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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Eighty-third Meeting
Montreal, 27– 31 May 2019

STATUS REPORTS AND REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS

1. This document serves as a follow-up to the issues raised in the last annual progress and financial reports submitted to the 82nd 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 seven parts and an Addendum:

Part I:	Projects with implementation delays and for which special status reports were requested
Part II:	ODS waste disposal projects
Part III:	Temporary use of a high-global-warming-potential technology in approved projects
Part IV:	Reports related to HCFC phase-out management plans (HPMPs)
Part V:	Demonstration projects for low-global-warming-potential alternatives to HCFCs and feasibility studies for district cooling (decision 72/40)
Part VI:	Change of implementing agency for stage II of the HCFC phase-out management plan (HPMP) and enabling activities for HFC phase-down for the Philippines
Part VII:	Requests for extension of enabling activities
Add.1:	Consists of reports related to China in five parts (UNEP/OzL.Pro/ExCom/83/11/Add.1)

[1] UNEP/OzL.Pro/ExCom/82/14-19.

3. Each part contains a brief description of progress, and the Secretariat's comments and recommendations.

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

Project implementation progress in 2018

4. The Secretariat held discussions with relevant bilateral and implementing agencies on projects for which status reports were requested at the 82nd meeting. Further to the discussions, several issues were satisfactorily addressed.

5. The projects with outstanding issues are listed in Annex I to the present document.

Secretariat's recommendation

6. The Executive Committee may wish:

(a) To note:

(i) The status reports submitted by bilateral and implementing agencies to the 83rd meeting, contained in document UNEP/OzL.Pro/ExCom/83/11;

(ii) That bilateral and implementing agencies would report to the 84th meeting on 54 projects recommended for additional status reports, as indicated in Annex I to the present document; and

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

REPORTS ON PROJECTS WITH SPECIFIC REPORTING REQUIREMENTS

7. Table 1 presents a list of all projects covered in the present document and brief explanations on the related issues.

Table 1. Reports on projects with specific reporting requirements submitted to the 83rd meeting

Country	Project title	Issue
II. ODS waste disposal projects		
Cuba	Pilot demonstration project on ODS waste management and disposal - final report Annex II: Final report	Completed. Agencies requested to use findings and recommendations, where appropriate
III. Temporary use of a high-global-warming-potential (GWP) technology in approved projects		
Brazil	Temporary use of high-GWP HFC polyol systems (stage I of the HPMP)	To continue reporting as a low-GWP technology not yet introduced
Cuba	Temporary use of a high-GWP technology by enterprises that had been converted to a low-GWP technology (stage I of the HPMP)	To continue reporting as a low-GWP technology not yet introduced
Lebanon	Use of interim technology – progress report (stage II of the HPMP)	To continue reporting as a low-GWP technology not yet introduced

Country	Project title	Issue
Trinidad and Tobago	Temporary use of a high-GWP technology at an enterprise (stage I of the HPMP)	To continue reporting as a low-GWP technology not yet introduced. To note that balances from one cancelled project will be returned when the next tranche is submitted
IV. Reports related to HCFC phase-out management plans (HPMPs)		
Bahamas	HPMP (stage I – report on the study to explore best available options for the pilot retrofitting project)	To urge UNEP to provide, at the 84th meeting, an updated final report on the findings of the study
Bangladesh	HPMP (stage I – final progress report)	Completed. To request return of balances no later than the 84th meeting
Egypt	HPMP (stage I – progress report on the foam sector and temporary use of high-GWP technology)	To continue reporting on progress on the foam sector and on temporary use of high-GWP technology as a low-GWP technology not yet introduced
Equatorial Guinea	HPMP (stage I – report on the status of signature of the Agreement)	Agreement signed. No further reporting required
Honduras	HPMP (stage I – progress report on UNEP activities)	To continue reporting on UNEP's activities and disbursements
India	HPMP (stage I – final financial report)	Completed. US $83,405, plus agency support costs of US $5,838 had been returned to the 83rd meeting
India	HPMP (stage II – progress report on the assessment of enterprises in the foam sector)	Assessment requested still ongoing. To provide a report at the 84th meeting.
Indonesia	HPMP (stage I – status of conversion of the refrigeration and air-conditioning (RAC) manufacturing enterprises and of one systems house PT. TSG Chemical)	To continue reporting on the status of the RAC manufacturing enterprises. To note that PT. TSG Chemical withdrew from the HPMP and US $301,539, plus agency support costs of US $22,616 had been returned to the 83rd meeting
Islamic Republic of Iran	HPMP (stage I – final progress report)	To submit a revised PCR including final disbursement and information on destruction of baseline equipment
Jordan	HPMP (stage II – change in technology at five enterprises from HFO-1233zd(E) to cyclopentane-based foam blowing agent	To approve the change of technology noting that the enterprises would bear any additional costs for conversion from HCFC-141b to cyclopentane
Maldives	HPMP (demonstration project for HCFC-free low-GWP alternatives in refrigeration in the fisheries sector)	To submit final report to the 84th meeting
North Macedonia	HPMP (stage I – progress report on the conversion of foam enterprise Sileks)	To note that the foam enterprise Sileks withdrew, and that US $30,000, plus agency support costs of US $2,250 had been returned to the 83rd meeting
Suriname	HPMP (stage I – progress report on addressing issues identified in the verification report)	To note the report
Tunisia	HPMP (stage I – request for the cancellation of the AC sector plan and updating of the Agreement Annex III: Revised Agreement	To note removal of the AC sector plan; to note the revision of the Agreement; and to request agencies to return US $900,489 associated to the AC sector plan to the 84th meeting
V. Demonstration projects for low-GWP alternatives to HCFCs and feasibility studies for district cooling		
Egypt	Demonstration of low-cost options for the conversion to non-ODS technologies in polyurethane (PU) foams at very small users (progress report, final report was due at the 83rd meeting)	To extend project completion to 31 July 2019, on an exceptional basis, noting the substantial progress so far achieved, on the understanding that no further extension would be requested, and to request UNDP to submit the final report no later than the 84th meeting

