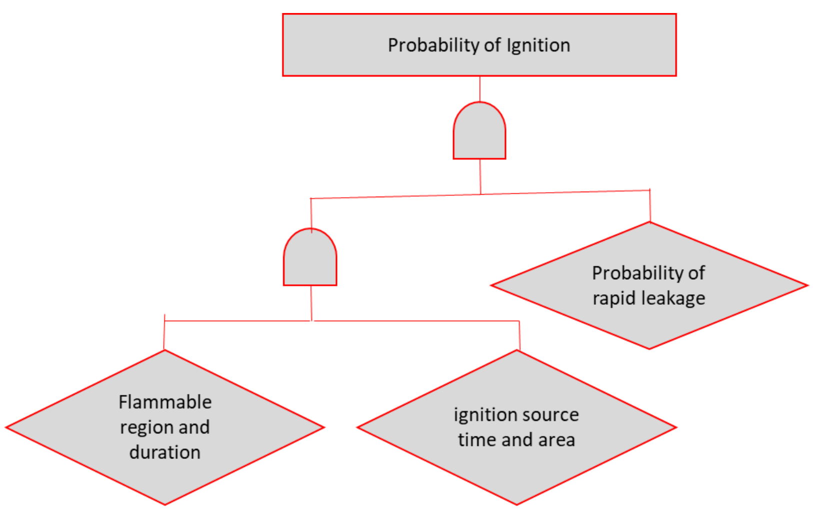


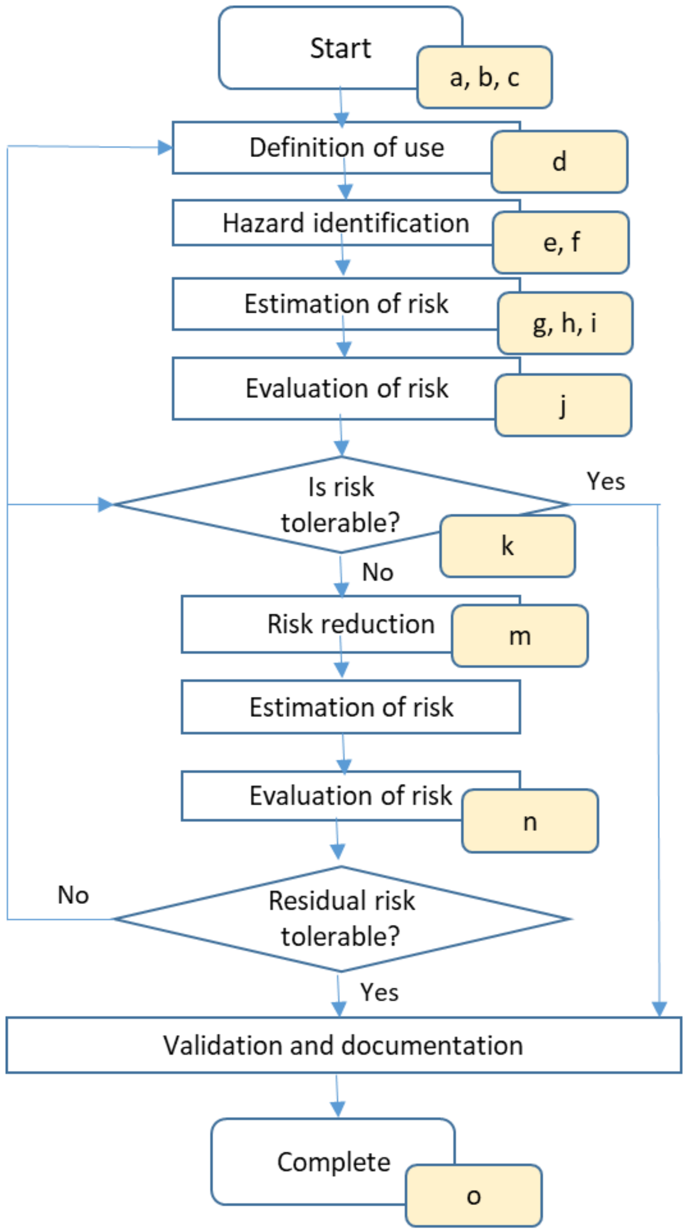
FIGURE 19: PROBABILITY OF IGNITION FTA

In the development of FTA for flammability, the presence of the flammable region and the ignition source correspond to independent trees. Then, their probabilities are multiplied in the final step to calculate the accident probability.

When the contents are reviewed, the risk is evaluated against the risk map in item III above and the calculated accident probability is compared to the acceptable probability in the risk map. The risk tolerance propriety is then determined.

VIII. Suggest Measure to Mitigate Intolerable Risk

When the tolerance from the risk evaluation in the steps above is satisfactory, the risk assessment ends. If the risk exceeds the tolerance, countermeasures to reduce the risk should be taken. These countermeasures include the implementation of regulations and other measures like introducing safety procedures in order to reduce the risk of accidents. In some instances, it might be necessary to revise laws and regulations in order to ensure that they cover the accepted probability. The reiterative process, which is explained in Figure 20, is as follows:



a) Select risk assessment method
b) Select product
c) Select stages of the product life, i.e. usage or service etc.
d) Investigate installation circumstances
e) Determine severity of hazard
f) Set tolerance levels
g) Investigate refrigerant leak rate, speed and amount
h) Determine flammable time volume
i) Consider ignition sources
j) Develop FTA
k) Compare against tolerance
l) Evaluate risk against tolerance
m) Reduce risk with countermeasures
n) Redevelop FTA
o) Confirm and publish

FIGURE 20: FTA REITERATIVE PROCESS

IX. Recommend Standards and Codes

Once the countermeasures have been introduced, the FTA factors are reviewed and these countermeasures are added in the appropriate position of the tree. A new calculation can then be made and repeated until the calculations confirm the accepted tolerance according to the risk map. The results can then be released to the public and standards and codes can be drawn.

4.3. Example of a Risk Assessment Model

The team chose a case study of an office space in a government building during the usage phase when the equipment is running and during the repair/service stage. The target product is a 5.3 kW split system using an A2L refrigerant. The team selected the Fault Tree Analysis method which is described under item VII below. The target product and the indoor and outdoor conditions plus the service case are shown in the tables below.

At the workshop in Tokyo in April 2019, the PRAHA team worked with the JRAIA experts to do two case studies using the information provided by the PRAHA team. The two case studies are:

- During usage of an air conditioner in a government office. The sources of ignition are extreme including charcoal and lighter used for incense burning, an aroma candle, as well as cigarettes and lighters as smoking is still allowed.
- During the repair stage during brazing with sources of ignition including the brazing burner, a cigarette and a lighter.

Table 18 lists the equipment as well as the indoor and outdoor conditions

TABLE 18: INFORMATION FOR THE RISK ASSESSMENT MODEL USED BY PRAHA TEAM

Target Product	Value
Model number	CS-PC36JKF
Type(cooling / HP)	HP
Capacity(kW)	10.5
Refrigerant type	A2L
Refrigerant amount(kg)	2.7
Alternative refrigerant type	HFC-32, R-454B

Indoor Condition during usage of target product		Value
Room size (m^2)	max	25
	min	16
Height of installation(m)		2.1
Ceiling height(m)		2.8
Ventilation	yes/no	YES
	Ventilation amount (m^3/hr.)	80
The area of the gap under the door (m^2)		0.02
other openings, if any (m^2)		0

Outdoor Condition during usage of target product		Value
Size of the place enclosed with walls , or fences etc.(m^2)	max	8
	min	4

Condition during repair of target product	value
Average size of outdoor spaces for repairs (m^3)	20
Percentage of single outdoor unit installations(A%)	50
Percentage of the installations of multiple outdoor units (B%)	50
Average working hours per repair (outdoor unit) (hr.)	1
Average working hours per repair (indoor unit)(hr.)	0.5
Wind condition (wind velocity) (m/s)	1 TO 3
Windless condition percentage (%)	10

(Windless condition; 0.1m/s or less. the windless rate in one year.)

Notes:

- No alternative refrigerant is available from the manufacturer for this product;
- Ventilation amount was calculated based on 1.5 air changes per hour;
- Gap under door was based on the door width is 1.00 m, gap with floor is 2 cm;
- The outdoor unit was assumed to be installed on a roof open area.

The methodology is to calculate the probability of ignition due to a space factor and a time factor.

Space Factor

The space factor takes into consideration the space volume, the volume of the flammable cloud, and the volume of the source of ignition. The volume of the flammable cloud depends on the leakage rate and other considerations such as pressure. The volume of the source of ignition can be very small as in the case of a spark, or sizeable as in the case of an open flame.

Time Factor

The time factor takes into consideration the number of occurrences of the ignition source and the duration of each occurrence.

Terminology

The following terminology will be used in the calculation example:

T_{Ref} = Time of application: 24 hours for usage or duration of maintenance for service
T_S = Time of Ignition Source
T_F = Time of Flammable Cloud
V_{FT} = Flammable Volume Time Integration
V_{SOI} = Volume of source of Ignition
$V_{F\,Cloud}$ = Volume of Flammable Cloud
V_{Ref} = Volume of space or room
$P_{A,\,B\,or\,C}$ = Probability of ignition for the different sources of ignition (A), (B), or (C)
P_R = Refrigerant Leak Probability

Equations

The Volume of Flammable Cloud is the Flammable Volume Time Integration divided by the Time of Flammable Cloud

$\mathbf{V_{F\ Cloud} = V_{FT} / T_F}$

The probability of ignition is the sum of the space and time factors for each source of ignition.

The probability of time is calculated as the sum of the time of the flammable cloud plus time of source of ignition divided by the time of reference (usage or service time).

$\mathbf{P_T = (T_F + T_S) / T_{Ref}}$

The Probability for Space is similarly calculated as the sum of the volume of source of ignition plus the volume of the flammable cloud divided by the reference volume which is the volume of the room or space where service is done.

$\mathbf{P_S = (V_{F\ Cloud} + V_{SOI}) / V_{Ref}}$

The probability for one source of ignition (A), referred to as "Event" is the multiple of the Time probability and the Space probability:

$\mathbf{P_A = P_T \times P_S}$

The probability for all events is sum of the probabilities for all sources of ignition. The three sources identified in the example i.e. charcoal, cigarette and candle are herein called A, B, and C

$\mathbf{P_{Events} = P_A + P_B + P_C}$

$\mathbf{P_R}$ = Leak Frequency x Number of Occurrence in a 24 hour period

The Total probability is the multiple of the probability of each event by the Refrigerant Leak probability

$\mathbf{P_{Total} = P_{Events} \times P_R}$

4.3.1. Simulation of Time Factor and Space factor During Usage Stage

The data in Table 19 was provided by the PRAHA-II team for the workshop.

TABLE 19: DATA FOR THE CALCULATION OF RISK FOR USAGE STAGE

Event	Ignition source	No. of Occurrence	Duration per day	T_S = Time of Source
A	Charcoal + lighter	2	1 hour	I hr/2
B	Cigarette+ lighter	2	0.2 hour	0.2 hr/2
C	Aroma candle	4	3 hours	3 hr/4

Flammable volume Time Integration:

- $T_F =$ 18 minutes/60 minutes = 18/60 hour Time of the flammable cloud. The time is derived from lab data for the type of refrigerant
- Ts is show in table 19
- $V_{F\ Cloud} = 6.4 \times 10^{-2}\ m^3$ min/ 18 minutes: Volume of the flammable cloud for indoor unit is derived from simulation data for the class of refrigerant and type of application.
- V_{SOI} is negligible.
- T_{Ref} = 24 hours: Time of application is 24 hours since usage is throughout the day
- $V_{Ref} = 25\ m^2$ floor area x 2.1 m height of the indoor unit.
- 1×10^{-3} = Leak frequency per year taken from a study for Japan as data is not available from the countries under study.

Figure 21 shows the FTA calculation for the usage stage.

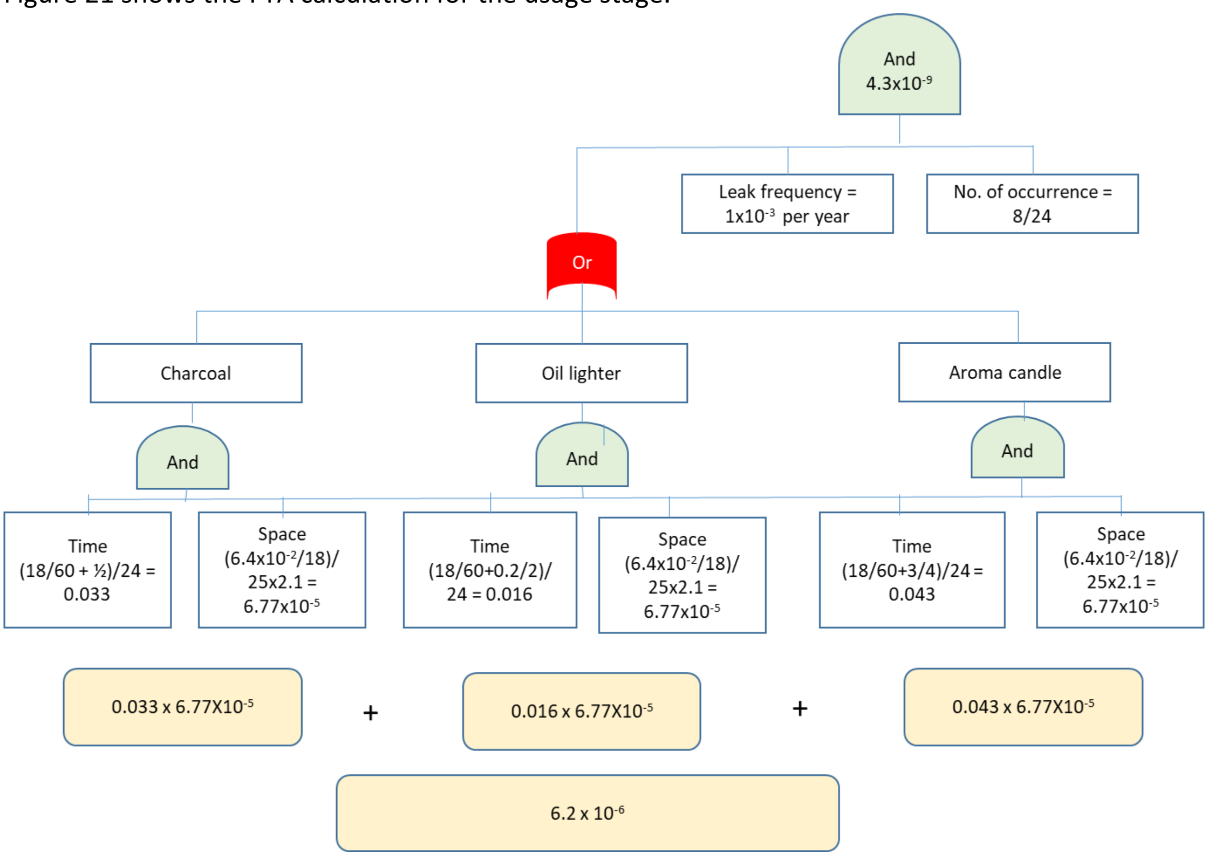


FIGURE 21: FTA FOR USAGE STAGE

For each event, i.e. charcoal, oil lighter, and aroma candle the probability of time and space are calculated according to the equations given above, for example:

- For charcoal the time factor is the sum of the time of the flammable cloud and the time of the ignition source divided by the usage time which is 24 hours. The probability equation is $(T_F + T_S)/T_{Ref.}$ T_F is 18/60 derived from data, Ts = ½ from table 19 and T_{Ref} is 24 hours.
- The space factor for charcoal is $(V_{F\ Cloud} + V_{SOI})/V_{Ref.}$ $V_{F\ Cloud}$ is 6.4×10^{-2} /18 while V_{SOI} is negligible. $V_{Ref.}$ is the volume up to the height of the unit = 25x2.1

- The addition of the three ignition sources gives a probability of $6.2x10^{-6}$ which is P_{Events}
- $P_{R} = 1x10^{-3} x (8/24) = 7x10^{-4}$
- The Total probability is P Events x PR = $(6.2x10^{-6}) x (7x10^{-4}) = 4.3x10^{-9}$ shown in the top "And". This puts the probability in the "Extremely Difficult" area of Figure 17: Risk Map.

4.3.2. Simulation of Time Factor and Space factor During Servicing Stage

TABLE 20: DATA FOR CALCULATION OF RISK FOR SERVICE STAGE

Event	Ignition source	No. of Occurrence	Duration per day	T_S = Time of Source
A	Burner	2	2 minutes	4/2
B	Cigarette	2	3 minutes	6/2
C	Lighter	2	10 seconds	0.167/2

Flammable Volume Time Integration

$V_{F\ Cloud} = 6.3 \times 10^4\ m^3$ sec/3600 sec Volume of the flammable cloud for outdoor unit is derived from simulation data for the class of refrigerant and type of application.

V_{SOI} is negligible

T_{Ref} = 60 minutes (I hour)

$V_{Ref} = 20\ m^2$ space x 3.5 m height. This is the volume of service space for the outdoor unit.

Ts is shown in table 20

T_F is 60 minutes is the time of the flammable cloud

T_{Ref} is the time of service which is 60 minutes

The FTA for servicing stage is shown in Figure 22.

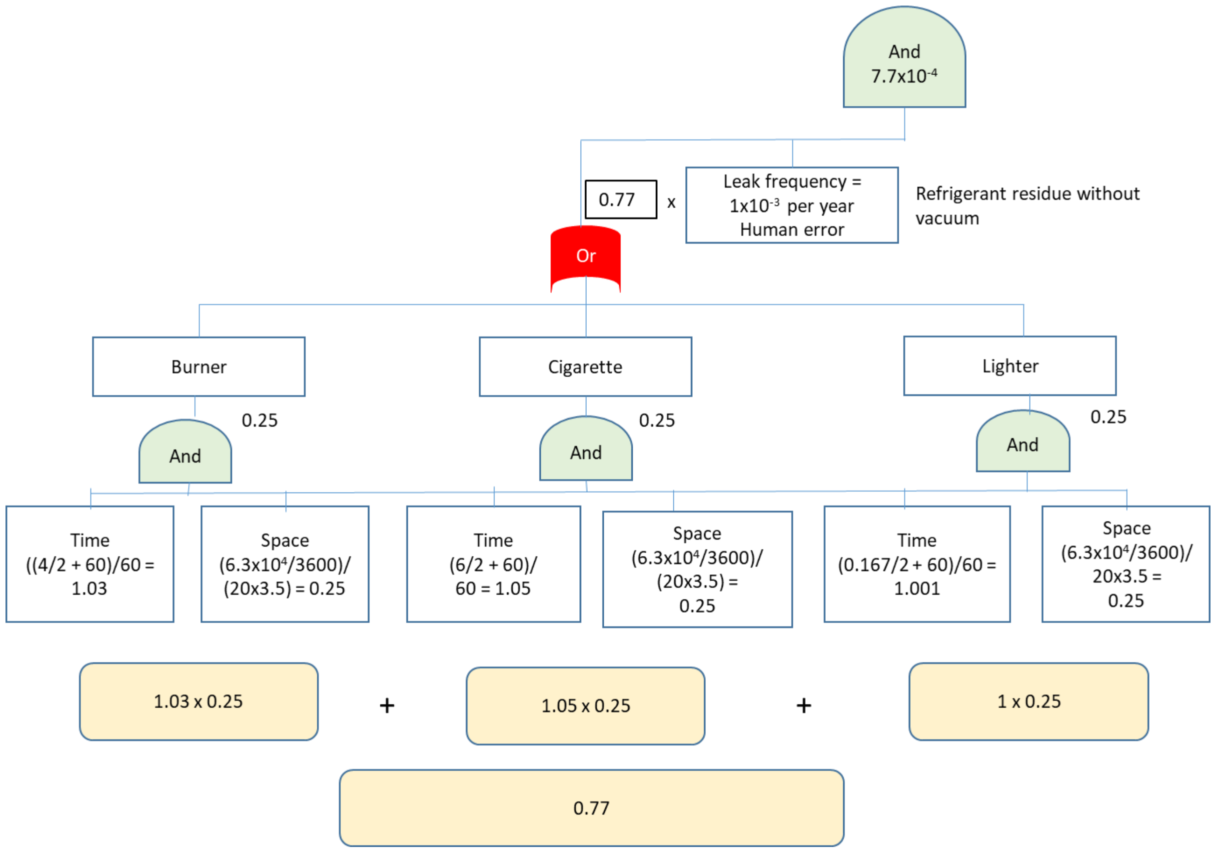


FIGURE 22: FTA FOR SERVICING STAGE

The calculations are similar to the usage stage example given above.
The Total probability is 0.77x $1x10^{-3}$ = $7.7x10^{-4}$ which is shown in the top "And". This puts it in the "Frequent" from the Risk Map of table 17 and mitigation measures should be taken. One evident measure is to ban smoking in the service area!

4.4. Conclusions and Recommendations from the Risk Assessment Element

The above two FTA were created in collaboration with HAT countries and Japan. The purpose of this FTA was to simulate a risk scenario in HAT region with unique climate, product-usage, lifestyle and culture which differs from Japan's case. The exercise has shown the need for a reliable data for the HAT region on leaks, practices etc.

Building a risk assessment model for the HAT countries that suits the climate and the service practices of the local technicians helps the HAT countries, as well as setting the foot for all A5 countries, in understanding the risk associated with flammable refrigerants and adopting the needed regulations and training programs especially in relation to the logistics of lower-GWP based technologies i.e. installation, transportation, storage, servicing and decommissioning.

The recommendation is for HAT countries to continue the risk assessment based on actual situations, and reduce the risk by implementing various measures that are verified by FTA. It is also important to minimize ignition probability by implementing various measures that are verified by FTA. In addition, the risk assessments of other stages matching cultural and lifestyle aspects should be studied.

References for chapter 4

AHRTI 8009, 2015. Risk Assessment of Refrigeration Systems Using A2L Flammable Refrigerants. April 2015

JSRAE, 2017. Risk Assessment of Mildly Flammable Refrigerants. Final Report 2016. March 2017

US Nuclear Regulatory Commission (US NRC). 1981. "Fault Tree Handbook." NUREG-0492. 209p. January.

5. Overall Conclusions and Recommendations

The outcomes of PRAHA-II components can draw several concluding remarks in relation to the main objectives of the project which can be summarized as follows:

In relation to support the process advancing the promotion and deployment of lower-GWP alternatives:

I. A tailored Risk Assessment is essential, not only for HAT countries, in better understanding safety implications associated with deploying alternative refrigerants, either A2L or A3, considering the specifics of different types of equipment and life stages.

II. Efforts in building risk assessment models should be exerted towards analyzing risks in the logistics side of the supply-chain i.e. Installation, In-door use, outdoor use, servicing and end of life (decommission); understanding the design and manufacturing risk assessment are covered by relevant international standards which should more or less apply to most countries.

III. The concept of risk assessment is quite similar worldwide, including methodologies in calculating and analyzing severity and frequency of risks. However, criteria for acceptable tolerance levels may differ depending on local considerations. Measures to mitigate risks would depend on type of exiting/operational standards and/or codes in each country noting

IV. Few Article 5 countries and some of the non-Article-5 countries have built similar models. Learning from the pioneers in risk assessment models through partnership and cooperation will leapfrog the technical difficulties and provide a quick access to building the model.

V. PRAHA-II was the first step in is providing the impetus for this leapfrogging. Similarly, Building the risk assessment model with the involvement of local research institutes and organizations will add depth and reach for those institutes and involve the HAT countries in the global research efforts on new alternatives as well as build countries' ownership.

VI. Building a risk assessment model for the HAT countries that suits the climate and the service practices of the local technicians will help the HAT countries will set the foot of A5 countries, not only HAT, in understanding and establishing local risk assessment models hence adopting the needed regulations and training programs especially in relation to the logistics of lower-GWP based technologies i.e. installation, transportation, storage, servicing and decommissioning.

In relation to building capacities of local industry to better design with lower-GWP alternatives:

VII. The optimization work on the prototypes of PRAHA-I is helping the OEMs who built the original prototypes get the best support in their R&D efforts. The activities of that element substantiated by result of testing of the optimized units confirm that enhanced design and the use of the proper components can lead to better performance and energy efficiency.

VIII. The optimization element of PRAHA-II also pointed out that components, especially compressors for the new refrigerants, are still not widely available. These and other limitations have to be dealt in order to help manufacturers make an informed decision on the way forward.

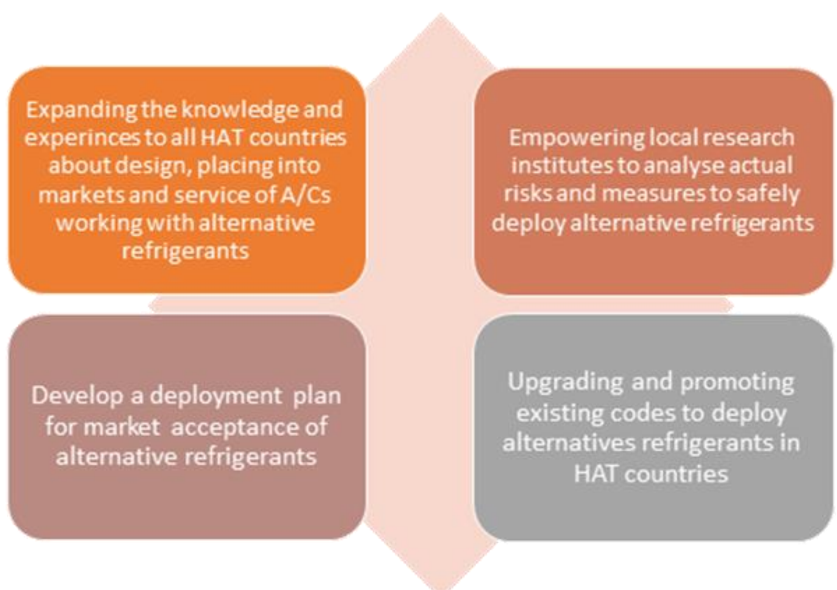
IX. PRAHA capacity building activities have helped the PRAHA stakeholders in acquiring added knowledge about working with alternative lower-GWP refrigerants that are flammable. The study tours have exposed stakeholders to the latest in technology for both A2L and A3 refrigerants at global technology centers. The capacity building activities helped many manufacturers in HAT countries in building or engaging in other research projects.

In relation to maintaining sustainable technical platform to support PRAHA process and sharing knowledge about up-to-date technological developments amongst HAT countries:

X. The capacity building efforts have turned PRAHA into a global process that can be extended to all 35 HAT counties and not only the Gulf and Middle East countries that were engaged with PRAHA-I.

XI. PRAHA-II events continued to attract global and regional participation in terms of government authorities, technology providers, manufacturers, and international/regional institutes. PRAHA presentations and knowledge sharing at networks of ozone officers and international conferences have become a fixture for exchanging experiences and knowledge about HAT technological related aspects. PRAHA-II has helped to spread the awareness of HAT challenges in optimization and risk assessment as well as opportunities.

Key take-home messages from PRAHA-II conclusions and recommendations can be illustrated as below.



Annex I – Examples of Risk Assessment Model Data Tables filled

A. Target Product

	value
model number	
type(cooling / HP)	
capacity(kW)	
refrigerant type	
refrigerant amount(kg)	
alternative refrigerant type	R32?

B-1. Indoor condition during usage of target product

		value
room size (m^2)	max	
	min	
height of installation(m)		
ceiling height(m)		
ventilation	yes/no	
	Ventilation (m^3/hr.)	
gap under door area (m^2)		
other openings, if any (m^2)		

B-2. Outdoor condition during usage of target product

		value
the size of the place enclosed with walls ,or fences etc.(m2)	max	
	min	

(ex. the internal area of a balcony)

C. Condition during repair of target product

	value
the average size of outdoor spaces for repairs (m3)	
the percentage of single outdoor unit installations (A%)	
the percentage of the installations of multiple outdoor units (B%)	
the average working hours per repair (outdoor unit) (hr.)	
the average working hours per repair (indoor unit) (hr.)	
wind condition (wind velocity) (m/s)	
windless condition (percentage %)	
(Windless condition; 0.1m/s or less. the windless rate in one year.)	

(note1)A+B=100% (note 2) multiple outdoor units installed with a considerable amount of spaces between them is included in the single installation category.

Praha-II List of Possible Ignition Source and estimation of ignition occurrence in Kuwait's case

(during usage - indoor)

Type of Ignition source	Ignition Source		Estimate of ignition occurrence / day: Occurrence (times/day)	Duration (hours/day)
Ignition source caused within flammable region (triggered by the ignition source)	open flame	cigarette		
	Electric spark (human conduct)	oil lighter		
		ignition switch of heater		
		connect / disconnect of electric plug		
		on/off relay within electrical equipment		
		relay operation of electrical equipment		
		brush motor		
	Electric spark (excluding human conduct)	malfunction of equipment		
		slip on / off the clothes		
	Human conduct	slip on / off the clothes		
open flame (triggered by flammable region)	open flame	candle		
		heater		
		stove burner		
		catch fire		
	High temperature surface	Electric heater		

Annex II - Safety

Overview of RACHP safety standards (Source: *TEAP report Volume 4: Decision XXX/5 on Cost and Availability of Low-GWP Technologies/Equipment that Maintain/Enhance Energy Efficiency*)

The requirements and implications of various international and regional safety standards covering RACHP sectors are detailed in report TEAP TF XXVIII/4.[3] This includes a table of relevant standards and the applicable various sub-sectors (Table 2-1). An extract of that table is provided below (Table I). Throughout the report there are discussions on what the upper charge limits are.

Table I: Scope of selected RACHP safety standards that include flammable refrigerants

Sector	Vertical (Product Standards)		Horizontal (Group Standards)
	IEC 60335-2-40	IEC 60335-2-89	ISO 5149-1,-2,-3,-4
Commercial refrigeration		×	×
Air-to-air air conditioners & heat pumps	×		×

Table II attempts to summarise the upper charge limits, where values have been separated into two categories.

- “with limited measures” means only with elimination of potential ignition sources
- “With additional measures” refers to situations where additional protective measures have to be applied, such as imposing a minimum room size, additional ventilation, etc.

It is not straight-forwards to summarise the “with additional measures” charge limits as they often depend upon the choice of several measures, installation conditions and so on. The exercise should be carried out on a case-by-case basis.

Table II: Maximum charge size limits for flammable refrigerants according to RACHP safety standards

	With limited measures			With additional measures		
	A3	A2	A2L	A3	A2	A2L
IEC 60335-2-89	0.15 kg	0.15 kg	0.15 kg	n/a	n/a	n/a
IEC 60335-2-40	0.15 kg	0.5 kg	1.8 kg	0.3 kg/1.0 kg	3.4 kg	8.0 kg/78 kg
ISO 5149	0.15 kg	0.5 kg	1.8 kg	1.5 kg/2.5 kg/ unlimited	3.4 kg/ unlimited	60 kg/ unlimited

All of these standards are in various stages of revision including with special attention to application of flammable refrigerants. Again, a summary of these may be found in the TEAP TF XXVIII/4 report.

Overview of safe refrigerant handling

In terms of refrigerant safe handling training, the situation differs widely amongst countries, due to the variety of national legislation. The IIR has published an information note on qualification and competence of technicians,[4] which offers an overview of schemes available in many countries.

[3] TEAP TASK FORCE Decision XXVIII/4 Report: on safety standards relevant for low-GWP alternatives

[4] http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_28_EN.pdf

Some international and regional standard touch on the topic. An international standard is under preparation, ISO 22712 - Refrigerating systems and heat pumps — Competence of personnel (currently in the form EN 13113), which addresses the required competence of technicians for all refrigerant types and tasks. More specifically, IEC 60335-2-40 includes an Annex (DD) covering requirements for operation, service and installation manuals of appliances using flammable refrigerants, which is essentially a compilation of procedures. Another annex (HH) addresses “Competence of service personnel”. Whilst neither IEC 60335-2-89 nor ISO 5149 contains any such material, EN 378-4 does have a short annex on competence of persons working with flammables.

Most countries tend to operate training programmes that are either national or private schemes. There are also a number of regional training programmes in existence, such as the “Real Alternatives” scheme, which covers most of the European countries.[5] In North America there are two such schemes: North America Training Excellence (NATE) for HVAC[6] and AHAM-Home Appliance[7]. China operates a national training scheme for flammables as does JRAIA in Japan.

The entire topic is rather disparate, but it is expected that the global approach will become more harmonised as introduction of flammable refrigerants become more prevalent.

[5] https://www.realalternatives.eu/learning-platform

[6] https://www.natex.org/site/1/Homehttp://

[7] www.aham.org/AHAM/Safety/Safe_Servicing_of_Cold_Appliances/AHAM/Safety/Safe_Servicing_of_Cold_Appliances.aspx?hkey=23d1344d-f8b0-410a-9e21-8181048b2b82

ANNEX-III: AHRTI Final Report

Promoting Alternative Refrigerants in High-Ambient Countries Phase (PRAHA-II):

Optimization Study on PRAHA I Equipment

September 2019

Air-Conditioning, Heating and Refrigeration Technology Institute

Final Report

AHRTI Report No. 9011

Promoting Alternative Refrigerants in High-Ambient Countries Phase II (PRAHA-II): Optimization Study on PRAHA I Equipment

Final Report

September 2019

By

Daniel Bacellar, Song Li, Paul Kalinowski, Cara Martin

Optimized Thermal Systems, Inc. (OTS)
7040 Virginia Manor Road, Beltsville, MD 20705

Prepared for

AIR-CONDITIONING, HEATING AND REFRIGERATION TECHNOLOGY INSTITUTE, INC

2311 Wilson Boulevard, Suite 400, Arlington, Virginia 22201

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Executive Summary

Over the past several years through the Promoting low- Global Warming Potential (GWP) Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA-I) project, 18 different prototypes have been developed and compared to respective baselines to support the assessment of alternative lower-GWP refrigerants for air-conditioning applications. Since the work originally started in 2012, researchers have identified gaps in the performance and operation of the PRAHA-1 prototypes. These gaps include the need to redesign and optimize prototype air-conditioning units, evaluate new alternative refrigerants, and improve component selection. As such, a new project, *Advancing the Designs of PRAHA-I for Meeting or Exceeding the Baseline Designs Performance*, conducted by Optimized Thermal Systems, Inc. (OTS) is herein presented.

The objectives of this project include the following:

1) Evaluate the design limitation of the PRAHA-I prototypes;
2) Optimize and physically evaluate selected prototypes with new refrigerants not evaluated during PRAHA-I; and,
3) Assess potential refrigerant fractionation impact due to leakage.

The project was organized into six activities for which a summary of the results, conclusions and recommendations are presented below:

1) Activity 1: Analyzing the Design of PRAHA-I Prototypes
    a. Certification laboratories, such as the one used for testing the units in PRAHA I, provide limited information for the purposes of product design and development. For future reference it is recommended that for research-oriented efforts such as this one, the units undergo a more rigorous testing process along with full characterization of the system and its individual components operating conditions and performance.
    b. In applications of high ambient temperatures, it is expected that performance will degrade as compared to operating under more temperate conditions and the resultant impact on performance must be considered. The key components for performance improvement identified herein were the compressor, condenser and expansion device.
        i. At higher temperatures, the saturation temperatures and refrigerant density at compressor's suction port can be very different than that from the rated conditions. Larger displacement volumes and efficiency curves optimized for higher pressure lifts might be required. Therefore, the proper selection of the compressor is paramount.
        ii. A better performance condenser will reduce the approach temperature between refrigerant and air, helping the compressor not to discharge refrigerant at very high pressure and temperatures, which degrade performance.
    c. At high ambient conditions, the system is forced to operate in higher pressure lift than at rated conditions, but still requires a certain refrigerant mass flow rate. Passive devices such as capillary tubes and orifices may not be able to provide enough expansion to allow the system to operate in higher temperature conditions. An active expansion device such as EXV's can adequately control operating conditions and maintain stable superheat.

2) Activity 2: Design Improvements (Summary results in Table 1)
    a. R290 and R32 have wider saturation regions allowing the system to operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer. Their cycles

may get closer to that of the ideal Carnot cycle compared to refrigerants with narrower saturation.

b. Refrigerants with high temperature glide may require new heat exchanger (HX) designs, namely condensers. The original designs proved to be sufficiently effective to allow for most systems to operate with the different refrigerants, however, better designs would allow for higher system efficiency and potentially less charge. HX designs are severely constrained by allowed envelope dimensions. A complete system re-design would provide an opportunity for designing HX's with even higher efficiency.

c. The results of this analysis suggest that for an effective refrigerant replacement, a proper compressor selection must be accompanied with it. Higher isentropic efficiencies are desired for higher temperatures, but most importantly, the displacement volume requirements can vary considerably from one refrigerant to another.

d. It is also imperative that having an active expansion device (preferably an Electronic Expansion valve (EXV)) to not only allow for more controlled superheat, but also to enable the unit to run with different refrigerants with very different thermophysical properties.

Table 1: Activity 2 Summary Modeling Results.

General Information			Hardware				Performance	
System	**Rated Capacity (@35°C)**	**System Configuration**	**Compressor**	**Condenser**	**Expansion Device**	**Ref.**	**Cooling Capacity (@46°C)**	**EER (@46°C)**
-	**BTU/hr**	**-**	**Efficiency (-)**	**Type**	**Type**	**-**	**BTU/hr**	**BTU/hr.W**
Unit 1	18000	**Baseline**	**0.66**	**Tube-Fin (5mm Tube)**	**Passive**	**R444B**	**17403**	**7.4**
		Alternate 1	0.7	Same as Baseline	Active (EXV)	R290	17639	8.01
		Alternate 2	0.69			R454C	18104	7.31
		Alternate 3	0.7			R444B	18140	8.14
		Alternate 4	0.68	MCHX		R457A	17749	7.63
Unit 4	24000	**Baseline**	**0.61**	**Tube-Fin (9.5mm Tube)**	**Passive**	**R290**	**17940**	**7.52**
		Alternate 1	0.7	Tube-Fin (5mm Tube)	Active (EXV)	R290	18147	9.12
		Alternate 2	0.7			R290	24120	6.72
Unit 6	24000	**Baseline**	**0.6**	**Tube-Fin (7mm Tube)**	**Passive**	**R32**	**23115**	**8.46**
		Alternate 1	0.65	Tube-Fin (5mm Tube)	Active (EXV)	R32	23798	9.41
		Alternate 2	0.67			R454B	22894	9.71
		Alternate 3	0.7			R452B	23702	9.6
Unit 10	36000	**Baseline**	**0.44**	**Tube-Fin (9.5mm Tube)**	**Passive**	**R32**	**29005**	**6.39**
		Alternate 1	0.65	Tube-Fin (5mm Tube)	Active (EXV)	R447B	30478	9.43
		Alternate 2	0.67			R452B	30796	10.27
		Alternate 3	0.67			R454B	30809	10

3) Activities 3-5: Prototype Modification and Testing (Summary results in Table 2)

a. Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing. It should be stressed that the baseline unit by design had its capillary tube located in the outdoor unit. This would cause liquid refrigerant leaving the outdoor unit to flash. The refrigerant enthalpy at the condenser outlet state was used to calculate the refrigerant-side capacity assuming an isentalphic expansion without heat loss in connecting pipe. This is different from the modified systems of which the capillary tube was removed, and a manual expansion valve was placed at the inlet of the indoor unit. For modified systems, the enthalpy at the expansion valve inlet was used to calculate the refrigerant-side capacity.

b. Unit 10 exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This supports the hypothesis of low compressor efficiency during PRAHA I tests, which also indicates the importance of proper compressor selection.

c. The above is also evidenced by the fact that even with R447B and R452B (zeotropic mixtures), Unit 10 had higher cooling capacity and efficiency than the baseline for the 46°C test condition, as projected in activity 2. The tests at 35°C, however, did not have the same trend.

d. The impact of refrigerant replacement was not very clear, in part due to the hardware change along with it. But because of the differences in saturation curves from the Activity 2 analysis, R32 tends to result in systems with higher efficiency and less charge. The zeotropic mixtures consistently required compressors with larger displacement volumes and even higher mass flow rates for cooling capacities of the same magnitude.

e. Refrigerant fractionation as evidenced by the leak tests, does not appear to a great concern since less than 2% in cooling capacity was observed after the system's re-charge.

f. The Unit 6 modified systems had lower performance than expected from the Activity 2 models. The R32 system configuration exhibited around 10% less flow rate than anticipated, which corresponded to 10% lower capacity. The R454B configuration exhibited a deviation of 5% between model and test due also in part to a 3% flow rate over prediction in the model. Unit 10, on the other hand, exhibited an excellent agreement to the models with less than 2% deviation in cooling capacity.

g. The model's validation adds confidence in the numerical simulation findings and recommendations provided in activity 2.

Table 2: Tests Summary Results.

Syst.	Test	Refrigerant	Charge	35°C			46°C		
				Cooling Capacity	Total Power	EER	Cooling Capacity	Total Power	EER
			lb	BTU/hr	kW	BTU/hr.W	BTU/hr	kW	BTU/hr.W
Unit 6	Performance	R32 (Baseline)	3.83	25192	2.43	10.4	23390	3.10	7.54
		R32 (Alternate 1)	4.27	23585	2.12	11.1	21450	2.74	7.84
		R454B (Alternate 2)	5.02	21966	2.10	10.4	21821	2.67	8.17
Unit 10	Performance	R32 (Baseline)*	5.63	34517	3.76	9.18	29005	3.84	7.55
		R447B (Alternate 1)	6.63	32195	3.62	8.88	31073	3.90	7.96
		R452B (Alternate 2)	6.63	28128	3.38	8.33	30292	3.90	7.76
	Liquid Line	Low Charge	4.23	N/A			14216	3.90	3.64
		Re-Charged	6.63				30865	4.16	7.42
	Vapor Line	Low Charge	4.27				15171	3.92	3.87
		Re-Charged	6.77				30587	-	-

**Original baseline values from PRAHA*

4) Conclusions: This report presented a comprehensive set of activities with the objectives of advancing the PRAHA program. The original scope and schedule were modified during the project as new findings and challenges surfaced. The tests that were carried out for PRAHA-I, while sufficient for the purpose of measuring capacity and energy efficiency for the purposes of PRAHA-I, did not have enough essential data to enable a complete cycle evaluation for optimization purposes. This is primarily due to using standard test rig on systems with critical hardware configuration differences. The analyses presented in Activity 2 (design assessment through modeling) provided good insights on adequate component design and/or selection for proper system functioning when using novel refrigerants. The tests in activities 3-5 partially served as validation for the models developed, and as check for previous test data from PRAHA I. The final recommendations for future development are listed as follows:
    a. Establish a baseline system by conducting comprehensive testing including measurements and metrics not typically performed in energy certification tests. Furthermore, testing systems with different configurations require custom test rigs as such to adequately measure working fluid's states to avoid mischaracterization of the operating conditions and performance. Such approach is considerably more labor-intensive which should be factored in the scope in future developments.
    b. Using alternate low-GWP refrigerants is viable and can be competitive to commonly used pure refrigerants but doing so requires proper component design and selection; compressor and expansion device particularly. Drop-in replacement without hardware change is never recommended as evidenced by the change requirements in Activity 2 and performance tests in the subsequent activities.
    c. It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses that will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.
    d. Always test the modified systems with the same instrumentation as the baseline, however mindful of the modifications as such to properly place sensors to obtain adequate readings as suggested in item a above.

2. Introduction

Over the past several years through the Promoting low- Global Warming Potential (GWP) Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA-I) project, 18 different prototypes have been developed and compared to respective baselines to support the assessment of alternative lower-GWP refrigerants for air-conditioning applications. Since the work originally started in 2012, researchers have identified gaps in the performance and operation of the PRAHA-1 prototypes. These gaps include the need to redesign and optimize prototype air-conditioning units, evaluate new alternative refrigerants, and improve component selection. As such, a new project, *Advancing the Designs of PRAHA-I for Meeting or Exceeding the Baseline Designs Performance*, is desired.