Country	Project title	Issue
Europe and Central Asia (ECA) Region	Development of a regional centre of excellence for training and certification and demonstration of low-GWP alternative refrigerants (progress report, final report was due at the 84th meeting)	To extend project completion to 31 December 2019, on an exceptional basis, noting the substantial progress so far achieved, on the understanding that no further extension would be requested, and to request the Government of the Russian Federation to submit the final report no later than the 85th meeting
Kuwait	Demonstration project to evaluate HCFC-free and low-GWP technology performance in air-conditioning (AC) applications (progress report)	To cancel the project, and to request UNDP to return, to the 84th meeting, US $293,000, plus agency support costs of US $20,510
Morocco	Demonstration project on the use of low-cost pentane foaming technology for the conversion to non-ODS technologies in the PU foam manufacturing sector at small and medium-sized enterprises (progress report, final report was due at the 83rd meeting)	To extend the project completion date to 30 September 2019, noting the advanced progress in implementation and the potential replicability of the results in several Article 5 countries, and to request UNIDO to submit the final report of the project to the 84th meeting and to return all remaining balances by the 85th meeting
Saudi Arabia	Demonstration project at AC manufacturers to develop window and packaged air conditioners using low-GWP refrigerants (final report) Annex IV: Final report	Completed. Agencies requested to take into account final report when assisting Article 5 countries in preparing projects for manufacturing packaged air conditioners using refrigerants with low GWP
Saudi Arabia	Demonstration project on promoting HFO-based low-GWP refrigerants for the AC sector in high ambient temperatures (progress report, final report was due at the 83rd meeting)	To extend project completion to 31 December 2019, noting the advanced progress in implementation and the potential replicability of the results in several Article 5 countries, and to request UNIDO to submit the final report of the project no later than the 85th meeting and to return all remaining balances by the 86th meeting
Saudi Arabia	Demonstration project for the phase-out of HCFCs by using HFO as foam blowing agent in the spray foam applications in high ambient temperatures (progress report, final report was due at the 83rd meeting)	To extend project completion to 31 October 2019, on an exceptional basis, noting the substantial progress so far achieved, 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
Thailand	Demonstration project at foam system houses in Thailand to formulate pre-blended polyols for spray PU foam applications using a low-GWP blowing agent (final report) Annex V: Final report	Completed. Agencies requested to take into account the final report when assisting Article 5 countries in preparing spray foam projects with HFO-blown foam
West Asia (regional)	Demonstration project on promoting alternative refrigerants in AC for high-ambient countries in West Asia – PRAHA II (progress report, final report was due at the 83rd meeting)	To extend the date of completion to 15 November 2019 in order to complete ongoing activities, and to request UNEP and UNIDO to submit the final report no later than the 84th meeting, and to return all remaining balances by the 85th meeting
Kuwait	Feasibility study comparing three not-in-kind technologies for use in central AC (final report) Annex VI: Final report	Completed. To submit the PCR and return any balances to the 84th meeting
VI. Request for a change of agency for the implementation of stage II of the HPMP		
Philippines	Stage II of the HPMP and enabling activities (request for a change of implementing agency)	To note that the World Bank returned at the 83rd meeting US $1,010,023, plus agency support costs of US $70,701 from the HPMP, and US $225,992, plus

Country	Project title	Issue
	Annex VII: Revised Agreement	agency support costs of US $15,819 from enabling activities; and to approve the transfer of such funds to UNIDO. To note the update to the HPMP Agreement
VII. Requests for extension of enabling activities		
Various	Requests for extension of enabling activities	To extend the completion date to December 2019 for three countries or to June 2020 for 48 countries listed in Table 15, on the understanding that no further extension would be requested, and that agencies would submit, within six months of the project completion date, a final report

PART II: ODS WASTE DISPOSAL PROJECTS

Background

8. At its 79th meeting, the Executive Committee requested, *inter alia*, the bilateral and implementing agencies to submit final reports on outstanding ozone-depleting substances (ODS) disposal pilot projects[2] 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 meetings (decision 79/18(d)). A synthesis report on all completed ODS disposal pilot projects was considered by the Executive Committee at the 82nd meeting.[3] This did not include the project for Cuba, as the final report had not been completed at that time. At the 82nd meeting, the Executive Committee decided to urge UNIDO to return remaining balances for the regional project for ODS waste management and disposal in Europe and Central Asia (ECA) to the 83rd meeting, in line with decision 79/18(d); and to urge UNDP to submit the final report for the demonstration project on ODS waste management and disposal in Cuba, which had been completed in 2015, as soon as possible and no later than the 83rd meeting (decision 82/41(c) and (d)(ii)).

Cuba: Pilot demonstration project on ODS waste management and disposal - final report (UNDP)

9. UNDP, as the designated implementing agency, submitted the final report on the implementation of the pilot demonstration project on ODS waste management and disposal in Cuba, in line with decision 82/41(d)(ii). The full report is attached as Annex II to the present document.

10. The project for Cuba proposed to dispose of 45.3 metric tonnes (mt) of ODS waste that had already been collected[4] under the Government's Energy Programme,[5] and to demonstrate a cost-effective way for the collection, storage and disposal of unwanted ODS using a cement kiln.

11. The final report provided details on project implementation; the strengthening of the national system for refrigerant collection, in particular the scheme for the collection and transport of recovered refrigerants; and the design and construction of a refrigerant disposal facility.

[2] The final reports of pilot projects for Georgia, Ghana and Nepal were submitted to the 79th meeting, while those for the Europe and Central Asia (ECA) region and Mexico were submitted to the 80th meeting.
[3] UNEP/OzL.Pro/ExCom/82/21.
[4] UNEP/OzL.Pro/ExCom/62/28.
[5] Under the Energy Programme, over 2.7 million refrigerators and 276,000 air-conditioning units, on average 20 to 60 years old, have been decommissioned by the Government and replaced with energy-efficient units between 2005 and 2010.

12. The project reported that Cuba had collected and aggregated ODS waste through local workshops, where the collected ODS were fed into municipal centres and aggregated by designated larger collections centres located in the main cities and provinces. The recovered refrigerants were then weighed, identified and segregated into recyclable and disposable material.

13. The substances identified for disposal were transported using a specialized truck designed and equipped with appropriate instruments (e.g., tanks with safety valves, pressure gauges, oil drain valve, manhole for cleaning; high capacity refrigerant transfer and recovery machines) to the storage centres and eventually to the destruction facility. The entire process was recorded in authorization log books.

14. The technology selected for the destruction of unwanted ODS involves a rotary cement kiln employing a humid process. The facility (Siguaney Cement Plant) had to undergo modifications, such as automation of the gas burning line with the existing kiln, installation of a new control panel and supply lines for air, fuel and water, and a feed port for the waste gas. Civil works were carried out to establish a storage area for refrigerant cylinders and other equipment, and a fire prevention system was installed. The project was subject to environmental licensing by the Ministry of Science, Technology and Environment.

15. The installed facility had a nominal destruction capacity of 10 tonnes/year. A total of 1.745 mt of ODS (i.e., 0.268 mt of CFC-11, 1.262 mt of CFC-12 and 0.215 mt of HCFC-22) were destroyed through the facility from 2015 to 2016 and in 2018; there was no destruction of ODS in 2017.

16. One of the challenges identified during the implementation of the project was how to transport the recovered refrigerant to the larger collection centres, and to the destruction facility. This required the design and acquisition of a specialized vehicle (i.e., mobile workshop) with specific features. Other challenges faced included: lack of capacity of smaller workshops to collect refrigerants; delay in the recovery and transportation of refrigerant gases; delay in the importation and subsequent installation of equipment required for the destruction facility; and additional training required for kiln operators in order to adapt to the newly installed automatic controls of the assembled disposal system. There were also delays in the destruction process due to unexpected plant breakdowns, water supply problems caused by severe drought in the area, and plant breakdowns due to lack of spare parts.

17. Lessons learned during project implementation included the importance of coordination among the different institutions involved in the project, monitoring progress of tasks and resolving issues that arise as soon as possible to avoid delays in project implementation; advance planning for logistical arrangements for the transportation of collected ODS waste to a destruction facility; and consideration of the possible challenges and delays when selecting older, existing plants to be used as potential ODS destruction facilities.

Secretariat's comments

18. The project proposed to dispose of 45.3 mt of ODS waste collected through the Government's Energy Programme; however, only 1.75 mt were destroyed. This was due to a combination of factors related to difficulties in the start of operation of the destruction facility. In addition, the low production level of the cement plant limited the amount of ODS waste that could be destroyed.[6] The plant is currently operational and it is expected to continue the destruction of the remaining ODS waste collected under the Energy Programme, presently stored in a warehouse under the Ministry of Internal Trade.

19. In clarifying the approach used for monitoring and verifying the amounts of ODS destroyed in the facility, UNDP explained that no new monitoring systems were developed, but rather the enterprise itself recorded the amounts of ODS waste charged into the kiln and confirmed its destruction by calculating this

[6] A maximum amount of 0.1 kg per tonne of cement can be injected, which guarantees complete gas destruction.

with the resulting cement production. This quantity was reported to the national ozone unit (NOU) for recording. UNDP also clarified that the destruction and removal efficiency of the selected disposal facility was not calculated, nor verified.

20. UNDP further explained that emission testing of the stacks of the cement kiln was not performed, as the identified laboratories that could analyse these emissions were either unwilling to work in the country or could not operate in Cuba due to the economic blockade. Due to the age of the cement kiln, it also did not have a sampling platform installed, which made sample collection difficult.

21. With regard to the sustainability of ODS destruction in the country resulting from the pilot project, UNDP reported that the project contributed to closing the life cycle of ODS, giving the country an environmentally sound option for ODS waste disposal. The outcomes of the pilot project revealed the difficulties of sustaining ODS destruction in low-volume consuming countries due to small amounts of waste collected; however, they also provided an opportunity for the country to modify a cement kiln that could be used for ODS destruction in future, when waste streams become available.

Recommendation

22. The Executive Committee may wish:

(a) To note the final report on the pilot demonstration project on ODS waste management and disposal in Cuba, as submitted by UNDP and contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To request bilateral and implementing agencies to apply, where appropriate, the findings and recommendations of the pilot demonstration project on ODS waste management and disposal in Cuba.

PART III: TEMPORARY USE OF A HIGH-GLOBAL-WARMING-POTENTIAL TECHNOLOGY IN APPROVED PROJECTS

23. In line with decision 74/20, bilateral and implementing agencies reported to the 83rd meeting the status of use of temporary high-GWP technology in Brazil, Cuba, Lebanon, and Trinidad and Tobago, as described in this section. Egypt and Indonesia also reported temporary use of high-GWP alternatives, which will be discussed in Part IV along with other issues related to their HPMPs.

Brazil: Temporary use of high-GWP HFC polyol systems (stage I of the HCFC phase-out management plan) (UNDP and the Government of Germany)

Background

24. At the 80th meeting, UNDP submitted the annual progress report on the implementation of the work programme associated with the fifth tranche of the HPMP for Brazil.[7] [8] UNDP explained that two systems houses (Shimtek and U-Tech) had requested the temporary use of HFC polyol systems with high GWP, as hydrofluoro-olefins (HFOs) were not yet available on a commercial scale in the country. Both systems houses

[7] 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 $110,313 for UNDP, and US $409,091 plus agency support costs of US $45,000 for Germany.
[8] UNEP/OzL.Pro/ExCom/80/34.

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.

25. Further to a discussion, 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 any incremental operating costs would not be paid until the alternative technology originally selected or another technology with a low-GWP had been fully introduced. UNDP was also requested to report on the status of use of the interim technology selected by the systems houses at each meeting until the technology originally selected or another technology with a low-GWP had been fully introduced (decision 80/12(e)), 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 (decision 81/9(b)).

26. In line with decisions 80/12(e) and 81/9(b), UNDP has reported that Shimtek has stopped using HFCs and has opted for water-based technology to replace the use of HFOs for flexible foam production, using its own resources for the necessary adjustments made in the formulations. The enterprise reported that the high cost of HFOs on the national market continued to be the biggest barrier to producing systems at competitive prices.

27. U-Tech is still temporarily using HFC-134a in the production of the froth system, as initial tests with the low-GWP alternative did not yield satisfactory results, with persistent problems in the stability and reactivity of the system. After awaiting the delivery of HFO-1234ze samples from March to September 2018 for additional tests, the enterprise decided to import such samples directly, without the mediation of the HFO provider. Currently, the samples are undergoing customs clearance. U-Tech reported that the process of acquiring samples had presented major difficulties, with only one HFO provider in the market. The systems house also reaffirmed that the present scenario of gaseous HFO costs makes substitution in this market segment unfeasible for the enterprise.

Secretariat's comments

28. The Secretariat notes the efforts by UNDP and the two systems houses to secure a supply of low-GWP foam blowing agents. In the case of Shimtek, the Secretariat notes that the issue was resolved through the introduction of water-based technology, which can be used in flexible foam applications (the sub-sector addressed in stage I by Shimtek). The additional cost of system reformulation has been covered by the systems house.

29. Noting that HFO-1233zd(E) could not be introduced by Shimtek in stage I, and that in stage II several systems houses (Shimtek, U-Tech, Comfibras, Basf and Dow) are expected to introduce HFOs in multiple applications in a large number of downstream users, the Secretariat enquired how this issue is being addressed. UNDP indicated that under stage II, systems houses were expressing interest in working with multiple technological options (methyl formate (MF), methylal, HFO and water-based), in order to better meet the specific needs of their customers. UNDP also expects that larger-scale consumption of HFOs would enable a better long-term cost-benefit ratio.

30. In the case of U-Tech, UNDP reported that the price of the HFO-1234ze samples procured was US $22.00/kg, not including the costs of direct import and customs clearance; such costs could make U-Tech's continued participation in this market segment (froth system) unfeasible. UNDP continues to analyze the situation with the systems house.

31. In order to better understand this issue, the Secretariat requested UNDP to also provide prices/kg of other blowing agents (i.e., HCFC-141b, HFC-245fa, HFC-134a and HFO-1233zd(E)) for foam users for the last three years (or the cost of the samples, if not commercially available yet). UNDP indicated that this

information was not available, as the NOU did not have it and the system houses were reluctant to share the information.