The objectives of this project include the following:

4) Evaluate the design limitation of the PRAHA-I prototypes;
5) Optimize and physically evaluate selected prototypes with new refrigerants not evaluated during PRAHA-I; and,
6) Characterize leaks.

The project is divided into six activities namely:

- **Activity 1 – Analyzing the Design of PRAHA-I Prototypes**: evaluate systems performance from selected units tested in PRAHA-I, and assess potential design improvements
- **Activity 2 – Design Improvement**: improve design of specific units targeting higher efficiencies while using alternate low-GWP refrigerants
- **Activity 3 - Prototype Units Fabrication**: modify the a sub-set of the units according to modifications proposed in Activity 2
- **Activity 4 - Evaluation of the Optimized Prototypes**: conduct performance tests on modified units at standard and high ambient temperature conditions (35°C and 46°C)
- **Activity 5 - Analyzing Leaks of Alternatives**: simulate refrigerant leakage and evaluate possible impact of zeotropic mixtures fractionation on performance
- **Activity 6 - Reporting and Data Management**: simulation and test data processing, preparing progress and final reports

3. Activity 1 - Analyzing the Design of PRAHA-I Prototypes

Activity 1 was comprised of three major tasks including: reception of 12 physical units at the OTS facility followed by visual inspection and parts identification; review of performance test reports from PRAHA I tests; and lastly, analyze data and identify, for units of interest, opportunity for improvement targeting higher performance and minimal charge. OTS has completed this activity and an executive summary of the findings are presented herein.

3.1. Physical Units

All 12 units of interest to this project (Table 3) were received on November 8th, 2018. Visual inspection indicated no evident signs of damage. Relevant information to the project such as compressor model, heat exchanger (HX) geometry and circuiting, as well as expansion device were also received.

Table 3: Unit Specifications Summary.

Category	Unit #	Ref.	Designed Capacity Btu/h	Measured Cap. Btu/h	Voltage	Ref. (New designs)	Ref. (Tests)
Window	**1**	**L-20 (R-444B)**	**18,000**	**19,104**	**208-230/60/1**	**L-20, R454C, R290, R457A**	**R290**
	2	L-20 (R-444B)	18,000	16,924	208-230/60/1		
	3	DR-3 (R-454C)	18,000	18,063	208-230/60/1		
Decorative splits	**4**	**R-290**	**24000 (18,000)**	**19,000**	**208-230/60/1**	**R-290**	**R-290**
	5	R-32	24000 (18,000)	19,328	208-230/60/1		
	6	**R-32**	**24,000**	**25,456**	**208-230/60/1**	**R32, R459A**	**R32, R459A**
	7	L-41 (R-447A)	24,000	24,830	208-230/60/1		
	8	L-20 (R-444B)	24,000	22,740	208-230/60/1		
	9	DR-3	24,000	14,638	208-230/60/1		
Ducted splits	**10**	**R-32**	**36,000**	**35,500**	**220-240/50/1**	**R447B, R452B**	**R447B, R452B**
	11	L-20	36,000	36,553	220-240/50/1		
	12	DR-3 (R-454C)	36,000	33,032	220-240/50/1		

3.2. PRAHA-I Performance Reports Assessment

OTS received a complete package of files containing the performance reports for all units tested in PRAHA I. The tests conducted in PRAHA I were meant to assess high-level performance of these units focusing on a large control volume where only total energy in and out was evaluated. As such, these tests were not comprehensive in terms of measurements for cycle analysis required in PRAHA II. Refrigerant side measurements, in most cases, were very limited (few pressure and temperature measurements and no flow rates); thus, it is not possible to fully characterize the cycle and perform energy balances between air and refrigerant sides of the system. Common issues found in the reports include:

- Tag mislabeling and / or mismatching sensor location and tag
- No independent outdoor capacity reported – typically reported the same as indoor capacity
- Missing energy balance checks
- Missing measurement on either airside pressure drop and temperature or fan power
- Inconsistent reported measurements with thermophysical properties for units tested with L-20
- Systematic inconsistency in reported superheat and subcooling
- Missing measurements on refrigerant side at evaporator inlet
- Missing temperature and/or pressure measurements on refrigerant side
- Missing refrigerant mass flow measurements

A summary of the original PRAHA-1 data and results of the data reduction are provided under separate documentation.

3.3. Hardware Improvement Assessment

3.3.1. Heat Exchanger (HX) First Order Analysis (FOA)

This section outlines a FOA for the HXs of Units 1, 4, 6 and 10 to identify improvement potential. The project's objective, as stated above, is to improve performance while minimizing charge. One way of addressing both objectives is by reducing tube / channel diameter. Heat transfer coefficients are inversely proportional to surface hydraulic diameters, however, so is pressure drop. Smaller tubes result in more compact (C = surface area / footprint volume), with reduced internal volume, HXs.

A qualitative analysis using values from literature was carried out to demonstrate the relative impact of diameter over abovementioned metrics, specifically: heat transfer coefficient, compactness and overall thermal conductance (UA). The left-hand side plot in Figure 1 show three curves inversely proportional to the diameter; a 5mm tube can achieve, in this example, 70% greater UA than a conventional 9.5mm, within the same footprint volume (or cabinet).

These are further explored to illustrate the impact on a system level. Systems respond to UA of both condenser and evaporators, but for the purposes of this analysis, condenser only is considered. The UA represents the overall thermal conductance, which will impact the approach temperatures in the system (ΔT_{app}). If the heat rejection is kept constant, the higher the UA, the smaller are the ΔT_{app}'s, thus allowing the condenser to operate in lower pressure levels, which will consequently increase the system performance. An example using a hypothetical R32 cycle with an EER of 12 as base is shown in the right-hand side plot in Figure 1. Performance improvement is limited by the Second Law, when the approach temperatures near zero; however, in this illustration, the EER has potential to increase in over 20% with better condenser design alone.

It is imperative to note that the results presented in this section are for **illustration purposes only**. Further in this report it is presented in more detail a re-design framework, applied to the units of interest in this project, using the metrics outlined in this section.
Unit 1 already had a 5mm condenser, which limits the options for HX re-design. Unit 6 had a 7mm HX on both the indoor and outdoor units, which allows some room for improvement if reducing to 5mm. Lastly, both coils for Unit 10 had 9.5mm tubes, thus there is greater potential for charge reduction and performance improvement for that unit in particular.

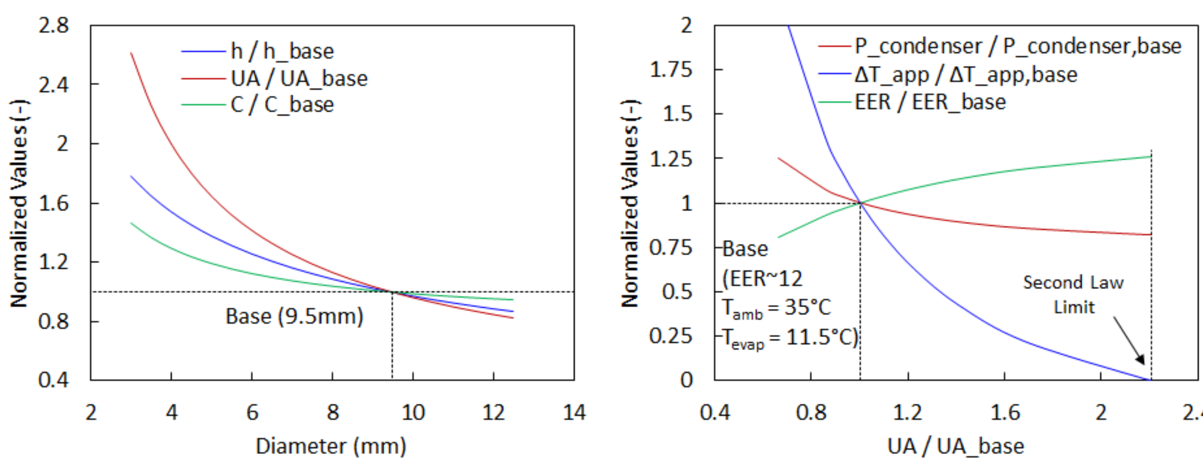


Figure 1. Heat Exchangers FOA.

3.3.2. Compressors
The existing units mostly use compressors sized specifically for R410A or R22 and in some cases custom made for this effort. There is, however, opportunity for a better compressor selection when migrating from R32 to R454B or R447B on Units 6 and 10, respectively.

3.3.3. Expansion Devices
Expansion devices such as TXV's and EXV's may allow for better control and reduced losses in connecting pipes if located near the evaporator. Some units, such as 6 and 10, have a capillary tube in the outdoor unit, which forces the refrigerant to travel in two-phase along the connecting pipes, and at lower temperatures, thus increasing pressure drop and heat gain.

3.3.4. Fan and Blower
Replacing the fan and blower may be necessary if newly designed HXs offer considerable change in pressure drop over the baseline since the flow rates are kept constant. The lack of test data on pressure drop forces us to rely on predicted values only. These will be considered for replacement as a last priority.

3.3.5. Units Component Modification Potential
Table 4 shows the detailed existing components for the units of interest for modification.

Table 4: Units 1, 4, 6 and 10 Components.

System	Unit 1	Unit 4	Unit 6	Unit 10
Refrigerant	**R444B**	**R290**	**R32**	**R32**
Compressor	HIGHLY SL260DG-C8EU	HIGHLY PSH356DG-C8DU3	GMCC KSG226N1UMT	Copeland ZP42K5E-PFJ-XXX
Condenser	5mm Louver TFHX	9.5mm Wavy TFHX	7mm Louver TFHX	9.5mm Louver TFHX
Expansion Device	Capillary Tube	Capillary Tube	Capillary Tube	Capillary Tube
Evaporator	9.5mm Louver TFHX	7mm Louver TFHX	7mm Slit TFHX	9.5mm Louver TFHX

3.4. Conclusions and Recommendations
The first part of this activity regarded data analysis and processing from the original tests conducted in the original PRAHA-I project, which was designed to conduct testing and comparison of cooling capacity vs. EER for the prototypes against the baseline units from same manufacturers. Since limited certification tests were required then, more testing parameters would have been needed to support the optimization and/or redesign process within the scope of PRAHA-II. The second part pertained assessing potential hardware modifications that could result in higher performance and less charge, with the intent of replacing the original refrigerants with alternative, low-GWP ones. The key conclusions and recommendations are:

1- Certification laboratories, such as the one used for testing the units in PRAHA I, provide limited information for the purposes of product design and development. For future reference it is recommended that for research-oriented efforts such as this one, the units undergo a more rigorous testing process along with full characterization of the system and its individual components operating conditions and performance.

2- In applications of high ambient temperatures, it is expected that performance will degrade as compared to operating under more temperate conditions and the resultant impact on performance must be considered. The key components for performance improvement identified herein were the compressor, condenser and expansion device.

   a. At higher temperatures, the saturation temperatures and refrigerant density at compressor's suction port can be very different than that from the rated conditions. Larger displacement volumes and efficiency curves optimized for higher pressure lifts might be required. Therefore, the proper selection of the compressor is paramount.
   b. A better performance condenser will reduce the approach temperature between refrigerant and air, helping the compressor not to discharge refrigerant at very high pressure and temperatures, which degrade performance.

3- At high ambient conditions, the system is forced to operate in higher pressure lift than at rated conditions, but still requires a certain refrigerant mass flow rate. Passive devices such as capillary tubes and orifices may not be able to provide enough expansion to allow the system to operate in higher temperature conditions. An active expansion device such as EXV's can adequately control operating conditions and maintain stable superheat.

4. Activity 2 - Design Improvements

The details of modeling and simulation results are provided in a separate document submitted in conjunction with this one, while in this section only the summarized performance results are presented.

4.1. Hardware

A general design improvement assessment was presented in the report for Activity 1, focusing on the units of interest to this study. A first order analysis on the HX's showed that moving towards smaller hydraulic diameter tubes can be beneficial from a material savings and charge reduction standpoint. Units 4 and 10 use conventional 9.5mm diameter tube condensers (Table 4), making them good candidates for condenser replacement with either a smaller tube diameter or a microchannel heat exchanger (MCHX). The compressors used on Units 1, 4 and 6 do not have available performance maps making it difficult to assess their fitness for the system. The focus of this study is on proper compressor selection and condenser re-design.

4.2. Refrigerant

R32 and R290 have wide saturation regions (Figure 2 and Figure 3) putting them at an advantage since they may operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer. Their cycles may get closer to that of the ideal Carnot cycle compared to refrigerants with narrower saturation.

Amongst the blends investigated for Unit 1, R444B has the widest saturation region while also having the highest temperature glide (Figure 4). The latter is typically not beneficial, in particular for evaporators, but it may help the condenser. The glide enables the refrigerant temperature profile to get closer to the air temperature profile without crossing (Figure 4). From a thermodynamic perspective, this means R444B can have its condensing pressure reduced further, resulting in higher theoretical COP.

For Units 6 and 10, the investigated blends, although having narrower saturation than the baseline R32, have similar thermophysical characteristics (Figure 3) with lower temperature glides (Figure 4) making them more competitive from a capacity and performance perspective.

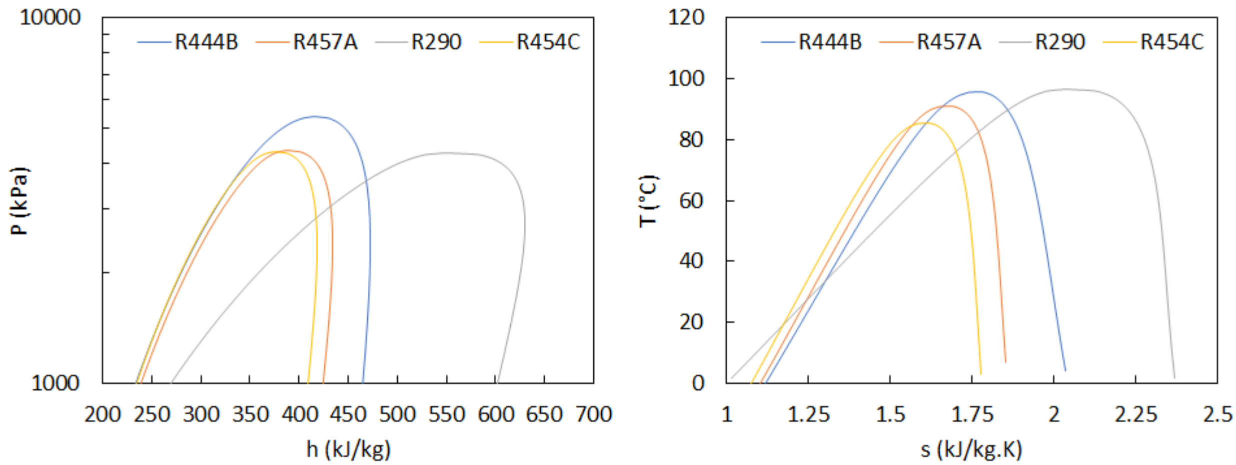


Figure 2. Refrigerants Investigated for Units 1 and 4.

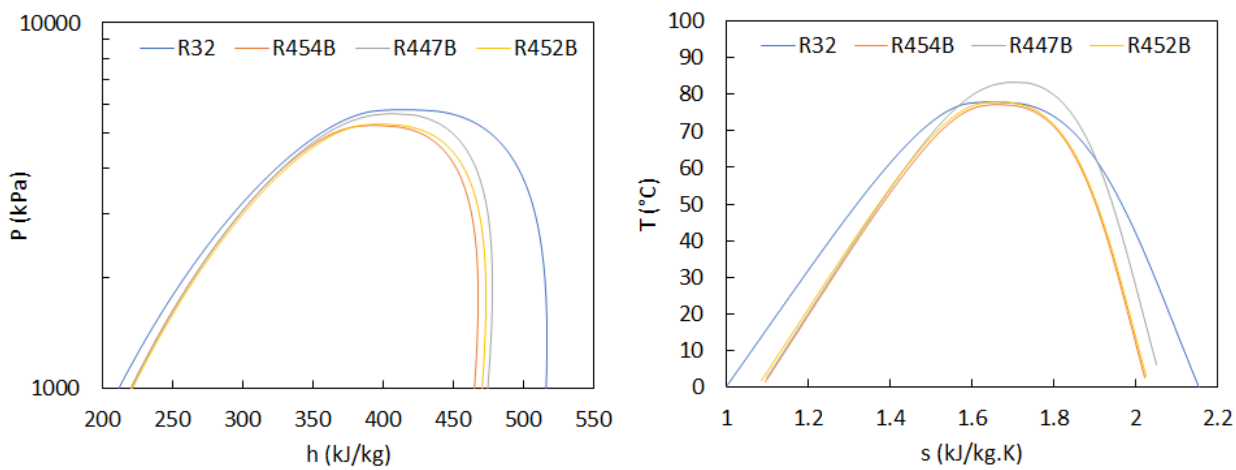


Figure 3. Refrigerants Investigated for Units 6 and 10.

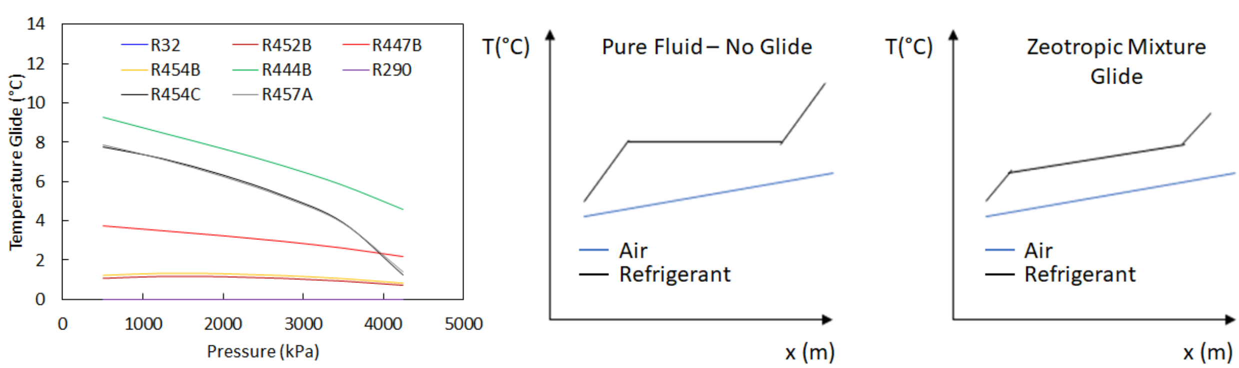


Figure 4. Refrigerant Temperature Glides.

4.3. System Design Modification Framework

The systems' re-design herein presented ultimately consists of a retrofit of the existing units by properly designing and selecting components that can be replaced as drop-ins, with minimal or no modification of the packaging (cabinets). In other words, any component replaced must occupy the same envelope as the baseline component. The focus of the re-design is on:

- Compressor
- Condenser, and
- Expansion valve

The evaporator designs were not changed for two main reasons: a) some are custom-made wrap-around the blower units, such as in Unit 6, making it harder to quickly find an off-the-shelf option; and, b) the goal is to deliver the same cooling capacity while improving efficiency. For the latter, there's more room for improvement in the condenser by reducing condensing pressure, assuming the evaporator can already deliver the expected capacity.

The fans and blowers were also not considered for change, in part due to the lack of information on the performance curves from the baseline models, but also due to potential high cost and lead time for replacement with secondary impact on performance since 80-90% of the power consumed comes from the compressor.

The first step to assess the level of performance required for each component is to investigate an improved theoretical cycle, which will indicate how much COP improvement can be expected, as well as refrigerant flow rate needs and HX size (UA). To improve the performance of a vapor compression cycle, the pressure lift between evaporating and condensing pressures must be reduced. Consequently, the approach temperatures between air and refrigerant will be reduced as well (Figure 5), thus the thermal capacitance of the heat exchangers must increase. Furthermore, the closer to the saturation region, the closer the cycle reaches the ideal Carnot efficiency (Figure 6).

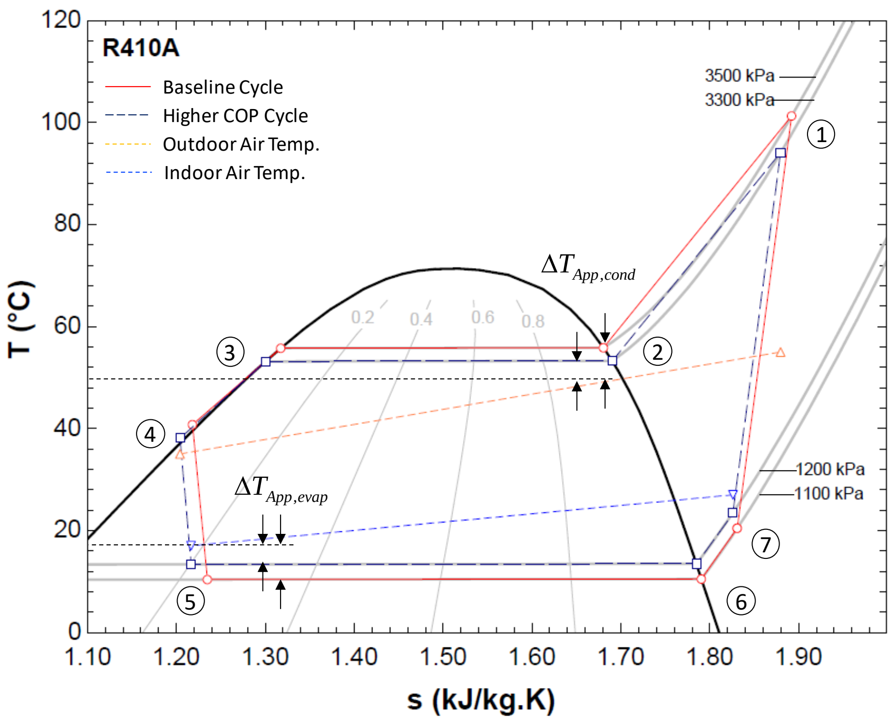


Figure 5. Illustrative T-s diagram for baseline and improved cycles.

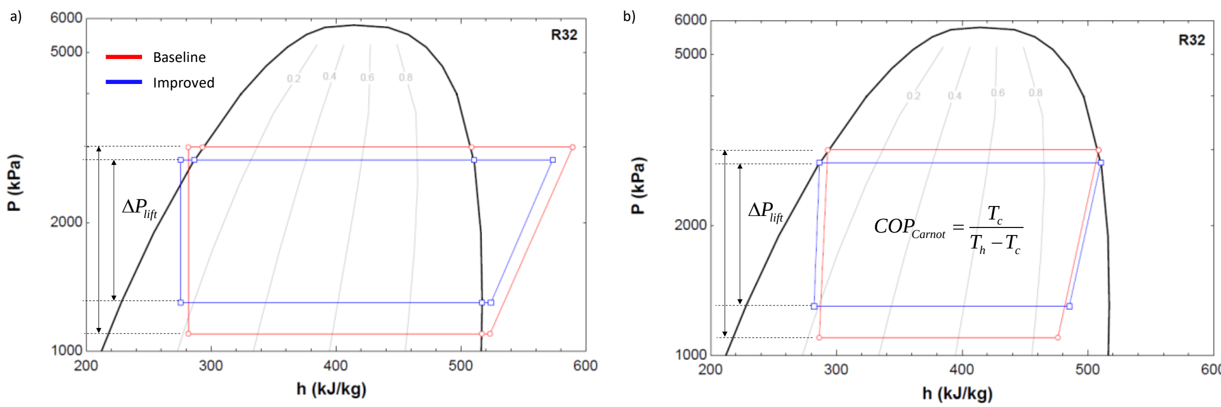


Figure 6. P-h Diagrams Illustrating COP Improvement: a) Real Cycle; b) Ideal Cycle (Carnot).

The system design framework is performed according to Figure 7.

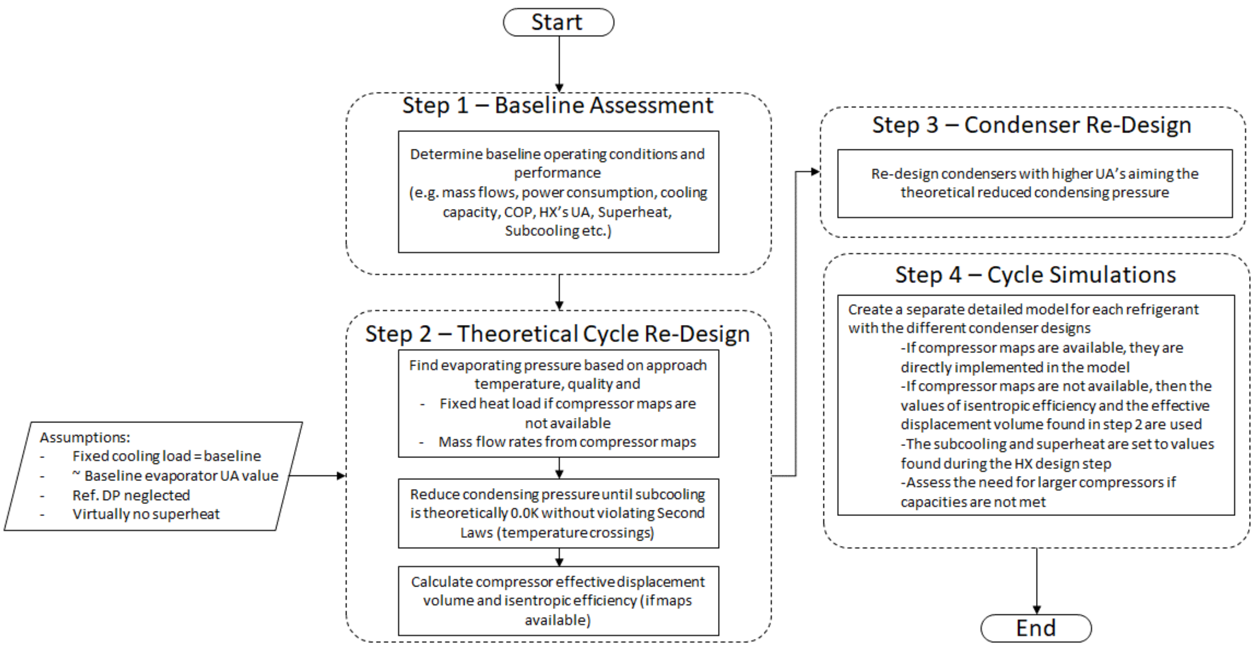


Figure 7. System Re-Design Framework,

4.3.1. Compressors

Modeling compressors are handled in two possible ways, as suggested previously: using performance maps when available or using fixed isentropic efficiency and effective displacement volume. For the larger capacity units (6 and 10), performance maps were provided. Although these compressors were originally designed for R410A refrigerant they may operate – not necessarily optimally – with other refrigerants. Compressor manufacturers supporting this project used proprietary simulation tools, with aid from available empirical data (tests with other refrigerants), to develop theoretical maps for the various refrigerants of interest (Table 5) and made them available to OTS for modeling purposes. It is understood that the predictions are for reference only, and the compressor manufacturer does not guarantee performance for any refrigerants for which the compressors haven't been fully tested.

Table 5: Compressor Models.

Model	Capacity (BTU/hr)	Frequency (Hz)	Refrigerants
ZP20K5E-PFV	24,000	60	R32, R459A, R454B, R410A
ZP21K5E-PFV	24,000		
ZP31K6E-PFV	36,000	50/60	R447B, R452B, R454B, R410A
ZP34K6E-PFV	36,000		

For the smaller units (1 and 4), which were re-designed using R290 (Propane), compressor performance maps were not available. The approach for these units then was to set a target isentropic efficiency of 0.7 (baseline data suggests that the compressor efficiencies ranged from 0.55 to 0.65). The required mass flow rate is calculated based on capacity in the theoretical cycle model described above. From there, the effective displacement volume can be determined (eq. (1))[1]. The latter serves to determine whether a system can use the same compressors for different refrigerants.

$$V_{eff} = \eta_{vol} \cdot V_{disp} = \frac{\dot{m}_{required}}{f \cdot \rho_{suction}} \tag{1}$$

4.3.2. HX Design and Selection

The condensers design procedure takes into consideration the following:

- **Face area**: baseline face area must be preserved or at most reduced. Furthermore, the aspect ratio must also match that of the baseline so the HX can be drop-in replaced in the same cabinet.
    - Find the number of tube rows and tube length to match as closely as possible to tube face area and aspect ratio

- **Airside pressure drop and flow rate**: the test data from reports contain only air flow rate measurements, while no information on pressure drop is provided. Additionally, the fan performance curves are also not available, which limits the ability to find the exact operating condition. The baseline models provide an estimate prediction for the pressure drop, which is used as reference.

- **Thermal performance**: this step must be iteratively conducted with the previous step, as such for each design change the air flow rate and capacity are evaluated under the new conditions found in the theoretical cycle re-design.
    - Gradually increment the condensing pressure until attainable performance is achieved. This process is done iteratively using the theoretical cycle model, to find new expected operating conditions for evaporating pressure, superheat, subcooling and refrigerant flow rate.

- **HX Form**: as indicated previously, the HX design is constrained by cabinet dimensions as well as form. In the case of units 1 and 4, the condensers are flat coils placed 90° inside the cabinet (Figure 8), which makes it simpler for drop-in replacement as long as new designs have the same overall dimensions. For units 6 and 10, however, the condensers are L-shaped inside the cabinet (Figure 8). Forming coils is widely done, however, for custom coils it may be a challenge, in particular for MCHX. For this reason, the MCHX designs for units 6 and 10 are sized for a full-face area, assuming the coil can be formed, and a second design that is a single flat slab placed in longer side of the "L" shape(Figure 9).

[1] Variable definitions in the Nomenclature list after final conclusions section in this document.

- **HX Name Tag Convention:** for practical purposes, the HX's will be tagged according to the following W XX YY Z
    - **W:** B = Baseline or N = New Design
    - **XX:** TF **=** Tube-Fin or MC = Microchannel
    - **YY:** D# = Tube Diameter or Height
    - **Z:** R = Reduced Face Area
    - **Example:** New Tube Fin Design with 5.0mm diameter with same face area as the baseline → NTFD5

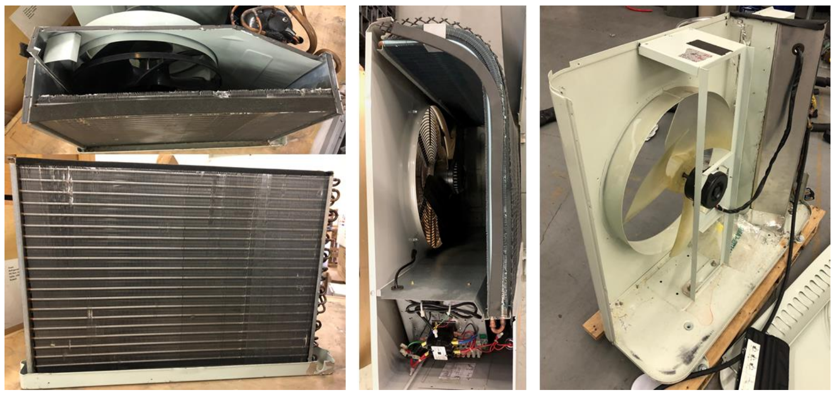


Figure 8. Condenser Forms: Unit 1 (left), Unit 10 (center), Unit 6 Cabinet (right).

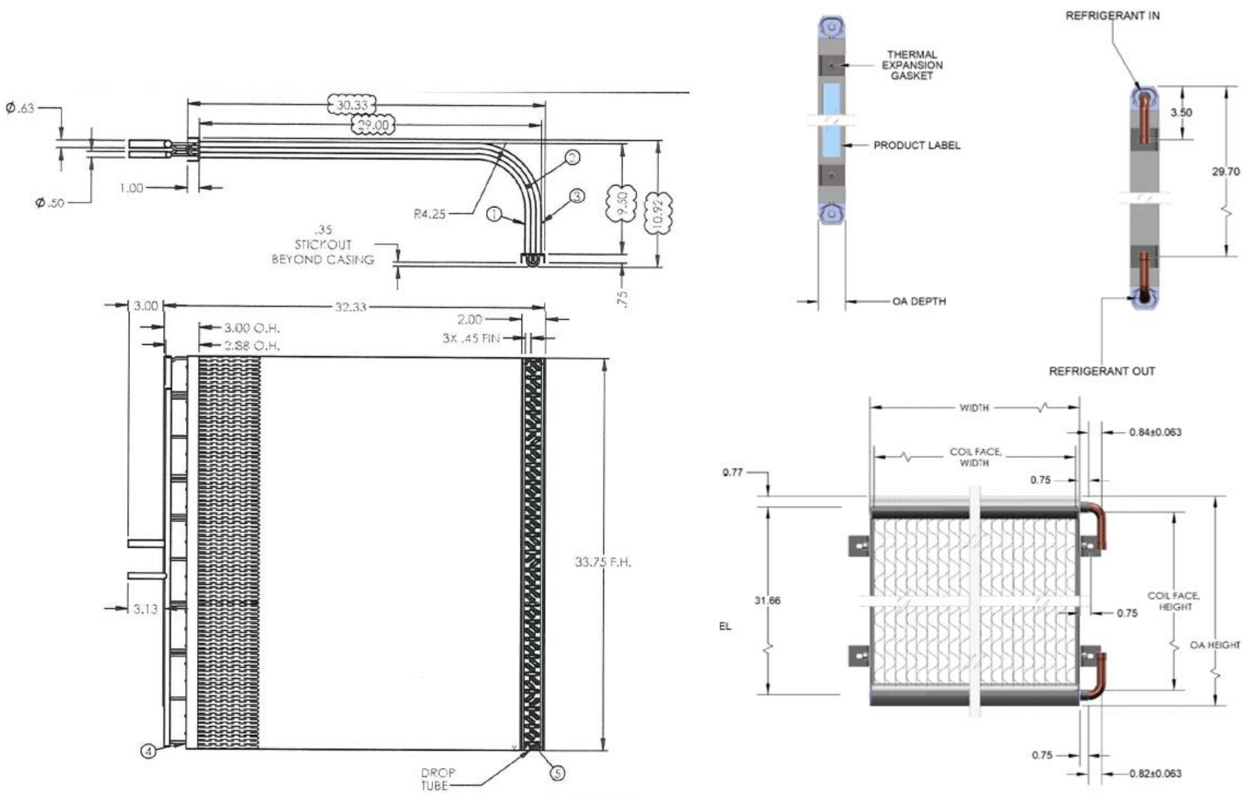


Figure 9. HX Form Examples: L-shape (left), Flat (right).

4.3.3. System Design

In the final step, the modified systems are evaluated holistically through system level modeling and simulation using an in-house Steady-State vapor compression cycle software that has the capability to integrate with the HX and compressor models (performance maps, generic etc.). For each modified system and each refrigerant, a system model was created.

4.4. Modified Systems Results Summary

The final results of Activity 2 are summarized in Table 6. For more detailed results in the framework steps refer to APPENDIX A .

4.5. Conclusions and Recommendations

This section presents a systematic approach based on first order analysis providing educated guidance towards the direction of more efficient systems with fewer simulations and minimal changes to the systems. The study includes a wide variety of refrigerants as well as condenser designs and compressor model options. Given the challenges with original test data the baseline models serve as a numerical reference only. The findings are strictly valid to comparisons against the baseline models and OTS does not guarantee that results would be reflected in actual systems as herein reported. The key conclusions and recommendations are:

1- R290 and R32 have wider saturation regions allowing the system to operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer.

2- Refrigerants with high temperature glide may require new heat exchanger (HX) designs, namely condensers. The original designs proved to be sufficiently effective to allow for most systems to operate with the different refrigerants, however, better designs would allow for higher system efficiency and potentially less charge. HX designs are severely constrained by allowed envelope dimensions. A complete system re-design would provide an opportunity for designing HX's with even higher efficiency.

3- The results of this analysis suggest that for an effective use of alternate low-GWP refrigerant, a proper compressor selection must be accompanied with it. Higher isentropic efficiencies are desired for higher temperatures, but most importantly, the displacement volume requirements can vary considerably from one refrigerant to another.

4- It is also imperative that having an active expansion device (preferably an EXV) to not only allow for more controlled superheat, but also to enable the unit to run with different refrigerants with very different thermophysical properties.

Table 6: Activity 2 Results.

General Information			Hardware					Ref.	Performance			
System	Rated Capacity (@35°C)	System Configuration	Compressor		Condenser		Expansion Device		Cooling Capacity (@46°C)		EER (@46°C)	
-	BTU/hr	-	Effective Disp. Vol. (cm³)*	Efficiency (-)	Type	Effectiveness (-)	Type	-	BTU/hr	%	BTU/hr. W	%
Unit 1	18000	**Baseline**	**19.8**	**0.66**	**Tube-Fin (5mm Tube)**	**0.20**	**Passive**	**R444B**	**17403**	**0.00%**	**7.4**	**0.00%**
		Alternate 1	25.9	0.70	Same as Baseline	0.35	Active (EXV)	R290	17639	1.40%	8.01	8.20%
		Alternate 2	24.8	0.69		0.26		R454C	18104	4.00%	7.31	-1.30%
		Alternate 3	19.6	0.70		0.23		R444B	18140	4.20%	8.14	9.90%
		Alternate 4	25.3	0.68	MCHX	0.24		R457A	17749	2.00%	7.63	3.10%
Unit 4	24000	**Baseline**	**26.4**	**0.61**	**Tube-Fin (9.5mm Tube)**	**0.24**	**Passive**	**R290**	**17940**	**0.00%**	**7.52**	**0.00%**
		Alternate 1	26.3	0.70	Tube-Fin (5mm Tube)	0.26	Active (EXV)	R290	18147	1.20%	9.12	21.40%
		Alternate 2	37.9	0.70		0.20		R290	24120	34.40%	6.72	-10.60%
Unit 6	24000	**Baseline**	**16.0**	**0.60**	**Tube-Fin (7mm Tube)**	**0.12**	**Passive**	**R32**	**23115**	**0.00%**	**8.46**	**0.00%**
		Alternate 1	16.9	0.65	Tube-Fin (5mm Tube)	0.15	Active (EXV)	R32	23798	3.00%	9.41	11.20%
		Alternate 2	18.4	0.67		0.19		R454B	22894	-1.00%	9.71	14.80%
		Alternate 3	19.0	0.70		0.17		R452B	23702	2.50%	9.6	13.50%
Unit 10	36000	**Baseline**	**19.6**	**0.44**	**Tube-Fin (9.5mm Tube)**	**0.13**	**Passive**	**R32**	**29005**	**0.00%**	**6.39**	**0.00%**
		Alternate 1	22.3	0.65	Tube-Fin (5mm Tube)	0.25	Active (EXV)	R447B	30478	5.10%	9.43	47.50%
		Alternate 2	23.0	0.67		0.25		R452B	30796	6.20%	10.27	60.70%
		Alternate 3	23.3	0.67		0.25		R454B	30809	6.20%	10	56.50%

** Product of displacement volume and volumetric efficiency*

5. Activities 3, 4 & 5 - Prototype Units Fabrication, Evaluation of the Optimized Prototypes and Analyzing Leaks of Alternatives

Activities 3-5 officially began in April 2019 when the first round of tests on modified Unit 6 were carried out. Initial tests resulting in unsuccessful outcomes leading OTS to change the system modifications and the scope. Additional information found in APPENDIX B . The detailed test data and charge optimization for Units 6 and 10 are presented in APPENDIX C through APPENDIX E . Comparisons between Activity 2 model validations and experimental data are presented in APPENDIX F .

5.1. Unit 6

Some modifications were made to Unit 6 to improve its efficiency. The baseline compressor was replaced with alternate models to account for the change in refrigerant and to improve efficiency. The compressor used with R454B had a higher displacement volume than the one used with R32. Furthermore, the capillary tubes were replaced with a manual TXV that was installed directly at the evaporator inlet to increase the cooling capacity of the evaporator. A summary of the design modifications evaluated for Unit 6 is listed in Table 7, while Table 8 and Table 9 show the performance of Unit 6 for baseline and modifications at 35°C and 46°C ambient, respectively. The baseline system performed similar, within 2%, to reported performance in PRAHA I. There is a discrepancy in the measurements from condenser outlet to expansion inlet in the baseline case, since the capillary tube (removed in the modified systems) was located in the outdoor unit The expansion causes the refrigerant to flash in the liquid line thus compromising the readings at the expansion device. For calculation purposes, the condenser outlet enthalpy was used instead of the expansion inlet.

Table 7: Unit 6 Modifications for Testing.

System	Unit 6		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R32	R454B
Compressor	GMCC KSG226N1UMT	Copeland ZP20K5E	Copeland ZP21K5E
Expansion Device	Capillary Tube (Outdoor unit)	Manual Valve (Indoor Unit)[2]	Manual Valve (Indoor Unit)[2]

Cooling capacity for the modified unit with either refrigerant was consistently lower by 6-12% than the baseline. The modified R32 system reportedly showed lower mass flow rate than expected, likely the main cause for the lower-than-expected thermal performance. The R454B system resulted in a poorer performance but was less sensitive to ambient temperature than its R32 counterpart - i.e. cooling capacity was near the same at both 35°C and 46°C, while for R32 there was a ~2,000BTU/hr reduction with the temperature increase. It is also possible that there is a mismatch between thermophysical property library and actual refrigerant properties for R454B which can happen with newer fluids. The libraries need periodic update as more test data become available.

[2] A manual valve was used to mimic a TXV or EXV recommended as component modification in these systems configurations.

Table 8: Unit 6 - Performance Test Summary for R32 Baseline (OTS) @ 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	**R32**	**R32**	**R454B**	-	-
Charge	lb	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	25192	23585	21966	-6.4%	-12.8%
Energy Balance	%	-2.28%	-4.66%	-3.06%	-	-
Compressor Power	kW	2.11	1.79	1.77	-15.1%	-16.2%
Fan Power	kW	0.32	0.33	0.33	2.2%	4.2%
Total Power	kW	2.43	2.12	2.10	-12.8%	-13.5%
EER	BTU/hr.W	10.37	11.12	10.44	7.2%	0.68%

Table 9: Unit 6 - Performance Test Summary for R32 Baseline (OTS) @ 46°C.

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	**R32**	**R32**	**R454B**	-	-
Charge	lb	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	23390	21450	21821	-8.3%	-6.7%
Energy Balance	%	-1.78%	-4.42%	-7.61%	-	-
Compressor Power	kW	2.71	2.32	2.25	-14.2%	-16.6%
Fan Power	kW	0.40	0.42	0.42	5.3%	5.3%
Total Power	kW	3.10	2.74	2.67	-11.7%	-13.8%
EER	BTU/hr.W	7.55	7.84	8.17	3.8%	8.2%

5.2. Unit 10

Applying what was learned in the initial modifications to Unit 6, modifications to Unit 10 were limited to include the compressor and expansion device only. Unlike Unit 6, however, the re-test of the baseline system was not successful; refer to APPENDIX D for additional information. However since Unit 6 baseline re-test showed good reproducibility from original data, it is assumed that the Unit 10 original baseline is appropriate for comparison against the modified system configurations. A summary of the design modifications evaluated for Unit 10 is listed in Table 10. The detailed test data is presented in APPENDIX E .

At 35°C the modified units exhibited almost 20% less cooling capacity with 10% less power consumption, resulting in up to 11% less EER (Table 11). These results were not unexpected since the modified units were re-designed using the 46°C temperature, when the baseline system's performance showed a great degradation of performance. At 46°C condition, the tests exhibited 2-5% greater cooling capacity with up to 12% less power consumption compared to the baseline, which was equivalent to 13-17% greater system performance.

In Activity 2 the compressor power consumptions were underestimated, as well as the total fan power consumption, leaving the impression the overall performance improvement would considerably be greater than the observed. The cooling capacity, on the other hand, was predicted with less than 2% deviation from test data, validating at least the models created.

Table 10: Unit 10 Modifications for Testing.