32. UNDP will continue reporting on any additional progress by U-Tech in line with decision 80/12(e).

Secretariat's recommendation

33. The Executive Committee may wish:

(a) To note, with appreciation, the report provided by UNDP and the efforts made to facilitate the supply of technology with low global-warming potential (GWP) to the systems houses Shimtek and U-Tech, funded under stage I of the HCFC phase-out management plan for Brazil, contained in document UNEP/Ozl.Pro/ExCom/83/11;

(b) To note the introduction by the systems house Shimtek of low-GWP technology; and

(c) To request UNDP to continue assisting the Government of Brazil in securing the supply of low-GWP alternative technologies to the systems house U-Tech, on the understanding that no incremental operating costs would be paid until the technology originally selected or another low-GWP technology had been fully introduced, and to provide a report on the status of its conversion at each meeting of the Executive Committee until the technology originally selected or another low-GWP technology had been fully introduced, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available in the country on a commercial basis.

Cuba: Temporary use of a high-GWP technology by enterprises that had been converted to a low-GWP technology (stage I of the HCFC phase-out management plan) (UNDP)

Background

34. At the 77th meeting, the Government of Cuba submitted a request for approval of the third tranche of stage I of its HPMP,[9] indicating that, although two PU foam enterprises (namely Friarc and IDA) had received assistance to convert to water-blown technology (a low-GWP technology), they were currently using, on a temporary basis, a blend of HFC-365mfc and HFC-227ea (a high-GWP technology), because the technology initially selected was not available, and did not provide the required insulation performance.

35. Upon consideration of the issue, the Executive Committee requested UNDP to continue assisting the Government in securing the supply of low-GWP technology and to report on the status of the use of the interim technology at each meeting until the technology originally selected or another low-GWP technology had been fully introduced and the enterprises had been converted (decision 77/50(b)), along with a detailed analysis of the incremental capital and operational costs in the event of use of a technology other than that selected when the project was approved, as well as an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available in the country on a commercial basis (decision 81/10(b)).

36. In line with decisions 77/50(b) and 81/10(b), UNDP reported that HFO-based systems had been supplied by a regional systems house for trials conducted at both enterprises in November 2018. As the initial set of trials had yielded unsatisfactory results, the supplier recently visited Cuba to conduct a second set of trials. In the case of Friarc, the enterprise had used more isocyanate than required in the first set of trials;

[9] UNEP/OzL.Pro/ExCom/77/39.

however, on 26 March 2019 a second set of trials was successfully conducted in the presence of the supplier. In the case of IDA, both trials were unsatisfactory, due to problems with the polyol, which seems to have had stability problems. The supplier will send new samples for additional trials. In the meantime, the enterprises continue using a high-GWP blowing agent.

Secretariat's comments

37. The Secretariat notes the efforts by UNDP to assist the two enterprises in Cuba to secure a supply of low-GWP foam blowing agents. The Secretariat asked for the supply and cost of HFO-1233zd(E), noting that once the alternative is proven technically feasible, it should also be commercially available and affordable; however, there is no information yet on the prices of HFO-based systems in Cuba. The Secretariat also asked for price/kg of the blowing agent being used temporarily (HFC-227ea/HFC-365mfc blend), but had not received that information at the time of issuance of the present document.

Secretariat's recommendation

38. The Executive Committee may wish:

(a) To note with appreciation, the report provided by UNDP and the efforts made to facilitate the supply of technology with low global-warming potential (GWP) to the enterprises Friarc and IDA funded under stage I of the HCFC phase-out management plan for Cuba, contained in document UNEP/Ozl.Pro/ExCom/83/11; and

(b) To request UNDP to continue assisting the Government of Cuba in securing the supply of low-GWP alternative technology and to provide, to the 84th meeting, a report on the status of the conversion of the two enterprises mentioned in sub-paragraph (a), including, in the event of use of a technology other than that selected when the project was approved, a detailed analysis of the incremental capital and operating costs, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available in the country on a commercial basis.

<u>Lebanon: Use of interim technology (stage II of the HCFC phase-out management plan – progress report)</u> (UNDP)

Background

39. On behalf of the Government of Lebanon, UNDP as designated implementing agency has submitted a progress report on the implementation of conversions at five enterprises in the foam, refrigeration and air-conditioning (AC) manufacturing sectors, in the context of stage II of the HPMP, in line with decisions 82/25(b)(i)[10] and (ii).[11]

[10] To request UNDP to continue assisting the Government of Lebanon in securing the supply of low-GWP alternative technology and to provide a report on the status of the conversion of Iceberg SARL and CGI Halawany at each meeting until the technology originally selected or another technology with low-GWP had been fully introduced, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available in the country on a commercial basis.

[11] To request UNDP to report, at the 83rd meeting, on the progress and status of implementation of the conversion, including funding distribution, at the remaining enterprises: Frigo Liban, UNIC, CGI Halawany and Industrial and Commercial Refrigerators (ICR).

Progress report

40. UNDP reported that the conversions at Iceberg[12] and Frigo Liban[13] had been completed, resulting in the phase-out of 1.61 ODP tonnes of HCFC-22 and 1.54 ODP tonnes of HCFC-141b. The conversion at UNIC to HFC-32 started in April 2019 and is expected to be completed by December 2019, with the resulting phase-out of 0.88 ODP tonnes of HCFC-22. For the other two enterprises, CGI Halawany and ICR, negotiations with the enterprises are ongoing for the introduction of the HFC-32 technology. Conversions of these two enterprises are expected by the end of 2020.

41. UNDP further reported that the funding allocations for the AC and foam enterprises were consistent with the revised funding allocations at the enterprise level as submitted to the 81st meeting, when the second tranche of stage II of the HPMP was approved. The Government of Lebanon and UNDP continued to monitor these allocations to ensure the cost-effective conversion of the whole sector within the agreed overall funding approved, and confirmed that any funding remaining at the end of the conversions would be returned to the Multilateral Fund.

42. The foam sector plan of stage II of the HPMP included technical assistance for the conversion of 11 small and medium-sized enterprises (SMEs) using 37.9 mt (4.17 ODP tonnes) of HCFC-141b for insulation in the production of solar and electric water heaters. UNDP reported that with regard to the foam conversion, the continued unavailability of HFO systems in the market remained a challenge, especially for small enterprises. The Government is exploring other low-GWP blowing agents that could facilitate the conversion of all remaining foam applications/enterprises (SPEC, Prometal and the solar and electric water heaters sector) in a cost-effective and sustainable manner. However, given that the ban on HCFC-141b will become effective in January 2020, the lack of commercially available low-GWP alternatives in the local market has forced the Government to also consider the possible interim use of HFC-based blowing agents to complete the phase-out of HCFC-141b in the remaining foam enterprises. A similar situation was reported at the 81st meeting, when one enterprise in the AC manufacturing sector used HFC-365mfc as a blowing agent for conversion of the foam component.

43. The Government of Lebanon also expressed concerns regarding the use of pre-blended HFO-based systems in small enterprises once they become available, as consultations with foam experts have revealed that these systems would require special catalysts and stabilizers which are very expensive.

Secretariat's comments

44. The Secretariat noted the efforts taken by UNDP to assist the remaining foam enterprises, especially small enterprises, to explore other low-GWP foam blowing alternatives in the face of continued difficulties to source HFOs. UNDP was requested to ensure that, where high-GWP options were used (e.g., HFC-245fa), the Executive Committee should be informed accordingly. It was reiterated that due to the ban on the use and imports of HCFC-141b starting January 2020, enterprises were obliged to convert to non-ODS technology as soon as possible.

45. With regard to Iceberg, which completed the conversion in 2017, UNDP reported that it had continued to use HFC-365mfc for foam insulation, consistent with the challenges related to lack of HFO systems in the local market. UNDP also confirmed that the enterprise had committed to convert to HFO

[12] The enterprise had phased out 0.69 ODP tonnes of HCFC-22 and 1.54 ODP tonnes of HCFC-141b and converted to the alternatives of HFC-32 and HFC-365mfc, respectively, where HFC-365mfc is used as an interim substitute technology.

[13] The enterprise had converted to HFC-32 and phased out 0.92 ODP tonnes of HCFC-22.

systems or other low-GWP alternatives for insulation foam using its own resources when these alternatives become available.

46. It was noted that UNDP and the Government of Lebanon would continue to monitor the funding allocations for each enterprise and that the revised enterprise-level allocation agreed at the 81st meeting would be used for agreements with the enterprises. UNDP confirmed that once the conversion of these enterprises were completed, any balances would be returned to the Fund in line with decision 81/50.

Secretariat's recommendation

47. The Executive Committee may wish:

(a) To note the report provided by UNDP and the Government of Lebanon, describing the continued challenges being faced by the Government in sourcing commercially available low-global-warming-potential (GWP) alternatives (i.e., HFOs), and the efforts made by the Government of Lebanon 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, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To request UNDP to continue assisting the Government of Lebanon in securing the supply of low-GWP alternative technology, and to report to the 84th meeting on the status of the conversion of the remaining beneficiary enterprises in both the foam and air-conditioning manufacturing sectors, including the small foam enterprises, at each meeting until the technology originally selected or another technology with low GWP had been fully introduced, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, are available in the country on a commercial basis.

Trinidad and Tobago: HCFC phase-out management plan (stage I – fourth tranche) (UNDP)

Background

48. At the 81st meeting, UNDP informed that one of the enterprises in the foam sector was using a different foam blowing agent from the one that had been approved by the Executive Committee. Subsequently, the Executive Committee requested UNDP to provide, to the 82nd meeting, a status report on the use of MF and the alternative blowing agent being used, under stage I of the HPMP, in the enterprise being assisted by the Multilateral Fund (decision 81/52(b)). At the 82nd meeting, UNDP informed that due to inability in scheduling the expert mission, it was not possible to provide the update on the status of use of the substance at the enterprise. In light of this, the Executive Committee urged UNDP to provide the above-mentioned report at the 83rd meeting (decision 82/26).

49. In line with decisions 81/52(b) and 82/26, UNDP, on behalf of the Government of Trinidad and Tobago, reported that it undertook a mission to Trinidad and Tobago to review project implementation. Table 2 provides a summary of the list of enterprises and the status of adoption of alternative technologies in the foam sector; stage I funding would result in the full phase-out of the remaining eligible consumption of 2.5 ODP tonnes of HCFC-141b in the country.

Table 2. Summary of status of conversion of foam enterprises in Trinidad and Tobago as of April 2019

Enterprise	Funds approved (US $)	Technology option	Status update
Ice Con	43,900	MF	The enterprise has decided to opt out of the project due to change in management and would stop its business operations in foam applications. The project would be cancelled, and remaining funds estimated at US $20,000 would be returned after completing administrative and financial procedures
Ice Fab	31,900	MF	Procuring equipment for conversion to MF technology.
Seal Sprayed Solutions (Seal)	30,500	MF	Using MF/water, and offers this as a standard system to clients. In case of projects that specifically request HFC-based blowing agents be used, those blowing agents are used
Tropical Marine	31,900	Water	Using selected alternative
Vetter	35,600	MF	Using selected alternative
Total	**173,800**		

Secretariat's comments

50. The Secretariat requested UNDP to return the unspent balances of Ice Con, estimated at US $20,000, to the 83rd meeting, as the project was proposed to be cancelled. However, UNDP mentioned that funds could be returned only when the next tranche was submitted, after completing the administrative and financial closure process.

51. The Secretariat noted with concern the use of HFC-based blowing agent by Seal for specific projects and had discussions with UNDP on the reasons behind the specification of HFC-based blowing agents in certain orders. UNDP informed that it was not fully aware of the reasons associated with procurement requests having specific blowing agents; the enterprises would have to supply products in line with consumer demands and as a result, HFCs are used as a blowing agent by Seal when the blowing agent is specifically requested by customers. UNDP also mentioned that HFC-based systems were available from international systems house suppliers and were suitable for the spray foam applications in the markets. In line with decision 77/35(b), UNDP is requested to assist the Government of Trinidad and Tobago in considering taking measures, if possible, to aid the introduction of low-GWP technology in applications covered under the respective sector and/or sub-sector.

Secretariat's recommendation

52. The Executive Committee may wish:

(a) To note the report provided by UNDP on the status of use of different technologies and the challenges faced while adopting low-global-warming-potential (GWP) foam blowing agents by enterprises that were provided assistance under stage I of the HCFC phase-out management plan in Trinidad and Tobago, contained in document UNEP/OzL.Pro/ExCom/83/11;

(b) To also note that UNDP would return unspent balances of Ice Con after completing the necessary administrative and financial procedures for cancellation of the project when the next tranche is submitted; and

(c) To request UNDP to continue assisting the Government of Trinidad and Tobago in securing the supply of low-GWP alternative technology and to provide, to the 84th meeting, a report on the status of the conversion of the proposed technology.

PART IV: REPORTS RELATED TO HCFC PHASE-OUT MANAGEMENT PLANS (HPMPs)

53. This part consists of progress reports for stages I or II of HPMPs for the Bahamas, Bangladesh, Egypt, Equatorial Guinea, Honduras, India, Indonesia, the Islamic Republic of Iran, Jordan, Maldives, North Macedonia, Suriname and Tunisia.

Bahamas (the): HCFC phase-out management plan (stage I – third tranche) (UNEP)

Background

54. At its 80th meeting, the Executive Committee considered the request for the third tranche of stage I of the HPMP for the Bahamas. It noted that the Secretariat had drawn attention to safety concerns associated with the use of R-22a, a flammable refrigerant, for the retrofitting of appliances using HCFC-22, and that UNEP would conduct a study to explore the best available options. In light of this, the Executive Committee requested UNEP to provide an update at the 82nd meeting on the findings of the study to explore the best available options for the pilot project to assess, monitor and retrofit two AC systems (decision 80/62(b)). As the report on the study was not provided by UNEP at the 82nd meeting, the Executive Committee urged UNEP to provide, at the 83rd meeting, an update on the findings of the above-mentioned study, in line with decision 80/62(b) (decision 82/27).