System	Unit 10		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R447B	R452B
Compressor	Copeland ZP42K6E	Copeland ZP34K5E	Copeland ZP31K5E
Expansion Device	Orifice	Manual Valve	Manual Valve

Table 11: Unit 10 - Performance Test Summary for R32 Baseline @ 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**447B**	**452B**	**-**	**-**
Charge	lb	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	35543	32195	28128	-9.42%	-20.86%
Energy Balance	%	---	7.52%	-3.29%	-	-
Compressor Power	kW	-	2.67	2.4	-	-
Fan Power	kW	-	0.95	0.98	-	-
Total Power	kW	3.761	3.62	3.38	-3.75%	-10.13%
EER	BTU/hr.W	9.451	8.894	8.322	-5.89%	-11.94%

Table 12: Unit 10 - Performance Test Summary for R32 Baseline @ 46°C.

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**447B**	**452B**	**-**	**-**
Charge	lb	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	29633	31073	30292	4.86%	2.22%
Energy Balance	%	---	4.21%	1.21%	-	-
Compressor Power	kW	---	3.18	2.93	-	-
Fan Power	kW	---	0.95	0.97	-	-
Total Power	kW	4.466	4.13	3.9	-7.52%	-12.67%
EER	BTU/hr.W	6.64	7.52	7.76	13.33%	16.95%

5.3. Leak Tests

In the interest of time the leak tests were conducted only on Unit 10 for R447B. The choice of refrigerant was based on temperature glide, where R447B exhibits the highest glide amongst the refrigerants evaluated between Unit 6 and Unit 10 (refer to Figure 4). The leak tests were conducted to closely represent field operation. The procedure applied includes the following steps:

1- Run unit until steady-state is achieved (repeat 46°C performance test), monitoring capacity and subcooling
2- Gradually remove refrigerant from vapor line until capacity is reduced to approximately 50%, if possible
3- Store and weigh removed refrigerant
4- Re-charge with new refrigerant until same subcooling is achieved
5- Compare cooling capacities; if more than 5% deviation is observed, repeat steps 1-4, however in step 2, reduce capacity to 25% only
6- Repeat steps 1-5 for the liquid line

The comparison herein presented refers to a leakage of approximately 30% of charge, while reducing capacity by approximately 50% based on airside only. The leak tests showed less than 2% deviation in cooling capacity after re-charge from both vapor and liquid lines (Table 13). Since the capacity deviation was less than 5%, no further testing for 25% capacity reduction was conducted. The results suggest little impact due to fractionation.

Table 13: Unit 10 – R447B Leak Test Summary Results.

System			*Liquid Line Leak*		*Vapor Line Leak*	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Charge	lb	6.625	4.27	6.625	4.23	6.77
Cooling Capacity	BTU/hr	31073	14216	30865	15171	30587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	-[3]
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	-[3]
EER	BTU/hr.W	7.52	3.64	7.42	3.87	-[3]

5.4. Conclusions and Recommendations

This section presented the performance tests conducted on units 6 and 10. The key conclusions and recommendations are:

1- Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing. It should be stressed that the baseline unit by design had its capillary tube located in the outdoor unit. This would cause liquid refrigerant leaving the outdoor unit to flash. The refrigerant enthalpy at the condenser outlet state was used to calculate the refrigerant-side capacity assuming an isentalphic expansion without heat loss in connecting pipe. This is different from the modified systems of which the capillary tube was removed, and a manual expansion valve was placed at the inlet of the indoor unit. For modified systems, the enthalpy at the expansion valve inlet was used to calculate the refrigerant-side capacity.

2- Unit 10 exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This also indicates the importance of proper compressor selection.

3- The higher-than-expected power consumption in the Unit 10 baseline tests is also evidenced by the fact that even with zeotropic mixtures (R447B and R452B), Unit 10 had higher cooling capacity and efficiency than the baseline for the 46°C test condition, as projected in activity 2.

4- Because of the differences in saturation curves from the Activity 2 analysis, R32 tends to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed however, that making appropriate component selection, such as compressors with larger displacement volumes and higher mass flow rates for the zeotropic mixtures, cooling capacities and overall performance were of the same order of magnitude.

5- Refrigerant fractionation as evidenced by the leak tests, does not appear to be a great concern since less than 2% deviation in cooling capacity was observed after the system's re-charge.

6- The Unit 6 modified systems had lower performance than expected from the Activity 2 models. The R32 system configuration exhibited more than 10% less flow rate than anticipated due to performance

[3] Compressor power consumption was not properly recorded for this test; the error was identified after the fact and the team was unable to retrieve that information. While that compromises the assessment of the overall system performance, the deviations are expected to be marginal. The leak test on liquid line suggest minimal impact on power consumption after re-charge, while cooling capacity was reportedly fully recovered after recharge on both leak tests.

maps overprediction, which corresponded to 10% lower capacity. The R454B configuration exhibited a deviation of 5% between model and test due also in part to a 3% flow rate over prediction in the model. Unit 10, on the other hand, exhibited an excellent agreement to the models with less than 2% deviation in cooling capacity.

7- The model's validation adds confidence in the numerical simulation findings and recommendations provided in activity 2.

6. Conclusions

This report presents a comprehensive set of activities with the objectives of advancing the PRAHA program. The original scope and schedule were modified during the project as new findings and challenges surfaced. The tests that were carried out for PRAHA-I, while sufficient for the purpose of measuring capacity and energy efficiency for the purposes of PRAHA-I, did not have enough essential data to enable a complete cycle evaluation for optimization purposes. This is primarily due to using standard test rig on systems with critical hardware configuration differences. The analyses presented in Activity 2 (design assessment through modeling) provided good insights on adequate component design and/or selection for proper system functioning, when using novel refrigerants.

The final recommendations for future development are listed as follows:

1- Establish a baseline system by conducting comprehensive testing including measurements and metrics not typically performed in energy certification tests. Furthermore, testing systems with different configurations require custom test rigs as such to adequately measure working fluid's states to avoid mischaracterization of the operating conditions and performance. Such approach is considerably more labor-intensive which should be factored in the scope in future developments.

2- Using alternate low-GWP refrigerants is viable and can be competitive to presently used refrigerants but doing so requires proper component design and selection; compressor and expansion device particularly. Drop-in replacement without hardware change is never recommended as evidenced by the change requirements in Activity 2 and performance tests in the subsequent activities.

3- It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses that will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.

4- Always test the modified systems with the same instrumentation as the baseline, however mindful of the modifications as such to properly place sensors to obtain adequate readings as suggested in item 1 above.

Nomenclature

COP	Coefficient of Performance	-
D_o	Tube Outer Diameter	mm
f	Frequency	Hz
FPI	Fins per Inch	1/in
h	Enthalpy	kJ/kg
h_t	Tube Height	mm
HX	Heat Exchanger	-
$\dot{m}$	Mass Flow Rate	kg/s
MCHX	Microchannel Heat Exchanger	-
P	Pressure	kPa
P_l	Tube Longitudinal Pitch	mm
P_t	Tube Transverse Pitch	mm
s	Entropy	kJ/kg.K
T	Temperature	°C
TFHX	Tube-Fin Heat Exchanger	-
UA	Thermal Conductance	kW/K
V	Volume	m^3
w_t	Tube Width	mm
η_{vol}	Volumetric Efficiency	-
ρ	Density	kg/m^3

APPENDIX A - Activity 2 Design Framework Results

Table 14: Unit 1 – Theoretical Cycle Re-Design Summary.

System		*Baseline*	*Alternative 1*	*Alternative 2*	*Alternative 3*	*Alternative 4*
Case	-	Simulation	Target			
Refrigerant	**-**	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Condenser	-	BTFD5	-	-	-	-
Compressor	-	SL260DG-C8EU	-	-	-	-
Cooling Capacity	BTU/hr	17403	17477	17477	17477	17477
Compressor Power	kW	1.92	1.49	1.49	1.33	1.43
Fan Power	kW	0.43	0.43	0.43	0.43	0.43
Total Power	kW	2.35	1.92	1.93	1.76	1.86
COP	-	2.17	2.66	2.66	2.91	2.75
COP Gain	-	1.00	1.23	1.23	1.34	1.27

Table 15: Unit 1 – HX Analysis Summary

Condenser		**R444B**		**R290**		**R454C**		**R457A**	
Inputs		***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Refrigerant Pressure	kPa	2875.0	2875.0	2170.7	2170.7	2436.4	2436.4	2183.9	2183.9
Saturation Temperature at Inlet	°C	61	61	61	61	61	61	61	61
Refrigerant Temperature	°C	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Mass Flow Rate	kg/s	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03
Outputs									
Heat Load	W	7512.9	7441.2	8232.4	8016.6	6168.0	6040.0	6592.0	6429.0
Air Dry-Bulb Temperature	°C	58.6	58.2	59.7	59.6	56.3	56.3	57.0	56.9
Refrigerant Temperature	°C	46.7	48.1	50.3	53.8	47.2	49.5	48.0	51.1
LMTD	°C	12	15	19	23	14	18	16	21
UA	W/K	635.57	482.84	439.36	350.35	451.67	327.93	424.35	313.48
NTU	-	1.04	0.79	0.72	0.57	0.74	0.53	0.69	0.51
Effectiveness	-	0.1915	0.1896	0.2098	0.2043	0.1572	0.1539	0.1680	0.1638
Refrigerant Pressure Drop	kPa	78.2	1.4	85.0	1.7	79.3	1.4	87.2	1.7
Airside DP	Pa	75.1	75.5	75.1	75.5	75.1	75.5	75.1	75.5
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	130.0	148.3	130.0	148.3	130.0	148.3	130.0	148.3
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	3341.0	1721.0	4113.0	2033.0	3040.0	1382.0	3423.0	1601.0
Subcooling	°C	13.20	13.14	8.96	7.35	6.77	5.93	5.34	4.05
Charge	kg	0.3822	0.1143	0.1079	0.0352	0.3097	0.094	0.2522	0.0764

Table 16: Unit 1 – Compressor Performance Summary.

Compressor		Baseline				
Refrigerant	-	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Isentropic efficiency	-	0.66	0.70	0.69	0.70	0.68
Power	kW	1.9175	1.7682	2.0449	1.7966	1.8932
Pressure Lift	kPa	2284.8	1556.0	2087.7	1902.2	1904.9
Effective Displacement Volume	cm^3	19.80	25.87	24.80	19.64	25.35
Rotation Speed	RPM	3600	3600	3600	3600	3600

Table 17: Unit 1 – Expected Modified System Performances.

System		***Baseline***				
Case	-	**Simulation**	**Expected**			
Refrigerant	**-**	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Condenser	-	BTFD5	BTFD5	BTFD5	BTFD5	NMCD2
Compressor	-	SL260DG-C8EU	-	-	-	-
Cooling Capacity	BTU/hr	17403	17639	18104	18140	17749
Compressor Power	kW	1.92	1.77	2.04	1.80	1.89
Fan Power	kW	0.43	0.43	0.43	0.43	0.43
Total Power	kW	2.35	2.20	2.48	2.23	2.33
COP	-	2.17	2.35	2.14	2.38	2.24
COP Gain	-	1.00	1.08	0.99	1.10	1.03

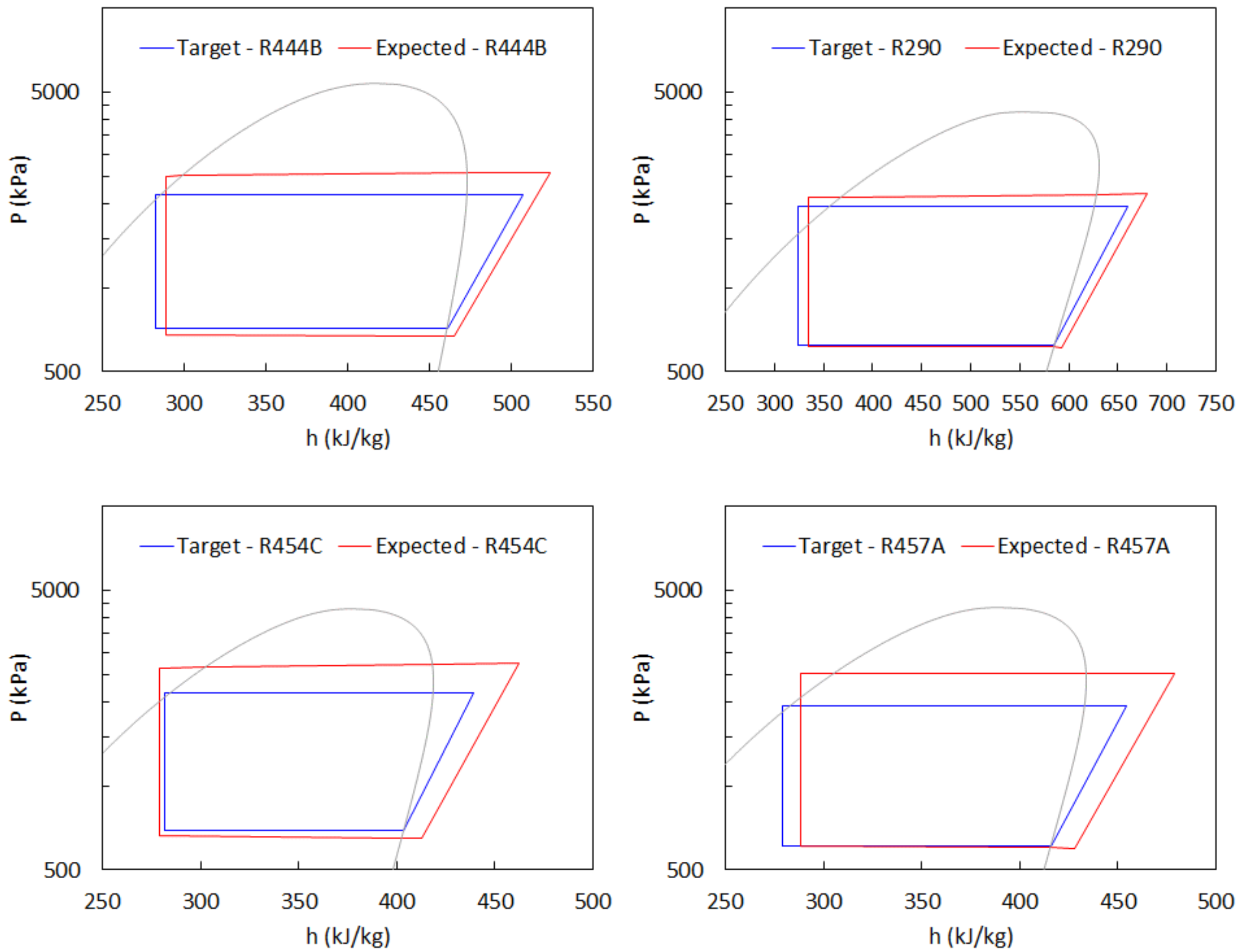


Figure 10. Unit 1 – Modified Systems P-h Diagrams.

Table 18: Unit 4 – Theoretical Cycle Re-Design Summary.

System		*Baseline*	*Alternative 1*	*Alternative 2*
			Target	
Refrigerant	-	**R290**	**R290**	**R290**
Condenser	-	BTFD9	-	-
Compressor	-	PSH356DG-C8DU4	-	-
Cooling Capacity	BTU/hr	17940	17940	23920
Compressor Power	kW	2.11	1.40	3.23
Fan Power	kW	0.28	0.28	0.28
Total Power	kW	2.39	1.68	3.51
COP	-	2.20	3.14	2.00
COP Gain	-	1.00	1.42	0.91

Table 19: Unit 4 – HX Analysis Summary.

Condenser		**R290 - 18kBTU**		**R290 - 24kBTU**	
Inputs		***BTFD9***	***NTFD5***	***BTFD9***	***NTFD5***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	0.81	0.76	0.81	0.76
Refrigerant Pressure	kPa	2875	2875	2875	2875
Saturation Temperature at Inlet	°C	75.5	75.5	75.5	75.5

Condenser		R290 - 18kBTU		R290 - 24kBTU	
Inputs		***BTFD9***	***NTFD5***	***BTFD9***	***NTFD5***
Refrigerant Temperature	°C	110	110	110	110
Mass Flow Rate	kg/s	0.02	0.02	0.03	0.03
Outputs					
Heat Load	W	8139	8148	12080	12190
Air Dry-Bulb Temperature	°C	55.0	56.1	59.5	61.2
Refrigerant Temperature	°C	46.2	46.0	47.7	46.4
LMTD	°C	9.6	7.4	14.3	10.0
UA	W/K	848	1097	846	1216
NTU	-	0.97	1.34	0.97	1.48
Effectiveness	-	0.15	0.16	0.22	0.23
Refrigerant Pressure Drop	kPa	4.2	13.4	11.0	35.2
Airside DP	Pa	16.0	15.9	16.0	15.9
Air Heat Transfer Coefficient (Average)	W/m².K	82.9	100.7	82.9	100.7
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	1535.2	1493.7	2382.4	2505.6
Subcooling	°C	29.2	29.2	27.6	28.4
Charge in Tubes	kg	0.90	0.46	0.76	0.39

Table 20: Unit 4 – Compressor Performance Summary.

Compressor		**Baseline**	**18kBTU/Hr**		**24kBTU/Hr**	
Refrigerant	**-**	**R290**	**R290**	**R290**	**R290**	**R290**
Isentropic efficiency	-	0.61	0.70	0.70	0.70	0.70
Power	kW	2.1067	1.7364	1.7093	3.3152	3.31
Pressure Lift	kPa	1457.6	1556.3	1513.7	2947.1	2937.4
Effective Displacement Volume	cm³	26.394	26.309	26.309	37.866	37.866
Rotation Speed	RPM	3600	3600	3600	3600	3600

Table 21: Unit 4 – Expected Modified System Performances.

System		***Baseline***	***Alternative 1***		***Alternative 2***	
			Expected			
Refrigerant	**-**	**R290**	**R290**	**R290**	**R290**	**R290**
Condenser	-	BTFD9	BTFD9	NTFD5	BTFD9	NTFD5
Compressor	-	PSH356DG-C8DU4	-	-	-	-
Cooling Capacity	BTU/hr	17940	17991	18147	24045	24120
Compressor Power	kW	2.11	1.74	1.71	3.32	3.31
Fan Power	kW	0.28	0.28	0.28	0.28	0.28
Total Power	kW	2.39	2.02	1.99	3.60	3.59
COP	-	2.20	2.61	2.67	1.96	1.97
COP Gain	-	1.00	1.19	1.21	0.89	0.89

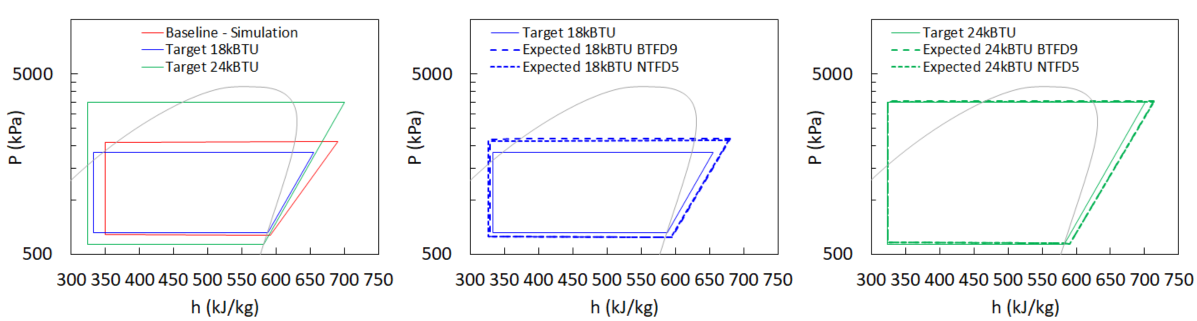


Figure 11. Unit 4 – Modified Systems P-h Diagrams.

Table 22: Unit 6 – Theoretical Cycle Re-Design Summary.

System			*Alternate 1*	*Alternate 2*	*Alternate 3*
		Simulation	Target		
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R452B**
Condenser	-	BTFD9	-	-	-
Compressor	-	GMCC KSG226N1UMT	ZP20K5E	ZP21K5E	-
Cooling Capacity	BTU/hr	23115	23114	23114	23115
Compressor Power	kW	2.73	2.37	2.29	2.04
Fan Power	kW	8.46	9.75	10.10	11.31
Total Power	kW	2.73	2.37	2.29	2.04
COP	-	2.48	2.86	2.96	3.32
COP Gain	-	1.00	1.15	1.19	1.34

Table 23: Unit 6 – HX Analysis for R32

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3562	3562	3562	3562
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	9159	9416	9332	9113
Air Dry-Bulb Temperature	°C	53.63	55.35	54.27	55.24
Refrigerant Temperature	°C	49.78	46.15	47.40	50.47
LMTD	°C	19.94	9.46	15.13	20.57
UA	W/K	459.40	995.12	616.75	443.09
NTU	-	0.39	0.97	0.52	0.43
Refrigerant Pressure Drop	kPa	100.98	26.10	3.06	4.70
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	5543.00	2624.00	2353.00	2978.00
Subcooling	°C	4.48	9.04	8.10	5.07
Charge	kg	0.39	0.71	0.17	0.11

Table 24: Unit 6 – HX Analysis for R452B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3247	3247	3247	3247
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7876	7964	7936	7866
Air Dry-Bulb Temperature	°C	52.52	53.94	53.06	53.99
Refrigerant Temperature	°C	47.41	46.05	46.53	47.61
LMTD	°C	15.49	8.09	12.37	15.72
UA	W/K	508.37	984.95	641.46	500.33
NTU	-	0.43	0.96	0.55	0.49
Refrigerant Pressure Drop	kPa	71.90	21.03	2.60	3.70
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	4252.00	2077.00	2103.00	2112.00
Subcooling	°C	6.14	8.20	7.99	6.89
Charge	kg	0.55	0.90	0.21	0.15

Table 25: Unit 6 – HX Analysis for R447B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m³/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3025	3025	3025	3025
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7607	8241	8157	7914
Air Dry-Bulb Temperature	°C	52.41	54.19	53.25	54.04
Refrigerant Temperature	°C	50.00	46.24	47.63	51.40
LMTD	°C	20.58	10.45	15.92	22.14
UA	W/K	369.65	788.34	512.32	357.47
NTU	-	0.31	0.77	0.44	0.35
Refrigerant Pressure Drop	kPa	185.90	27.30	3.18	4.90
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	W/m².K	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	5396.00	2439.00	2397.00	3281.00
Subcooling	°C	0.00	6.05	5.17	1.22
Charge	kg	0.33	0.70	0.16	0.11

Table 26: Unit 6 – HX Analysis for R454B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m³/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3204	3204	3204	3204
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7993	8094	8060	7976
Air Dry-Bulb Temperature	°C	52.61	54.06	53.16	54.10
Refrigerant Temperature	°C	47.59	46.06	46.61	47.91
LMTD	°C	15.95	8.28	12.72	16.40
UA	W/K	501.09	977.17	633.67	486.37
NTU	-	0.43	0.96	0.54	0.48
Refrigerant Pressure Drop	kPa	74.70	22.02	2.70	4.10
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	W/m².K	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	4445.93	2140.00	2008.00	2201.00
Subcooling	°C	5.75	8.03	7.75	6.43
Charge	kg	0.51	0.87	0.20	0.14

Table 27: Unit 6 – Compressor Performance Summary.

		Baseline	***Alternate 1***	***Alternate 2***	***Alternate 3***
Refrigerant		***R32***	***R32***	***R454B***	***R452B***
Isentropic Efficiency	-	0.60	0.64	0.66	0.70
Volumetric Efficiency	-	-	0.87	0.90	-
Displacement Volume	cm³	-	19.34	20.31	-
Frequency	Hz	60	60	60	60
Effective Displacement	cm³	16.0	16.8	18.3	19.0
Compressor Power	kW	2.4	2.3	2.3	2.1

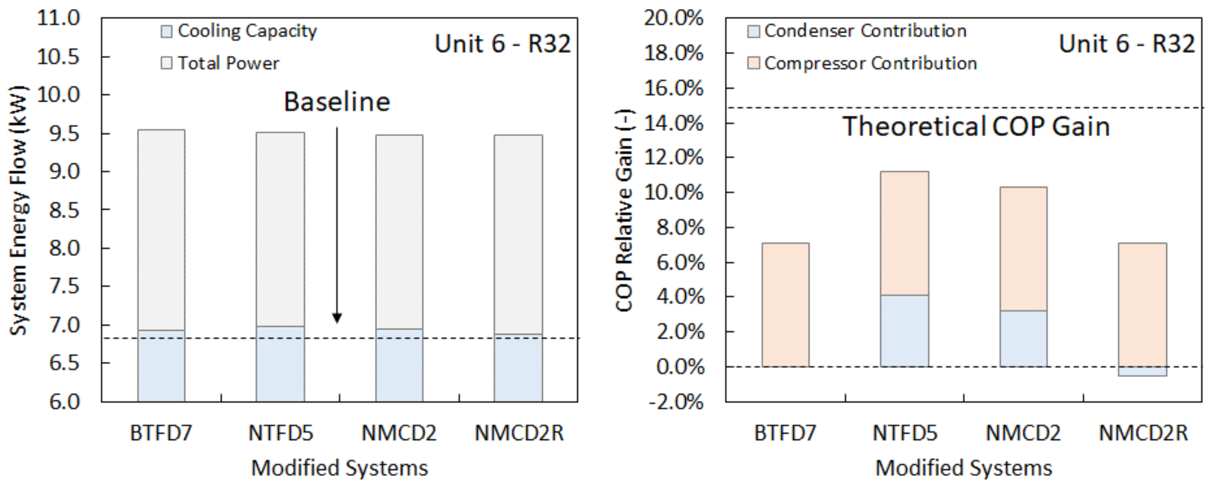


Figure 12. Unit 6 – System Level Analysis: Performance Results for R32.

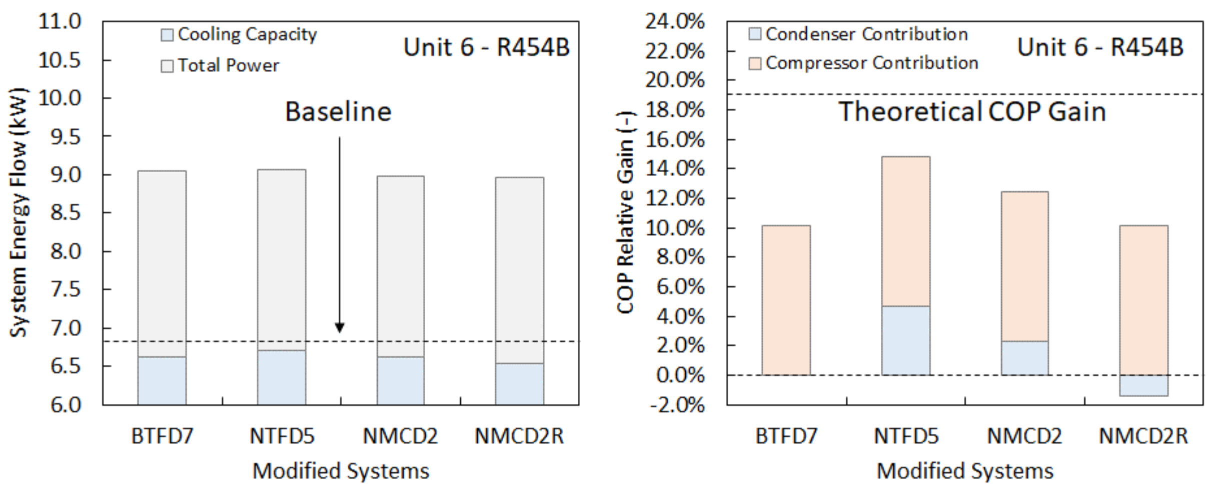


Figure 13. Unit 6 – System Level Analysis: Performance Results for R454B.

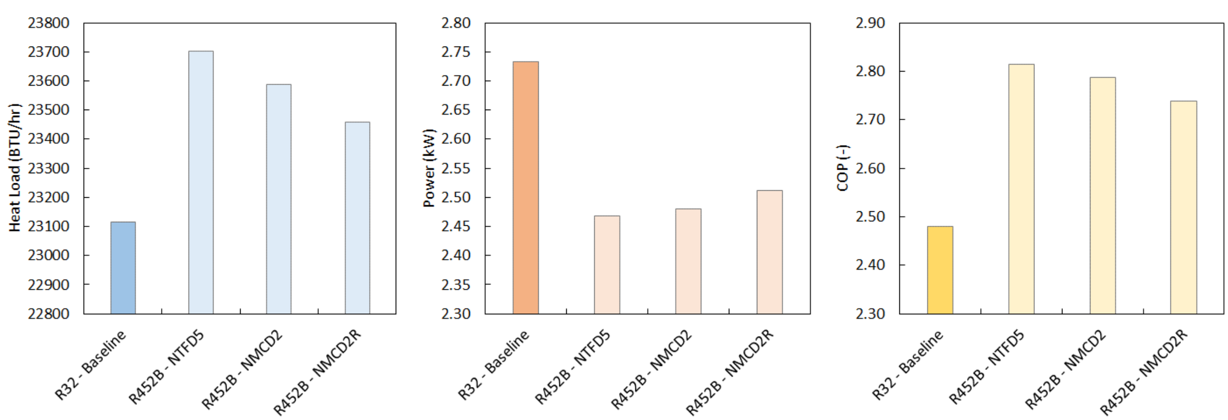


Figure 14. Unit 6 - Comparative System Performance Summary for R452B.

Table 28: Unit 10 – Theoretical Cycle Re-Design Summary.

System		***Baseline***	***Alternate 1***	***Alternate 2***	***Alternate 3***
		Simulation		**Target**	
Refrigerant	**-**	**R32**	**R452B**	**R447B**	**R454B**
Condenser	-	BTFD9	-	-	-
Compressor	-	ZP42K5E	ZP31K5E	ZP34K5E	ZP31K5E
Cooling Capacity	BTU/hr	29005	34311	31611	34608
Compressor Power	kW	3.84	2.81	2.31	2.65
Fan Power	kW	0.70	0.70	0.70	0.70
Total Power	kW	4.54	3.51	3.01	3.35
COP	-	1.87	2.87	3.08	3.03
COP Gain	-	1.00	1.53	1.64	1.62

Table 29: Unit 10 – HX Analysis for R32

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3562	3562	3562	3562
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	10693	11074	11435	10669
Air Dry-Bulb Temperature	°C	54.1	57.0	54.9	55.8
Refrigerant Temperature	°C	55.2	52.9	49.3	55.4
LMTD	°C	22.8	19.8	15.9	22.5
UA	W/K	468	560	717	475
NTU	-	0.35	0.55	0.54	0.42
Refrigerant Pressure Drop	kPa	26.7	67.1	6.8	10.1
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	3823	4239	3050	3991
Subcooling	°C	0.00	1.75	6.17	0.00
Charge	kg	0.61	0.43	0.17	0.11

Table 30: Unit 10 – HX Analysis for R452B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3247	3247	3247	3247
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9549	9812	9751	9500
Air Dry-Bulb Temperature	°C	53.2	55.8	53.6	54.8
Refrigerant Temperature	°C	49.5	46.4	47.1	50.1
LMTD	°C	16.7	9.2	12.2	17.1
UA	W/K	573	1067	802	557
NTU	-	0.43	1.04	0.60	0.49
Refrigerant Pressure Drop	kPa	17.2	47.1	5.6	8.2
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	2974	3038	2537	2812
Subcooling	°C	4.82	7.51	7.34	4.38
Charge	kg	0.83	0.79	0.23	0.15

Table 31: Unit 10 – HX Analysis for R447B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3025	3025	3025	3025
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9016	9632	9923	9085
Air Dry-Bulb Temperature	°C	52.9	55.6	53.8	54.4
Refrigerant Temperature	°C	52.4	51.7	49.9	52.7
LMTD	°C	20.4	18.9	17.1	20.3
UA	W/K	441	510	579	448
NTU	-	0.33	0.50	0.43	0.40
Refrigerant Pressure Drop	kPa	29.2	67.3	7.2	10.8
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	3528	3833	2999	3458
Subcooling	°C	0.00	0.00	2.67	0.00
Charge	kg	0.56	0.45	0.17	0.10

Table 32: Unit 10 – HX Analysis for R454B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3204	3204	3204	3204
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9634	9953	9901	9597
Air Dry-Bulb Temperature	°C	53.3	55.9	53.8	54.9
Refrigerant Temperature	°C	50.4	46.7	47.3	50.8
LMTD	°C	17.9	10.5	12.7	18.0
UA	W/K	537	952	782	532
NTU	-	0.40	0.93	0.59	0.47
Refrigerant Pressure Drop	kPa	18.8	51.1	5.9	8.7
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	3095	3211	2633	2942
Subcooling	°C	3.71	6.98	6.98	3.40
Charge	kg	0.78	0.71	0.22	0.14

Table 33. Unit 10 - Compressor Performance Summary.

Compressor			Copeland ZP31K5E-PFV	Copeland ZP34K5E-PFV	Copeland ZP31K5E-PFV
Refrigerant		***R32***	***R452B***	***R447B***	***R454B***
Isentropic Efficiency	-	0.439	0.638	0.662	0.662
Volumetric Efficiency	-		0.760	0.803	0.790
Displacement Volume	cm³		29.350	29.350	29.350
Frequency	Hz	50	50	50	50
Effective Displacement Volume	cm³	19.646	22.301	23.581	23.183

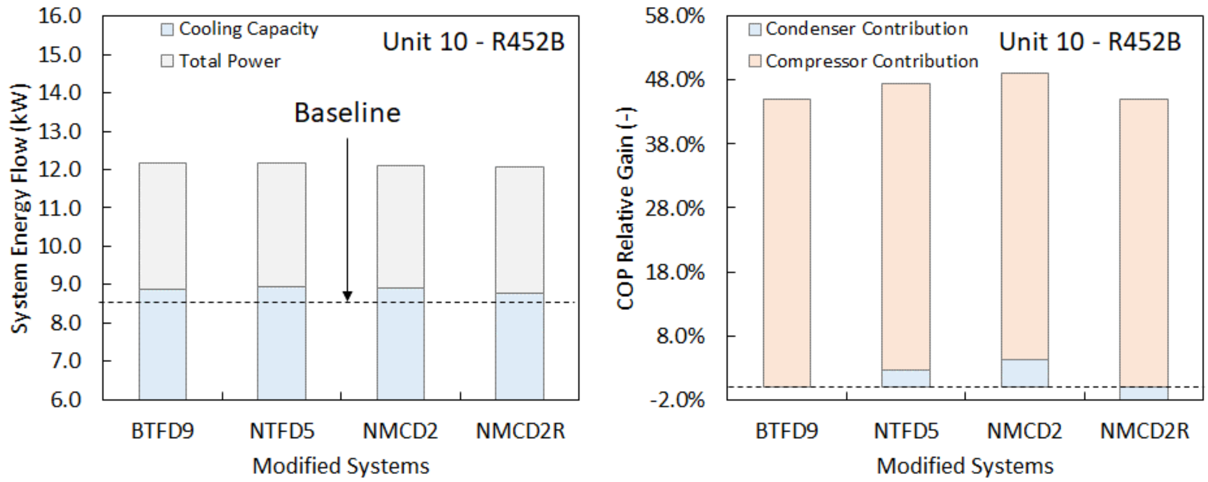


Figure 15. Unit 10 – System Level Analysis: Performance Results for R452B.

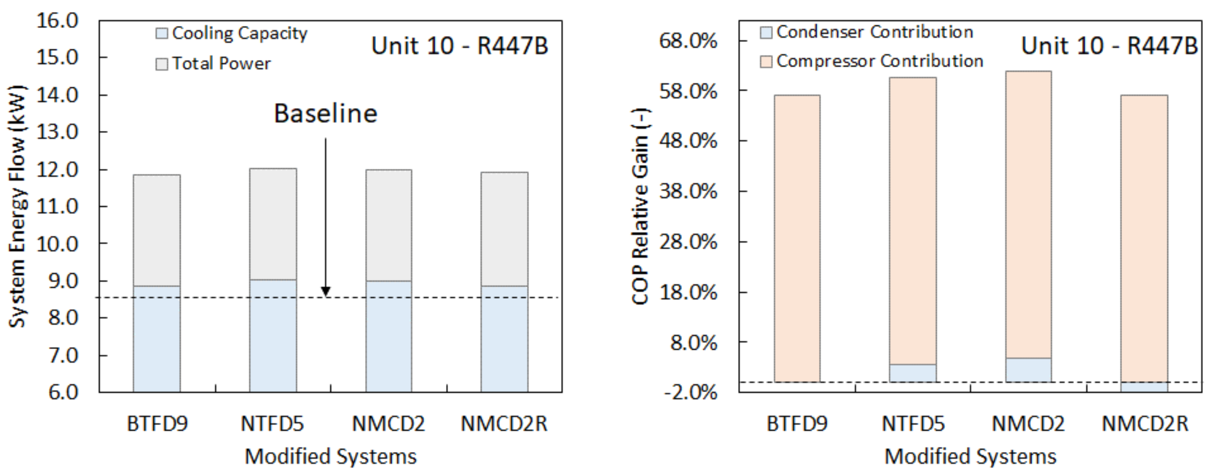


Figure 16. Unit 10 – System Level Analysis: Performance Results for R447B.

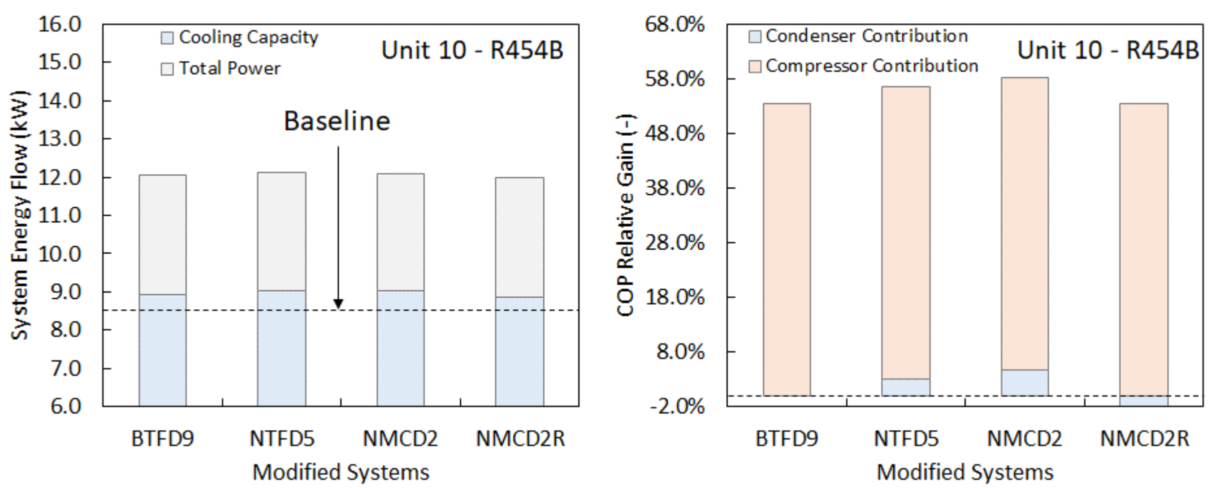


Figure 17. Unit 10 – System Level Analysis: Performance Results for R454B.

APPENDIX B – Unit 6 Initial Tests, Scope Change and Test Setup

Unit 6 was initially modified and tested at a separate facility and the test results exhibited a considerably lower cooling capacity than expected (~20%). Power consumption was also greater than designed. The condensing pressures were 20-30% above expectations, and the refrigerant pressure drop across the condenser was at least twice as high as expected. The outlet conditions of the condenser for R32 were possibly in two-phase. The condenser airflow rate was 10%-15% lower than expected. Superheat hardly met the setpoint values.

OTS formulated a hypothesis that the degraded performance was due to the condenser not being fully active; i.e. some regions were not transferring heat. One way for this to happen is by having severe maldistribution thus impeding heat transfer, increasing pressure drop – thus the condensing pressure – and possibly reducing the flow rate as well; all of which were observed in the test data. OTS tested the hypothesis by running hot water through the HX and observing with a thermal camera (Figure 18), which revealed the "dead zones". Upon inspection by the manufacturer, it was confirmed there were blockages in some of the tubes. A new HX was built, but the same pattern was observed, forcing OTS to remove the condenser replacement from the scope given the project schedule.

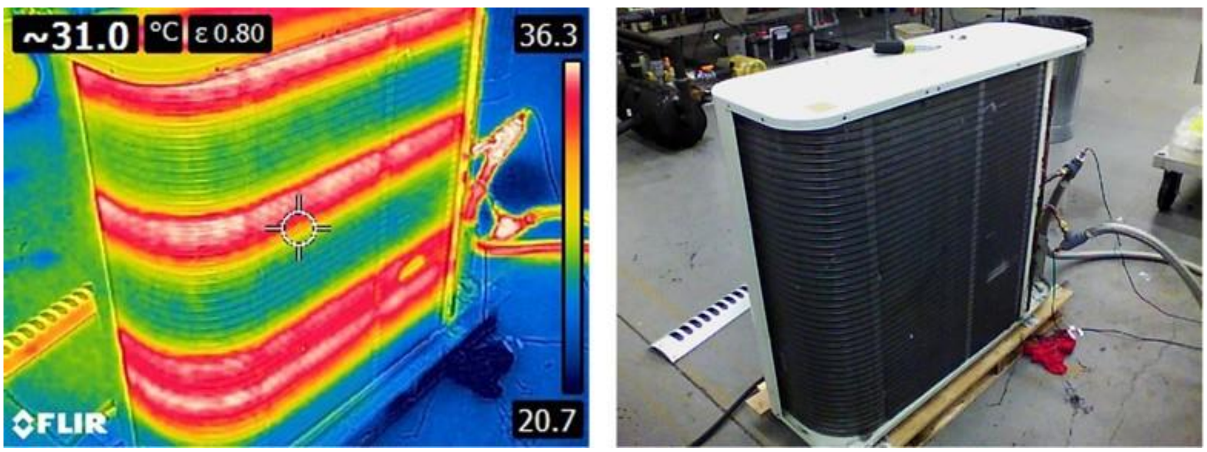


Figure 18. Hot Water Thermal Imaging.

Given the challenges with the initial tests and unit modification, the scope was re-defined. The original test plan was changed to accommodate time and resources as appropriate. Table 34 outlines the major changes to the scope. The tests were conducted at the OTS laboratory (Figure 19 to Figure 22). A summary of the key differences between the test setups (original and at OTS) is presented in Table 35.

Table 34: Test Scope Change.

Unit	Refrigerant	Test	Original Scope		New Scope	
			Planned	Actual	Planned	Actual
Unit 1	R290	Charge Optimization	Yes	No	No	No
		Performance Tests	Yes	No	No	No
Unit 6	R32 (Baseline)	Charge Optimization	No	No	Yes	Yes
		Performance Tests	No	No	Yes	Yes
	R32 (Modified)	Charge Optimization	Yes	Yes	Yes	Yes
		Performance Tests	Yes	Yes	Yes	Yes
	R454B	Charge Optimization	Yes	Yes	Yes	Yes
		Performance Tests	Yes	Yes	Yes	Yes
		Leak Tests	Yes	Yes	No	No
Unit 10	R32 (Baseline)	Charge Optimization	No	No	Yes	Yes*
		Performance Tests	No	No	Yes	Yes*
	R447B	Charge Optimization	Yes	No	Yes	Yes
		Performance Tests	Yes	No	Yes	Yes
		Leak Tests	Yes	No	Yes	Yes
	R452B	Charge Optimization	Yes	No	Yes	Yes
		Performance Tests	Yes	No	Yes	Yes
		Leak Tests	Yes	No	No	No

** Tests were conducted; however, no useful data was obtained (see section 5.2)*

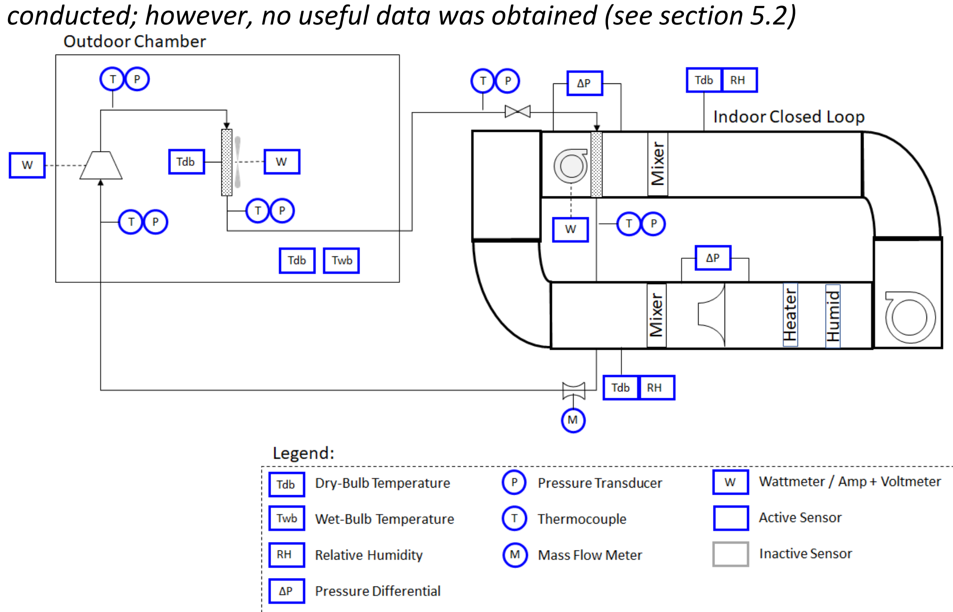


Figure 19. Test Diagram.