Secretariat's comments

55. The Secretariat noted with concern that the update on the findings of the study were not available for consideration at the 83rd meeting.

56. UNEP explained that the consultant was identified in 2018 and undertook a mission in February 2019; the final draft of the document was currently being prepared. Once the report is finalised, it will be submitted to the Secretariat.

Secretariat's recommendation

57. The Executive Committee may wish to urge UNEP to provide, at the 84th meeting, an updated final report on the findings of the study to explore the best available options for the pilot project to assess, monitor and retrofit two air-conditioning systems under stage I of the HCFC phase-out management plan for the Bahamas.

Bangladesh[14]: HCFC phase-out management plan (stage I – final progress report) (UNDP and UNEP)

58. On behalf of the Government of Bangladesh, UNDP, as lead implementing agency, has submitted the final progress report on the implementation of the work programme associated with the stage I of the HPMP,[15] in line with decision 82/28(b).

59. Stage I was operationally completed by 31 March 2019, and the PCR (project completion report) was submitted on 1 April 2019; no further reporting is required.

HCFC consumption

60. The overall HCFC consumption reported in 2018 under the country programme (CP) implementation report is 46.78 ODP tonnes, which is eight per cent below the 50.86 ODP tonnes allowable for that year in the Agreement between the Government and the Executive Committee, and 35 per cent below the established baseline of 72.65 ODP tonnes.

Progress report

61. The following activities were implemented under stage I of the HPMP:

(a) Amendment of the Ozone Depleting Substances Control Rules (2004) in 2014 to include a ban on the import and manufacture of products using HCFC-141b in bulk; establishment of a licensing and quota system for HCFCs; training of 249 customs and enforcement officers on HCFC import control and regulations; thematic meeting on monitoring and control of ODS trade with customs representatives, NOUs and Border Security of five neighboring countries (Bhutan, China, India, Myanmar and Nepal); provision of five refrigerant identifiers to customs entry points;

(b) Phase-out of 20.20 ODP tonnes (183.70 mt) of HCFC-141b used in the manufacture of insulation foam for refrigeration equipment after the conversion in Walton Hi-Tech Industries Limited[16] in 2014;

(c) Training of 105 trainers and 3,944 technicians on good servicing practices with cooperation from the Bangladesh Refrigeration and Air-conditioning Merchants Association (BRAMA); inclusion of technical issues related to ODS phase-out in the national curricula of polytechnic and vocational institutions through cooperation with the Directorate of Technical Education and Technical Education Board; booklet and training video on good servicing practices produced in local language; and

(d) Awareness raising activities including Ozone Day celebrations, distribution of 7,500 items of awareness building materials, including Customs Quick Tool and Training Handbook, UNEP training manual and two videos promoting zero-ODP, low-GWP alternative refrigerants.

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[14] Stage I of the HPMP for Bangladesh was approved at the 65th meeting for a total of US $1,556,074, plus agency support costs of US $136,231 to reduce HCFC consumption by 30 per cent in 2018.
[15] The combined third and fourth (final) tranches of stage I of the HPMP was approved at the 80th meeting in the amount of US $35,000, plus agency support costs of US $4,550 for UNEP.
[16] Approved at the 62nd meeting (decision 62/31) and included in stage I of the HPMP.

62. Project implementation and monitoring was undertaken by the Ozone Cell of Bangladesh, which is chaired by the Director General of the Department of Environment. The Ozone Cell activities were supervised by a National Technical Committee on Ozone Depleting Substances.

Level of fund disbursement

63. As at March 2019, of the US $1,556,074 approved, US $1,545,405 had been disbursed, as shown in Table 3. In line with decision 82/28(b), the remaining balance of US $11,856 (US $3,628, plus agency support costs of US $272 for UNDP and US $7,041, plus agency support costs of US $915 for UNEP) will be returned to the 84th meeting.

Table 3. Financial report of stage I of the HPMP for Bangladesh

Agency	Approved (US $)	Disbursed (US $)	Disbursement rate (%)
UNDP	1,201,074	1,197,446	99.7
UNEP	355,000	347,959	98.0
Total	**1,556,074**	**1,545,405**	**99.3**

Secretariat's comments

64. The Secretariat noted that UNDP and UNEP had completed the activities planned for stage I of the HPMP for Bangladesh in line with the revised work plan presented at the 82nd meeting. The completion of stage I of the HPMP for Bangladesh had phased out a total of 24.53 ODP tonnes of HCFCs (i.e., 20.20 ODP tonnes of HCFC-141b from the conversion at Walton Hi-Tech Industries Limited in the manufacture of insulation foam; 3.48 ODP tonnes of HCFC-22, 0.57 ODP tonnes of HCFC-142b, 0.21 ODP tonnes of HCFC-123, and 0.07 ODP tonnes of HCFC-124 from the servicing sector).

65. The Government has committed to ensure the sustainability of the phase-out achieved as a result of the conversion of Walton Hi-Tech Industries Limited by banning the use and imports of HCFC-141b since 2014, and regularly monitoring the enterprise's use of cyclopentane in their operations. With regard to the sustainability of the training programme for technicians and for customs officers, UNDP informed that these activities are also being implemented in stage II of the HPMP with the cooperation of BRAMA, which is the main training partner for service technicians in the country. In addition, the NOU is also working with the ministry of education to ensure that all training curricula are integrated into the vocational education programme in the country. For customs training, the training modules are included as part of the regular training curriculum of the Customs Directorate.

Secretariat's recommendation

66. The Executive Committee may wish:

(a) To note the final progress report on the implementation of stage I of the HCFC phase-out management plan (HPMP) for Bangladesh, submitted by UNDP and contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To request the Government of Bangladesh and UNDP to return the balance of US $11,856 (US $3,628, plus agency support costs of US $272 for UNDP and US $7,041, plus agency support costs of US $915 for UNEP) from stage I of the HPMP, no later than the 84th meeting in line with decision 82/28(b).

Egypt: HCFC phase-out management plan (stage I – third tranche) (UNDP)

Background

67. Stage I of the HPMP included a project to convert 81 SMEs and 350 micro users to MF or other low-GWP technology (to be selected during implementation), with the support from their systems houses and distributors, to phase out 75.74 ODP tonnes of HCFC-141b. Funding was approved for the equipment conversion at two Article 5-owned systems houses, and included technical assistance to all systems houses and distributors, and for the conversion of SMEs.

68. At the 82nd meeting, it was reported that one local systems house (Technocom) and one non-Article 5-owned (Dow) systems house converted. No funding from the Multilateral Fund for equipment conversion was provided to Dow; however, technical assistance for the introduction of alternative foam blowing agents to downstream users was funded. One systems house withdrew from the project (Obeigi) and a memorandum of agreement (MOA)[17] with another (Baalbaki) was expected to be signed. A total of 24 downstream users had been assisted. The conversion of the remaining 57 downstream users was expected to be completed by the end of 2019.

69. The Secretariat noted the substantial delay in the conversion of 81 SMEs and 350 micro users through systems houses, which had been expected to be completed by August 2013 (i.e. only 24 SMEs and two systems houses were converted so far). The Secretariat further noted that the Government of Egypt banned the import of HCFC-141b in pre-blended polyols as of 1 January 2018 and committed to ban the import, use and export of HCFC-141b in bulk and the export of HCFC-141b contained in pre-blended polyols by 1 January 2020.

70. Also at the 82nd meeting, it was reported that two systems houses (Dow and Technocom) were developing low-GWP formulations with water and HFO, but also with HFC-245fa, HFC-365mfc and HFC-227ea, substances controlled under the Kigali Amendment, notwithstanding that the use of high-GWP alternatives had been expected to be temporary, and their use phased out by 2015 at the latest. UNDP confirmed that no further assistance would be requested for the downstream users that had received assistance under stage I systems houses project as they agreed to convert to low-GWP technologies.

71. Subsequent to informal consultations, and noting the commitment of the Government of Egypt to submit the PCR for stage I of the HPMP to the first meeting in 2020 and to financially complete stage I and return any remaining balances by 31 December 2020, the Executive Committee *inter alia* requested (decision 82/72(b)(i) and (iv)):

(b)(i) The Government of Egypt and UNDP to submit, at each meeting through completion of stage I, a report on the status of conversion of the systems houses, the 81 SMEs and the 350 micro users, including: the status of systems-house conversion, the formulations developed and related disbursement; an updated list of the SMEs converted with the selected technology, related disbursement and the commitment of each SME; and an update on the number of micro users assisted; and

(b)(iv) UNDP to report to the Executive Committee on the status of use of the interim technology selected by the Government of Egypt at each meeting until a technology with low GWP, as agreed, had been fully introduced, along with an update from the suppliers on the progress

[17] UNDP's project implementation arrangement.

made towards ensuring that the selected technologies, including associated components, were available on a commercial basis in the country.

72. The Executive Committee further requested UNDP to continue assisting the Government of Egypt in securing the supply of the alternative technologies selected for the conversion of the 81 SMEs through the systems houses (decision 82/72(b)(iii)), and approved the third and final tranche of stage I of the HPMP on the understanding that the request for the second tranche of stage II could be submitted only if the following conditions had been met: the MOA had been signed with the systems house Baalbaki; at least 40 of the SMEs included in stage I under the systems-houses project had been converted; and UNDP had disbursed at least an additional US $350,000 from the funding approved for the systems-houses project to final foam beneficiaries (decision 82/72(c)).

73. UNDP, on behalf of the Government of Egypt, submitted the two reports, on the status of conversion of the systems houses and downstream users and on the status of use of the interim technology, in line with decision 82/72(b)(i) and (iv).

Progress report

74. The MOA with Baalbaki to convert eight customers to phase out 53.7 mt of HCFC-141b has been signed. An addendum to the MOA with Technocom has been prepared to convert an additional 12 customers to phase out 11.37 ODP tonnes of HCFC-141b; that MOA is expected to be signed by May 2019. The alternative technologies for Baalbaki include water and MF, while for Technocom they include water-based and HFO systems; in both cases, HFCs are foreseen on an interim basis. To date, no micro users have been converted; those conversions are expected to start in the second half of 2019.

75. Regarding the status on the use of technology, UNDP reported that water-based systems have been introduced by Dow and Technocom and approved by customers for certain applications; an update on the introduction of MF will be provided to the 84th meeting; and further studies on the performance of HFOs in polyols were required as some systems houses reported problems in preparing systems, including their stability. UNDP continues to monitor the situation, and consultations with the NOU on barriers to the introduction of low-GWP technologies are planned for May 2019.

76. An additional US $388,072 was disbursed since the 82nd meeting, bringing the total disbursement for UNDP to US $2,407,924 (out of US $4,000,00). UNDP confirmed that incremental operating costs have not, nor will they be provided to customers unless a low-GWP technology is being used, in line with decision 77/35(a)(vi).

Secretariat's comments

77. The conversion at Dow and Technocom has been completed, including the conversion of 24 downstream customers to water-based, HFOs and, on an interim basis, HFCs, with an associated phase-out of HCFC-141b of 4.44 ODP tonnes and 13.09 ODP tonnes, respectively. While a commitment to stop the use of HCFC-based systems has been duly signed by those 24 downstream customers, a similar commitment to stop using HFCs was not provided as the interim transition is still in process. While an estimate of when it was expected that the downstream customers will start using the agreed low-GWP technology could not be provided, UNDP expects to be able to provide an update following the mission planned in May 2019.

78. UNDP was not able to provide the relative proportion of HFCs being used on an interim basis versus low-GWP blowing agents (i.e., water and HFOs) at the downstream customers converted by Dow and Technocom as the use depended on the specific client needs. Similarly, for the additional 20 downstream

users that will be converted by Baalbaki and under the addendum to the MOA for Technocom, the relative proportion of enterprises expected to temporarily use HFCs will depend on client needs and was not available.

79. Regarding the challenges in the introduction of HFOs, UNDP clarified that there were both commercial and technical challenges. While HFOs are available in Egypt, price is a factor clients consider when selecting a technology. UNDP planned to continue to provide technical assistance to address the concerns on the performance of HFOs-based systems, including through the May 2019 mission.

80. UNDP confirmed that the Government remained committed to complete stage I of the HPMP by 31 December 2019, and to establish the ban on the import, use and export of HCFC-141b in bulk and the export of HCFC-141b contained in pre-blended polyols by 1 January 2020.

Secretariat's recommendation

81. The Executive Committee may wish:

(a) To note the report, submitted by UNDP, on the status of conversion of the systems houses, the 81 small and medium-sized enterprises and the 350 micro users, and a report on the status of use of the interim technology in Egypt, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To request UNDP to continue assisting the Government of Egypt in securing the supply of low-GWP alternative technologies, on the understanding that no incremental operating costs would be paid until the technology originally selected or another low-GWP technology had been fully introduced, and to provide a report on the status of its conversion at each meeting of the Executive Committee until the technology originally selected or another low-GWP technology had been fully introduced, along with an update from the suppliers on the progress made towards ensuring that the selected technologies, including associated components, were available in the country on a commercial basis.

Equatorial Guinea: Report on the status of signature of the Agreement (decision 82/73(c)(i)) (UNEP)

Background

82. Stage I of the HPMP for Equatorial Guinea was approved at the 65th meeting to achieve a 35 per cent reduction in HCFC consumption by 2020. The implementation of the first and second tranches was delayed due to travel constraints caused by social disruptions, the customs clearance process for the procured equipment, and difficulty in completing the verification report due to the security situation in the country.