Figure 20. OTS Setup: outdoor chamber (left), Unit 10 and frequency converter inside chamber (right).

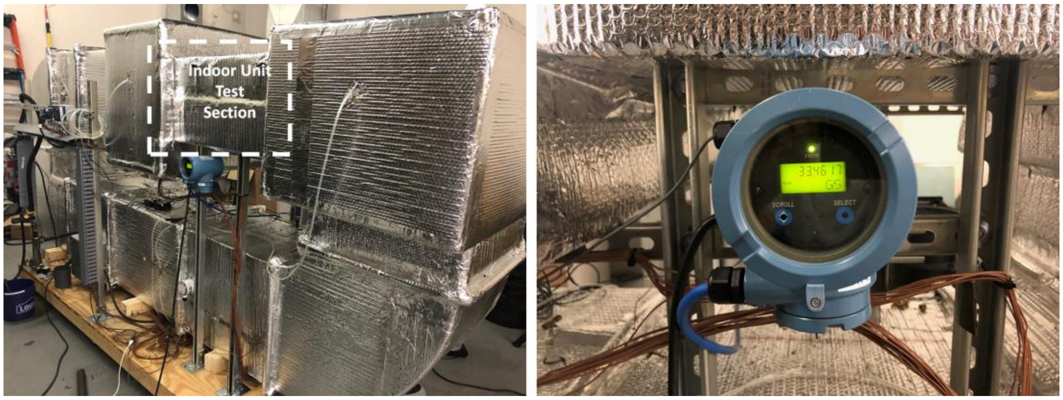


Figure 21. OTS Setup: indoor closed loop left side view (left), refrigerant mass flow meter (right).

Figure 22. OTS Setup: indoor closed loop right side view (left), vapor / liquid lines, sight glasses and TXV (right).

Table 35: List of Measurements.

Component	Refrigerant Side			Air Side		
	Measurement	**Original Scope**	**New Scope**	**Measurement**	**Original Scope**	**New Scope**
Condenser	Inlet Temperature	Yes	Yes	Air Flow Rate	Yes	**No**
	Inlet Pressure	Yes	Yes	Air Pressure Drop	No	No
	Outlet Temperature	Yes	Yes	Fan Power	No	**Yes**
	Outlet Pressure	Yes	Yes	Inlet Dry-bulb	Yes	Yes
	Subcooling	Yes*	**Yes**	Inlet Wet-Bulb / RH	Yes	Yes
				Outlet Dry-bulb	Yes	Yes
				Outlet Wet-Bulb / RH	Yes	Yes
Evaporator	Inlet Temperature	No	No	Air Flow Rate	Yes	Yes
	Inlet Pressure	No	No	Air Pressure Drop	No	**Yes****
	Outlet Temperature	Yes	Yes	Blower Power	No	**Yes**
	Outlet Pressure	Yes	Yes	Inlet Dry-bulb	Yes	Yes
	Superheat	Yes*	**Yes**	Inlet Wet-Bulb / RH	Yes	Yes
	Refrigerant Mass Flow Rate	No	**Yes**	Outlet Dry-bulb	Yes	Yes
				Outlet Wet-Bulb / RH	Yes	Yes
Compressor	Suction Temperature	Yes	Yes			
	Suction Pressure	Yes	Yes			
	Discharge Temperature	Yes	Yes			
	Discharge Pressure	Yes	Yes			
	Compressor Power	No	**Yes**			
Expansion Device	Suction Temperature	Yes	Yes			
	Suction Pressure	Yes	Yes			
	Discharge Temperature	No	No			
	Discharge Pressure	No	No			

Charge Optimization

The charge optimization procedure as originally scoped was not implemented due to the following:

a. The systems responded less sensitively to charge on subcooling and superheat, which were difficult to control with charging alone. A manual valve was added (Unit 10 exhibited little expansion) such that superheat could be better controlled. The valve also allowed for better control over the pressure levels compared to charge levels alone.

b. For the modified systems, the charge was gradually increased, departing from the original charge from PRAHA I tests, until it was observed that the superheat and subcooling better matched design conditions for validation purposes.

c. For the refrigerant blends, removing charge could result in fractionation (evaluated as a separate task), so it was decided to only incrementally increase charge, without removing it. For this procedure, a small gradual increment is necessary to avoid overcharging.

APPENDIX C - Unit 6 Raw and Processed Tested Data

Table 36: Unit 6 – Performance Tests

		Baseline (35°C)	**Alternate 1 (35°C)**	**Alternate 2 (35°C)**	**Baseline (46°C)**	**Alternate 1 (46°C)**	**Alternate 2 (46°C)**
Refrigerant	-	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Charge	lb	3.83	4.27	5.02	3.83	4.27	5.02
Cooling Capacity	BTU/hr	25193	23585	21966	23390	21450	21821
Energy Balance	%	-2.28%	-4.66%	-3.06%	-1.78%	-4.42%	-7.61%
Compressor Power	kW	2.11	1.79	1.77	2.71	2.32	2.25
Fan Power	kW	0.32	0.33	0.33	0.40	0.42	0.42
Total Power	kW	2.43	2.12	2.10	3.10	2.74	2.67
EER	BTU/hr.W	10.36	11.12	10.44	7.54	7.84	8.17
Evaporator							
Airside							
Inlet							
Air Flow Rate	m^3/s	0.31	0.31	0.31	0.31	0.31	0.30

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Temperature	°C	27.0	27.0	27.0	29.0	29.0	29.0
Wet Bulb	°C	19.68	19.68	19.68	21.33	21.33	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.011	0.011	0.011	0.013	0.013	0.013
Density	kg/m³	1.15	1.15	1.15	1.14	1.14	1.14
Enthalpy	kJ/kg	56.3	56.2	56.2	61.9	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0	1.0
Outlet							
Air Flow Rate	m³/s	0.29	0.29	0.29	0.29	0.29	0.29
Temperature	°C	14.3	15.1	15.8	16.9	17.7	18.1
Wet Bulb	°C	14.35	14.35	14.35	14.35	14.35	14.35
Relative Humidity	%	83.6	82.4	80.0	84.5	83.3	81.3
Humidity Ratio	kg/kg	0.008	0.009	0.009	0.010	0.011	0.011
Density	kg/m³	1.21	1.20	1.20	1.19	1.19	1.19
Enthalpy	kJ/kg	35.8	37.5	38.5	42.7	44.7	45.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0	1.0
Refrigerant Side							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	4.58	6.19	4.76	7.49	8.33	8.47
Pressure	kPa	939.13	986.90	876.76	1026.70	1053.10	979.34
Quality	-	0.16	0.19	0.20	0.20	0.25	0.27
Enthalpy	kJ/kg	273.64	269.78	268.60	301.30	291.37	289.89
Entropy	kJ/kg.K	1.20	1.25	1.30	1.27	1.32	1.37
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	8.08	9.26	9.46	9.08	13.54	11.80
Pressure	kPa	939	987	877	1027	1053	979
Superheat	K	3.50	3.07	4.89	1.59	5.20	3.58
Enthalpy	kJ/kg	520.49	520.22	473.43	518.52	523.27	472.93
Entropy	kJ/kg.K	2.15	2.15	2.03	2.13	2.15	2.02
HX Level							
Average Cooling Capacity	kW	7.384	6.912	6.438	6.855	6.287	6.395
Energy Balance (Qair - Qref)/Qref	%	-2.28%	-4.66%	-3.06%	-1.78%	-4.42%	-7.61%
Sensible Heat Ratio	-	0.64	0.66	0.65	0.64	0.67	0.66
Superheat	K	3.500	3.066	4.885	1.593	5.205	3.582
LMTD	K	13.783	12.822	14.015	13.985	12.184	13.041
UA	kW/K	0.573	0.539	0.459	0.550	0.516	0.490
Air Pressure Drop	Pa	N/A	N/A	N/A	N/A	N/A	N/A
Refrigerant Pressure Drop	kPa	N/A	N/A	N/A	N/A	N/A	N/A
Fan Power	kW	0.120	0.127	0.134	0.196	0.217	0.217
Condenser							
Airside							
Inlet							
Air Flow Rate	m³/s	0.9516	0.9838	1.0091	0.9580	0.9735	1.0613
Temperature	°C	35.01	34.76	35.12	46.06	45.93	46.05
Wet Bulb	°C	20.0	19.8	20.0	27.4	27.3	27.4
Humidity Ratio	kg/kg	0.008	0.008	0.009	0.015	0.015	0.015
Density	kg/m³	1.13	1.13	1.13	1.08	1.08	1.08
Enthalpy	kJ/kg	57.0	56.4	57.2	86.2	85.8	86.2
Specific Heat	kJ/kg.K	1.01	1.01	1.01	1.02	1.02	1.02
Outlet							
Air Flow Rate	m³/s	0.98	1.01	1.03	0.98	1.00	1.09
Temperature	°C	43.40	42.29	42.08	54.74	53.60	53.19
Wet Bulb	°C	22.4	22.0	22.1	29.3	29.0	29.0
Humidity Ratio	kg/kg	0.008	0.008	0.009	0.015	0.015	0.015
Density	kg/m³	1.10	1.10	1.10	1.05	1.05	1.05
Enthalpy	kJ/kg	65.6	64.1	64.3	95.2	93.7	93.6
Specific Heat	kJ/kg.K	1.01	1.01	1.01	1.02	1.02	1.02

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Refrigerant Side							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	89.78	82.73	78.33	109.00	107.24	90.75
Pressure	kPa	2724.15	2643.18	2360.90	3464.77	3365.88	3010.13
Superheat	K	45.9	40.1	35.9	54.7	54.2	38.0
Enthalpy	kJ/kg	580.73	573.07	523.39	594.42	593.52	528.90
Entropy	kJ/kg.K	2.20	2.18	2.08	2.21	2.21	2.07
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	39.17	34.52	34.68	51.79	45.63	45.79
Pressure	kPa	2675.81	2598.75	2310.89	3416.39	3324.50	2958.91
Subcooling	K	4.00	7.44	5.59	1.89	6.84	5.07
Enthalpy	kJ/kg	273.6	264.0	266.4	301.3	287.0	287.8
Entropy	kJ/kg.K	1.24	1.21	1.28	1.33	1.28	1.34
HX Level							
Heat Rejection	kW	9.19	8.53	8.08	9.25	8.31	8.42
Subcooling	K	4.00	7.44	5.59	1.89	6.84	5.07
Refrigerant Pressure Drop	kPa	48.34	44.43	50.01	48.38	41.38	51.22
Fan Power	kW	0.20	0.20	0.20	0.20	0.20	0.20
TXV							
Refrigerant							
Inlet		[4]			[4]		
Temperature	°C	30.64	37.31	35.83	39.70	47.55	46.78
Pressure	kPa	1991.01	2587.20	2301.38	2528.52	3317.42	2945.62
Subcooling	°C	*(Two-Phase)	4.47	4.27	*(Two-Phase)	4.83	3.88
Enthalpy	kJ/kg	*(Two-Phase)	269.8	268.6	*(Two-Phase)	291.4	289.9
Entropy	kJ/kg.K	*(Two-Phase)	1.233	1.284	*(Two-Phase)	1.299	1.349
Compressor							
Refrigerant							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	11.57	12.55	12.76	13.81	17.63	13.07
Pressure	kPa	936.06	984.95	874.98	1024.91	1052.17	969.56
Superheat	K	7.09	6.43	8.26	6.38	9.32	5.18
Enthalpy	kJ/kg	524.9	524.4	477.3	524.6	528.3	474.8
Entropy	kJ/kg.K	2.170	2.161	2.048	2.156	2.166	2.028
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	89.8	82.7	78.3	109.0	107.2	90.8
Pressure	kPa	2724.2	2643.2	2360.9	3464.8	3365.9	3010.1
Superheat	K	45.9	40.1	35.9	54.7	54.2	38.0
Enthalpy	kJ/kg	580.7	573.1	523.4	594.4	593.5	528.9
Entropy	kJ/kg.K	2.200	2.183	2.084	2.205	2.207	2.074
Compressor Level							
Power Consumption	kW	2.11	1.79	1.77	2.71	2.32	2.25
Isentropic Efficiency	-	0.80	0.84	0.73	0.74	0.76	0.69
Frequency	Hz	60	60	60	60	60	60

[4] The baseline configuration does not have an expansion valve, the state point herein presented refers to measurement readings at indoor unit inlet.

APPENDIX D - Unit 10 Baseline Re-Test

Prior to modifying Unit 10, it was tested in its received, baseline condition with the components used to test during PRAHA I. Given the results of the data review in Activity 1, and the challenges experienced in the initial testing of Unit 6, the project team agreed that testing the units in their baseline configuration would be important for more accurate comparison.

The electrical components for Unit 10 have phase mismatch, i.e. the fan and blower are three-phase while the compressor is single-phase, but all operate in 50Hz. OTS does not have a Variable Frequency Drive (VFD) for single-phase motors, requiring the use of a frequency converter to reduce the compressor speed. According to the baseline data from PRAHA 1, the total power consumption of Unit 10 varied between 3.5-4.5kW; OTS has a 5.0kW converter, which should be sufficiently large to meet testing needs.

Initial tests suggested that the compressor peak start current exceeds the converter threshold, causing the latter to trip and shut off. Although the blower and the fan run normally with the converter, the compressor alone does not. The compressor motor was tested at 60Hz direct from the grid and it works, thus confirming that the issue is indeed the peak current. A soft starter was acquired with the objective to mitigate the issue. The soft starter capacitors weren't fast enough to smooth the peak current, however, thus requiring manual charging, which eventually lead to component failure.

The last tentative to run the baseline was connecting the compressor to 60Hz and the fans to 50Hz. The refrigerant mass flow rate was too high impeding full condensation and full evaporation. A manual TXV was added along with two sight glasses in the liquid and vapor lines and reasonable data was obtained for the 35°C ambient temperature condition. While attempting to test the system under the 46°C ambient temperature, the compressor overheats and shuts down. Heavier gauge wire, new contactors and switch bypass were unsuccessfully employed. In the interest of time, the baseline re-tests were discontinued. The analysis will be carried out using the original baseline performance for comparison purposes.

APPENDIX E - Unit 10 Raw and Processed Tested Data

Table 37: Unit 10 – Performance Tests.

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	-	**R447B**	**R452B**	**R447B**	**R452B**
Charge	lb	6.625	6.625	6.625	6.625
Cooling Capacity	BTU/hr	32195	28128	31073	30292
Energy Balance	%	7.52%	-3.29%	4.21%	1.21%
Compressor Power	kW	2.67	2.40	3.16	2.93
Fan Power	kW	0.95	0.98	0.95	0.97
Total Power	kW	3.62	3.38	4.11	3.90
EER	BTU/hr.W	8.88	8.33	7.55	7.76
Evaporator					
Airside					
Inlet					
Air Flow Rate	m³/s	0.74	0.73	0.74	0.73
Temperature	°C	27.0	27.0	29.0	29.0
Wet Bulb	°C	19.68	19.69	21.33	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.011	0.011	0.013	0.013
Density	kg/m³	1.15	1.15	1.14	1.14
Enthalpy	kJ/kg	56.2	56.3	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R447B**	**R452B**	**R447B**	**R452B**
Outlet					
Air Flow Rate	m³/s	0.72	0.71	0.71	0.70
Temperature	°C	17.4	19.1	19.7	19.8
Wet Bulb	°C	15.80	16.64	17.91	18.06
Relative Humidity	%	85.1	78.5	84.7	84.5
Humidity Ratio	kg/kg	0.011	0.011	0.012	0.012
Density	kg/m³	1.19	1.18	1.18	1.18
Enthalpy	kJ/kg	44.3	46.8	50.7	51.1
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0
Refrigerant Side					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	9.81	5.53	12.90	13.09
Pressure	kPa	996.41	907.20	1085.49	1133.86
Quality	-	0.19	0.19	0.27	0.25
Enthalpy	kJ/kg	272.43	264.74	296.09	288.71
Entropy	kJ/kg.K	1.32	1.30	1.40	1.38
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	15.22	25.20	16.76	23.36
Pressure	kPa	996	907	1085	1134
Superheat	K	5.79	19.82	4.42	10.47
Enthalpy	kJ/kg	477.29	485.20	476.43	477.36
Entropy	kJ/kg.K	2.04	2.09	2.03	2.03
HX Level					
Average Cooling Capacity	kW	9.436	8.244	9.107	8.878
Energy Balance (Qair - Qref)/Qref	%	7.52%	-3.29%	4.21%	1.21%
Sensible Heat Ratio	-	0.81	0.85	0.83	0.87
Superheat	K	5.794	19.818	4.422	10.474
LMTD	K	9.534	5.829	9.222	6.171
UA	kW/K	0.990	1.414	0.988	1.439
Air Pressure Drop	Pa	N/A	N/A	N/A	N/A
Refrigerant Pressure Drop	kPa	N/A	N/A	N/A	N/A
Fan Power	kW	0.502	0.523	0.501	0.519
Condenser					
Airside					
Inlet					
Air Flow Rate	m³/s	1.44	1.50	1.44	1.42
Temperature	°C	35.03	35.08	46.14	46.22
Wet Bulb	°C	20.0	20.0	27.4	27.5
Humidity Ratio	kg/kg	0.008	0.009	0.016	0.016
Density	kg/m³	1.13	1.13	1.08	1.07
Enthalpy	kJ/kg	57.0	57.2	86.5	86.7
Specific Heat	kJ/kg.K	1.01	1.01	1.02	1.02
Outlet					
Air Flow Rate	m³/s	1.47	1.53	1.48	1.45
Temperature	°C	41.90	40.83	53.36	53.26
Wet Bulb	°C	22.0	21.7	29.0	29.1
Humidity Ratio	kg/kg	0.008	0.009	0.016	0.016
Density	kg/m³	1.10	1.11	1.05	1.05
Enthalpy	kJ/kg	64.0	63.0	94.0	94.0
Specific Heat	kJ/kg.K	1.01	1.01	1.02	1.02
		0.00010	0.00038	0.00011	-0.00001
Refrigerant Side					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R447B**	**R452B**	**R447B**	**R452B**
Temperature	°C	78.84	92.46	93.29	97.45
Pressure	kPa	2493.84	2600.61	3199.13	3357.43
Superheat	K	31.5	46.5	35.3	40.4
Enthalpy	kJ/kg	522.20	532.28	529.64	527.68
Entropy	kJ/kg.K	2.09	2.11	2.08	2.07
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	40.68	35.54	53.44	48.65
Pressure	kPa	2481.63	2599.27	3187.26	3351.92
Subcooling	K	3.37	9.26	1.62	7.33
Enthalpy	kJ/kg	274.8	266.6	300.2	291.9
Entropy	kJ/kg.K	1.32	1.29	1.39	1.37
HX Level					
Heat Rejection	kW	11.39	9.94	11.59	11.10
Energy Balance (Qair - Qref)	kW	N/A	N/A	N/A	N/A
Subcooling	K	3.37	9.26	1.62	7.33
Air Pressure Drop	Pa	-	-	-	-
Refrigerant Pressure Drop	kPa	12.21	1.34	11.87	5.51
Fan Power	kW	0.45	0.45	0.45	0.45
TXV					
Refrigerant					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	39.42	34.55	51.55	47.11
Pressure	kPa	2462.98	2583.59	3166.49	3331.97
Subcooling	°C	4.31	9.99	3.21	8.59
Enthalpy	kJ/kg	272.4	264.7	296.1	288.7
Entropy	kJ/kg.K	1.310	1.284	1.382	1.358
Compressor					
Refrigerant					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	16.84	26.01	17.17	24.96
Pressure	kPa	993.13	902.34	1082.17	1128.72
Superheat	K	7.52	20.81	4.94	12.23
Enthalpy	kJ/kg	479.3	486.2	477.0	479.4
Entropy	kJ/kg.K	2.052	2.090	2.035	2.042
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	78.8	92.5	93.3	97.5
Pressure	kPa	2493.8	2600.6	3199.1	3357.4
Superheat	K	31.5	46.5	35.3	40.4
Enthalpy	kJ/kg	522.2	532.3	529.6	527.7
Entropy	kJ/kg.K	2.087	2.112	2.082	2.073
Compressor Level					
Power Consumption	kW	2.67	2.40	3.16	2.93
Isentropic Efficiency	-	0.72	0.83	0.68	0.77
Frequency	Hz	60	60	60	60

Table 38: Unit 10 – R447B Leak Tests

System			***Liquid Line Leak***		***Vapor Line Leak***	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Charge	lb	6.625	4.27	6.625	4.23	6.77

System			***Liquid Line Leak***		***Vapor Line Leak***	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Cooling Capacity	BTU/hr	31073	14216	30865	15171	30587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	-
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	-
EER	BTU/hr.W	7.52	3.64	7.42	3.87	-
Evaporator						
Airside						
Inlet						
Air Flow Rate	m³/s	0.74	0.73	0.74	0.73	0.74
Temperature	°C	29.0	29.0	29.0	29.0	29.0
Wet Bulb	°C	21.33	21.34	21.34	21.34	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.013	0.013	0.013	0.013	0.013
Density	kg/m³	1.14	1.14	1.14	1.14	1.14
Enthalpy	kJ/kg	62.0	62.0	62.0	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0
Outlet						
Air Flow Rate	m³/s	0.71	0.72	0.71	0.72	0.71
Temperature	°C	19.7	23.3	19.6	23.2	19.7
Wet Bulb	°C	17.91	19.87	18.08	19.77	18.05
Relative Humidity	%	84.7	73.1	86.3	73.6	86.0
Humidity Ratio	kg/kg	0.012	0.013	0.012	0.013	0.012
Density	kg/m³	1.18	1.16	1.18	1.16	1.18
Enthalpy	kJ/kg	50.7	57.0	51.2	56.7	51.1
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0
Refrigerant Side						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	12.90	2.61	12.94	2.81	12.75
Pressure	kPa	1085.49	794.22	1086.62	799.23	1080.50
Quality	-	0.27	0.30	0.27	0.30	0.27
Enthalpy	kJ/kg	296.09	291.52	296.48	290.79	296.24
Entropy	kJ/kg.K	1.40	1.40	1.41	1.40	1.41
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	16.76	28.23	17.07	27.95	17.01
Pressure	kPa	1085	794	1087	799	1080
Superheat	K	4.42	26.24	4.70	25.76	4.82
Enthalpy	kJ/kg	476.43	496.65	476.77	496.25	476.88
Entropy	kJ/kg.K	2.03	2.14	2.03	2.13	2.03
HX Level						
Average Cooling Capacity	kW	9.107	4.167	9.046	4.446	8.965
Energy Balance (Qair – Qref)/Qref	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Sensible Heat Ratio	-	0.83	1.18	0.90	1.12	0.89
Superheat	K	4.422	26.235	4.695	25.756	4.823
LMTD	K	9.222	6.051	9.065	6.501	9.217
UA	kW/K	0.988	0.689	0.998	0.684	0.973
Fan Power	kW	0.501	0.524	0.524	0.524	0.524
Condenser						
Airside						
Inlet						
Air Flow Rate	m³/s	1.44	1.49	1.42	1.48	1.42
Temperature	°C	46.14	46.08	46.21	45.77	46.02
Wet Bulb	°C	27.4	27.4	27.5	27.2	27.4
Humidity Ratio	kg/kg	0.016	0.015	0.016	0.015	0.015
Density	kg/m³	1.08	1.08	1.07	1.08	1.08
Enthalpy	kJ/kg	86.5	86.3	86.7	85.3	86.1
Specific Heat	kJ/kg.K	1.02	1.02	1.02	1.02	1.02

System			*Liquid Line Leak*		*Vapor Line Leak*	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Outlet						
Air Flow Rate	m³/s	1.48	1.52	1.46	1.50	1.46
Temperature	°C	53.36	51.27	53.52	51.05	53.28
Wet Bulb	°C	29.0	28.6	29.1	28.4	29.0
Humidity Ratio	kg/kg	0.016	0.015	0.016	0.015	0.015
Density	kg/m³	1.05	1.06	1.05	1.06	1.05
Enthalpy	kJ/kg	94.0	91.7	94.3	90.8	93.6
Specific Heat	kJ/kg.K	1.02	1.02	1.02	1.02	1.02
Refrigerant Side						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	93.29	121.77	94.07	120.31	94.34
Pressure	kPa	3199.13	2846.79	3200.02	2847.47	3175.47
Superheat	K	35.3	68.9	36.1	67.4	36.7
Enthalpy	kJ/kg	529.64	569.70	530.67	567.95	531.39
Entropy	kJ/kg.K	2.08	2.20	2.08	2.20	2.09
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	53.44	50.27	53.37	50.13	53.28
Pressure	kPa	3187.26	2843.00	3188.61	2843.11	3164.31
Subcooling	K	1.62	-0.33	1.71	-0.19	1.45
Enthalpy	kJ/kg	300.2	293.2	300.0	293.2	299.9
Entropy	kJ/kg.K	1.39	1.37	1.39	1.37	1.39
HX Level						
Heat Rejection	kW	11.59	8.60	11.57	8.69	11.49
Energy Balance (Qair – Qref)	kW	N/A	N/A	N/A	N/A	N/A
Subcooling	K	1.62	-0.33	1.71	-0.19	1.45
Refrigerant Pressure Drop	kPa	11.87	3.79	11.40	4.36	11.16
Fan Power	kW	0.45	0.45	0.45	0.45	0.45
TXV						
Refrigerant						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	51.55	49.15	51.74	48.80	51.60
Pressure	kPa	3166.49	2827.45	3168.66	2827.31	3144.31
Subcooling	°C	3.21	0.54	3.06	0.89	2.84
Enthalpy	kJ/kg	296.1	291.5	296.5	290.8	296.2
Entropy	kJ/kg.K	1.382	1.369	1.383	1.366	1.382
Compressor						
Refrigerant						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	17.17	29.26	18.00	28.98	18.47
Pressure	kPa	1082.17	793.15	1082.65	797.99	1076.58
Superheat	K	4.94	27.30	5.75	26.83	6.41
Enthalpy	kJ/kg	477.0	497.7	478.0	497.3	478.8
Entropy	kJ/kg.K	2.035	2.140	2.038	2.138	2.041
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	93.3	121.8	94.1	120.3	94.3
Pressure	kPa	3199.1	2846.8	3200.0	2847.5	3175.5
Superheat	K	35.3	68.9	36.1	67.4	36.7
Enthalpy	kJ/kg	529.6	569.7	530.7	568.0	531.4
Entropy	kJ/kg.K	2.082	2.200	2.085	2.195	2.087
Compressor Level						
Power Consumption	kW	3.18	2.93	3.18	2.94	0.00
Isentropic Efficiency	-	0.68	0.68	0.68	0.69	0.68
Frequency	Hz	60	60	60	60	60

System			*Liquid Line Leak*		*Vapor Line Leak*	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	-	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**

APPENDIX F - Model Verification and Validation

Table 39: Unit 6 – Model Verification and Validation for Alternative 1 – R32 @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	27	31	14%
Cooling Capacity	BTU/hr	21450	23653	10%
Total Power	kW	2.74	2.67	-2%
EER	BTU/hr.W	7.84	8.86	13%

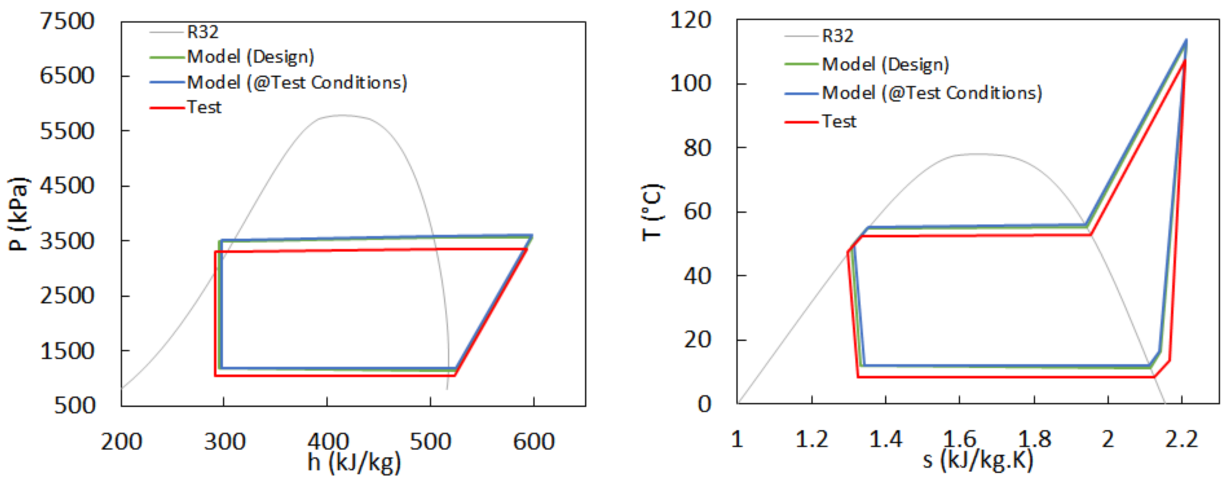


Figure 23. Unit 6 – R32 Performance Test Summary P-h and T-s Diagrams.

Table 40: Unit 6 – Model Verification and Validation for Alternative 2 – R454B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	35	36	3%
Cooling Capacity	BTU/hr	21821	22969	5%
Total Power	kW	2.67	2.49	-7%
EER	BTU/hr.W	8.17	9.24	13%

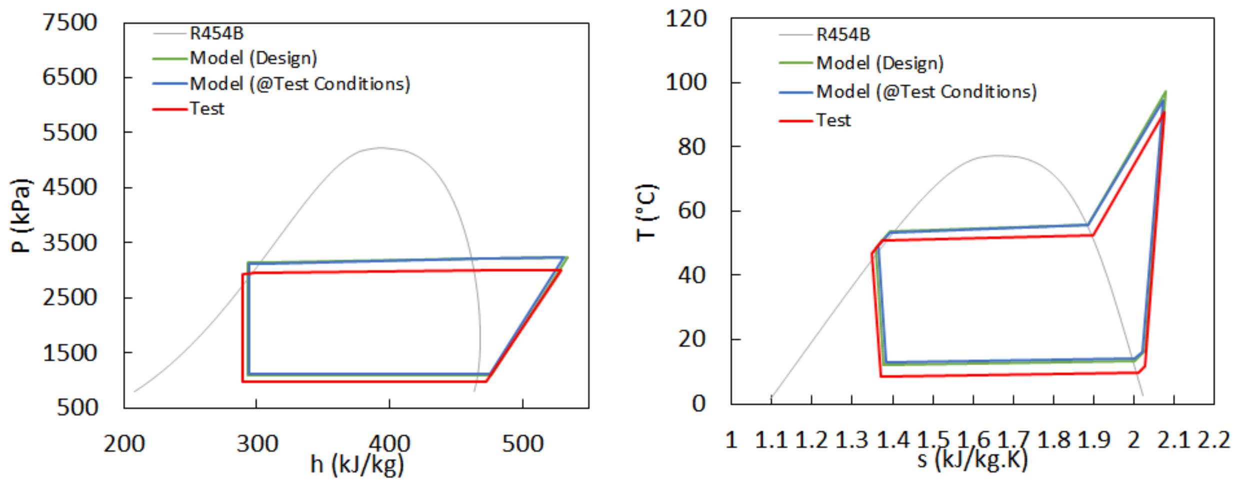


Figure 24. Unit 6 – R454B Performance Test Summary P-h and T-s Diagrams.

Table 41: Unit 10 – Model Verification and Validation for Alternative 1 – R447B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	51	49	-3%
Cooling Capacity	BTU/hr	31169	31026	-0.5%
Total Power	kW	2.70	3.00	11%
EER	BTU/hr.W	11.54	10.34	-10%

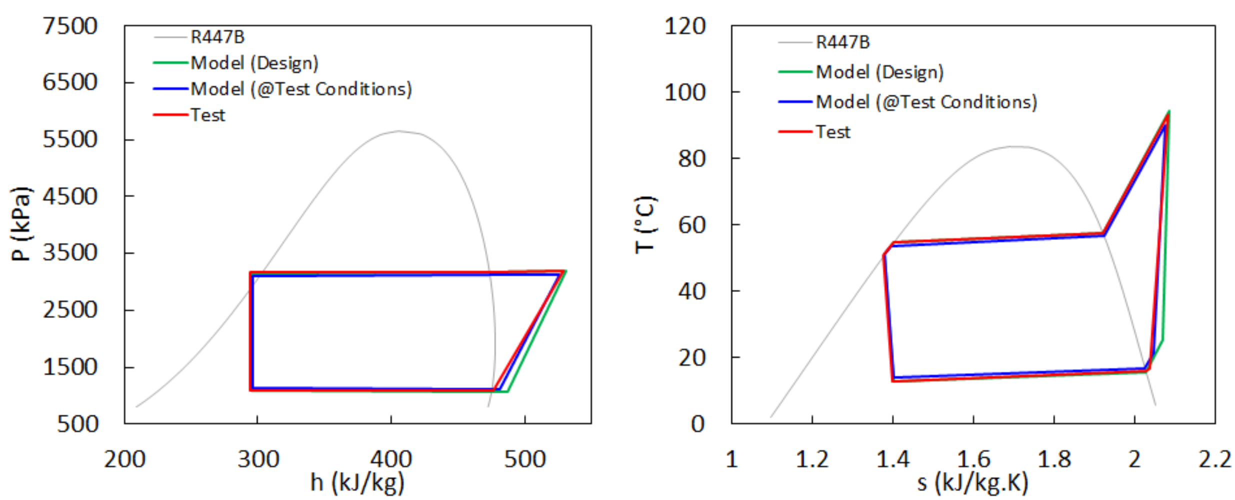


Figure 25. Unit 10 – R447B P-h and T-s Diagrams.

Table 42: Unit 10 – Model Verification and Validation for Alternative 2 – R452B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	47	48	2%
Cooling Capacity	BTU/hr	30292	30704	1.4%
Total Power	kW	3.90	3.34	-14%
EER	BTU/hr.W	7.76	9.19	18%

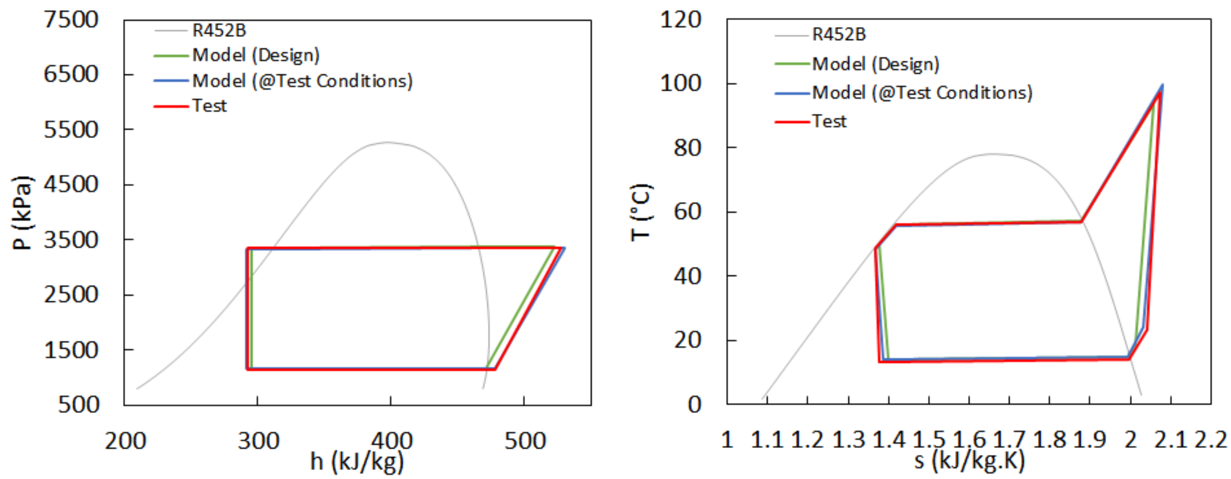


Figure 26. Unit 10 – R452B P-h and T-s Diagrams.

Air-Conditioning, Heating and Refrigeration Technology Institute

Final Report

AHRTI Report No. 9011

Promoting Alternative Refrigerants in High-Ambient Countries Phase II (PRAHA-II): Optimization Study on PRAHA I Equipment

Final Report

September 2019

By

Daniel Bacellar, Song Li, Paul Kalinowski, Cara Martin

Optimized Thermal Systems, Inc. (OTS)
7040 Virginia Manor Road, Beltsville, MD 20705

Prepared for

AIR-CONDITIONING, HEATING AND REFRIGERATION TECHNOLOGY INSTITUTE, INC

2311 Wilson Boulevard, Suite 400, Arlington, Virginia 22201

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Executive Summary

Over the past several years through the Promoting low- Global Warming Potential (GWP) Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA-I) project, 18 different prototypes have been developed and compared to respective baselines to support the assessment of alternative lower-GWP refrigerants for air-conditioning applications. Since the work originally started in 2012, researchers have identified gaps in the performance and operation of the PRAHA-1 prototypes. These gaps include the need to redesign and optimize prototype air-conditioning units, evaluate new alternative refrigerants, and improve component selection. As such, a new project, *Advancing the Designs of PRAHA-I for Meeting or Exceeding the Baseline Designs Performance*, conducted by Optimized Thermal Systems, Inc. (OTS) is herein presented.

The objectives of this project include the following:

1) Evaluate the design limitation of the PRAHA-I prototypes;
2) Optimize and physically evaluate selected prototypes with new refrigerants not evaluated during PRAHA-I; and,
3) Assess potential refrigerant fractionation impact due to leakage.

The project was organized into six activities for which a summary of the results, conclusions and recommendations are presented below:

1) Activity 1: Analyzing the Design of PRAHA-I Prototypes
    a. Certification laboratories, such as the one used for testing the units in PRAHA I, provide limited information for the purposes of product design and development. For future reference it is recommended that for research-oriented efforts such as this one, the units undergo a more rigorous testing process along with full characterization of the system and its individual components operating conditions and performance.
    b. In applications of high ambient temperatures, it is expected that performance will degrade as compared to operating under more temperate conditions and the resultant impact on performance must be considered. The key components for performance improvement identified herein were the compressor, condenser and expansion device.
        i. At higher temperatures, the saturation temperatures and refrigerant density at compressor's suction port can be very different than that from the rated conditions. Larger displacement volumes and efficiency curves optimized for higher pressure lifts might be required. Therefore, the proper selection of the compressor is paramount.
        ii. A better performance condenser will reduce the approach temperature between refrigerant and air, helping the compressor not to discharge refrigerant at very high pressure and temperatures, which degrade performance.
    c. At high ambient conditions, the system is forced to operate in higher pressure lift than at rated conditions, but still requires a certain refrigerant mass flow rate. Passive devices such as capillary tubes and orifices may not be able to provide enough expansion to allow the system to operate in higher temperature conditions. An active expansion device such as EXV's can adequately control operating conditions and maintain stable superheat.

2) Activity 2: Design Improvements (Summary results in Table 1)
    a. R290 and R32 have wider saturation regions allowing the system to operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer. Their cycles

may get closer to that of the ideal Carnot cycle compared to refrigerants with narrower saturation.

b. Refrigerants with high temperature glide may require new heat exchanger (HX) designs, namely condensers. The original designs proved to be sufficiently effective to allow for most systems to operate with the different refrigerants, however, better designs would allow for higher system efficiency and potentially less charge. HX designs are severely constrained by allowed envelope dimensions. A complete system re-design would provide an opportunity for designing HX's with even higher efficiency.

c. The results of this analysis suggest that for an effective refrigerant replacement, a proper compressor selection must be accompanied with it. Higher isentropic efficiencies are desired for higher temperatures, but most importantly, the displacement volume requirements can vary considerably from one refrigerant to another.

d. It is also imperative that having an active expansion device (preferably an Electronic Expansion valve (EXV)) to not only allow for more controlled superheat, but also to enable the unit to run with different refrigerants with very different thermophysical properties.

Table 1: Activity 2 Summary Modeling Results.

General Information			Hardware				Performance	
System	Rated Capacity (@35°C)	System Configuration	Compressor	Condenser	Expansion Device	Ref.	Cooling Capacity (@46°C)	EER (@46°C)
-	BTU/hr	-	Efficiency (-)	Type	Type	-	BTU/hr	BTU/hr.W
Unit 1	18000	**Baseline**	**0.66**	**Tube-Fin (5mm Tube)**	**Passive**	**R444B**	**17403**	**7.4**
		Alternate 1	0.7	Same as Baseline	Active (EXV)	R290	17639	8.01
		Alternate 2	0.69			R454C	18104	7.31
		Alternate 3	0.7			R444B	18140	8.14
		Alternate 4	0.68	MCHX		R457A	17749	7.63
Unit 4	24000	**Baseline**	**0.61**	**Tube-Fin (9.5mm Tube)**	**Passive**	**R290**	**17940**	**7.52**
		Alternate 1	0.7	Tube-Fin (5mm Tube)	Active (EXV)	R290	18147	9.12
		Alternate 2	0.7			R290	24120	6.72
Unit 6	24000	**Baseline**	**0.6**	**Tube-Fin (7mm Tube)**	**Passive**	**R32**	**23115**	**8.46**
		Alternate 1	0.65	Tube-Fin (5mm Tube)	Active (EXV)	R32	23798	9.41
		Alternate 2	0.67			R454B	22894	9.71
		Alternate 3	0.7			R452B	23702	9.6
Unit 10	36000	**Baseline**	**0.44**	**Tube-Fin (9.5mm Tube)**	**Passive**	**R32**	**29005**	**6.39**
		Alternate 1	0.65	Tube-Fin (5mm Tube)	Active (EXV)	R447B	30478	9.43
		Alternate 2	0.67			R452B	30796	10.27
		Alternate 3	0.67			R454B	30809	10

3) Activities 3-5: Prototype Modification and Testing (Summary results in Table 2)

a. Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing. It should be stressed that the baseline unit by design had its capillary tube located in the outdoor unit. This would cause liquid refrigerant leaving the outdoor unit to flash. The refrigerant enthalpy at the condenser outlet state was used to calculate the refrigerant-side capacity assuming an isentalphic expansion without heat loss in connecting pipe. This is different from the modified systems of which the capillary tube was removed, and a manual expansion valve was placed at the inlet of the indoor unit. For modified systems, the enthalpy at the expansion valve inlet was used to calculate the refrigerant-side capacity.

b. Unit 10 exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This supports the hypothesis of low compressor efficiency during PRAHA I tests, which also indicates the importance of proper compressor selection.
c. The above is also evidenced by the fact that even with R447B and R452B (zeotropic mixtures), Unit 10 had higher cooling capacity and efficiency than the baseline for the 46°C test condition, as projected in activity 2. The tests at 35°C, however, did not have the same trend.
d. The impact of refrigerant replacement was not very clear, in part due to the hardware change along with it. But because of the differences in saturation curves from the Activity 2 analysis, R32 tends to result in systems with higher efficiency and less charge. The zeotropic mixtures consistently required compressors with larger displacement volumes and even higher mass flow rates for cooling capacities of the same magnitude.
e. Refrigerant fractionation as evidenced by the leak tests, does not appear to a great concern since less than 2% in cooling capacity was observed after the system's re-charge.
f. The Unit 6 modified systems had lower performance than expected from the Activity 2 models. The R32 system configuration exhibited around 10% less flow rate than anticipated, which corresponded to 10% lower capacity. The R454B configuration exhibited a deviation of 5% between model and test due also in part to a 3% flow rate over prediction in the model. Unit 10, on the other hand, exhibited an excellent agreement to the models with less than 2% deviation in cooling capacity.
g. The model's validation adds confidence in the numerical simulation findings and recommendations provided in activity 2.

Table 2: Tests Summary Results.

Syst.	Test	Refrigerant	Charge	35°C			46°C		
				Cooling Capacity	Total Power	EER	Cooling Capacity	Total Power	EER
			lb	BTU/hr	kW	BTU/hr. W	BTU/hr	kW	BTU/hr. W
Unit 6	Perfor mance	R32 (Baseline)	3.83	25192	2.43	10.4	23390	3.10	7.54
		R32 (Alternate 1)	4.27	23585	2.12	11.1	21450	2.74	7.84
		R454B (Alternate 2)	5.02	21966	2.10	10.4	21821	2.67	8.17
Unit 10	Perfor mance	R32 (Baseline)*	5.63	34517	3.76	9.18	29005	3.84	7.55
		R447B (Alternate 1)	6.63	32195	3.62	8.88	31073	3.90	7.96
		R452B (Alternate 2)	6.63	28128	3.38	8.33	30292	3.90	7.76
	Liquid Line	Low Charge	4.23	N/A			14216	3.90	3.64
		Re-Charged	6.63				30865	4.16	7.42
	Vapor Line	Low Charge	4.27				15171	3.92	3.87
		Re-Charged	6.77				30587	-	-

**Original baseline values from PRAHA*

4) Conclusions: This report presented a comprehensive set of activities with the objectives of advancing the PRAHA program. The original scope and schedule were modified during the project as new findings and challenges surfaced. The tests that were carried out for PRAHA-I, while sufficient for the purpose of measuring capacity and energy efficiency for the purposes of PRAHA-I, did not have enough essential data to enable a complete cycle evaluation for optimization purposes. This is primarily due to using standard test rig on systems with critical hardware configuration differences. The analyses presented in Activity 2 (design assessment through modeling) provided good insights on adequate component design and/or selection for proper system functioning when using novel refrigerants. The tests in activities 3-5 partially served as validation for the models developed, and as check for previous test data from PRAHA I. The final recommendations for future development are listed as follows:
   a. Establish a baseline system by conducting comprehensive testing including measurements and metrics not typically performed in energy certification tests. Furthermore, testing systems with different configurations require custom test rigs as such to adequately measure working fluid's states to avoid mischaracterization of the operating conditions and performance. Such approach is considerably more labor-intensive which should be factored in the scope in future developments.
   b. Using alternate low-GWP refrigerants is viable and can be competitive to commonly used pure refrigerants but doing so requires proper component design and selection; compressor and expansion device particularly. Drop-in replacement without hardware change is never recommended as evidenced by the change requirements in Activity 2 and performance tests in the subsequent activities.
   c. It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses that will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.
   d. Always test the modified systems with the same instrumentation as the baseline, however mindful of the modifications as such to properly place sensors to obtain adequate readings as suggested in item a above.

2. Introduction

Over the past several years through the Promoting low- Global Warming Potential (GWP) Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA-I) project, 18 different prototypes have been developed and compared to respective baselines to support the assessment of alternative lower-GWP refrigerants for air-conditioning applications. Since the work originally started in 2012, researchers have identified gaps in the performance and operation of the PRAHA-1 prototypes. These gaps include the need to redesign and optimize prototype air-conditioning units, evaluate new alternative refrigerants, and improve component selection. As such, a new project, *Advancing the Designs of PRAHA-I for Meeting or Exceeding the Baseline Designs Performance*, is desired.

The objectives of this project include the following:

4) Evaluate the design limitation of the PRAHA-I prototypes;
5) Optimize and physically evaluate selected prototypes with new refrigerants not evaluated during PRAHA-I; and,
6) Characterize leaks.

The project is divided into six activities namely:

- **Activity 1 – Analyzing the Design of PRAHA-I Prototypes**: evaluate systems performance from selected units tested in PRAHA-I, and assess potential design improvements
- **Activity 2 – Design Improvement**: improve design of specific units targeting higher efficiencies while using alternate low-GWP refrigerants
- **Activity 3 - Prototype Units Fabrication**: modify the a sub-set of the units according to modifications proposed in Activity 2
- **Activity 4 - Evaluation of the Optimized Prototypes**: conduct performance tests on modified units at standard and high ambient temperature conditions (35°C and 46°C)
- **Activity 5 - Analyzing Leaks of Alternatives**: simulate refrigerant leakage and evaluate possible impact of zeotropic mixtures fractionation on performance
- **Activity 6 - Reporting and Data Management**: simulation and test data processing, preparing progress and final reports

3. Activity 1 - Analyzing the Design of PRAHA-I Prototypes

Activity 1 was comprised of three major tasks including: reception of 12 physical units at the OTS facility followed by visual inspection and parts identification; review of performance test reports from PRAHA I tests; and lastly, analyze data and identify, for units of interest, opportunity for improvement targeting higher performance and minimal charge. OTS has completed this activity and an executive summary of the findings are presented herein.

3.1. Physical Units

All 12 units of interest to this project (Table 3) were received on November 8th, 2018. Visual inspection indicated no evident signs of damage. Relevant information to the project such as compressor model, heat exchanger (HX) geometry and circuiting, as well as expansion device were also received.

Table 3: Unit Specifications Summary.

Category	Unit #	Ref.	Designed Capacity Btu/h	Measured Cap. Btu/h	Voltage	Ref. (New designs)	Ref. (Tests)
Window	**1**	**L-20 (R-444B)**	**18,000**	**19,104**	**208-230/60/1**	**L-20, R454C, R290, R457A**	**R290**
	2	L-20 (R-444B)	18,000	16,924	208-230/60/1		
	3	DR-3 (R-454C)	18,000	18,063	208-230/60/1		
Decorative splits	**4**	**R-290**	**24000 (18,000)**	**19,000**	**208-230/60/1**	**R-290**	**R-290**
	5	R-32	24000 (18,000)	19,328	208-230/60/1		
	6	**R-32**	**24,000**	**25,456**	**208-230/60/1**	**R32, R459A**	**R32, R459A**
	7	L-41 (R-447A)	24,000	24,830	208-230/60/1		
	8	L-20 (R-444B)	24,000	22,740	208-230/60/1		
	9	DR-3	24,000	14,638	208-230/60/1		
Ducted splits	**10**	**R-32**	**36,000**	**35,500**	**220-240/50/1**	**R447B, R452B**	**R447B, R452B**
	11	L-20	36,000	36,553	220-240/50/1		
	12	DR-3 (R-454C)	36,000	33,032	220-240/50/1		

3.2. PRAHA-I Performance Reports Assessment

OTS received a complete package of files containing the performance reports for all units tested in PRAHA I. The tests conducted in PRAHA I were meant to assess high-level performance of these units focusing on a large control volume where only total energy in and out was evaluated. As such, these tests were not comprehensive in terms of measurements for cycle analysis required in PRAHA II. Refrigerant side measurements, in most cases, were very limited (few pressure and temperature measurements and no flow rates); thus, it is not possible to fully characterize the cycle and perform energy balances between air and refrigerant sides of the system. Common issues found in the reports include:

- Tag mislabeling and / or mismatching sensor location and tag
- No independent outdoor capacity reported – typically reported the same as indoor capacity
- Missing energy balance checks
- Missing measurement on either airside pressure drop and temperature or fan power
- Inconsistent reported measurements with thermophysical properties for units tested with L-20
- Systematic inconsistency in reported superheat and subcooling
- Missing measurements on refrigerant side at evaporator inlet
- Missing temperature and/or pressure measurements on refrigerant side
- Missing refrigerant mass flow measurements

A summary of the original PRAHA-1 data and results of the data reduction are provided under separate documentation.

3.3. Hardware Improvement Assessment

3.3.1. Heat Exchanger (HX) First Order Analysis (FOA)

This section outlines a FOA for the HXs of Units 1, 4, 6 and 10 to identify improvement potential. The project's objective, as stated above, is to improve performance while minimizing charge. One way of addressing both objectives is by reducing tube / channel diameter. Heat transfer coefficients are inversely proportional to surface hydraulic diameters, however, so is pressure drop. Smaller tubes result in more compact (C = surface area / footprint volume), with reduced internal volume, HXs.

A qualitative analysis using values from literature was carried out to demonstrate the relative impact of diameter over abovementioned metrics, specifically: heat transfer coefficient, compactness and overall thermal conductance (UA). The left-hand side plot in Figure 1 show three curves inversely proportional to the diameter; a 5mm tube can achieve, in this example, 70% greater UA than a conventional 9.5mm, within the same footprint volume (or cabinet).

These are further explored to illustrate the impact on a system level. Systems respond to UA of both condenser and evaporators, but for the purposes of this analysis, condenser only is considered. The UA represents the overall thermal conductance, which will impact the approach temperatures in the system (ΔT_{app}). If the heat rejection is kept constant, the higher the UA, the smaller are the ΔT_{app}'s, thus allowing the condenser to operate in lower pressure levels, which will consequently increase the system performance. An example using a hypothetical R32 cycle with an EER of 12 as base is shown in the right-hand side plot in Figure 1. Performance improvement is limited by the Second Law, when the approach temperatures near zero; however, in this illustration, the EER has potential to increase in over 20% with better condenser design alone.

It is imperative to note that the results presented in this section are for **illustration purposes only**. Further in this report it is presented in more detail a re-design framework, applied to the units of interest in this project, using the metrics outlined in this section.
Unit 1 already had a 5mm condenser, which limits the options for HX re-design. Unit 6 had a 7mm HX on both the indoor and outdoor units, which allows some room for improvement if reducing to 5mm. Lastly, both coils for Unit 10 had 9.5mm tubes, thus there is greater potential for charge reduction and performance improvement for that unit in particular.

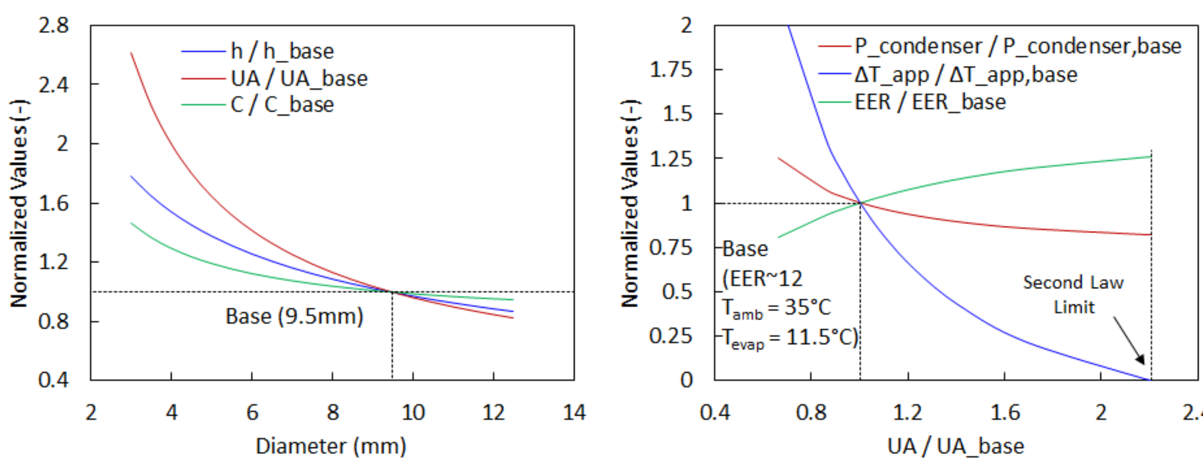


Figure 1. Heat Exchangers FOA.

3.3.2. Compressors

The existing units mostly use compressors sized specifically for R410A or R22 and in some cases custom made for this effort. There is, however, opportunity for a better compressor selection when migrating from R32 to R454B or R447B on Units 6 and 10, respectively.

3.3.3. Expansion Devices

Expansion devices such as TXV's and EXV's may allow for better control and reduced losses in connecting pipes if located near the evaporator. Some units, such as 6 and 10, have a capillary tube in the outdoor unit, which forces the refrigerant to travel in two-phase along the connecting pipes, and at lower temperatures, thus increasing pressure drop and heat gain.

3.3.4. Fan and Blower

Replacing the fan and blower may be necessary if newly designed HXs offer considerable change in pressure drop over the baseline since the flow rates are kept constant. The lack of test data on pressure drop forces us to rely on predicted values only. These will be considered for replacement as a last priority.

3.3.5. Units Component Modification Potential

Table 4 shows the detailed existing components for the units of interest for modification.

Table 4: Units 1, 4, 6 and 10 Components.

System	Unit 1	Unit 4	Unit 6	Unit 10
Refrigerant	**R444B**	**R290**	**R32**	**R32**
Compressor	HIGHLY SL260DG-C8EU	HIGHLY PSH356DG-C8DU3	GMCC KSG226N1UMT	Copeland ZP42K5E-PFJ-XXX
Condenser	5mm Louver TFHX	9.5mm Wavy TFHX	7mm Louver TFHX	9.5mm Louver TFHX
Expansion Device	Capillary Tube	Capillary Tube	Capillary Tube	Capillary Tube
Evaporator	9.5mm Louver TFHX	7mm Louver TFHX	7mm Slit TFHX	9.5mm Louver TFHX

3.4. Conclusions and Recommendations

The first part of this activity regarded data analysis and processing from the original tests conducted in the original PRAHA-I project, which was designed to conduct testing and comparison of cooling capacity vs. EER for the prototypes against the baseline units from same manufacturers. Since limited certification tests were required then, more testing parameters would have been needed to support the optimization and/or redesign process within the scope of PRAHA-II. The second part pertained assessing potential hardware modifications that could result in higher performance and less charge, with the intent of replacing the original refrigerants with alternative, low-GWP ones. The key conclusions and recommendations are:

1- Certification laboratories, such as the one used for testing the units in PRAHA I, provide limited information for the purposes of product design and development. For future reference it is recommended that for research-oriented efforts such as this one, the units undergo a more rigorous testing process along with full characterization of the system and its individual components operating conditions and performance.

2- In applications of high ambient temperatures, it is expected that performance will degrade as compared to operating under more temperate conditions and the resultant impact on performance must be considered. The key components for performance improvement identified herein were the compressor, condenser and expansion device.

a. At higher temperatures, the saturation temperatures and refrigerant density at compressor's suction port can be very different than that from the rated conditions. Larger displacement volumes and efficiency curves optimized for higher pressure lifts might be required. Therefore, the proper selection of the compressor is paramount.
b. A better performance condenser will reduce the approach temperature between refrigerant and air, helping the compressor not to discharge refrigerant at very high pressure and temperatures, which degrade performance.

3- At high ambient conditions, the system is forced to operate in higher pressure lift than at rated conditions, but still requires a certain refrigerant mass flow rate. Passive devices such as capillary tubes and orifices may not be able to provide enough expansion to allow the system to operate in higher temperature conditions. An active expansion device such as EXV's can adequately control operating conditions and maintain stable superheat.

4. Activity 2 - Design Improvements

The details of modeling and simulation results are provided in a separate document submitted in conjunction with this one, while in this section only the summarized performance results are presented.

4.1. Hardware

A general design improvement assessment was presented in the report for Activity 1, focusing on the units of interest to this study. A first order analysis on the HX's showed that moving towards smaller hydraulic diameter tubes can be beneficial from a material savings and charge reduction standpoint. Units 4 and 10 use conventional 9.5mm diameter tube condensers (Table 4), making them good candidates for condenser replacement with either a smaller tube diameter or a microchannel heat exchanger (MCHX). The compressors used on Units 1, 4 and 6 do not have available performance maps making it difficult to assess their fitness for the system. The focus of this study is on proper compressor selection and condenser re-design.

4.2. Refrigerant

R32 and R290 have wide saturation regions (Figure 2 and Figure 3) putting them at an advantage since they may operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer. Their cycles may get closer to that of the ideal Carnot cycle compared to refrigerants with narrower saturation.

Amongst the blends investigated for Unit 1, R444B has the widest saturation region while also having the highest temperature glide (Figure 4). The latter is typically not beneficial, in particular for evaporators, but it may help the condenser. The glide enables the refrigerant temperature profile to get closer to the air temperature profile without crossing (Figure 4). From a thermodynamic perspective, this means R444B can have its condensing pressure reduced further, resulting in higher theoretical COP.

For Units 6 and 10, the investigated blends, although having narrower saturation than the baseline R32, have similar thermophysical characteristics (Figure 3) with lower temperature glides (Figure 4) making them more competitive from a capacity and performance perspective.

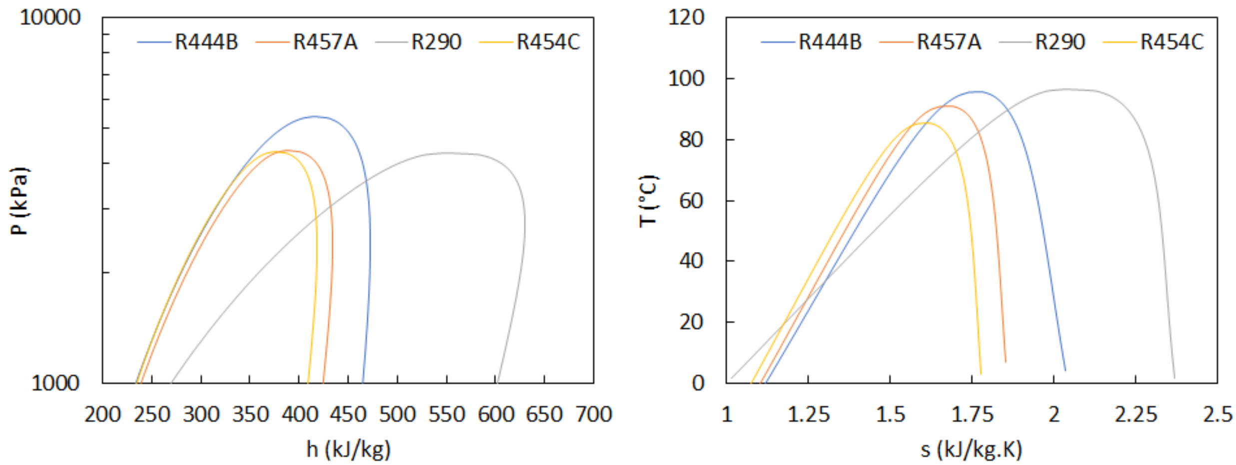


Figure 2. Refrigerants Investigated for Units 1 and 4.

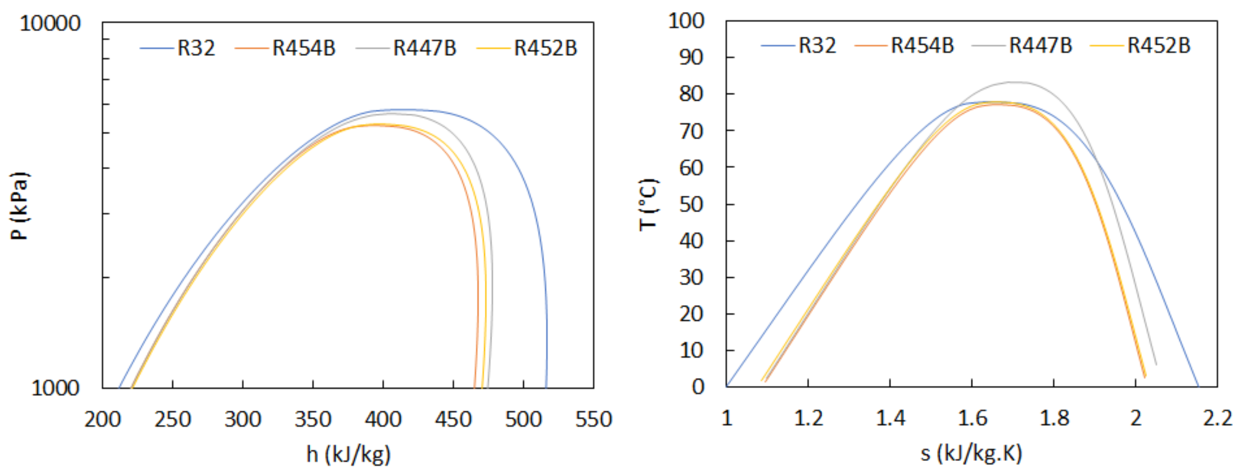


Figure 3. Refrigerants Investigated for Units 6 and 10.

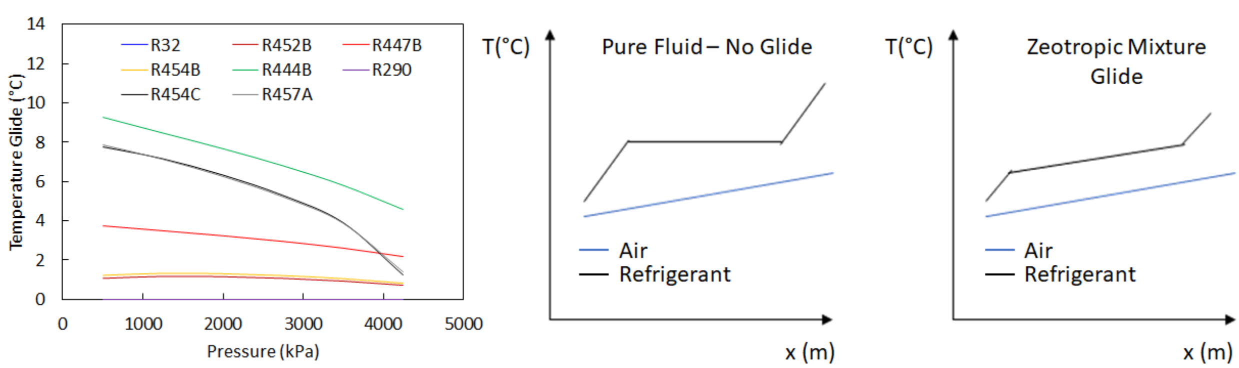


Figure 4. Refrigerant Temperature Glides.

4.3. System Design Modification Framework

The systems' re-design herein presented ultimately consists of a retrofit of the existing units by properly designing and selecting components that can be replaced as drop-ins, with minimal or no modification of the packaging (cabinets). In other words, any component replaced must occupy the same envelope as the baseline component. The focus of the re-design is on:

- Compressor
- Condenser, and
- Expansion valve

The evaporator designs were not changed for two main reasons: a) some are custom-made wrap-around the blower units, such as in Unit 6, making it harder to quickly find an off-the-shelf option; and, b) the goal is to deliver the same cooling capacity while improving efficiency. For the latter, there's more room for improvement in the condenser by reducing condensing pressure, assuming the evaporator can already deliver the expected capacity.

The fans and blowers were also not considered for change, in part due to the lack of information on the performance curves from the baseline models, but also due to potential high cost and lead time for replacement with secondary impact on performance since 80-90% of the power consumed comes from the compressor.

The first step to assess the level of performance required for each component is to investigate an improved theoretical cycle, which will indicate how much COP improvement can be expected, as well as refrigerant flow rate needs and HX size (UA). To improve the performance of a vapor compression cycle, the pressure lift between evaporating and condensing pressures must be reduced. Consequently, the approach temperatures between air and refrigerant will be reduced as well (Figure 5), thus the thermal capacitance of the heat exchangers must increase. Furthermore, the closer to the saturation region, the closer the cycle reaches the ideal Carnot efficiency (Figure 6).

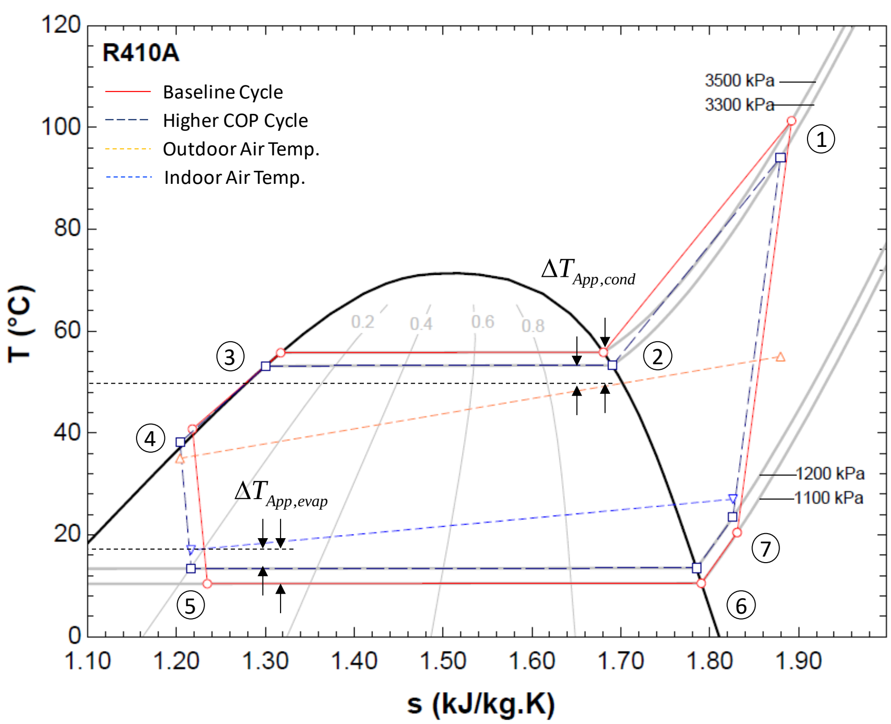


Figure 5. Illustrative T-s diagram for baseline and improved cycles.

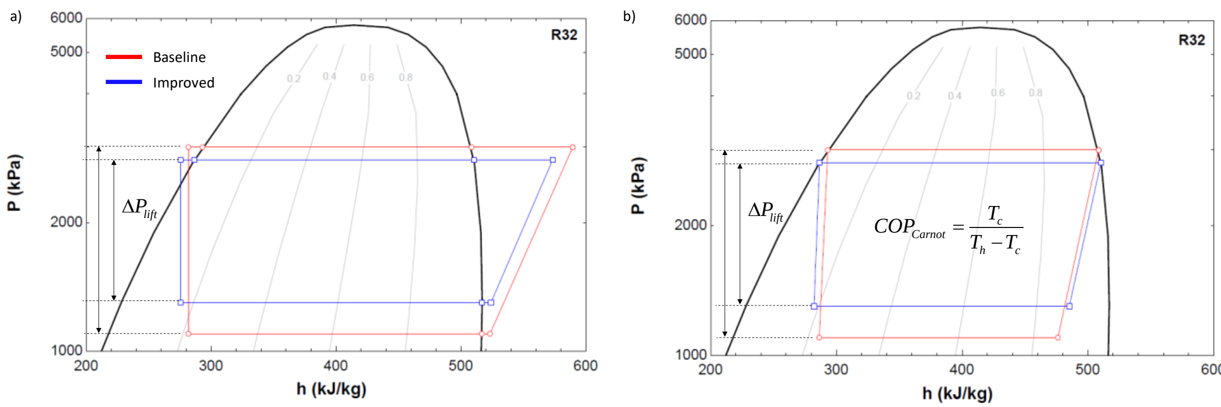


Figure 6. P-h Diagrams Illustrating COP Improvement: a) Real Cycle; b) Ideal Cycle (Carnot).

The system design framework is performed according to Figure 7.

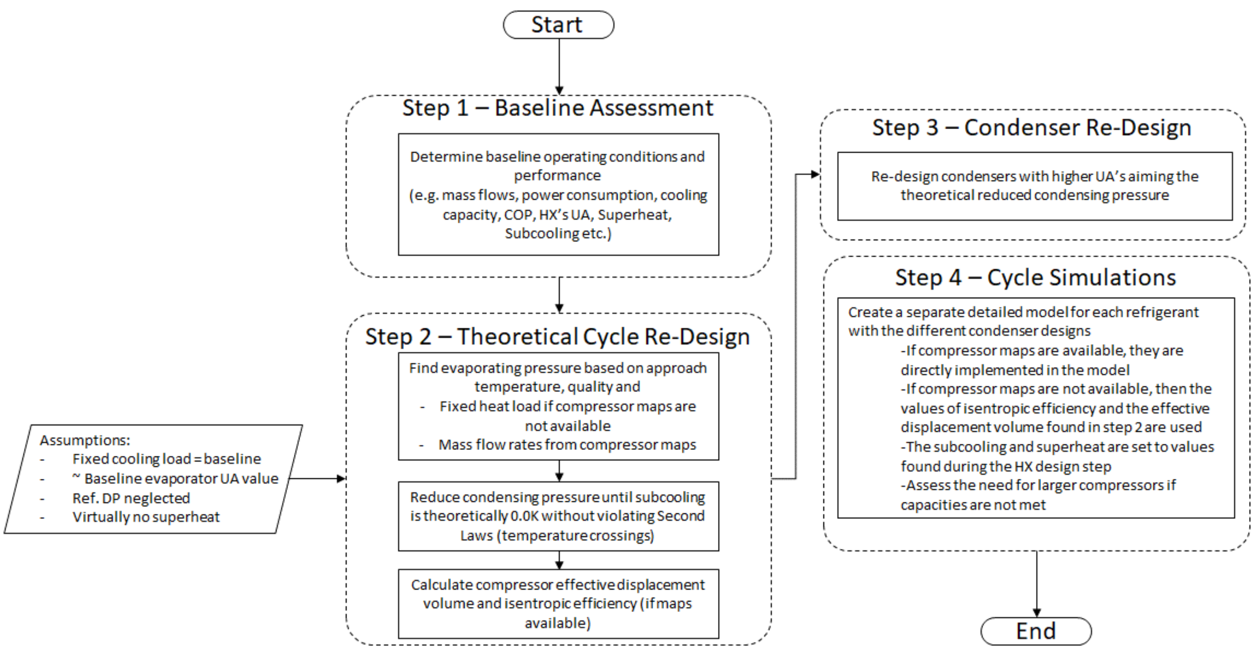


Figure 7. System Re-Design Framework,

4.3.1. Compressors

Modeling compressors are handled in two possible ways, as suggested previously: using performance maps when available or using fixed isentropic efficiency and effective displacement volume. For the larger capacity units (6 and 10), performance maps were provided. Although these compressors were originally designed for R410A refrigerant they may operate – not necessarily optimally – with other refrigerants. Compressor manufacturers supporting this project used proprietary simulation tools, with aid from available empirical data (tests with other refrigerants), to develop theoretical maps for the various refrigerants of interest (Table 5) and made them available to OTS for modeling purposes. It is understood that the predictions are for reference only, and the compressor manufacturer does not guarantee performance for any refrigerants for which the compressors haven't been fully tested.

Table 5: Compressor Models.

Model	Capacity (BTU/hr)	Frequency (Hz)	Refrigerants
ZP20K5E-PFV	24,000	60	R32, R459A, R454B, R410A
ZP21K5E-PFV	24,000		
ZP31K6E-PFV	36,000	50/60	R447B, R452B, R454B, R410A
ZP34K6E-PFV	36,000		

For the smaller units (1 and 4), which were re-designed using R290 (Propane), compressor performance maps were not available. The approach for these units then was to set a target isentropic efficiency of 0.7 (baseline data suggests that the compressor efficiencies ranged from 0.55 to 0.65). The required mass flow rate is calculated based on capacity in the theoretical cycle model described above. From there, the effective displacement volume can be determined (eq. (1))[1]. The latter serves to determine whether a system can use the same compressors for different refrigerants.

$$V_{eff} = \eta_{vol} \cdot V_{disp} = \frac{\dot{m}_{required}}{f \cdot \rho_{suction}} \tag{1}$$

4.3.2. HX Design and Selection

The condensers design procedure takes into consideration the following:

- **Face area**: baseline face area must be preserved or at most reduced. Furthermore, the aspect ratio must also match that of the baseline so the HX can be drop-in replaced in the same cabinet.
    - Find the number of tube rows and tube length to match as closely as possible to tube face area and aspect ratio

- **Airside pressure drop and flow rate**: the test data from reports contain only air flow rate measurements, while no information on pressure drop is provided. Additionally, the fan performance curves are also not available, which limits the ability to find the exact operating condition. The baseline models provide an estimate prediction for the pressure drop, which is used as reference.

- **Thermal performance**: this step must be iteratively conducted with the previous step, as such for each design change the air flow rate and capacity are evaluated under the new conditions found in the theoretical cycle re-design.
    - Gradually increment the condensing pressure until attainable performance is achieved. This process is done iteratively using the theoretical cycle model, to find new expected operating conditions for evaporating pressure, superheat, subcooling and refrigerant flow rate.

- **HX Form**: as indicated previously, the HX design is constrained by cabinet dimensions as well as form. In the case of units 1 and 4, the condensers are flat coils placed 90° inside the cabinet (Figure 8), which makes it simpler for drop-in replacement as long as new designs have the same overall dimensions. For units 6 and 10, however, the condensers are L-shaped inside the cabinet (Figure 8). Forming coils is widely done, however, for custom coils it may be a challenge, in particular for MCHX. For this reason, the MCHX designs for units 6 and 10 are sized for a full-face area, assuming the coil can be formed, and a second design that is a single flat slab placed in longer side of the "L" shape(Figure 9).

[1] Variable definitions in the Nomenclature list after final conclusions section in this document.

- **HX Name Tag Convention:** for practical purposes, the HX's will be tagged according to the following W XX YY Z
    - **W:** B = Baseline or N = New Design
    - **XX:** TF **=** Tube-Fin or MC = Microchannel
    - **YY:** D# = Tube Diameter or Height
    - **Z:** R = Reduced Face Area
    - **Example:** New Tube Fin Design with 5.0mm diameter with same face area as the baseline → NTFD5

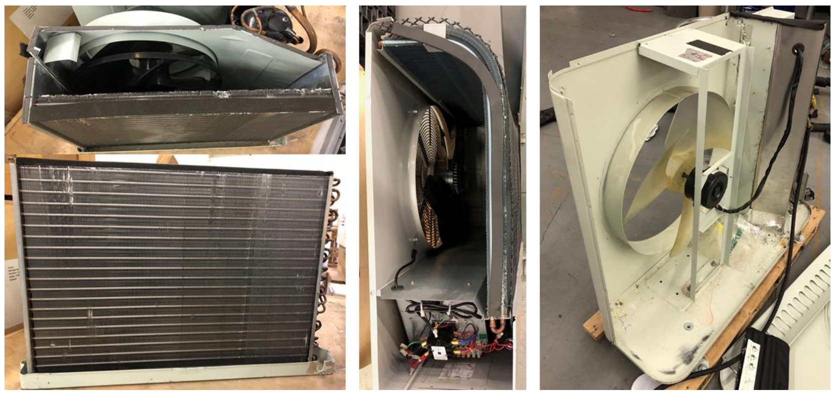


Figure 8. Condenser Forms: Unit 1 (left), Unit 10 (center), Unit 6 Cabinet (right).

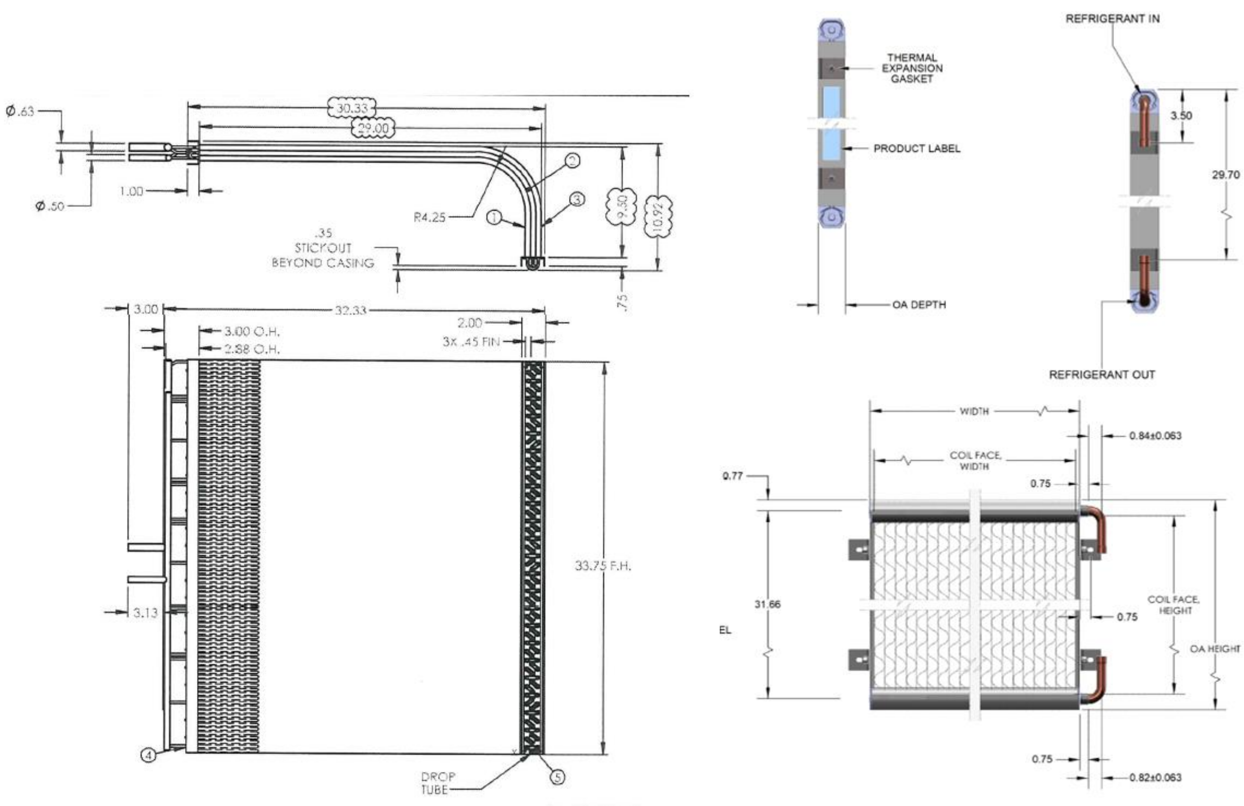


Figure 9. HX Form Examples: L-shape (left), Flat (right).

4.3.3. System Design

In the final step, the modified systems are evaluated holistically through system level modeling and simulation using an in-house Steady-State vapor compression cycle software that has the capability to integrate with the HX and compressor models (performance maps, generic etc.). For each modified system and each refrigerant, a system model was created.

4.4. Modified Systems Results Summary

The final results of Activity 2 are summarized in Table 6. For more detailed results in the framework steps refer to APPENDIX A .

4.5. Conclusions and Recommendations

This section presents a systematic approach based on first order analysis providing educated guidance towards the direction of more efficient systems with fewer simulations and minimal changes to the systems. The study includes a wide variety of refrigerants as well as condenser designs and compressor model options. Given the challenges with original test data the baseline models serve as a numerical reference only. The findings are strictly valid to comparisons against the baseline models and OTS does not guarantee that results would be reflected in actual systems as herein reported. The key conclusions and recommendations are:

1- R290 and R32 have wider saturation regions allowing the system to operate with smaller superheat and subcooling, while benefiting from two-phase heat transfer.

2- Refrigerants with high temperature glide may require new heat exchanger (HX) designs, namely condensers. The original designs proved to be sufficiently effective to allow for most systems to operate with the different refrigerants, however, better designs would allow for higher system efficiency and potentially less charge. HX designs are severely constrained by allowed envelope dimensions. A complete system re-design would provide an opportunity for designing HX's with even higher efficiency.

3- The results of this analysis suggest that for an effective use of alternate low-GWP refrigerant, a proper compressor selection must be accompanied with it. Higher isentropic efficiencies are desired for higher temperatures, but most importantly, the displacement volume requirements can vary considerably from one refrigerant to another.

4- It is also imperative that having an active expansion device (preferably an EXV) to not only allow for more controlled superheat, but also to enable the unit to run with different refrigerants with very different thermophysical properties.

Table 6: Activity 2 Results.

General Information			Hardware					Ref.	Performance			
System	Rated Capacity (@35°C)	System Configuration	Compressor		Condenser		Expansion Device		Cooling Capacity (@46°C)		EER (@46°C)	
-	BTU/hr	-	Effective Disp. Vol. (cm³)*	Efficiency (-)	Type	Effectiveness (-)	Type	-	BTU/hr	%	BTU/hr. W	%
Unit 1	18000	**Baseline**	**19.8**	**0.66**	**Tube-Fin (5mm Tube)**	**0.20**	**Passive**	**R444B**	**17403**	**0.00%**	**7.4**	**0.00%**
		Alternate 1	25.9	0.70	Same as Baseline	0.35	Active (EXV)	R290	17639	1.40%	8.01	8.20%
		Alternate 2	24.8	0.69		0.26		R454C	18104	4.00%	7.31	-1.30%
		Alternate 3	19.6	0.70		0.23		R444B	18140	4.20%	8.14	9.90%
		Alternate 4	25.3	0.68	MCHX	0.24		R457A	17749	2.00%	7.63	3.10%
Unit 4	24000	**Baseline**	**26.4**	**0.61**	**Tube-Fin (9.5mm Tube)**	**0.24**	**Passive**	**R290**	**17940**	**0.00%**	**7.52**	**0.00%**
		Alternate 1	26.3	0.70	Tube-Fin (5mm Tube)	0.26	Active (EXV)	R290	18147	1.20%	9.12	21.40%
		Alternate 2	37.9	0.70		0.20		R290	24120	34.40%	6.72	-10.60%
Unit 6	24000	**Baseline**	**16.0**	**0.60**	**Tube-Fin (7mm Tube)**	**0.12**	**Passive**	**R32**	**23115**	**0.00%**	**8.46**	**0.00%**
		Alternate 1	16.9	0.65	Tube-Fin (5mm Tube)	0.15	Active (EXV)	R32	23798	3.00%	9.41	11.20%
		Alternate 2	18.4	0.67		0.19		R454B	22894	-1.00%	9.71	14.80%
		Alternate 3	19.0	0.70		0.17		R452B	23702	2.50%	9.6	13.50%
Unit 10	36000	**Baseline**	**19.6**	**0.44**	**Tube-Fin (9.5mm Tube)**	**0.13**	**Passive**	**R32**	**29005**	**0.00%**	**6.39**	**0.00%**
		Alternate 1	22.3	0.65	Tube-Fin (5mm Tube)	0.25	Active (EXV)	R447B	30478	5.10%	9.43	47.50%
		Alternate 2	23.0	0.67		0.25		R452B	30796	6.20%	10.27	60.70%
		Alternate 3	23.3	0.67		0.25		R454B	30809	6.20%	10	56.50%

** Product of displacement volume and volumetric efficiency*

5. Activities 3, 4 & 5 - Prototype Units Fabrication, Evaluation of the Optimized Prototypes and Analyzing Leaks of Alternatives

Activities 3-5 officially began in April 2019 when the first round of tests on modified Unit 6 were carried out. Initial tests resulting in unsuccessful outcomes leading OTS to change the system modifications and the scope. Additional information found in APPENDIX B . The detailed test data and charge optimization for Units 6 and 10 are presented in APPENDIX C through APPENDIX E . Comparisons between Activity 2 model validations and experimental data are presented in APPENDIX F .

5.1. Unit 6

Some modifications were made to Unit 6 to improve its efficiency. The baseline compressor was replaced with alternate models to account for the change in refrigerant and to improve efficiency. The compressor used with R454B had a higher displacement volume than the one used with R32. Furthermore, the capillary tubes were replaced with a manual TXV that was installed directly at the evaporator inlet to increase the cooling capacity of the evaporator. A summary of the design modifications evaluated for Unit 6 is listed in Table 7, while Table 8 and Table 9 show the performance of Unit 6 for baseline and modifications at 35°C and 46°C ambient, respectively. The baseline system performed similar, within 2%, to reported performance in PRAHA I. There is a discrepancy in the measurements from condenser outlet to expansion inlet in the baseline case, since the capillary tube (removed in the modified systems) was located in the outdoor unit The expansion causes the refrigerant to flash in the liquid line thus compromising the readings at the expansion device. For calculation purposes, the condenser outlet enthalpy was used instead of the expansion inlet.

Table 7: Unit 6 Modifications for Testing.

System	Unit 6		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R32	R454B
Compressor	GMCC KSG226N1UMT	Copeland ZP20K5E	Copeland ZP21K5E
Expansion Device	Capillary Tube (Outdoor unit)	Manual Valve (Indoor Unit)[2]	Manual Valve (Indoor Unit)[2]

Cooling capacity for the modified unit with either refrigerant was consistently lower by 6-12% than the baseline. The modified R32 system reportedly showed lower mass flow rate than expected, likely the main cause for the lower-than-expected thermal performance. The R454B system resulted in a poorer performance but was less sensitive to ambient temperature than its R32 counterpart - i.e. cooling capacity was near the same at both 35°C and 46°C, while for R32 there was a ~2,000BTU/hr reduction with the temperature increase. It is also possible that there is a mismatch between thermophysical property library and actual refrigerant properties for R454B which can happen with newer fluids. The libraries need periodic update as more test data become available.

[2] A manual valve was used to mimic a TXV or EXV recommended as component modification in these systems configurations.

Table 8: Unit 6 - Performance Test Summary for R32 Baseline (OTS) @ 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**R32**	**R454B**	**-**	**-**
Charge	lb	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	25192	23585	21966	-6.4%	-12.8%
Energy Balance	%	-2.28%	-4.66%	-3.06%	-	-
Compressor Power	kW	2.11	1.79	1.77	-15.1%	-16.2%
Fan Power	kW	0.32	0.33	0.33	2.2%	4.2%
Total Power	kW	2.43	2.12	2.10	-12.8%	-13.5%
EER	BTU/hr.W	10.37	11.12	10.44	7.2%	0.68%

Table 9: Unit 6 - Performance Test Summary for R32 Baseline (OTS) @ 46°C.

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**R32**	**R454B**	**-**	**-**
Charge	lb	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	23390	21450	21821	-8.3%	-6.7%
Energy Balance	%	-1.78%	-4.42%	-7.61%	-	-
Compressor Power	kW	2.71	2.32	2.25	-14.2%	-16.6%
Fan Power	kW	0.40	0.42	0.42	5.3%	5.3%
Total Power	kW	3.10	2.74	2.67	-11.7%	-13.8%
EER	BTU/hr.W	7.55	7.84	8.17	3.8%	8.2%

5.2. Unit 10

Applying what was learned in the initial modifications to Unit 6, modifications to Unit 10 were limited to include the compressor and expansion device only. Unlike Unit 6, however, the re-test of the baseline system was not successful; refer to APPENDIX D for additional information. However since Unit 6 baseline re-test showed good reproducibility from original data, it is assumed that the Unit 10 original baseline is appropriate for comparison against the modified system configurations. A summary of the design modifications evaluated for Unit 10 is listed in Table 10. The detailed test data is presented in APPENDIX E .

At 35°C the modified units exhibited almost 20% less cooling capacity with 10% less power consumption, resulting in up to 11% less EER (Table 11). These results were not unexpected since the modified units were re-designed using the 46°C temperature, when the baseline system's performance showed a great degradation of performance. At 46°C condition, the tests exhibited 2-5% greater cooling capacity with up to 12% less power consumption compared to the baseline, which was equivalent to 13-17% greater system performance.

In Activity 2 the compressor power consumptions were underestimated, as well as the total fan power consumption, leaving the impression the overall performance improvement would considerably be greater than the observed. The cooling capacity, on the other hand, was predicted with less than 2% deviation from test data, validating at least the models created.

Table 10: Unit 10 Modifications for Testing.

System	Unit 10		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R447B	R452B
Compressor	Copeland ZP42K6E	Copeland ZP34K5E	Copeland ZP31K5E
Expansion Device	Orifice	Manual Valve	Manual Valve

Table 11: Unit 10 - Performance Test Summary for R32 Baseline @ 35°C.

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**447B**	**452B**	**-**	**-**
Charge	lb	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	35543	32195	28128	-9.42%	-20.86%
Energy Balance	%	---	7.52%	-3.29%	-	-
Compressor Power	kW	-	2.67	2.4	-	-
Fan Power	kW	-	0.95	0.98	-	-
Total Power	kW	3.761	3.62	3.38	-3.75%	-10.13%
EER	BTU/hr.W	9.451	8.894	8.322	-5.89%	-11.94%

Table 12: Unit 10 - Performance Test Summary for R32 Baseline @ 46°C.

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	**-**	**R32**	**447B**	**452B**	**-**	**-**
Charge	lb	5.625	6.625	6.625	17.78%	17.78%
Cooling Capacity	BTU/hr	29633	31073	30292	4.86%	2.22%
Energy Balance	%	---	4.21%	1.21%	-	-
Compressor Power	kW	---	3.18	2.93	-	-
Fan Power	kW	---	0.95	0.97	-	-
Total Power	kW	4.466	4.13	3.9	-7.52%	-12.67%
EER	BTU/hr.W	6.64	7.52	7.76	13.33%	16.95%

5.3. Leak Tests

In the interest of time the leak tests were conducted only on Unit 10 for R447B. The choice of refrigerant was based on temperature glide, where R447B exhibits the highest glide amongst the refrigerants evaluated between Unit 6 and Unit 10 (refer to Figure 4). The leak tests were conducted to closely represent field operation. The procedure applied includes the following steps:

1- Run unit until steady-state is achieved (repeat 46°C performance test), monitoring capacity and subcooling
2- Gradually remove refrigerant from vapor line until capacity is reduced to approximately 50%, if possible
3- Store and weigh removed refrigerant
4- Re-charge with new refrigerant until same subcooling is achieved
5- Compare cooling capacities; if more than 5% deviation is observed, repeat steps 1-4, however in step 2, reduce capacity to 25% only
6- Repeat steps 1-5 for the liquid line

The comparison herein presented refers to a leakage of approximately 30% of charge, while reducing capacity by approximately 50% based on airside only. The leak tests showed less than 2% deviation in cooling capacity after re-charge from both vapor and liquid lines (Table 13). Since the capacity deviation was less than 5%, no further testing for 25% capacity reduction was conducted. The results suggest little impact due to fractionation.

Table 13: Unit 10 – R447B Leak Test Summary Results.

System			***Liquid Line Leak***		***Vapor Line Leak***	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Charge	lb	6.625	4.27	6.625	4.23	6.77
Cooling Capacity	BTU/hr	31073	14216	30865	15171	30587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	-[3]
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	-[3]
EER	BTU/hr.W	7.52	3.64	7.42	3.87	-[3]

5.4. Conclusions and Recommendations

This section presented the performance tests conducted on units 6 and 10. The key conclusions and recommendations are:

1- Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing. It should be stressed that the baseline unit by design had its capillary tube located in the outdoor unit. This would cause liquid refrigerant leaving the outdoor unit to flash. The refrigerant enthalpy at the condenser outlet state was used to calculate the refrigerant-side capacity assuming an isentalphic expansion without heat loss in connecting pipe. This is different from the modified systems of which the capillary tube was removed, and a manual expansion valve was placed at the inlet of the indoor unit. For modified systems, the enthalpy at the expansion valve inlet was used to calculate the refrigerant-side capacity.

2- Unit 10 exhibited a considerable reduction in power consumption at the high ambient test condition (46°C) as compared to the original test data. This also indicates the importance of proper compressor selection.

3- The higher-than-expected power consumption in the Unit 10 baseline tests is also evidenced by the fact that even with zeotropic mixtures (R447B and R452B), Unit 10 had higher cooling capacity and efficiency than the baseline for the 46°C test condition, as projected in activity 2.

4- Because of the differences in saturation curves from the Activity 2 analysis, R32 tends to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed however, that making appropriate component selection, such as compressors with larger displacement volumes and higher mass flow rates for the zeotropic mixtures, cooling capacities and overall performance were of the same order of magnitude.

5- Refrigerant fractionation as evidenced by the leak tests, does not appear to be a great concern since less than 2% deviation in cooling capacity was observed after the system's re-charge.

6- The Unit 6 modified systems had lower performance than expected from the Activity 2 models. The R32 system configuration exhibited more than 10% less flow rate than anticipated due to performance

[3] Compressor power consumption was not properly recorded for this test; the error was identified after the fact and the team was unable to retrieve that information. While that compromises the assessment of the overall system performance, the deviations are expected to be marginal. The leak test on liquid line suggest minimal impact on power consumption after re-charge, while cooling capacity was reportedly fully recovered after recharge on both leak tests.

maps overprediction, which corresponded to 10% lower capacity. The R454B configuration exhibited a deviation of 5% between model and test due also in part to a 3% flow rate over prediction in the model. Unit 10, on the other hand, exhibited an excellent agreement to the models with less than 2% deviation in cooling capacity.

7- The model's validation adds confidence in the numerical simulation findings and recommendations provided in activity 2.

6. Conclusions

This report presents a comprehensive set of activities with the objectives of advancing the PRAHA program. The original scope and schedule were modified during the project as new findings and challenges surfaced. The tests that were carried out for PRAHA-I, while sufficient for the purpose of measuring capacity and energy efficiency for the purposes of PRAHA-I, did not have enough essential data to enable a complete cycle evaluation for optimization purposes. This is primarily due to using standard test rig on systems with critical hardware configuration differences. The analyses presented in Activity 2 (design assessment through modeling) provided good insights on adequate component design and/or selection for proper system functioning, when using novel refrigerants.

The final recommendations for future development are listed as follows:

1- Establish a baseline system by conducting comprehensive testing including measurements and metrics not typically performed in energy certification tests. Furthermore, testing systems with different configurations require custom test rigs as such to adequately measure working fluid's states to avoid mischaracterization of the operating conditions and performance. Such approach is considerably more labor-intensive which should be factored in the scope in future developments.

2- Using alternate low-GWP refrigerants is viable and can be competitive to presently used refrigerants but doing so requires proper component design and selection; compressor and expansion device particularly. Drop-in replacement without hardware change is never recommended as evidenced by the change requirements in Activity 2 and performance tests in the subsequent activities.

3- It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses that will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.

4- Always test the modified systems with the same instrumentation as the baseline, however mindful of the modifications as such to properly place sensors to obtain adequate readings as suggested in item 1 above.

Nomenclature

COP	Coefficient of Performance	-
D_o	Tube Outer Diameter	mm
f	Frequency	Hz
FPI	Fins per Inch	1/in
h	Enthalpy	kJ/kg
h_t	Tube Height	mm
HX	Heat Exchanger	-
$\dot{m}$	Mass Flow Rate	kg/s
MCHX	Microchannel Heat Exchanger	-
P	Pressure	kPa
P_l	Tube Longitudinal Pitch	mm
P_t	Tube Transverse Pitch	mm
s	Entropy	kJ/kg.K
T	Temperature	°C
TFHX	Tube-Fin Heat Exchanger	-
UA	Thermal Conductance	kW/K
V	Volume	m^3
w_t	Tube Width	mm
η_{vol}	Volumetric Efficiency	-
ρ	Density	kg/m^3

APPENDIX A - Activity 2 Design Framework Results

Table 14: Unit 1 – Theoretical Cycle Re-Design Summary.

System		*Baseline*	*Alternative 1*	*Alternative 2*	*Alternative 3*	*Alternative 4*
Case	-	**Simulation**	**Target**			
Refrigerant	**-**	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Condenser	-	BTFD5	-	-	-	-
Compressor	-	SL260DG-C8EU	-	-	-	-
Cooling Capacity	BTU/hr	17403	17477	17477	17477	17477
Compressor Power	kW	1.92	1.49	1.49	1.33	1.43
Fan Power	kW	0.43	0.43	0.43	0.43	0.43
Total Power	kW	2.35	1.92	1.93	1.76	1.86
COP	-	2.17	2.66	2.66	2.91	2.75
COP Gain	-	1.00	1.23	1.23	1.34	1.27

Table 15: Unit 1 – HX Analysis Summary

Condenser		**R444B**		**R290**		**R454C**		**R457A**	
Inputs		***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***	***BTFD5***	***NMCD2***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Refrigerant Pressure	kPa	2875.0	2875.0	2170.7	2170.7	2436.4	2436.4	2183.9	2183.9
Saturation Temperature at Inlet	°C	61	61	61	61	61	61	61	61
Refrigerant Temperature	°C	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Mass Flow Rate	kg/s	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03
Outputs									
Heat Load	W	7512.9	7441.2	8232.4	8016.6	6168.0	6040.0	6592.0	6429.0
Air Dry-Bulb Temperature	°C	58.6	58.2	59.7	59.6	56.3	56.3	57.0	56.9
Refrigerant Temperature	°C	46.7	48.1	50.3	53.8	47.2	49.5	48.0	51.1
LMTD	°C	12	15	19	23	14	18	16	21
UA	W/K	635.57	482.84	439.36	350.35	451.67	327.93	424.35	313.48
NTU	-	1.04	0.79	0.72	0.57	0.74	0.53	0.69	0.51
Effectiveness	-	0.1915	0.1896	0.2098	0.2043	0.1572	0.1539	0.1680	0.1638
Refrigerant Pressure Drop	kPa	78.2	1.4	85.0	1.7	79.3	1.4	87.2	1.7
Airside DP	Pa	75.1	75.5	75.1	75.5	75.1	75.5	75.1	75.5
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	130.0	148.3	130.0	148.3	130.0	148.3	130.0	148.3
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	3341.0	1721.0	4113.0	2033.0	3040.0	1382.0	3423.0	1601.0
Subcooling	°C	13.20	13.14	8.96	7.35	6.77	5.93	5.34	4.05
Charge	kg	0.3822	0.1143	0.1079	0.0352	0.3097	0.094	0.2522	0.0764

Table 16: Unit 1 – Compressor Performance Summary.

Compressor		Baseline				
Refrigerant	-	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Isentropic efficiency	-	0.66	0.70	0.69	0.70	0.68
Power	kW	1.9175	1.7682	2.0449	1.7966	1.8932
Pressure Lift	kPa	2284.8	1556.0	2087.7	1902.2	1904.9
Effective Displacement Volume	cm^3	19.80	25.87	24.80	19.64	25.35
Rotation Speed	RPM	3600	3600	3600	3600	3600

Table 17: Unit 1 – Expected Modified System Performances.

System		*Baseline*				
Case	-	**Simulation**	**Expected**			
Refrigerant	**-**	**R444B**	**R290**	**R454C**	**R444B**	**R457A**
Condenser	-	BTFD5	BTFD5	BTFD5	BTFD5	NMCD2
Compressor	-	SL260DG-C8EU	-	-	-	-
Cooling Capacity	BTU/hr	17403	17639	18104	18140	17749
Compressor Power	kW	1.92	1.77	2.04	1.80	1.89
Fan Power	kW	0.43	0.43	0.43	0.43	0.43
Total Power	kW	2.35	2.20	2.48	2.23	2.33
COP	-	2.17	2.35	2.14	2.38	2.24
COP Gain	-	1.00	1.08	0.99	1.10	1.03

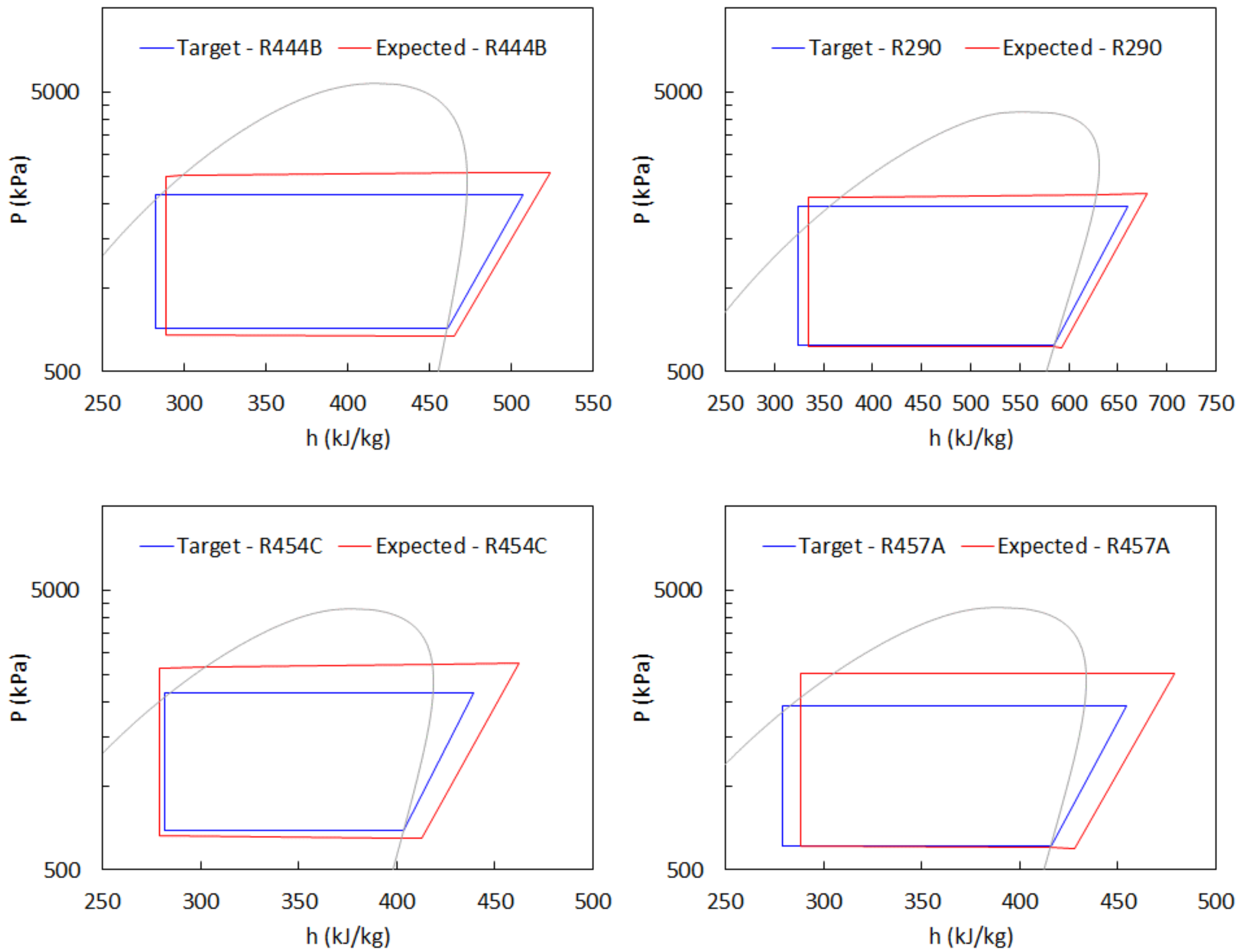


Figure 10. Unit 1 – Modified Systems P-h Diagrams.

Table 18: Unit 4 – Theoretical Cycle Re-Design Summary.

System		***Baseline***	***Alternative 1***	***Alternative 2***
			Target	
Refrigerant	-	**R290**	**R290**	**R290**
Condenser	-	BTFD9	-	-
Compressor	-	PSH356DG-C8DU4	-	-
Cooling Capacity	BTU/hr	17940	17940	23920
Compressor Power	kW	2.11	1.40	3.23
Fan Power	kW	0.28	0.28	0.28
Total Power	kW	2.39	1.68	3.51
COP	-	2.20	3.14	2.00
COP Gain	-	1.00	1.42	0.91

Table 19: Unit 4 – HX Analysis Summary.

Condenser		**R290 - 18kBTU**		**R290 - 24kBTU**	
Inputs		***BTFD9***	***NTFD5***	***BTFD9***	***NTFD5***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	0.81	0.76	0.81	0.76
Refrigerant Pressure	kPa	2875	2875	2875	2875
Saturation Temperature at Inlet	°C	75.5	75.5	75.5	75.5

Condenser		R290 - 18kBTU		R290 - 24kBTU	
Inputs		***BTFD9***	***NTFD5***	***BTFD9***	***NTFD5***
Refrigerant Temperature	°C	110	110	110	110
Mass Flow Rate	kg/s	0.02	0.02	0.03	0.03
Outputs					
Heat Load	W	8139	8148	12080	12190
Air Dry-Bulb Temperature	°C	55.0	56.1	59.5	61.2
Refrigerant Temperature	°C	46.2	46.0	47.7	46.4
LMTD	°C	9.6	7.4	14.3	10.0
UA	W/K	848	1097	846	1216
NTU	-	0.97	1.34	0.97	1.48
Effectiveness	-	0.15	0.16	0.22	0.23
Refrigerant Pressure Drop	kPa	4.2	13.4	11.0	35.2
Airside DP	Pa	16.0	15.9	16.0	15.9
Air Heat Transfer Coefficient (Average)	W/m².K	82.9	100.7	82.9	100.7
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	1535.2	1493.7	2382.4	2505.6
Subcooling	°C	29.2	29.2	27.6	28.4
Charge in Tubes	kg	0.90	0.46	0.76	0.39

Table 20: Unit 4 – Compressor Performance Summary.

Compressor		**Baseline**	**18kBTU/Hr**		**24kBTU/Hr**	
Refrigerant	**-**	**R290**	**R290**	**R290**	**R290**	**R290**
Isentropic efficiency	-	0.61	0.70	0.70	0.70	0.70
Power	kW	2.1067	1.7364	1.7093	3.3152	3.31
Pressure Lift	kPa	1457.6	1556.3	1513.7	2947.1	2937.4
Effective Displacement Volume	cm³	26.394	26.309	26.309	37.866	37.866
Rotation Speed	RPM	3600	3600	3600	3600	3600

Table 21: Unit 4 – Expected Modified System Performances.

System		***Baseline***	***Alternative 1***		***Alternative 2***	
			Expected			
Refrigerant	**-**	**R290**	**R290**	**R290**	**R290**	**R290**
Condenser	-	BTFD9	BTFD9	NTFD5	BTFD9	NTFD5
Compressor	-	PSH356DG-C8DU4	-	-	-	-
Cooling Capacity	BTU/hr	17940	17991	18147	24045	24120
Compressor Power	kW	2.11	1.74	1.71	3.32	3.31
Fan Power	kW	0.28	0.28	0.28	0.28	0.28
Total Power	kW	2.39	2.02	1.99	3.60	3.59
COP	-	2.20	2.61	2.67	1.96	1.97
COP Gain	-	1.00	1.19	1.21	0.89	0.89

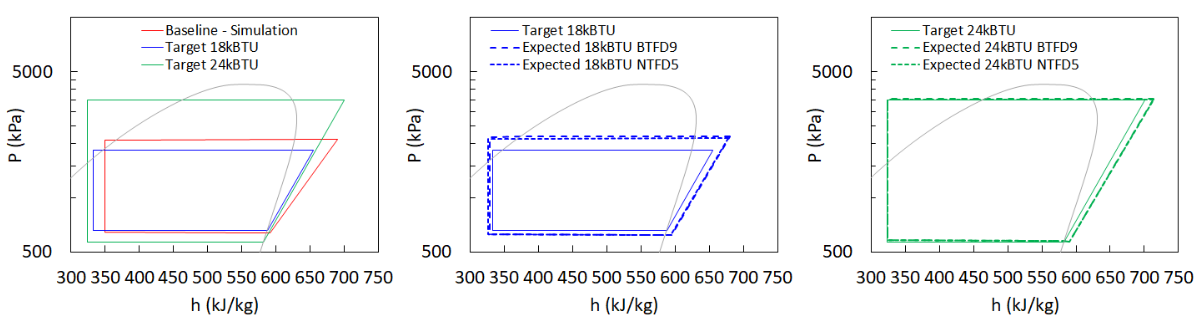


Figure 11. Unit 4 – Modified Systems P-h Diagrams.

Table 22: Unit 6 – Theoretical Cycle Re-Design Summary.

System			*Alternate 1*	*Alternate 2*	*Alternate 3*
		Simulation	Target		
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R452B**
Condenser	-	BTFD9	-	-	-
Compressor	-	GMCC KSG226N1UMT	ZP20K5E	ZP21K5E	-
Cooling Capacity	BTU/hr	23115	23114	23114	23115
Compressor Power	kW	2.73	2.37	2.29	2.04
Fan Power	kW	8.46	9.75	10.10	11.31
Total Power	kW	2.73	2.37	2.29	2.04
COP	-	2.48	2.86	2.96	3.32
COP Gain	-	1.00	1.15	1.19	1.34

Table 23: Unit 6 – HX Analysis for R32

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3562	3562	3562	3562
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	9159	9416	9332	9113
Air Dry-Bulb Temperature	°C	53.63	55.35	54.27	55.24
Refrigerant Temperature	°C	49.78	46.15	47.40	50.47
LMTD	°C	19.94	9.46	15.13	20.57
UA	W/K	459.40	995.12	616.75	443.09
NTU	-	0.39	0.97	0.52	0.43
Refrigerant Pressure Drop	kPa	100.98	26.10	3.06	4.70
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	5543.00	2624.00	2353.00	2978.00
Subcooling	°C	4.48	9.04	8.10	5.07
Charge	kg	0.39	0.71	0.17	0.11

Table 24: Unit 6 – HX Analysis for R452B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m^3/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3247	3247	3247	3247
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7876	7964	7936	7866
Air Dry-Bulb Temperature	°C	52.52	53.94	53.06	53.99
Refrigerant Temperature	°C	47.41	46.05	46.53	47.61
LMTD	°C	15.49	8.09	12.37	15.72
UA	W/K	508.37	984.95	641.46	500.33
NTU	-	0.43	0.96	0.55	0.49
Refrigerant Pressure Drop	kPa	71.90	21.03	2.60	3.70
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	4252.00	2077.00	2103.00	2112.00
Subcooling	°C	6.14	8.20	7.99	6.89
Charge	kg	0.55	0.90	0.21	0.15

Table 25: Unit 6 – HX Analysis for R447B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m³/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3025	3025	3025	3025
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7607	8241	8157	7914
Air Dry-Bulb Temperature	°C	52.41	54.19	53.25	54.04
Refrigerant Temperature	°C	50.00	46.24	47.63	51.40
LMTD	°C	20.58	10.45	15.92	22.14
UA	W/K	369.65	788.34	512.32	357.47
NTU	-	0.31	0.77	0.44	0.35
Refrigerant Pressure Drop	kPa	185.90	27.30	3.18	4.90
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	W/m².K	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	5396.00	2439.00	2397.00	3281.00
Subcooling	°C	0.00	6.05	5.17	1.22
Charge	kg	0.33	0.70	0.16	0.11

Table 26: Unit 6 – HX Analysis for R454B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46.01	46.01	46.01	46.01
Relative Humidity	%	16.37	16.37	16.37	16.37
Air Flowrate	m³/s	1.08	0.94	1.08	0.94
Refrigerant Pressure	kPa	3204	3204	3204	3204
Saturation Temperature at Inlet	°C	55.53	55.53	55.53	55.53
Refrigerant Temperature	°C	112.00	112.00	112.00	112.00
Mass Flow Rate	kg/s	0.03	0.03	0.03	0.03
Outputs					
Heat Load	W	7993	8094	8060	7976
Air Dry-Bulb Temperature	°C	52.61	54.06	53.16	54.10
Refrigerant Temperature	°C	47.59	46.06	46.61	47.91
LMTD	°C	15.95	8.28	12.72	16.40
UA	W/K	501.09	977.17	633.67	486.37
NTU	-	0.43	0.96	0.54	0.48
Refrigerant Pressure Drop	kPa	74.70	22.02	2.70	4.10
Airside DP	Pa	26.30	29.30	27.70	28.90
Air Heat Transfer Coefficient (Average)	W/m².K	109.57	126.69	128.70	130.84
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	4445.93	2140.00	2008.00	2201.00
Subcooling	°C	5.75	8.03	7.75	6.43
Charge	kg	0.51	0.87	0.20	0.14

Table 27: Unit 6 – Compressor Performance Summary.

		Baseline	***Alternate 1***	***Alternate 2***	***Alternate 3***
Refrigerant		***R32***	***R32***	***R454B***	***R452B***
Isentropic Efficiency	-	0.60	0.64	0.66	0.70
Volumetric Efficiency	-	-	0.87	0.90	-
Displacement Volume	cm³	-	19.34	20.31	-
Frequency	Hz	60	60	60	60
Effective Displacement	cm³	16.0	16.8	18.3	19.0
Compressor Power	kW	2.4	2.3	2.3	2.1

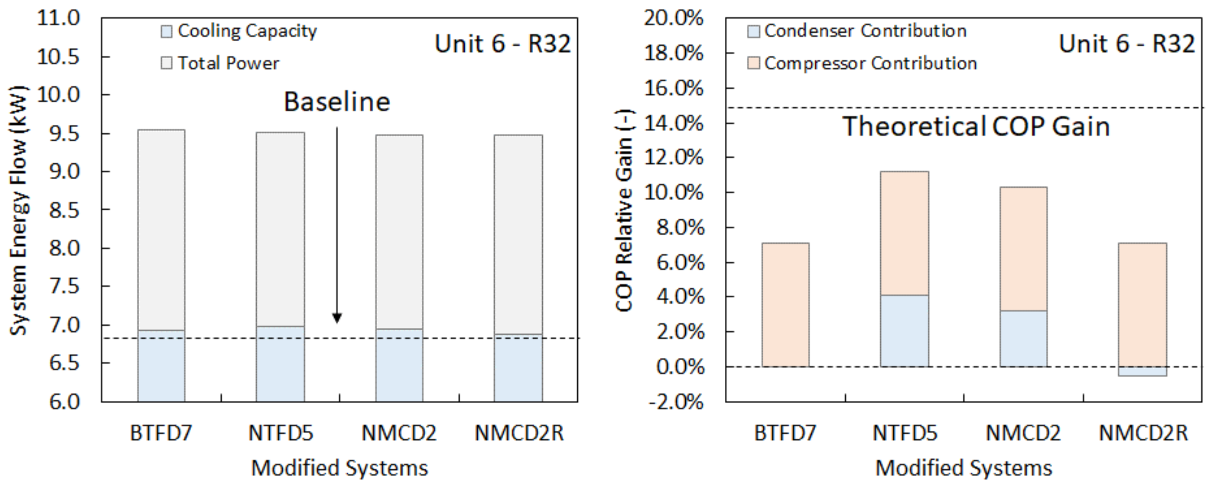


Figure 12. Unit 6 – System Level Analysis: Performance Results for R32.

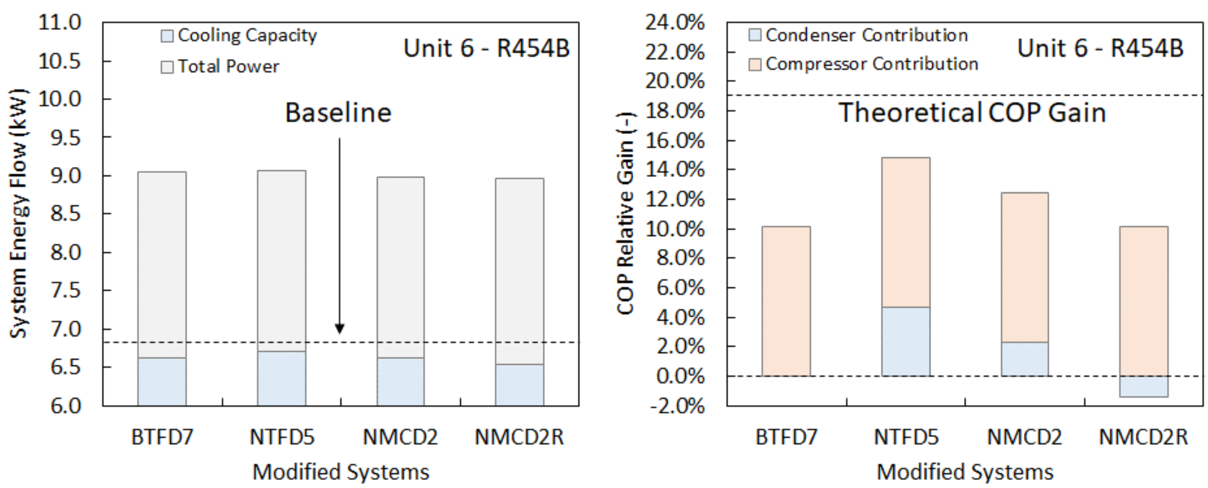


Figure 13. Unit 6 – System Level Analysis: Performance Results for R454B.

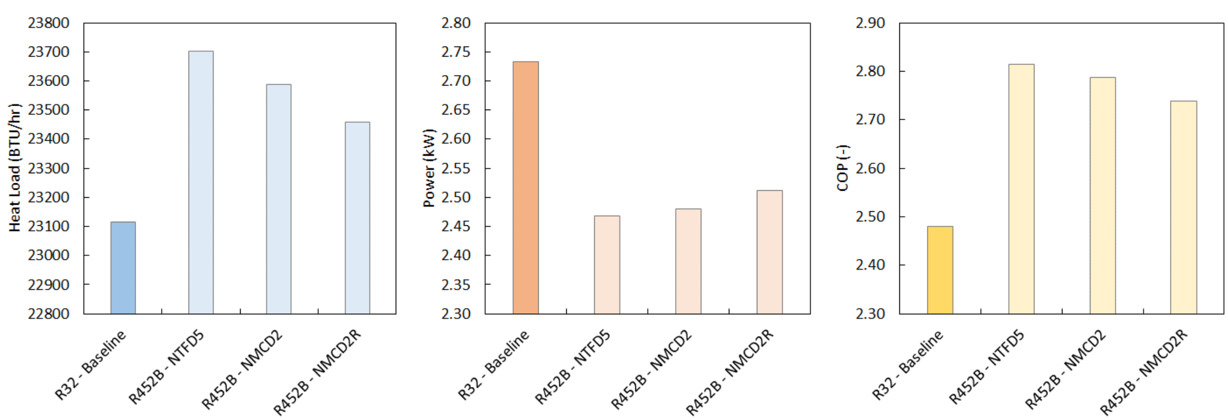


Figure 14. Unit 6 - Comparative System Performance Summary for R452B.

Table 28: Unit 10 – Theoretical Cycle Re-Design Summary.

System		*Baseline*	*Alternate 1*	*Alternate 2*	*Alternate 3*
		Simulation		**Target**	
Refrigerant	**-**	**R32**	**R452B**	**R447B**	**R454B**
Condenser	-	BTFD9	-	-	-
Compressor	-	ZP42K5E	ZP31K5E	ZP34K5E	ZP31K5E
Cooling Capacity	BTU/hr	29005	34311	31611	34608
Compressor Power	kW	3.84	2.81	2.31	2.65
Fan Power	kW	0.70	0.70	0.70	0.70
Total Power	kW	4.54	3.51	3.01	3.35
COP	-	1.87	2.87	3.08	3.03
COP Gain	-	1.00	1.53	1.64	1.62

Table 29: Unit 10 – HX Analysis for R32

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m^3/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3562	3562	3562	3562
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	10693	11074	11435	10669
Air Dry-Bulb Temperature	°C	54.1	57.0	54.9	55.8
Refrigerant Temperature	°C	55.2	52.9	49.3	55.4
LMTD	°C	22.8	19.8	15.9	22.5
UA	W/K	468	560	717	475
NTU	-	0.35	0.55	0.54	0.42
Refrigerant Pressure Drop	kPa	26.7	67.1	6.8	10.1
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	3823	4239	3050	3991
Subcooling	°C	0.00	1.75	6.17	0.00
Charge	kg	0.61	0.43	0.17	0.11

Table 30: Unit 10 – HX Analysis for R452B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m^3/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3247	3247	3247	3247
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9549	9812	9751	9500
Air Dry-Bulb Temperature	°C	53.2	55.8	53.6	54.8
Refrigerant Temperature	°C	49.5	46.4	47.1	50.1
LMTD	°C	16.7	9.2	12.2	17.1
UA	W/K	573	1067	802	557
NTU	-	0.43	1.04	0.60	0.49
Refrigerant Pressure Drop	kPa	17.2	47.1	5.6	8.2
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	$W/m^2.K$	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	$W/m^2.K$	2974	3038	2537	2812
Subcooling	°C	4.82	7.51	7.34	4.38
Charge	kg	0.83	0.79	0.23	0.15

Table 31: Unit 10 – HX Analysis for R447B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3025	3025	3025	3025
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9016	9632	9923	9085
Air Dry-Bulb Temperature	°C	52.9	55.6	53.8	54.4
Refrigerant Temperature	°C	52.4	51.7	49.9	52.7
LMTD	°C	20.4	18.9	17.1	20.3
UA	W/K	441	510	579	448
NTU	-	0.33	0.50	0.43	0.40
Refrigerant Pressure Drop	kPa	29.2	67.3	7.2	10.8
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	3528	3833	2999	3458
Subcooling	°C	0.00	0.00	2.67	0.00
Charge	kg	0.56	0.45	0.17	0.10

Table 32: Unit 10 – HX Analysis for R454B

Condenser					
Inputs		***BTFD7***	***NTFD5***	***NMCD2***	***NMCD2R***
Air Dry-Bulb Temperature	°C	46	46	46	46
Relative Humidity	%	16.4	16.4	16.4	16.4
Air Flowrate	m³/s	1.23	0.94	1.23	1.04
Refrigerant Pressure	kPa	3204	3204	3204	3204
Saturation Temperature at Inlet	°C	56	56	56	56
Refrigerant Temperature	°C	100	100	100	100
Mass Flow Rate	kg/s	0.04	0.04	0.04	0.04
Outputs					
Heat Load	W	9634	9953	9901	9597
Air Dry-Bulb Temperature	°C	53.3	55.9	53.8	54.9
Refrigerant Temperature	°C	50.4	46.7	47.3	50.8
LMTD	°C	17.9	10.5	12.7	18.0
UA	W/K	537	952	782	532
NTU	-	0.40	0.93	0.59	0.47
Refrigerant Pressure Drop	kPa	18.8	51.1	5.9	8.7
Airside DP	Pa	29.6	26.7	25.7	26.0
Air Heat Transfer Coefficient (Average)	W/m².K	100.4	117.0	124.8	125.3
Refrigerant Heat Transfer Coefficient (Average)	W/m².K	3095	3211	2633	2942
Subcooling	°C	3.71	6.98	6.98	3.40
Charge	kg	0.78	0.71	0.22	0.14

Table 33. Unit 10 - Compressor Performance Summary.

Compressor			Copeland ZP31K5E-PFV	Copeland ZP34K5E-PFV	Copeland ZP31K5E-PFV
Refrigerant		***R32***	***R452B***	***R447B***	***R454B***
Isentropic Efficiency	-	0.439	0.638	0.662	0.662
Volumetric Efficiency	-		0.760	0.803	0.790
Displacement Volume	cm³		29.350	29.350	29.350
Frequency	Hz	50	50	50	50
Effective Displacement Volume	cm³	19.646	22.301	23.581	23.183

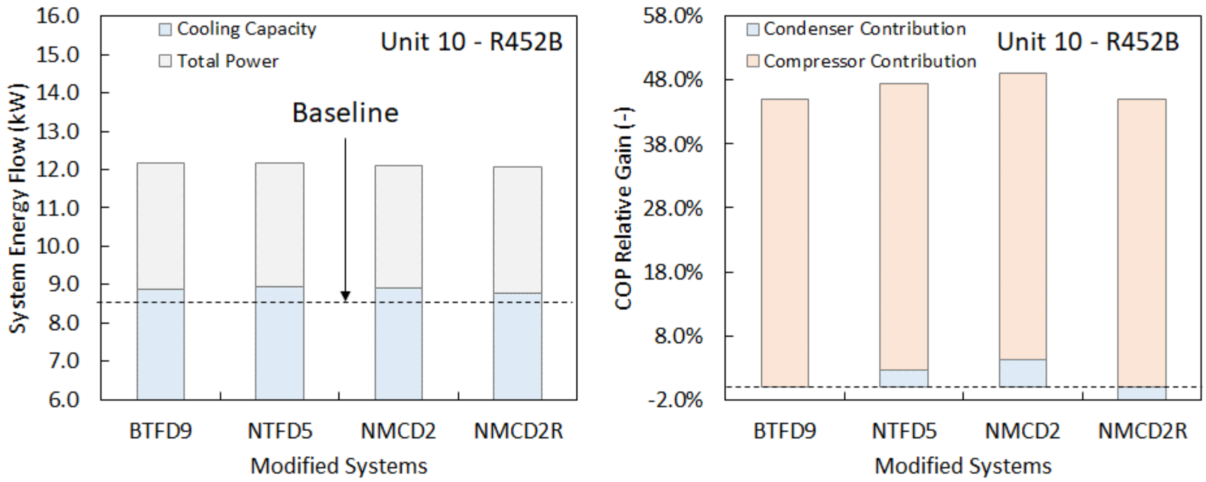


Figure 15. Unit 10 – System Level Analysis: Performance Results for R452B.

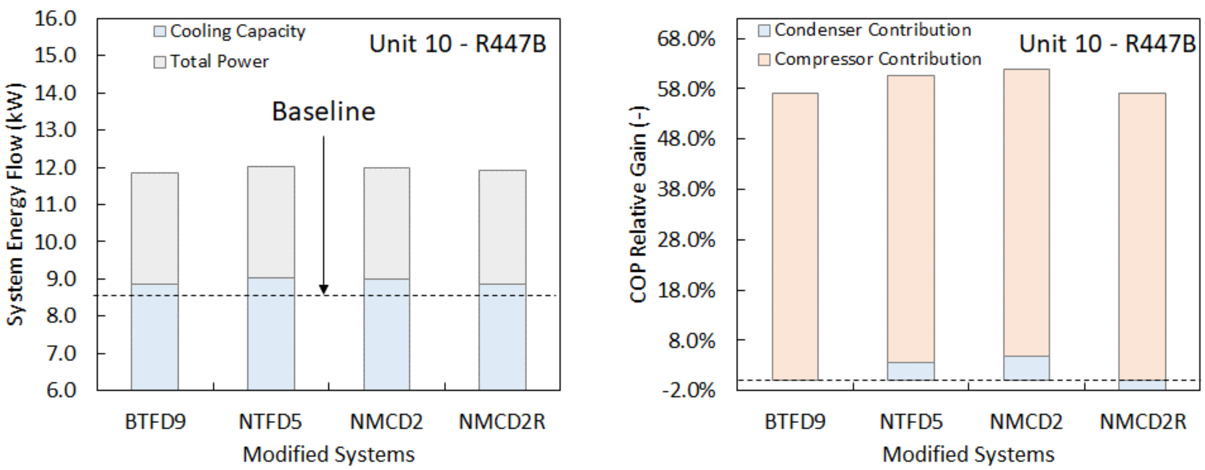


Figure 16. Unit 10 – System Level Analysis: Performance Results for R447B.

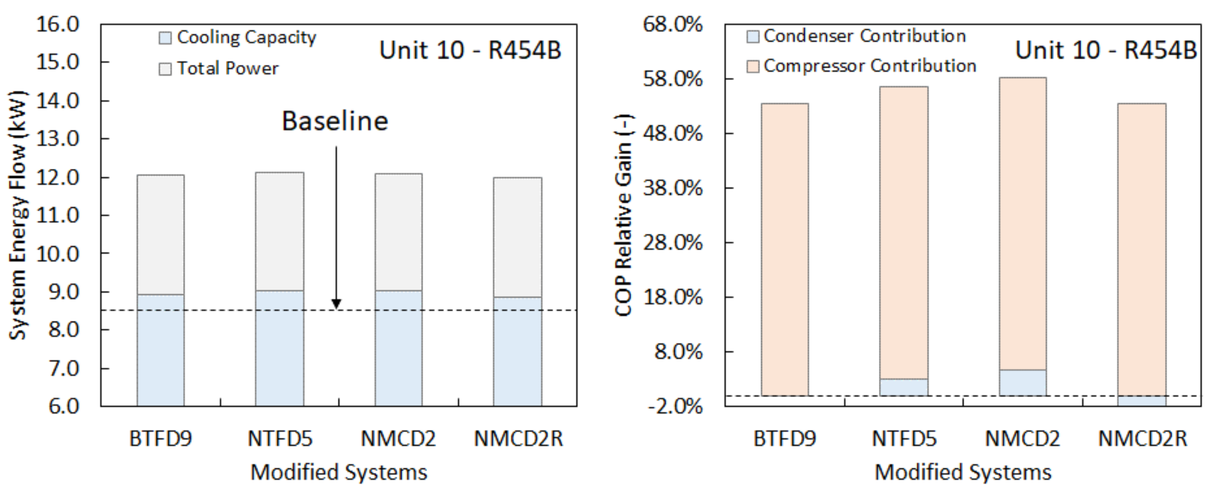


Figure 17. Unit 10 – System Level Analysis: Performance Results for R454B.

APPENDIX B – Unit 6 Initial Tests, Scope Change and Test Setup

Unit 6 was initially modified and tested at a separate facility and the test results exhibited a considerably lower cooling capacity than expected (~20%). Power consumption was also greater than designed. The condensing pressures were 20-30% above expectations, and the refrigerant pressure drop across the condenser was at least twice as high as expected. The outlet conditions of the condenser for R32 were possibly in two-phase. The condenser airflow rate was 10%-15% lower than expected. Superheat hardly met the setpoint values.

OTS formulated a hypothesis that the degraded performance was due to the condenser not being fully active; i.e. some regions were not transferring heat. One way for this to happen is by having severe maldistribution thus impeding heat transfer, increasing pressure drop – thus the condensing pressure – and possibly reducing the flow rate as well; all of which were observed in the test data. OTS tested the hypothesis by running hot water through the HX and observing with a thermal camera (Figure 18), which revealed the "dead zones". Upon inspection by the manufacturer, it was confirmed there were blockages in some of the tubes. A new HX was built, but the same pattern was observed, forcing OTS to remove the condenser replacement from the scope given the project schedule.

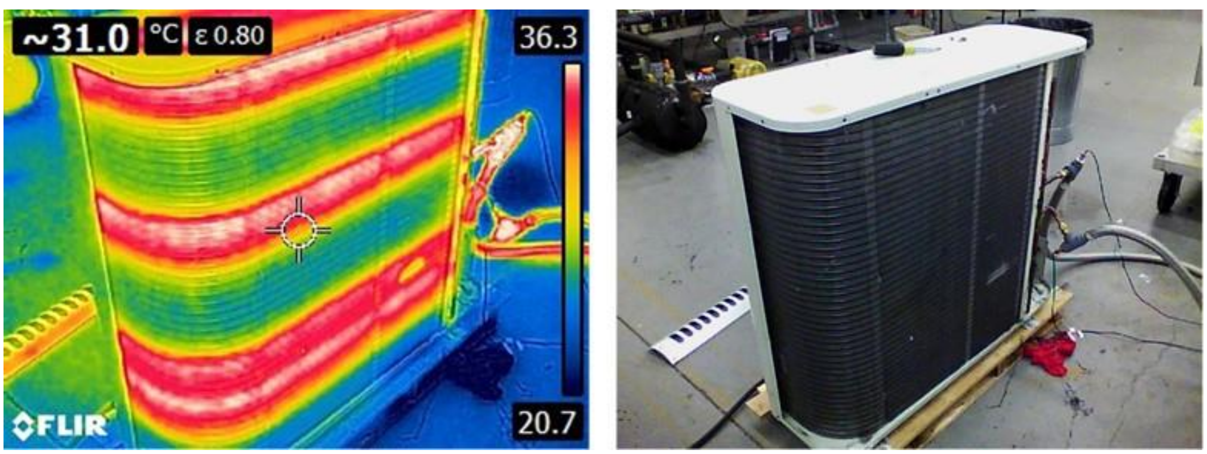


Figure 18. Hot Water Thermal Imaging.

Given the challenges with the initial tests and unit modification, the scope was re-defined. The original test plan was changed to accommodate time and resources as appropriate. Table 34 outlines the major changes to the scope. The tests were conducted at the OTS laboratory (Figure 19 to Figure 22). A summary of the key differences between the test setups (original and at OTS) is presented in Table 35.

Table 34: Test Scope Change.

Unit	Refrigerant	Test	Original Scope		New Scope	
			Planned	Actual	Planned	Actual
Unit 1	R290	Charge Optimization	Yes	No	No	No
		Performance Tests	Yes	No	No	No
Unit 6	R32 (Baseline)	Charge Optimization	No	No	Yes	Yes
		Performance Tests	No	No	Yes	Yes
	R32 (Modified)	Charge Optimization	Yes	Yes	Yes	Yes
		Performance Tests	Yes	Yes	Yes	Yes
	R454B	Charge Optimization	Yes	Yes	Yes	Yes
		Performance Tests	Yes	Yes	Yes	Yes
		Leak Tests	Yes	Yes	No	No
Unit 10	R32 (Baseline)	Charge Optimization	No	No	Yes	Yes*
		Performance Tests	No	No	Yes	Yes*
	R447B	Charge Optimization	Yes	No	Yes	Yes
		Performance Tests	Yes	No	Yes	Yes
		Leak Tests	Yes	No	Yes	Yes
	R452B	Charge Optimization	Yes	No	Yes	Yes
		Performance Tests	Yes	No	Yes	Yes
		Leak Tests	Yes	No	No	No

** Tests were conducted; however, no useful data was obtained (see section 5.2)*

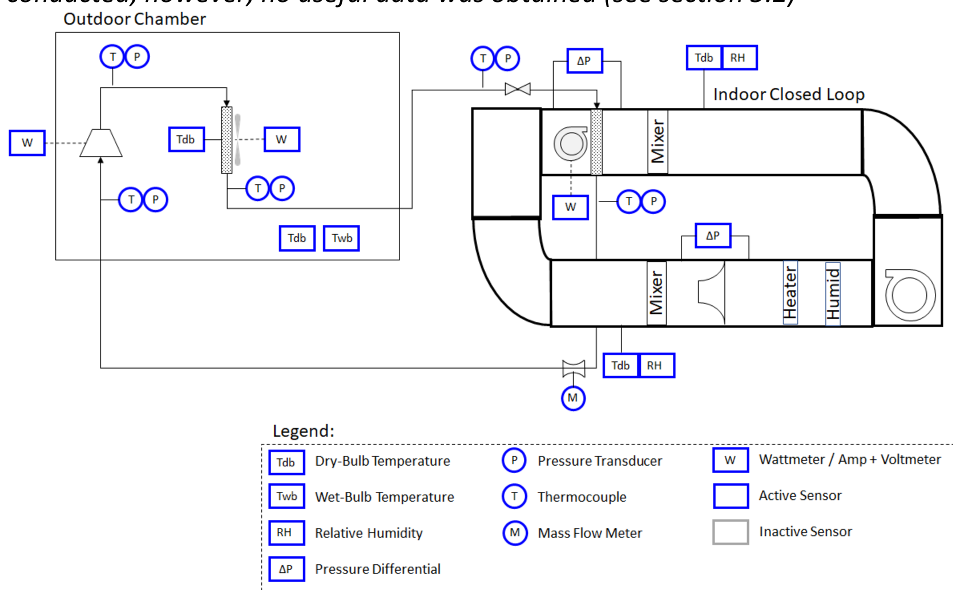


Figure 19. Test Diagram.

Figure 20. OTS Setup: outdoor chamber (left), Unit 10 and frequency converter inside chamber (right).

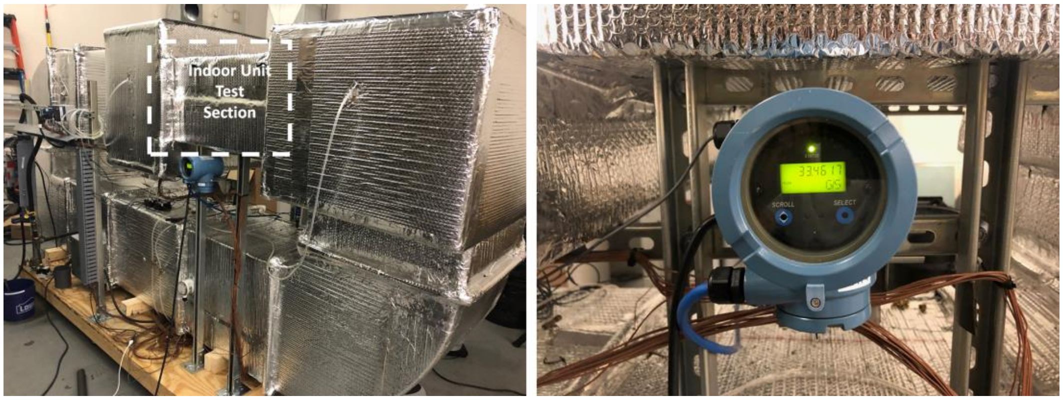


Figure 21. OTS Setup: indoor closed loop left side view (left), refrigerant mass flow meter (right).


Figure 22. OTS Setup: indoor closed loop right side view (left), vapor / liquid lines, sight glasses and TXV (right).

Table 35: List of Measurements.

Component	Refrigerant Side			Air Side		
	Measurement	Original Scope	New Scope	Measurement	Original Scope	New Scope
Condenser	Inlet Temperature	Yes	Yes	Air Flow Rate	Yes	**No**
	Inlet Pressure	Yes	Yes	Air Pressure Drop	No	No
	Outlet Temperature	Yes	Yes	Fan Power	No	**Yes**
	Outlet Pressure	Yes	Yes	Inlet Dry-bulb	Yes	Yes
	Subcooling	Yes*	**Yes**	Inlet Wet-Bulb / RH	Yes	Yes
				Outlet Dry-bulb	Yes	Yes
				Outlet Wet-Bulb / RH	Yes	Yes
Evaporator	Inlet Temperature	No	No	Air Flow Rate	Yes	Yes
	Inlet Pressure	No	No	Air Pressure Drop	No	**Yes****
	Outlet Temperature	Yes	Yes	Blower Power	No	**Yes**
	Outlet Pressure	Yes	Yes	Inlet Dry-bulb	Yes	Yes
	Superheat	Yes*	**Yes**	Inlet Wet-Bulb / RH	Yes	Yes
	Refrigerant Mass Flow Rate	No	**Yes**	Outlet Dry-bulb	Yes	Yes
				Outlet Wet-Bulb / RH	Yes	Yes
Compressor	Suction Temperature	Yes	Yes			
	Suction Pressure	Yes	Yes			
	Discharge Temperature	Yes	Yes			
	Discharge Pressure	Yes	Yes			
	Compressor Power	No	**Yes**			
Expansion Device	Suction Temperature	Yes	Yes			
	Suction Pressure	Yes	Yes			
	Discharge Temperature	No	No			
	Discharge Pressure	No	No			

Charge Optimization

The charge optimization procedure as originally scoped was not implemented due to the following:

a. The systems responded less sensitively to charge on subcooling and superheat, which were difficult to control with charging alone. A manual valve was added (Unit 10 exhibited little expansion) such that superheat could be better controlled. The valve also allowed for better control over the pressure levels compared to charge levels alone.
b. For the modified systems, the charge was gradually increased, departing from the original charge from PRAHA I tests, until it was observed that the superheat and subcooling better matched design conditions for validation purposes.
c. For the refrigerant blends, removing charge could result in fractionation (evaluated as a separate task), so it was decided to only incrementally increase charge, without removing it. For this procedure, a small gradual increment is necessary to avoid overcharging.

APPENDIX C - Unit 6 Raw and Processed Tested Data

Table 36: Unit 6 – Performance Tests

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Charge	lb	3.83	4.27	5.02	3.83	4.27	5.02
Cooling Capacity	BTU/hr	25193	23585	21966	23390	21450	21821
Energy Balance	%	-2.28%	-4.66%	-3.06%	-1.78%	-4.42%	-7.61%
Compressor Power	kW	2.11	1.79	1.77	2.71	2.32	2.25
Fan Power	kW	0.32	0.33	0.33	0.40	0.42	0.42
Total Power	kW	2.43	2.12	2.10	3.10	2.74	2.67
EER	BTU/hr.W	10.36	11.12	10.44	7.54	7.84	8.17
Evaporator							
Airside							
Inlet							
Air Flow Rate	m^3/s	0.31	0.31	0.31	0.31	0.31	0.30

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Temperature	°C	27.0	27.0	27.0	29.0	29.0	29.0
Wet Bulb	°C	19.68	19.68	19.68	21.33	21.33	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.011	0.011	0.011	0.013	0.013	0.013
Density	kg/m³	1.15	1.15	1.15	1.14	1.14	1.14
Enthalpy	kJ/kg	56.3	56.2	56.2	61.9	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0	1.0
Outlet							
Air Flow Rate	m³/s	0.29	0.29	0.29	0.29	0.29	0.29
Temperature	°C	14.3	15.1	15.8	16.9	17.7	18.1
Wet Bulb	°C	14.35	14.35	14.35	14.35	14.35	14.35
Relative Humidity	%	83.6	82.4	80.0	84.5	83.3	81.3
Humidity Ratio	kg/kg	0.008	0.009	0.009	0.010	0.011	0.011
Density	kg/m³	1.21	1.20	1.20	1.19	1.19	1.19
Enthalpy	kJ/kg	35.8	37.5	38.5	42.7	44.7	45.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0	1.0
Refrigerant Side							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	4.58	6.19	4.76	7.49	8.33	8.47
Pressure	kPa	939.13	986.90	876.76	1026.70	1053.10	979.34
Quality	-	0.16	0.19	0.20	0.20	0.25	0.27
Enthalpy	kJ/kg	273.64	269.78	268.60	301.30	291.37	289.89
Entropy	kJ/kg.K	1.20	1.25	1.30	1.27	1.32	1.37
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	8.08	9.26	9.46	9.08	13.54	11.80
Pressure	kPa	939	987	877	1027	1053	979
Superheat	K	3.50	3.07	4.89	1.59	5.20	3.58
Enthalpy	kJ/kg	520.49	520.22	473.43	518.52	523.27	472.93
Entropy	kJ/kg.K	2.15	2.15	2.03	2.13	2.15	2.02
HX Level							
Average Cooling Capacity	kW	7.384	6.912	6.438	6.855	6.287	6.395
Energy Balance (Qair - Qref)/Qref	%	-2.28%	-4.66%	-3.06%	-1.78%	-4.42%	-7.61%
Sensible Heat Ratio	-	0.64	0.66	0.65	0.64	0.67	0.66
Superheat	K	3.500	3.066	4.885	1.593	5.205	3.582
LMTD	K	13.783	12.822	14.015	13.985	12.184	13.041
UA	kW/K	0.573	0.539	0.459	0.550	0.516	0.490
Air Pressure Drop	Pa	N/A	N/A	N/A	N/A	N/A	N/A
Refrigerant Pressure Drop	kPa	N/A	N/A	N/A	N/A	N/A	N/A
Fan Power	kW	0.120	0.127	0.134	0.196	0.217	0.217
Condenser							
Airside							
Inlet							
Air Flow Rate	m³/s	0.9516	0.9838	1.0091	0.9580	0.9735	1.0613
Temperature	°C	35.01	34.76	35.12	46.06	45.93	46.05
Wet Bulb	°C	20.0	19.8	20.0	27.4	27.3	27.4
Humidity Ratio	kg/kg	0.008	0.008	0.009	0.015	0.015	0.015
Density	kg/m³	1.13	1.13	1.13	1.08	1.08	1.08
Enthalpy	kJ/kg	57.0	56.4	57.2	86.2	85.8	86.2
Specific Heat	kJ/kg.K	1.01	1.01	1.01	1.02	1.02	1.02
Outlet							
Air Flow Rate	m³/s	0.98	1.01	1.03	0.98	1.00	1.09
Temperature	°C	43.40	42.29	42.08	54.74	53.60	53.19
Wet Bulb	°C	22.4	22.0	22.1	29.3	29.0	29.0
Humidity Ratio	kg/kg	0.008	0.008	0.009	0.015	0.015	0.015
Density	kg/m³	1.10	1.10	1.10	1.05	1.05	1.05
Enthalpy	kJ/kg	65.6	64.1	64.3	95.2	93.7	93.6
Specific Heat	kJ/kg.K	1.01	1.01	1.01	1.02	1.02	1.02

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	-	**R32**	**R32**	**R454B**	**R32**	**R32**	**R454B**
Refrigerant Side							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	89.78	82.73	78.33	109.00	107.24	90.75
Pressure	kPa	2724.15	2643.18	2360.90	3464.77	3365.88	3010.13
Superheat	K	45.9	40.1	35.9	54.7	54.2	38.0
Enthalpy	kJ/kg	580.73	573.07	523.39	594.42	593.52	528.90
Entropy	kJ/kg.K	2.20	2.18	2.08	2.21	2.21	2.07
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	39.17	34.52	34.68	51.79	45.63	45.79
Pressure	kPa	2675.81	2598.75	2310.89	3416.39	3324.50	2958.91
Subcooling	K	4.00	7.44	5.59	1.89	6.84	5.07
Enthalpy	kJ/kg	273.6	264.0	266.4	301.3	287.0	287.8
Entropy	kJ/kg.K	1.24	1.21	1.28	1.33	1.28	1.34
HX Level							
Heat Rejection	kW	9.19	8.53	8.08	9.25	8.31	8.42
Subcooling	K	4.00	7.44	5.59	1.89	6.84	5.07
Refrigerant Pressure Drop	kPa	48.34	44.43	50.01	48.38	41.38	51.22
Fan Power	kW	0.20	0.20	0.20	0.20	0.20	0.20
TXV							
Refrigerant							
Inlet		[4]			[4]		
Temperature	°C	30.64	37.31	35.83	39.70	47.55	46.78
Pressure	kPa	1991.01	2587.20	2301.38	2528.52	3317.42	2945.62
Subcooling	°C	*(Two-Phase)	4.47	4.27	*(Two-Phase)	4.83	3.88
Enthalpy	kJ/kg	*(Two-Phase)	269.8	268.6	*(Two-Phase)	291.4	289.9
Entropy	kJ/kg.K	*(Two-Phase)	1.233	1.284	*(Two-Phase)	1.299	1.349
Compressor							
Refrigerant							
Inlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	11.57	12.55	12.76	13.81	17.63	13.07
Pressure	kPa	936.06	984.95	874.98	1024.91	1052.17	969.56
Superheat	K	7.09	6.43	8.26	6.38	9.32	5.18
Enthalpy	kJ/kg	524.9	524.4	477.3	524.6	528.3	474.8
Entropy	kJ/kg.K	2.170	2.161	2.048	2.156	2.166	2.028
Outlet							
Mass Flow Rate	kg/s	0.030	0.028	0.031	0.032	0.027	0.035
Temperature	°C	89.8	82.7	78.3	109.0	107.2	90.8
Pressure	kPa	2724.2	2643.2	2360.9	3464.8	3365.9	3010.1
Superheat	K	45.9	40.1	35.9	54.7	54.2	38.0
Enthalpy	kJ/kg	580.7	573.1	523.4	594.4	593.5	528.9
Entropy	kJ/kg.K	2.200	2.183	2.084	2.205	2.207	2.074
Compressor Level							
Power Consumption	kW	2.11	1.79	1.77	2.71	2.32	2.25
Isentropic Efficiency	-	0.80	0.84	0.73	0.74	0.76	0.69
Frequency	Hz	60	60	60	60	60	60

[4] The baseline configuration does not have an expansion valve, the state point herein presented refers to measurement readings at indoor unit inlet.

APPENDIX D - Unit 10 Baseline Re-Test

Prior to modifying Unit 10, it was tested in its received, baseline condition with the components used to test during PRAHA I. Given the results of the data review in Activity 1, and the challenges experienced in the initial testing of Unit 6, the project team agreed that testing the units in their baseline configuration would be important for more accurate comparison.

The electrical components for Unit 10 have phase mismatch, i.e. the fan and blower are three-phase while the compressor is single-phase, but all operate in 50Hz. OTS does not have a Variable Frequency Drive (VFD) for single-phase motors, requiring the use of a frequency converter to reduce the compressor speed. According to the baseline data from PRAHA 1, the total power consumption of Unit 10 varied between 3.5-4.5kW; OTS has a 5.0kW converter, which should be sufficiently large to meet testing needs.

Initial tests suggested that the compressor peak start current exceeds the converter threshold, causing the latter to trip and shut off. Although the blower and the fan run normally with the converter, the compressor alone does not. The compressor motor was tested at 60Hz direct from the grid and it works, thus confirming that the issue is indeed the peak current. A soft starter was acquired with the objective to mitigate the issue. The soft starter capacitors weren't fast enough to smooth the peak current, however, thus requiring manual charging, which eventually lead to component failure.

The last tentative to run the baseline was connecting the compressor to 60Hz and the fans to 50Hz. The refrigerant mass flow rate was too high impeding full condensation and full evaporation. A manual TXV was added along with two sight glasses in the liquid and vapor lines and reasonable data was obtained for the 35°C ambient temperature condition. While attempting to test the system under the 46°C ambient temperature, the compressor overheats and shuts down. Heavier gauge wire, new contactors and switch bypass were unsuccessfully employed. In the interest of time, the baseline re-tests were discontinued. The analysis will be carried out using the original baseline performance for comparison purposes.

APPENDIX E - Unit 10 Raw and Processed Tested Data

Table 37: Unit 10 – Performance Tests.

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	-	**R447B**	**R452B**	**R447B**	**R452B**
Charge	lb	6.625	6.625	6.625	6.625
Cooling Capacity	BTU/hr	32195	28128	31073	30292
Energy Balance	%	7.52%	-3.29%	4.21%	1.21%
Compressor Power	kW	2.67	2.40	3.16	2.93
Fan Power	kW	0.95	0.98	0.95	0.97
Total Power	kW	3.62	3.38	4.11	3.90
EER	BTU/hr.W	8.88	8.33	7.55	7.76
Evaporator					
Airside					
Inlet					
Air Flow Rate	m³/s	0.74	0.73	0.74	0.73
Temperature	°C	27.0	27.0	29.0	29.0
Wet Bulb	°C	19.68	19.69	21.33	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.011	0.011	0.013	0.013
Density	kg/m³	1.15	1.15	1.14	1.14
Enthalpy	kJ/kg	56.2	56.3	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R447B**	**R452B**	**R447B**	**R452B**
Outlet					
Air Flow Rate	m³/s	0.72	0.71	0.71	0.70
Temperature	°C	17.4	19.1	19.7	19.8
Wet Bulb	°C	15.80	16.64	17.91	18.06
Relative Humidity	%	85.1	78.5	84.7	84.5
Humidity Ratio	kg/kg	0.011	0.011	0.012	0.012
Density	kg/m³	1.19	1.18	1.18	1.18
Enthalpy	kJ/kg	44.3	46.8	50.7	51.1
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0
Refrigerant Side					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	9.81	5.53	12.90	13.09
Pressure	kPa	996.41	907.20	1085.49	1133.86
Quality	-	0.19	0.19	0.27	0.25
Enthalpy	kJ/kg	272.43	264.74	296.09	288.71
Entropy	kJ/kg.K	1.32	1.30	1.40	1.38
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	15.22	25.20	16.76	23.36
Pressure	kPa	996	907	1085	1134
Superheat	K	5.79	19.82	4.42	10.47
Enthalpy	kJ/kg	477.29	485.20	476.43	477.36
Entropy	kJ/kg.K	2.04	2.09	2.03	2.03
HX Level					
Average Cooling Capacity	kW	9.436	8.244	9.107	8.878
Energy Balance (Qair - Qref)/Qref	%	7.52%	-3.29%	4.21%	1.21%
Sensible Heat Ratio	-	0.81	0.85	0.83	0.87
Superheat	K	5.794	19.818	4.422	10.474
LMTD	K	9.534	5.829	9.222	6.171
UA	kW/K	0.990	1.414	0.988	1.439
Air Pressure Drop	Pa	N/A	N/A	N/A	N/A
Refrigerant Pressure Drop	kPa	N/A	N/A	N/A	N/A
Fan Power	kW	0.502	0.523	0.501	0.519
Condenser					
Airside					
Inlet					
Air Flow Rate	m³/s	1.44	1.50	1.44	1.42
Temperature	°C	35.03	35.08	46.14	46.22
Wet Bulb	°C	20.0	20.0	27.4	27.5
Humidity Ratio	kg/kg	0.008	0.009	0.016	0.016
Density	kg/m³	1.13	1.13	1.08	1.07
Enthalpy	kJ/kg	57.0	57.2	86.5	86.7
Specific Heat	kJ/kg.K	1.01	1.01	1.02	1.02
Outlet					
Air Flow Rate	m³/s	1.47	1.53	1.48	1.45
Temperature	°C	41.90	40.83	53.36	53.26
Wet Bulb	°C	22.0	21.7	29.0	29.1
Humidity Ratio	kg/kg	0.008	0.009	0.016	0.016
Density	kg/m³	1.10	1.11	1.05	1.05
Enthalpy	kJ/kg	64.0	63.0	94.0	94.0
Specific Heat	kJ/kg.K	1.01	1.01	1.02	1.02
		0.00010	0.00038	0.00011	-0.00001
Refrigerant Side					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047

		Alternate 1 (35°C)	Alternate 2 (35°C)	Alternate 1 (46°C)	Alternate 2 (46°C)
Refrigerant	**-**	**R447B**	**R452B**	**R447B**	**R452B**
Temperature	°C	78.84	92.46	93.29	97.45
Pressure	kPa	2493.84	2600.61	3199.13	3357.43
Superheat	K	31.5	46.5	35.3	40.4
Enthalpy	kJ/kg	522.20	532.28	529.64	527.68
Entropy	kJ/kg.K	2.09	2.11	2.08	2.07
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	40.68	35.54	53.44	48.65
Pressure	kPa	2481.63	2599.27	3187.26	3351.92
Subcooling	K	3.37	9.26	1.62	7.33
Enthalpy	kJ/kg	274.8	266.6	300.2	291.9
Entropy	kJ/kg.K	1.32	1.29	1.39	1.37
HX Level					
Heat Rejection	kW	11.39	9.94	11.59	11.10
Energy Balance (Qair - Qref)	kW	N/A	N/A	N/A	N/A
Subcooling	K	3.37	9.26	1.62	7.33
Air Pressure Drop	Pa	-	-	-	-
Refrigerant Pressure Drop	kPa	12.21	1.34	11.87	5.51
Fan Power	kW	0.45	0.45	0.45	0.45
TXV					
Refrigerant					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	39.42	34.55	51.55	47.11
Pressure	kPa	2462.98	2583.59	3166.49	3331.97
Subcooling	°C	4.31	9.99	3.21	8.59
Enthalpy	kJ/kg	272.4	264.7	296.1	288.7
Entropy	kJ/kg.K	1.310	1.284	1.382	1.358
Compressor					
Refrigerant					
Inlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	16.84	26.01	17.17	24.96
Pressure	kPa	993.13	902.34	1082.17	1128.72
Superheat	K	7.52	20.81	4.94	12.23
Enthalpy	kJ/kg	479.3	486.2	477.0	479.4
Entropy	kJ/kg.K	2.052	2.090	2.035	2.042
Outlet					
Mass Flow Rate	kg/s	0.046	0.037	0.051	0.047
Temperature	°C	78.8	92.5	93.3	97.5
Pressure	kPa	2493.8	2600.6	3199.1	3357.4
Superheat	K	31.5	46.5	35.3	40.4
Enthalpy	kJ/kg	522.2	532.3	529.6	527.7
Entropy	kJ/kg.K	2.087	2.112	2.082	2.073
Compressor Level					
Power Consumption	kW	2.67	2.40	3.16	2.93
Isentropic Efficiency	-	0.72	0.83	0.68	0.77
Frequency	Hz	60	60	60	60

Table 38: Unit 10 – R447B Leak Tests

System			***Liquid Line Leak***		***Vapor Line Leak***	
		Full Charge	**Low Charge**	**Re-Charged**	**Low Charge**	**Re-Charged**
Refrigerant	**-**	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Charge	lb	6.625	4.27	6.625	4.23	6.77

System			Liquid Line Leak		Vapor Line Leak	
		Full Charge	Low Charge	Re-Charged	Low Charge	Re-Charged
Refrigerant	-	**R447B**	**R447B**	**R447B**	**R447B**	**R447B**
Cooling Capacity	BTU/hr	31073	14216	30865	15171	30587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	-
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	-
EER	BTU/hr.W	7.52	3.64	7.42	3.87	-
Evaporator						
Airside						
Inlet						
Air Flow Rate	m³/s	0.74	0.73	0.74	0.73	0.74
Temperature	°C	29.0	29.0	29.0	29.0	29.0
Wet Bulb	°C	21.33	21.34	21.34	21.34	21.34
Relative Humidity	%	51.0	51.0	51.0	51.0	51.0
Humidity Ratio	kg/kg	0.013	0.013	0.013	0.013	0.013
Density	kg/m³	1.14	1.14	1.14	1.14	1.14
Enthalpy	kJ/kg	62.0	62.0	62.0	62.0	62.0
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0
Outlet						
Air Flow Rate	m³/s	0.71	0.72	0.71	0.72	0.71
Temperature	°C	19.7	23.3	19.6	23.2	19.7
Wet Bulb	°C	17.91	19.87	18.08	19.77	18.05
Relative Humidity	%	84.7	73.1	86.3	73.6	86.0
Humidity Ratio	kg/kg	0.012	0.013	0.012	0.013	0.012
Density	kg/m³	1.18	1.16	1.18	1.16	1.18
Enthalpy	kJ/kg	50.7	57.0	51.2	56.7	51.1
Specific Heat	kJ/kg.K	1.0	1.0	1.0	1.0	1.0
Refrigerant Side						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	12.90	2.61	12.94	2.81	12.75
Pressure	kPa	1085.49	794.22	1086.62	799.23	1080.50
Quality	-	0.27	0.30	0.27	0.30	0.27
Enthalpy	kJ/kg	296.09	291.52	296.48	290.79	296.24
Entropy	kJ/kg.K	1.40	1.40	1.41	1.40	1.41
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	16.76	28.23	17.07	27.95	17.01
Pressure	kPa	1085	794	1087	799	1080
Superheat	K	4.42	26.24	4.70	25.76	4.82
Enthalpy	kJ/kg	476.43	496.65	476.77	496.25	476.88
Entropy	kJ/kg.K	2.03	2.14	2.03	2.13	2.03
HX Level						
Average Cooling Capacity	kW	9.107	4.167	9.046	4.446	8.965
Energy Balance (Qair – Qref)/Qref	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Sensible Heat Ratio	-	0.83	1.18	0.90	1.12	0.89
Superheat	K	4.422	26.235	4.695	25.756	4.823
LMTD	K	9.222	6.051	9.065	6.501	9.217
UA	kW/K	0.988	0.689	0.998	0.684	0.973
Fan Power	kW	0.501	0.524	0.524	0.524	0.524
Condenser						
Airside						
Inlet						
Air Flow Rate	m³/s	1.44	1.49	1.42	1.48	1.42
Temperature	°C	46.14	46.08	46.21	45.77	46.02
Wet Bulb	°C	27.4	27.4	27.5	27.2	27.4
Humidity Ratio	kg/kg	0.016	0.015	0.016	0.015	0.015
Density	kg/m³	1.08	1.08	1.07	1.08	1.08
Enthalpy	kJ/kg	86.5	86.3	86.7	85.3	86.1
Specific Heat	kJ/kg.K	1.02	1.02	1.02	1.02	1.02

System			Liquid Line Leak		Vapor Line Leak	
		Full Charge	Low Charge	Re-Charged	Low Charge	Re-Charged
Refrigerant	-	R447B	R447B	R447B	R447B	R447B
Outlet						
Air Flow Rate	m³/s	1.48	1.52	1.46	1.50	1.46
Temperature	°C	53.36	51.27	53.52	51.05	53.28
Wet Bulb	°C	29.0	28.6	29.1	28.4	29.0
Humidity Ratio	kg/kg	0.016	0.015	0.016	0.015	0.015
Density	kg/m³	1.05	1.06	1.05	1.06	1.05
Enthalpy	kJ/kg	94.0	91.7	94.3	90.8	93.6
Specific Heat	kJ/kg.K	1.02	1.02	1.02	1.02	1.02
Refrigerant Side						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	93.29	121.77	94.07	120.31	94.34
Pressure	kPa	3199.13	2846.79	3200.02	2847.47	3175.47
Superheat	K	35.3	68.9	36.1	67.4	36.7
Enthalpy	kJ/kg	529.64	569.70	530.67	567.95	531.39
Entropy	kJ/kg.K	2.08	2.20	2.08	2.20	2.09
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	53.44	50.27	53.37	50.13	53.28
Pressure	kPa	3187.26	2843.00	3188.61	2843.11	3164.31
Subcooling	K	1.62	-0.33	1.71	-0.19	1.45
Enthalpy	kJ/kg	300.2	293.2	300.0	293.2	299.9
Entropy	kJ/kg.K	1.39	1.37	1.39	1.37	1.39
HX Level						
Heat Rejection	kW	11.59	8.60	11.57	8.69	11.49
Energy Balance (Qair – Qref)	kW	N/A	N/A	N/A	N/A	N/A
Subcooling	K	1.62	-0.33	1.71	-0.19	1.45
Refrigerant Pressure Drop	kPa	11.87	3.79	11.40	4.36	11.16
Fan Power	kW	0.45	0.45	0.45	0.45	0.45
TXV						
Refrigerant						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	51.55	49.15	51.74	48.80	51.60
Pressure	kPa	3166.49	2827.45	3168.66	2827.31	3144.31
Subcooling	°C	3.21	0.54	3.06	0.89	2.84
Enthalpy	kJ/kg	296.1	291.5	296.5	290.8	296.2
Entropy	kJ/kg.K	1.382	1.369	1.383	1.366	1.382
Compressor						
Refrigerant						
Inlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	17.17	29.26	18.00	28.98	18.47
Pressure	kPa	1082.17	793.15	1082.65	797.99	1076.58
Superheat	K	4.94	27.30	5.75	26.83	6.41
Enthalpy	kJ/kg	477.0	497.7	478.0	497.3	478.8
Entropy	kJ/kg.K	2.035	2.140	2.038	2.138	2.041
Outlet						
Mass Flow Rate	kg/s	0.051	0.031	0.050	0.032	0.050
Temperature	°C	93.3	121.8	94.1	120.3	94.3
Pressure	kPa	3199.1	2846.8	3200.0	2847.5	3175.5
Superheat	K	35.3	68.9	36.1	67.4	36.7
Enthalpy	kJ/kg	529.6	569.7	530.7	568.0	531.4
Entropy	kJ/kg.K	2.082	2.200	2.085	2.195	2.087
Compressor Level						
Power Consumption	kW	3.18	2.93	3.18	2.94	0.00
Isentropic Efficiency	-	0.68	0.68	0.68	0.69	0.68
Frequency	Hz	60	60	60	60	60

System			Liquid Line Leak		Vapor Line Leak	
		Full Charge	Low Charge	Re-Charged	Low Charge	Re-Charged
Refrigerant	-	R447B	R447B	R447B	R447B	R447B

APPENDIX F - Model Verification and Validation

Table 39: Unit 6 – Model Verification and Validation for Alternative 1 – R32 @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	27	31	14%
Cooling Capacity	BTU/hr	21450	23653	10%
Total Power	kW	2.74	2.67	-2%
EER	BTU/hr.W	7.84	8.86	13%

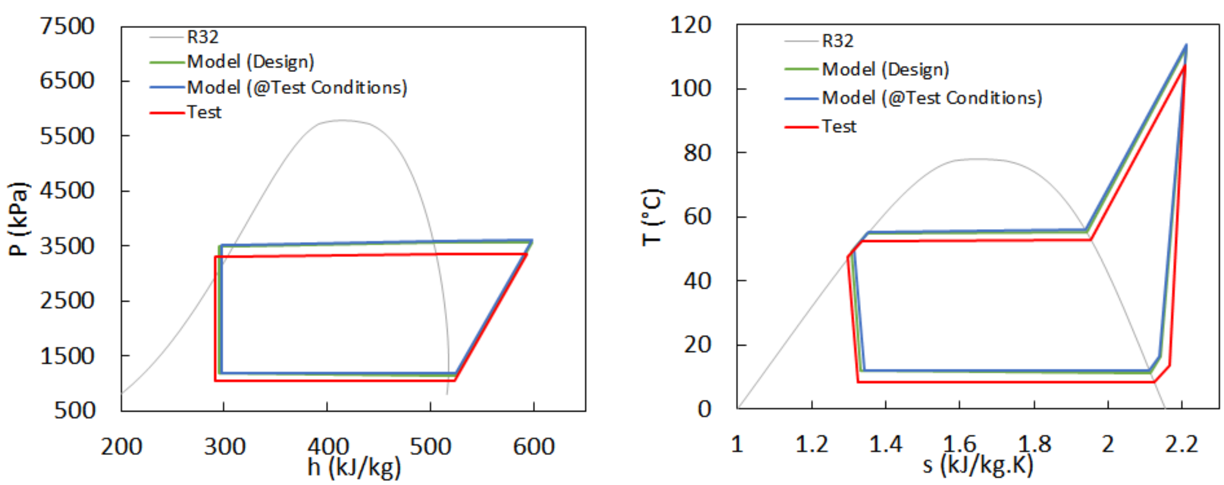


Figure 23. Unit 6 – R32 Performance Test Summary P-h and T-s Diagrams.

Table 40: Unit 6 – Model Verification and Validation for Alternative 2 – R454B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	35	36	3%
Cooling Capacity	BTU/hr	21821	22969	5%
Total Power	kW	2.67	2.49	-7%
EER	BTU/hr.W	8.17	9.24	13%

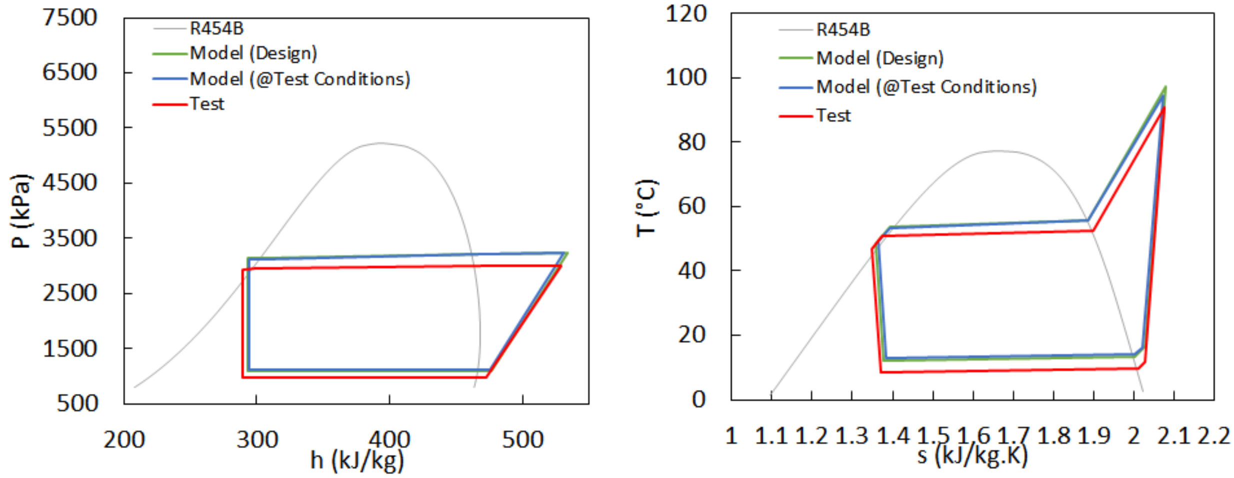


Figure 24. Unit 6 – R454B Performance Test Summary P-h and T-s Diagrams.

Table 41: Unit 10 – Model Verification and Validation for Alternative 1 – R447B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	51	49	-3%
Cooling Capacity	BTU/hr	31169	31026	-0.5%
Total Power	kW	2.70	3.00	11%
EER	BTU/hr.W	11.54	10.34	-10%

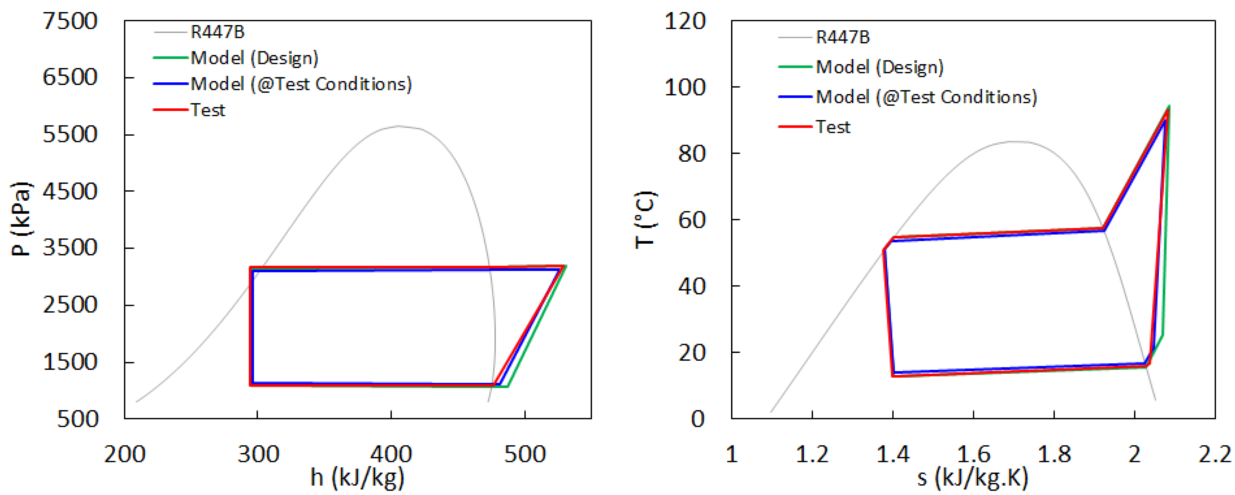


Figure 25. Unit 10 – R447B P-h and T-s Diagrams.

Table 42: Unit 10 – Model Verification and Validation for Alternative 2 – R452B @ 46°C.

		Test	Model (Test Conditions)	Relative Difference
Refrigerant Mass Flow Rate	g/s	47	48	2%
Cooling Capacity	BTU/hr	30292	30704	1.4%
Total Power	kW	3.90	3.34	-14%
EER	BTU/hr.W	7.76	9.19	18%

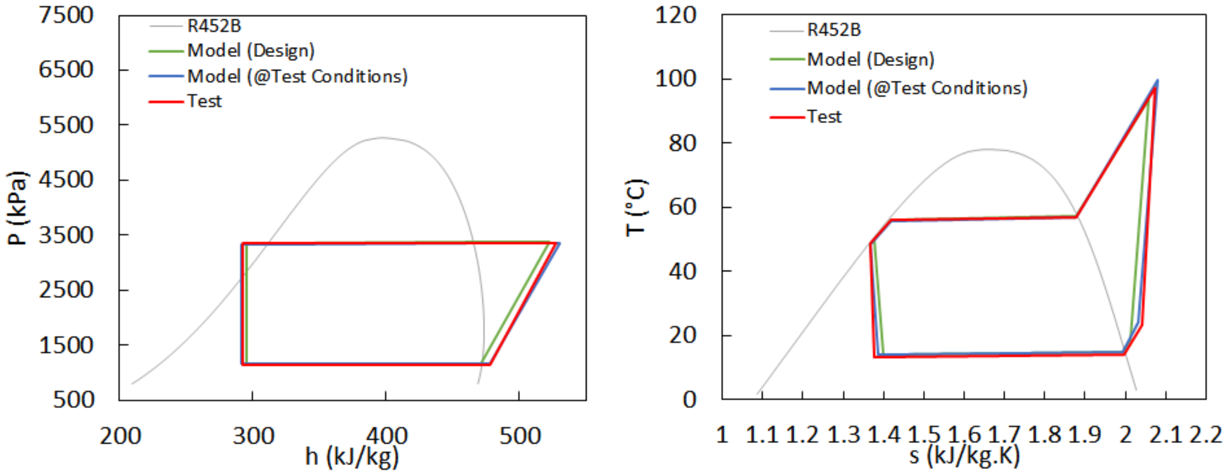


Figure 26. Unit 10 – R452B P-h and T-s Diagrams.

Annex VIII

LIST OF ENTERPRISES WITH REPORTS RELATING TO DECISIONS 84/27 AND 84/42

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Algeria	UNIDO	REF	Air-conditioning	Condor Electronics	HCFC-22	HFC-32	Delay due to higher costs of HFC-32-based units compared to HCFC-22-based units	
Argentina	UNIDO	FOA	Rigid	Friostar	HCFC-141b	Cyclopentane		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Argenpur	HCFC-141b	Cyclopentane		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Alkanos	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	BASF	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Dow	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Ecopur	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Huntsman	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Poliresinas San Luis	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Rigid	Química del Caucho	HCFC-141b	HFO-based blowing agent		Delay due to change in agency
Argentina	UNIDO	FOA	Polystyrene/ polyethylene	Celpak	HCFC-22	Carbon dioxide		Delay due to financial difficulties faced by enterprise
Argentina	UNIDO	FOA	Polystyrene/ polyethylene	Perfiles Revestidos	HCFC-22	Carbon dioxide		Delay due to change in agency
Bahrain	UNIDO	REF	Domestic	Awal Gulf Manufacturing Company	HCFC-22	HFC-410A or HFC-407C	Project cancelled; enterprise not inclined to adopt R-290/HFC-32 as R-410A technology is available in favorable commercial terms	
Bangladesh	UNDP	REF	Residential air-conditioning	Walton	HCFC-22	R-290		Delay in signing of project agreement with the Government
Bangladesh	UNDP	REF	Residential air-conditioning	Elite	HCFC-22	R-290		Delay in signing of project agreement with the Government
Bangladesh	UNDP	REF	Residential air-conditioning	AC Bazar	HCFC-22	R-290		Delay in signing of project agreement with the Government

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Bangladesh	UNDP	REF	Residential air-conditioning	Supreme AC	HCFC-22	R-290		Delay in signing of project agreement with the Government
Bangladesh	UNDP	REF	Residential air-conditioning	Unitech Products	HCFC-22	R-290		Delay in signing of project agreement with the Government
Bangladesh	UNDP	REF	Chiller	Cooling Point	HCFC-22	R-290		Delay in signing of project agreement with the Government
Brazil	UNDP	FOA	Rigid	Panisol	HCFC-141b	Methyl formate/HFO		Enterprise not going to be supported as they were not satisfied with the alternative technology and safety issues faced due to location in urban area
Brazil	UNDP	FOA	Systems house	Ecopur (Rodza)	HCFC-141b	HFOs	Delay due to high cost of HFO formulations	
Brazil	UNDP	FOA	Systems house	M.Cassab	HCFC-141b	HFOs	Delay due to high cost of HFO formulations	
Brazil	UNDP	FOA	Systems house	Polisystem	HCFC-141b	HFOs		Enterprise decided not to participate in HPMP due to business reasons
Brazil	UNDP	FOA	Systems house	Shimtek	HCFC-141b	HFOs	Delay due to non-availability of HFOs	
Brazil	UNDP	FOA	Systems house	U-Tech	HCFC-141b	HFOs	Delay due to non-availability of HFOs	
Brazil	UNIDO	REF	Air-conditioning	S.A. ELGIN	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs	Delay as enterprise not inclined to adopt R-290/HFC-32 as R-410A technology is available in favorable commercial terms and R-410A-based equipment have higher energy efficiency	
Brazil	UNIDO	REF	Air-conditioning	GREE	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs	Delay as enterprise not inclined to adopt R-290/HFC-32 as R-410A technology is available in favorable commercial terms and R-410A-based equipment have higher energy efficiency	
Brazil	UNIDO	REF	Air-conditioning	CLIMAZON	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs	Delay as enterprise not inclined to adopt R-290/HFC-32 as R-410A technology is available in favorable commercial terms and R-410A-based equipment have higher energy efficiency	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Brazil	UNIDO	REF	Commercial	CMR Refrigeração	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs		Change in enterprise due to economic situation in country and financial difficulties for enterprises
Brazil	UNIDO	REF	Commercial	Fermara Refrigeração Indústria e Comércio Ltda	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs		Change in enterprise due to economic situation in country and financial difficulties for enterprises
Brazil	UNIDO	REF	Commercial	Freeart Seral Brasil Metalúrgica Ltda.	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs		Change in enterprise due to economic situation in country and financial difficulties for enterprises
Brazil	UNIDO	REF	Commercial	Polifrio	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs		Change in enterprise due to economic situation in country and financial difficulties for enterprises
Brazil	UNIDO	REF	Commercial	Spacinox	HCFC-22	TBD: "alternative fluids": propane, Carbon dioxide and HFOs		Change in enterprise due to economic situation in country and financial difficulties for enterprises
Chile	UNDP	FOA	Rigid	Superfrigo ingenieria y Refrigeracion Ltda.	HCFC-141b	Different non-ODSs		Delay due to long time taken by enterprise in assessing technology options and review of agreement for project implementation
Chile	UNDP	FOA	Rigid	Ixom group project (6 companies)	HCFC-141b	Different non-ODSs	Delayed due to non-availability and high price of HFOs	
China	UNDP	ICR	Freezers and refrigeration and condensing units	Nanjing TICA	HCFC-22	NH_3/CO2		Delay due to enterprise works relocation
China	UNDP	ICR	Water Chiller (Heat pump)	Dalian Refrigeration	HCFC-22	R-290		Delay due to internal enterprise-level operational delays in project implementation

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
China	UNDP	SOL	Metal and Electronics	Guangdong Dechang Micromotor Co., Ltd.	HCFC-141b	HC solvent, Tans-1,2-dichloroethylene		Delay in testing of new alternatives for adoption
China	UNDP	SOL	Metal and Electronics	Dechang Micromotor (Beihai)Co., Ltd.	HCFC-141b	HC solvent, Tans-1,2-dichloroethylene		Delay in testing of new alternatives for adoption
China	UNDP	SOL	Metal and Electronics	Johnson Electric Industrial Manufactory Co., Ltd.	HCFC-141b	HC solvent, Tans-1,2-dichloroethylene		Delay in testing of new alternatives for adoption
China	UNDP	SOL	DMD	Jiangsu Yile Medical Device Co., Ltd.	HCFC-141b	HC diluent/solvent-free silicon		Delay in manufacturing equipment delivery
Colombia	UNDP	FOA	Demonstration	Espumlatex S.A.	HCFC-141b	Different non-ODSs	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Polyol production	Olaflex S.A.	HCFC-141b	Different non-ODSs	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Polyol production	Química Industrial y Comercial Limitada	HCFC-141b	Different non-ODSs	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Polyol production	Espumlatex S.A.	HCFC-141b	Different non-ODSs	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Polyol production	G.m.p. productos químicos S.A.	HCFC-141b	Different non-ODSs	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Rigid	Espumlatex S.A.	HCFC-141b	Water/carbon dioxide	Delay due to non-availability and high price of HFOs	
Colombia	UNDP	FOA	Rigid	Olaflex S.A.	HCFC-141b	Cyclopentane	Delay due to non-availability and high price of HFOs	
Croatia	UNIDO	FOA	Rigid	Pavusin	HCFC-141b	Pentane		Cancelled project – due to enterprise financial situation
Cuba	UNDP	FOA	Rigid	Friarc	HCFC-141b	Water/carbon dioxide	Delay due to non-availability and high price of HFOs	
Democratic People's Republic of Korea	UNIDO	FOA	Rigid	Pyongyang Sonbong Foam Factory	HCFC-141b	n.a.		Delay due to UN Security Council (UNSC) resolution resulting in inability to implement project

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Democratic People's Republic of Korea	UNIDO	FOA	Rigid	Puhung Building Materials Factory	HCFC-142b	n.a.		Delay due to UNSC resolution resulting in inability to implement project
Egypt	UNIDO	FOA	Rigid	Mondial Freezers Co.	HCFC-141b	Cyclopentane		Delay due political unrest during project implementation period (i.e., around 2011)
Egypt	UNIDO	FOA	Rigid	El Araby Company	HCFC-141b	Cyclopentane		Delay due political unrest during project implementation period (i.e., around 2011)
Egypt	UNIDO	FOA	Rigid	Bahgat	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Everest	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Fresh	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Ocean	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Siltal	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Star	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	TopMaker	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Egypt	UNIDO	FOA	Rigid	Tredco	HCFC-141b	Cyclopentane		Commissioning delayed due to COVID-19 outbreak
Indonesia	UNDP	REF	Air-conditioning	PT Gita Mandiri Teknik	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Air-conditioning	PT Fata Sarana Makmur	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Air-conditioning	PT ITU Airconco	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Air-conditioning	PT Metropolitan Bayu Industri	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Sumo Elco Mandiri	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Rotaryana Prima	HCFC-22	HC-290	Delay due to non-availability and high price of HFC-32-based components	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Indonesia	UNDP	REF	Commercial	PT Alpine Cool Utama	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Anekacool Citratama	HCFC-22	HFC-32	Delay due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Sabindo Refrigeration Technology	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Global Teknik	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Alpin Servis Triutama	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Aneka Froze Triutama	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Graha Cool Technic	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT United Refrigeration	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Gaya Tehnik Supply	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	PT Ilthabi Mandiri Technic	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Berkat Andijaya Elektrindo	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Cipta Karya Mandiri Insani	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Daikin Aircon	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Indonesia	UNDP	REF	Commercial	Jaya Teknik	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	LG Indonesia	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Maturnuwun Nusantara	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Planet Elektrindo	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Rodamas	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Sarana Aircon Utama	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Sarana Sumber Semesta	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Sekawan Abadi Jaya	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Seltech Utama	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Tata Solusi Pratama	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Trane Indonesia	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Waskita Prima Guna	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Indonesia	UNDP	REF	Commercial	Wira Kusuma Sejahtera	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Airtech Inti	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Jalur Sejuk	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Indo Prima Teknik	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Koronka Nusantara	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	ACR Kapuk	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Jasa Teknik	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Kulkasindo	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Intermas Pacific	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Pagoda Sakti Prima	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Rotaryana Engineering	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Indonesia	UNDP	REF	Commercial	Copel Andalan	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Indonesia	UNDP	REF	Commercial	Tegar Inti Sentosa	HCFC-22	HFC-32	Enterprise withdrew due to non-availability and high price of HFC-32-based components	
Iran (Islamic Republic of)	Germany	FOA	Rigid	Kian Panel Co.	HCFC-141b	Isopentane	Non-availability of suitable raw materials to meet performance standards and equipment supplier delays	
Iran (Islamic Republic of)	Germany	FOA	Rigid	Parlo Co.	HCFC-141b	Isopentane		Delay in obtaining enterprise counterpart funding
Iran (Islamic Republic of)	Germany	FOA	Rigid	Behdor Rangin Co.	HCFC-141b	Equipment modification		Enterprise stopped business operations; project cancelled and funds have been returned to MLF
Iran (Islamic Republic of)	Germany	FOA	INT	Zivar Khodro	HCFC-141b	Water-blown		Delay due to UN sanctions resulting in difficulties in supply of imported equipment for conversion and raw material
Iran (Islamic Republic of)	Germany	FOA	INT	Erish Khodro	HCFC-141b	Water-blown		Delay due to UN sanctions resulting in difficulties in supply of imported equipment for conversion and raw material
Iran (Islamic Republic of)	UNIDO	FOA	Rigid	Emersun	HCFC-141b	Cyclopentane		Delay due to UN sanctions resulting in financial restrictions affecting project implementation
Iran (Islamic Republic of)	UNIDO	FOA	Rigid	Parto Shiva Sanat	HCFC-141b	Cyclopentane		Delay due to UN sanctions resulting in high procurement costs for manufacturing equipment
Iran (Islamic Republic of)	UNIDO	FOA	Rigid	Javaheran Tehran	HCFC-141b	Cyclopentane		Delay due to UN sanctions resulting in high procurement costs for manufacturing equipment
Kuwait	UNIDO	FOA	Rigid	Kirby Building Systems	HCFC-141b	Cyclopentane		Delay due to lengthy process of issuing local regulations for implementing project and non-availability of standards for new product
Kuwait	UNIDO	FOA	Rigid	Kuwait Polyurethane Industry Co.	HCFC-141b	Cyclopentane		Delay due to the lengthy process of issuing local regulations for implementing project and non-availability of standards for new product

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Kuwait	UNIDO	FOA	XPS	Gulf	HCFC-22	Carbon dioxide/DME/ HFO		Delay due to the lengthy process of issuing local regulations for implementing project and non-availability of standards for new product
Kuwait	UNIDO	FOA	XPS	Isofoam	HCFC-22	Carbon dioxide/DME/ HFO		Delay due to the lengthy process of issuing local regulations for implementing project and non-availability of standards for new product
Lebanon	UNDP	FOA	Rigid	Iceberg S.A.L.	HCFC-141b	HFC-365mfc	Delay due to non-availability of HFOs	
Libya	UNIDO	FOA	Rigid	Al-Najah	HCFC-141b	Cyclopentane		Delay due to security situation in the country
Libya	UNIDO	FOA	Rigid	(Al-Amal Alkhadar) Al Najm	HCFC-141b	Cyclopentane		Delay due to security situation in the country
Libya	UNIDO	FOA	Rigid	Alyem Engineering	HCFC-141b	Cyclopentane		Delay due to security situation in the country
Mexico	UNDP	FOA	XPS	Termofoam	HCFC-142b	HFO-1234ze		Delay due to safety certification and commissioning of equipment
Nigeria	UNDP	FOA	Spray/Panel	Slavit Group	HCFC-141b	Cyclopentane/ Methyl formate		Delay in signing of project agreement with the Government
Nigeria	UNDP	FOA	Spray/Panel	Group project with 37 companies	HCFC-141b	Methyl formate		Delay in signing of project agreement with the Government
Nigeria	UNIDO	FOA	Multiple-subsectors	Group project for the conversions of foam manufacturing (75 enterprises)	HCFC-141b	Methyl formate/water		Delay due to financial difficulties faced by the beneficiaries resulting in delays in counter-part funding
Pakistan	UNIDO	FOA	Rigid	Shoaibee Industries	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Full Bright Plastic	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Asif Zubair & Co.,	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Tropical Plastic	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Unique Plastic	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Pakistan	UNIDO	FOA	Rigid	Delight Plastic	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Decent Plastic	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Informal Sector	HCFC-141b	Water/carbon dioxide		Delay in finalisation of implementation modalities with enterprise
Pakistan	UNIDO	FOA	Rigid	Pakistan Insulation (Pvt.) Ltd.,	HCFC-141b	Cyclopentane		Delay due to questions raised by NOU in assessment of eligibility of enterprise and eligibility of alternative technology
Pakistan	UNIDO	FOA	Rigid	PAECO	HCFC-141b	Cyclopentane		Delay due to questions raised by NOU in assessment of eligibility of enterprise and eligibility of alternative technology
Pakistan	UNIDO	FOA	Rigid	Foster Refrigerators (Pvt.) Ltd.,	HCFC-141b	Cyclopentane		Delay due to questions raised by NOU in assessment of eligibility of enterprise and eligibility of alternative technology
Pakistan	UNIDO	FOA	Rigid	Kold Kraft (Pvt.) Ltd.,	HCFC-141b	Cyclopentane		Delay due to questions raised by NOU in assessment of eligibility of enterprise and eligibility of alternative technology
Pakistan	UNIDO	FOA	Rigid	Informal Sector	HCFC-141b	Cyclopentane		Delay due to questions raised by NOU in assessment of eligibility of enterprise and eligibility of alternative technology
Philippines	UNIDO	REF	Air-conditioning	Panasonic	HCFC-22	HFC-32		Delay due to change of agency from World Bank to UNIDO and change in enterprises' business plans
Philippines	UNIDO	REF	Air-conditioning	Concepcion-Carrier	HCFC-22	HFC-32		Delay due to change of agency from World Bank to UNIDO, change in enterprises' business plans and financial issues faced by the enterprise
Philippines	UNIDO	REF	Air-conditioning	Hitachi	HCFC-22	HFC-32		Delay due to change of agency from World Bank to UNIDO and change in enterprises' business plans
Philippines	UNIDO	REF	Air-conditioning	Koppel	HCFC-22	HFC-32		Delay due to change of agency from World Bank to UNIDO, change in enterprises' business plans and financial issues faced by the enterprise
Qatar	UNIDO	FOA	Polystyrene/ polyethylene	Orient Insulation	HCFC-22	Carbon dioxide	Delay due to non-availability of equipment in manufacturing line resulting in delay	

Country	Agency	Sector	Sub-sector	Name	HCFC	Alternative	Delays due to availability of technology (decision 84/27)	Enterprises experiencing delays/changes in implementation plan (decision 84/42)
Sudan	UNIDO	FOA	Rigid	Mina Factory for Electrical and Home Appliances	HCFC-141b	Cyclopentane		Delay in finalisation of implementation modalities with enterprise
Sudan	UNIDO	FOA	Rigid	Target Group Factory for Insulation panels	HCFC-141b	Cyclopentane		Delay in finalisation of implementation modalities with enterprise
Syria Arab Republic	UNIDO	REF	Multiple-subsectors	Al Hafez Group	HCFC-22	HFC-410A		Delay due to security situation in the country
Trinidad and Tobago	UNDP	FOA	Multiple-subsectors	Seal Sprayed Solutions (TT) Ltd.	HCFC-141b	Methyl formate	Delay due to non-availability of methyl formate	
Tunisia	UNIDO	REF	Air-conditioning	Société Afrivision	HCFC-22	Propane (R-290)	Delay due to non-availability of alternative technology using R-290 in commercially attractive terms	
Tunisia	UNIDO	REF	Air-conditioning	Société Electrostar	HCFC-22	Propane (R-290)	Delay due to non-availability of alternative technology using R-290 in commercially attractive terms	
Tunisia	UNIDO	REF	Air-conditioning	Hachicha High World Wide (HHW)	HCFC-22	Propane (R-290)	Delay due to non-availability of alternative technology using R-290 in commercially attractive terms	
Tunisia	UNIDO	REF	Air-conditioning	Société Industrielle Mega	HCFC-22	Propane (R-290)	Delay due to non-availability of alternative technology using R-290 in commercially attractive terms	
Uruguay	UNDP	FOA	Multiple-subsectors	Group project (23 companies)	HCFC-141b	HFO-1234ze	Delay due to non-availability and high price of HFOs	
Zimbabwe	Germany	FOA	Rigid	Ref Air Ltd	HCFC-141b	Cyclopentane		Delay in procurement of raw materials by the enterprise
Zimbabwe	Germany	FOA	Rigid	Capri refrigeration Ltd	HCFC-141b	Cyclopentane		Delay in obtaining enterprise counterpart funding resulting in delays in installation of equipment

Annex IX

DETAILED INFORMATION ON HFC-RELATED INVESTMENT PROJECTS FUNDED UNDER ADDITIONAL CONTRIBUTIONS

<table>
<tr><td colspan="2">Country: Argentina</td><td colspan="2">Agency: UNIDO</td><td colspan="1">Meeting approved: 81st</td><td colspan="1">Status: Ongoing</td></tr>
<tr><td colspan="6">Project title and objective: Conversion project for replacement of HFC-134a with isobutane (R-600a)/propane (R-290)-based refrigerant in the manufacture of domestic and commercial refrigeration equipment at Briket, Bambi and Mabe-Kronen</td></tr>
<tr><td colspan="6">Sector/application: Domestic and commercial refrigeration</td></tr>
<tr><td>HFC (s)</td><td>Metric tonnes</td><td>CO_2 eq mt</td><td>Alternatives</td><td>Metric tonnes</td><td>CO_2 eq mt</td></tr>
<tr><td>HFC-134a</td><td>96.6</td><td>138,138</td><td>R-600a/R-290</td><td>48.28</td><td>145</td></tr>
<tr><td colspan="2">Funds approved (US $)</td><td colspan="2">Funds disbursed (US $)</td><td colspan="2">Date of completion</td></tr>
<tr><td colspan="2">1,840,755</td><td colspan="2">1,065,380</td><td colspan="2">December 2020</td></tr>
<tr><td colspan="6">Status of implementation: The project started in June 2018. Equipment is on site. Installation at the first company Bambi started in March 2019. All activities have to be suspended due to the COVID-19 pandemic. New appliances have been designed and tested.</td></tr>
<tr><td colspan="6">1. Signature of grant agreement (or equivalent)
UNIDO does not use grant agreements. After approval of the project in May 2018, UNIDO expert visited the site in June 2018, discussed and agreed with the Government and the enterprise the scope of activities and delineated the Multilateral Fund and counterpart inputs. Based on this, UNIDO prepared the terms of reference (TOR1) and received the counterparts’ agreement to it (July 2018). TOR2 were prepared for the assistance and advice in redesign of appliances by a national expert (September 2018); the three counterparts agreed to redesign the equipment under the guidance of a national expert and cover all the related costs.</td></tr>
<tr><td colspan="6">2. Status of planning for procurement of equipment
The equipment bidding process was initiated in September 2018; bids were received in November 2018 and evaluated by UNIDO and the lowest priced, technically acceptable bid was selected. UNIDO’s selection was discussed with the counterparts on the site and some adjustments were made. The purchase order was issued in February 2019; the supplier visited the counterpart to agree on the schedule of work. Minutes of meeting (MoM) were signed between the three counterparts and the supplier on June 2019. The supplier manufactured the equipment and delivered it to the site.</td></tr>
<tr><td colspan="6">3. Status of delivery and installation of equipment
The equipment was shipped from Europe, passed the customs in November 2019 and delivered to the three counterparts in December 2019. The installation started at Bambi in March 2020 but due to the COVID-19 all activities have been put on hold.</td></tr>
<tr><td colspan="6">4. Status of design of products using alternative technology
The counterparts have completed the design of the new appliances; additional details will be communicated upon resumption of the project.</td></tr>
<tr><td colspan="6">5. Status of commercial production of products using alternative technology
Not started yet on account of COVID-19.</td></tr>
<tr><td colspan="6">6. Energy efficiency performance
The details will be communicated to the Secretariat upon resumption of the project.</td></tr>
<tr><td colspan="6">7. Status of implementation of service sector component (as applicable)
N/A</td></tr>
<tr><td colspan="6">8. Key observations and lessons learnt relating to conversion
The details will be communicated upon completion of the project.</td></tr>
</table>

Country: Bangladesh		**Agency:** UNDP	**Meeting approved**: 80th	**Status:** Completed	
Project title and objective: Conversion from HFC-134a to isobutane as refrigerant in manufacturing household refrigerator and of reciprocating compressor of HFC-134a to energy efficient compressor (isobutane) in Walton Hi-Tech Industries Limited					
Sector/application: Domestic refrigeration					
HFC (s)	**Metric tonnes**	**CO_2 eq mt**	**Alternatives**	**Metric tonnes**	**CO_2 eq mt**
HFC-134a	230.63	329,801	R-600a	143	429
Funds approved (US $)		**Funds disbursed (US $)**		**Date of completion**	
3,131,610		3,126,415		December 2020	
Status of implementation: The project is completed. For details, please, refer to the final report being submitted separately to the 86th meeting.					
1. Signature of grant agreement (or equivalent) The project document is signed.					
2. Status of planning for procurement of equipment Done.					
3. Status of delivery and installation of equipment Done.					
4. Status of design of products using alternative technology Done.					
5. Status of commercial production of products using alternative technology Final report was submitted separately.					
6. Energy efficiency performance Final report was submitted separately.					
7. Status of implementation of service sector component (as applicable) Final report was submitted separately.					
8. Key observations and lessons learnt relating to conversion					

<table>
<tr><td colspan="2">Country: China</td><td>Agency: UNDP</td><td>Meeting approved: 82nd</td><td colspan="2">Status: Ongoing</td></tr>
<tr><td colspan="6">Project title and objective: Conversion from C5+HFC-245fa to C5+HFOs in a domestic refrigerator manufacturer (Hisense Kelon)</td></tr>
<tr><td colspan="6">Sector/application: Domestic refrigeration – insulation foam</td></tr>
<tr><td>HFC (s)</td><td>Metric tonnes</td><td>CO_2 eq mt</td><td>Alternatives</td><td>Metric tonnes</td><td>CO_2 eq mt</td></tr>
<tr><td>Cyclopentane +HFC-245fa</td><td>250</td><td>257,500</td><td>Cyclopentane +HFO-1233zd(E)</td><td>750</td><td>750</td></tr>
<tr><td colspan="2">Funds approved (US $)</td><td colspan="2">Funds disbursed (US $)</td><td colspan="2">Date of completion</td></tr>
<tr><td colspan="2">1,275,000</td><td colspan="2">380,000</td><td colspan="2">December 2020</td></tr>
<tr><td colspan="6">Status of implementation: Project document was signed in April 2019; total budget and work plan was signed in July 2019; the contract between FECO and Hisense-Kelon was signed in August 2019; and on-site verification for the CD line conversion was conducted in November 2019. Up to March 2020, Hisense-Kelon has completed the CD line conversion and started trial production in large scale.</td></tr>
<tr><td colspan="6">1. Signature of grant agreement (or equivalent)
Project document signed 30 April 2019 by FECO and UNDP; work plan for 2019 and 2020 was agreed and signed between UNDP and FECO on 24 July 2019; and the project agreement between FECO and Hisense-Kelon was signed 8 August 2019</td></tr>
<tr><td colspan="6">2. Status of planning for procurement of equipment
The planning for procurement related to modification of the seal rings in the pre-mix units, raw material storage tanks and pumps for converting to HFOs took place in August 2019</td></tr>
<tr><td colspan="6">3. Status of delivery and installation of equipment
The change/modification of the seal rings in the essential equipment took place during August to October 2019.</td></tr>
<tr><td colspan="6">4. Status of design of products using alternative technology
The capacity of the production manufacturing line is 1.2 million units per year. Details of testing of new blend is given in 5 below.</td></tr>
<tr><td colspan="6">5. Status of commercial production of products using alternative technology
Hisense-Kelon conducted trial production with cyclopentane/HFOs blend and sent samples for testing in October 2019. FECO contracted experts and undertook on-site visit to the beneficiary in November 2019, where it was reported that the beneficiary had gained the capacity of using the alternative technology for production.</td></tr>
<tr><td colspan="6">6. Energy efficiency performance
Since the enterprise manufactures various product models, additional time is needed for the energy efficiency performance testing. FECO will follow up on the progress.</td></tr>
<tr><td colspan="6">7. Status of implementation of service sector component (as applicable)
N/A</td></tr>
<tr><td colspan="6">8. Key observations and lessons learnt relating to conversion
The conversion required significant investment on equipment modification; besides the change of seal rings of essential equipment, the beneficiary enterprise had to modify the foam machines to enhance the control on metering of raw materials, temperature and other (the counterpart funding will be indicated in a future report). During onsite visits, it was reported that knowledge and experience was gained for other production lines that are not financially supported by the MLF.</td></tr>
</table>

Country: Lebanon	**Agency:** UNIDO	**Meeting approved**: 81st	**Status:** Ongoing

Project title and objective: Conversion from HFC-134a and R-404A to R-600a and R-290 in domestic refrigeration at Lematic Industries

Sector/application: Domestic refrigeration

HFC (s)	**Metric tonnes**	**CO_2 eq mt**	**Alternatives**	**Metric tonnes**	**CO_2 eq mt**
HFC-134a	78.5	112,198	R-600a	33.5	101
R-404A	34.08	133,662	R-290	6.5	19.5

Funds approved (US $)	**Funds disbursed (US $)**	**Date of completion**
1,053,858	842,975	July 2020

Status of implementation: The Government endorsed the project for submission in April 2018. The project was approved at the 81st meeting (decision 81/63). The contract with Lematic was signed in December 2018 with an agreed date of completion of 30 December 2019; however, due to the security problems in October 2019, the completion date was extended to July 2020. The conversion is ongoing; procurement equipment and components required for the production line modification is ongoing, all equipment procured from overseas has been received and some items have been installed. While the completion of the project is expected in July 2020, the factory is currently closed due to the COVID-19, and all work is paused until further notice.

1. Signature of grant agreement (or equivalent)
   Agreement with the enterprise was signed in December 2018.

2. Status of planning for procurement of equipment
   Modifications to the storage and refrigerant supply system to make these explosion-proof by replacing the refrigerant supply pumps, refrigerant charging units, installation of a safety system (i.e., leak detectors, fire-fighting equipment, shut-off valves, pressure sensors, water sprinkler, smoke detectors, and ventilation system); and relevant certifications needed for implementing the project.
   For the assembly line modifications, the installation of helium charging/recycling unit to complement the existing helium sniffer, safety system that includes the installation of HC sensors and ventilation, ultrasonic welding equipment for sealing of the refrigeration system, hand-held HC leak detector for storage area, and addition of repair area on assembly lines with safe recovery of R-600a/R-290, are needed.

3. Status of delivery and installation of equipment
   All equipment procured was delivered to the enterprise in January-February 2020.

4. Status of design of products using alternative technology
   As for the product development using the alternative technology, the enterprise made all the necessary engineering and safety design modifications. Once all the equipment are installed the products (domestic refrigerator and freezer) for the different categories will be produced within a period of two weeks.

5. Status of commercial production of products using alternative technology
   Same as above

6. Energy efficiency performance
   Lematic efforts to switch to more efficient appliances are met by several obstacles, among which the switch to testing their equipment and customizing their laboratory according to the new IEC 62552:2015 standard. The current measurement and testing process at Lematic are done with an international instrument acquisition using data system to record refrigerator temperature, ambient temperature, humidity, voltage, amperage, power, and test period using lab-view.
   In order to perform the testing following IEC 62552:2015, commercial analyzing software is needed, to communicate with the current testing equipment and produce energy calculations and level rating. UNIDO under the K-CEP global project will support Lematic with this transformation, through the purchase of a technical and software support through the delivery of a software package, offering training, and providing support throughout the process.

7. Status of implementation of service sector component (as applicable)
   Lematic have their own crew of servicing workshops and technicians spread all over Lebanon. All the service workshops were equipped with necessary equipment and tools such as recovery machines, vacuum pumps, leak detectors, scales, and recovery cylinders.
   A team of 15 senior technicians including the technical director from Lematic were trained on dealing with flammable refrigerants, charging, safety, recovery, in the newly established RAC training center in Beirut in September 2019. In February 2020, a training session was conducted by HEAT team (Germany) and OTB Consults (Lebanon) for lab technician on energy efficiency standards and MEPS that are proposed to be established in Lebanon. Additional training on installation and commissioning of the equipment are also planned.

8.	Key observations and lessons learnt relating to conversion Lematic was keen to move fast in the conversion process mainly by offering their products to the international market. The project helped in building their technical capacities dealing with flammable refrigerants, updating their products to include energy efficiency standards. The conversion of their products using the alternative technologies including energy efficiency standards led to an increase in their cost of production by 10 per cent. This might lead according to the enterprise to a tough competition with imported products into the local market. The conversion process time based on BAU could be done in 14-16 months. The cost of the conversion is acceptable without any additional cost from the enterprise.

<table>
<tr><td colspan="2">Country: Mexico</td><td colspan="2">Agency: UNIDO</td><td>Meeting approved: 81st</td><td>Status: Ongoing</td></tr>
<tr><td colspan="6">Project title and objective: Conversion of commercial refrigeration manufacturing in two facilities from the use of HFC-134a and R-404A as the refrigerants to propane (R-290) and isobutane (R-600a) at Imbera</td></tr>
<tr><td colspan="6">Sector/application: Commercial refrigeration</td></tr>
<tr><td>HFC (s)</td><td>Metric tonnes</td><td>CO_2 eq mt</td><td>Alternatives</td><td>Metric tonnes</td><td>CO_2 eq mt</td></tr>
<tr><td>HFC-134a</td><td>51.73</td><td>73,974</td><td>R-600a/R-290</td><td>28.3</td><td>84.9</td></tr>
<tr><td>R-404A</td><td>4.31</td><td>16,904</td><td>R-290</td><td></td><td></td></tr>
<tr><td colspan="2">Funds approved (US $)</td><td colspan="2">Funds disbursed (US $)</td><td colspan="2">Date of completion</td></tr>
<tr><td colspan="2">1,018,123</td><td colspan="2">41</td><td colspan="2">December 2020 (depending on the pandemic; UNIDO can provide update at the 86th meeting)</td></tr>
<tr><td colspan="6">Status of implementation: The project started in July 2018. As at 20 March 2020, equipment required for the conversion was shipped from Europe in mid February 2020 and expected to arrive to Mexico in March 2020; new appliances have been designed and tested, but all other activities had to be suspended due to the COVID-19 pandemic.</td></tr>
<tr><td colspan="6">1. Signature of grant agreement (or equivalent)
UNIDO does not use grant agreements. After approval of the project, UNIDO expert visited the site, discussed and agreed with the Government and the enterprise the scope of activities and delineated the Multilateral Fund and counterpart inputs. Based on this, UNIDO prepared TOR and received the counterparts' agreement to it (October 2018). The counterpart agreed to implement all redesign work as counterpart input.</td></tr>
<tr><td colspan="6">2. Status of planning for procurement of equipment
The equipment bidding process was initiated by UNIDO in November 2018; the bids were received in March 2019 and evaluated by UNIDO, and the lowest priced technically acceptable bid was selected. UNIDO selection was discussed with the counterparts on the site where adjustments were made. UNIDO and the counterpart signed a MoM reflecting their agreement on 24 April 2019. The purchase order was issued in May 2019. The supplier visited the counterpart to agree on the schedule of work. A MoM was signed between the counterpart and the supplier on 31 July 2019. The supplier manufactured the equipment in 2019, but delivery was delayed until March 2020.</td></tr>
<tr><td colspan="6">3. Status of delivery and installation of equipment
The equipment was shipped from Europe in the second half of February 2020 and arrival to Mexico expected around 20 March 2020.</td></tr>
<tr><td colspan="6">4. Status of design of products using alternative technology
The counterpart has completed the design of the new appliances. The details will be communicated upon resumption of the project.</td></tr>
<tr><td colspan="6">5. Status of commercial production of products using alternative technology
This has not started yet due to suspension of the project.</td></tr>
<tr><td colspan="6">6. Energy efficiency performance
The details will be communicated upon resumption of the project.</td></tr>
<tr><td colspan="6">7. Status of implementation of service sector component (as applicable)
N/A</td></tr>
<tr><td colspan="6">8. Key observations and lessons learnt relating to conversion
The details will be communicated upon completion of the project.</td></tr>
</table>

Country: Thailand		**Agency:** IBRD	**Meeting approved**: 82nd	**Status:** Ongoing	
Project title and objective: Conversion from HFC to propane (R-290) and isobutene (R-600a) as a refrigerant in manufacturing commercial refrigeration appliances in Pattana Intercool Co. Ltd.					
Sector / application: Commercial refrigeration					
HFC (s)	**Metric tonnes**	**CO_2 eq mt**	**Alternatives**	**Metric tonnes**	**CO_2 eq mt**
HFC-134a	8.78	12,555	R-600a	3.95	12
Funds approved (US $)		**Funds disbursed (US $)**		**Date of completion**	
	183,514	Not available; retroactive payment after sub-grant agreement signature		December 2020	
Status of implementation:					

1. Signature of grant agreement (or equivalent)
   The grant agreement between the Government and the World Bank has been presented to the Cabinet for its approval. Once the grant Agreement is approved, sub-grant agreement with Pattana Intercool will be processed. The company has already completed preparation of a safety plan focusing on occupational health and safety that meets the local authority's requirement. The plan has been reviewed and endorsed by the Bank.
2. Status of planning for procurement of equipment
   Pattana Intercool has developed specifications of equipment items to be financed by the Fund and confirmed its counterpart funding. The procurement process started in September 2019. Any expenditures incurred prior to the signing of the grant agreement will be reimbursed by the Bank through the retroactive financing provision agreed earlier by Department of Industrial Works (DIW) and the Bank. Key equipment includes vacuum pumps, charging machine, leak detectors, and safety equipment (ventilation system and sensor alarm system).
3. Status of delivery and installation of equipment
   Not all equipment has arrived. Due to COVID-19, the enterprise is not able to estimate when all equipment can be installed yet.
4. Status of design of products using alternative technology
   Not yet started.
5. Status of commercial production of products using alternative technology
   Not yet started.
6. Energy efficiency performance
   Not available.
7. Status of implementation of service sector component (as applicable)
   Not applicable.
8. Key observations and lessons learnt relating to conversion
   Not yet available.

Annex X

LIST OF COUNTRIES WITH ENABLING ACTIVITIES FUNDED UNDER ADDITIONAL CONTRIBUTIONS

Country	Agency	Date approved	Funds approved (US $)
Afghanistan	UNEP	Jun-2018	150,000
Albania	UNIDO	Nov-2017	94,978
Angola	UNEP	Nov-2017	150,000
Argentina	UNIDO	Jun-2018	250,000
Armenia	UNIDO	Nov-2017	150,000
Bahamas	UNEP	Dec-2018	95,000
Benin	UNEP	Jun-2018	150,000
Bhutan	UNEP	Nov-2017	50,000
Bolivia (Plurinational State of)	UNEP	Dec-2018	150,000
Bosnia and Herzegovina	UNIDO	Nov-2017	95,000
Botswana	UNEP	Jun-2018	150,000
Brunei Darussalam	UNEP	Dec-2018	150,000
Burkina Faso	UNIDO	Nov-2017	150,000
Cambodia	UNEP	Nov-2017	150,000
Cameroon	UNIDO	Nov-2017	150,000
Cabo Verde	UNEP	Dec-2018	95,000
Chad	UNEP	Jun-2018	150,000
Chile	UNIDO	Nov-2017	86,000
Chile	UNDP	Nov-2017	33,000
Chile	UNEP	Nov-2017	31,000
China	UNEP	Nov-2017	85,000
China	UNDP	Nov-2017	165,000
Colombia	UNDP	Nov-2017	250,000
Comoros	UNEP	Jun-2018	50,000
Congo	UNIDO	Nov-2017	150,000
Cook Islands	UNEP	Dec-2018	50,000
Costa Rica	UNDP	Nov-2017	150,000
Cote d'Ivoire	UNEP	Jun-2018	150,000
Democratic Republic of the Congo	UNEP	Jun-2018	150,000
Djibouti	UNEP	Jun-2018	50,000
Dominica	UNEP	Nov-2017	50,000
Dominican Republic	UNEP	Nov-2017	150,000
Ecuador	UNEP	Nov-2017	150,000
Egypt	UNIDO	Jun-2018	105,000
Egypt	UNEP	Jun-2018	145,000
Equatorial Guinea	UNEP	Jun-2018	150,000
Eritrea	UNEP	Nov-2017	95,000
Eswatini	UNEP	Jun-2018	95,000
Ethiopia	UNEP	Jun-2018	95,000
Fiji	UNDP	Nov-2017	150,000
Gabon	UNEP	Nov-2017	150,000
Gambia	UNIDO	Nov-2017	95,000
Georgia	UNEP	Jun-2018	95,000
Ghana	UNEP	Nov-2017	150,000
Grenada	UNIDO	Jun-2018	50,000
Guatemala	UNEP	Nov-2017	150,000
Guinea-Bissau	UNEP	Jun-2018	95,000

Country	Agency	Date approved	Funds approved (US $)
Guyana	UNEP	Jun-2018	95,000
Honduras	UNEP	Jun-2018	150,000
Indonesia	IBRD	Jun-2018	250,000
Jamaica	UNDP	Nov-2017	150,000
Kenya	UNEP	Jun-2018	150,000
Kiribati	UNEP	Jun-2018	50,000
Kyrgyzstan	UNEP	Nov-2017	95,000
Lao People's Democratic Republic	UNEP	Jun-2018	95,000
Lebanon	UNDP	Nov-2017	150,000
Lesotho	UNEP	Nov-2017	55,000
Lesotho	Italy	Nov-2017	40,000
Liberia	Germany	Nov-2017	95,000
Libya	UNIDO	Jun-2018	150,000
Madagascar	UNEP	Jun-2018	150,000
Malawi	UNEP	Jun-2018	150,000
Malaysia	IBRD	Nov-2017	250,000
Maldives	UNEP	Nov-2017	55,000
Maldives	Italy	Nov-2017	40,000
Mali	UNEP	Jun-2018	150,000
Marshall Islands	UNEP	Jun-2018	50,000
Mauritania	UNEP	Jun-2018	150,000
Mexico	UNIDO	Nov-2017	220,000
Mexico	UNEP	Nov-2017	30,000
Micronesia (Federated States of)	UNEP	Jun-2018	50,000
Mongolia	UNEP	Nov-2017	95,000
Montenegro	UNIDO	Nov-2017	49,973
Morocco	UNIDO	Jun-2018	150,000
Mozambique	UNEP	Jun-2018	150,000
Myanmar	UNEP	Jun-2018	95,000
Namibia	UNEP	Nov-2017	150,000
Nauru	UNEP	Jun-2018	50,000
Nepal	UNEP	Jun-2018	95,000
Nicaragua	UNIDO	Jun-2018	150,000
Niger	UNIDO	Jun-2018	150,000
Nigeria	UNEP	Nov-2017	250,000
Niue	UNEP	Jun-2018	50,000
North Macedonia	UNIDO	Nov-2017	95,000
Palau	UNEP	Nov-2017	50,000
Papua New Guinea	Germany	Nov-2017	95,000
Paraguay	UNDP	Jun-2018	75,000
Paraguay	UNEP	Jun-2018	75,000
Peru	UNDP	Nov-2017	150,000
Philippines	UNIDO	Nov-2017	225,992
Philippines	IBRD	Nov-2017	24,008
Rwanda	UNEP	Nov-2017	55,000
Rwanda	Italy	Nov-2017	40,000
Saint Kitts and Nevis	UNEP	Jun-2018	50,000
Saint Lucia	UNEP	Nov-2017	95,000
Saint Vincent and the Grenadines	UNEP	Nov-2017	50,000
Samoa	UNEP	Jun-2018	50,000
Sao Tome and Principe	UNEP	Jun-2018	95,000
Senegal	UNEP	Nov-2017	150,000
Serbia	UNIDO	Nov-2017	150,000

Country	**Agency**	**Date approved**	**Funds approved (US $)**
Seychelles	Germany	Nov-2017	95,000
Sierra Leone	UNEP	Jun-2018	95,000
Solomon Islands	UNEP	Jun-2018	95,000
Somalia	UNIDO	Nov-2017	150,000
South Africa	UNIDO	Dec-2018	240,000
South Sudan	UNEP	Jun-2018	95,000
Sri Lanka	UNEP	Jun-2018	150,000
Sudan	UNIDO	Nov-2017	75,000
Sudan	UNEP	Nov-2017	75,000
Suriname	UNEP	Nov-2017	95,000
Syrian Arab Republic	UNEP	May-2019	250,000
Thailand	IBRD	Nov-2017	250,000
Togo	UNEP	Nov-2017	150,000
Tonga	UNEP	Nov-2017	50,000
Trinidad and Tobago	UNDP	Nov-2017	150,000
Tunisia	Italy	Nov-2017	75,000
Tunisia	UNIDO	Nov-2017	75,000
Turkey	UNIDO	Nov-2017	250,000
Turkmenistan	UNEP	Nov-2017	150,000
Tuvalu	UNEP	Jun-2018	50,000
Uganda	UNEP	Jun-2018	50,000
United Republic of Tanzania	UNEP	Jun-2018	95,000
Uruguay	UNIDO	Nov-2017	50,000
Uruguay	UNDP	Nov-2017	100,000
Vanuatu	UNEP	Jun-2018	50,000
Venezuela (Bolivarian Republic of)	UNIDO	Jun-2018	250,000
Viet Nam	UNIDO	Nov-2017	250,000
Zambia	UNEP	Nov-2017	95,000
Zimbabwe	UNEP	Nov-2017	150,000
Total			**15,184,951**