83. At its 82nd meeting, the Executive Committee, *inter alia*, approved a combined third and fourth tranche of stage I of the HPMP and requested UNEP to provide a report at the first meeting of 2019 on the status of signature of the Agreement with the Government of Equatorial Guinea (decision 82/73(c)(i)).

84. UNEP reported that a small-scale funding agreement (SSFA) was signed by the Government of Equatorial Guinea and UNEP on 4 March 2019. The SSFA includes, *inter alia,* detailed activities, a budget and a timeline for implementation in line with the tranche implementation plan approved at the 82nd meeting. The implementation period is 24 months.

Secretariat's comments

85. The Secretariat noted the efforts by the Government of Equatorial Guinea and UNEP to avoid further delay in the implementation of the activities under the HPMP. With the signing of the SSFA, the implementation of activities had commenced and the final tranche is expected to be requested in 2020. UNEP confirmed that it would further support the Government of Equatorial Guinea through its Compliance Assistance Programme (CAP), and that it would submit a report on the assistance provided at the second meeting of 2019 in line with decision 82/73(c)(ii).

Secretariat's recommendation

86. The Executive Committee may wish to note that the Government of Equatorial Guinea and UNEP had signed an agreement for the implementation of the combined third and fourth tranches of stage I of the HCFC phase-out management plan.

Honduras: HCFC phase-out management plan (stage I - progress report) (UNEP)

87. At the 81st meeting, the Executive Committee approved (under the list of blanket approval projects) the fourth tranche of stage I of the HPMP for Honduras, and the corresponding 2018-2020 tranche implementation plan on the understanding:

(a) That UNEP and the Government of Honduras would intensify efforts to implement the training activities for refrigeration technicians associated with stage I of the HPMP;

(b) That UNEP would submit a progress report to each meeting on the implementation of activities under UNEP's components associated with stage I of the HPMP, including disbursements achieved, until the submission of the fifth and final tranche of stage I of the HPMP; and

(c) That the disbursement targets for the total amount of funds approved for the UNEP components of the first, second and third tranches of stage I of the HPMP for Honduras are 50 per cent by 30 September 2018, 80 per cent by 31 March 2019, and 100 per cent by December 2019, and for the UNEP component of the fourth tranche are 20 per cent disbursement by 31 March 2019 and 50 per cent disbursement by December 2019.

88. In line with the above request, UNEP has submitted to the 83rd meeting a progress and financial report on the implementation of the UNEP's activities under stage I.

Progress report on the implementation of stage I of the HPMP

89. The following activities have been implemented since the 82nd meeting:

(a) Signature of the memorandum of understanding between UNEP, the NOU (UTOH), the Environment Ministry, and the national training institute, to review the training and certification processes for good practices in the refrigeration and air-conditioning (RAC) servicing sector;

(b) Development of a guide and a training session to prepare instructors and evaluators to assess the competency of technicians applying for certification in the RAC servicing sector;

(c) Four additional workshops to train a total of 287 technicians on good refrigeration practices and safe handling of flammable refrigerants;

(d) Awareness-raising visits to 60 refrigeration workshops and 28 end users from supermarkets, hotels and the food industry to promote the technician training and certification programme, and to provide technical advice on refrigerant management to comply with the legal provisions established by the ODS regulations; and

(e) Signature of the agreement between UNEP and the Government for the implementation of the fourth tranche and the first cash advance expected in April 2019.

Level of fund disbursement

90. As at 25 April 2019, of the total amount of US $175,000 of funds approved for the first, second and third tranches for UNEP, US $118,520 (67.7 per cent) had been disbursed, as shown in Table 4. UNEP had advanced US $7,952 to the Government, bringing the total amount of funds advanced for the first, second and third tranches to US $126,472 (72.3 per cent). No disbursement of funds approved for the fourth tranche has taken place yet.

Table 4. Financial report of stage I of the HPMP for Honduras

Tranche	Approved (US $)	Expenditures recorded in UMOJA (US $)			Actual disbursement rate (%)	Target disbursement rate (%)	Advances (US $)	Advances (%)
		As at 30/9/2018	From 30/9/2018 to 25/4/2019	Total				
First	75,000	37,047	30,000	67,047	89.4		7,952	100.0
Second	50,000	33,529	5,883	39,412	78.8			78.8
Third	50,000	6,272	5,789	12,061	24.1			24.1
Sub-total	**175,000**	**76,848**	**41,672**	**118,520**	**67.7**	**80.0**	**126,472**	**72.3**
Fourth	50,000	0	0	0	0.0	20.0	0	0.0

Update on the implementation plan for stage I of the HPMP

91. The following activities are planned for the period from May to October 2019:

(a) Training of customs and enforcement officers, covering 31 customs entry points, on the control of imports of HCFC 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) Continued reformulation of the certification scheme for refrigeration technicians and promotion of its application; revision of the technical standards, including safety measures for flammable refrigerants; and updating of the technical and public awareness information material; and

(d) Training workshops for 400 refrigeration technicians and 1,800 RAC students on good practices and safe handling of ODS alternatives.

Secretariat's comments

92. The Secretariat noted that for the first three tranches the country achieved by 31 March 2019 a disbursement rate of 72 per cent against the target of 80 per cent, while for the fourth tranche no disbursement was made against a target of 20 per cent. UNEP explained that additional commitments of US $15,760 from the first three tranches would be recorded as disbursements by July 2019, bringing the disbursement rate to 81 per cent, and that US $12,500 from the fourth tranche would be recorded as a disbursement in July 2019, bringing the disbursement rate to 25 per cent.

93. Although the commitment on disbursement had not been fulfilled as of 31 March 2019, the Secretariat noted that efforts have been intensified to implement the training activities for refrigeration technicians associated with stage I. A total of 823 technicians and refrigeration students have been trained in the last year, and the setting up of the technician certification scheme continues to progress. UNEP explained that the instructors and evaluators being trained would be certified abroad by the Colombia Certification Institute, and that subsequently the system would be launched nationally. It is expected to be fully operational by December 2019.

94. The Secretariat suggests that UNEP continues to provide assistance to the country in completing other activities expected to be implemented during the reporting period, namely, training of additional customs officers and the development of an electronic registry of HCFC importers, suppliers and end users. During the discussions at the 81st meeting, UNEP explained that UTOH was a small team with a large number of responsibilities. Therefore, UNEP planned to directly hire three experts to provide UTOH with technical support to implement the planned activities. One of the experts is already working in the certification scheme and the recruitment of the remaining two will be completed in June 2019.

95. The Secretariat considers that the report to the 84th meeting should also include progress on these activities and an update on the level of disbursement with the objective of achieving, by December 2019, 100 per cent for the first, second and third tranches, and a 50 per cent disbursement rate for the fourth tranche, as required by decision 81/34(a).

Secretariat's recommendation

96. The Executive Committee may wish:

(a) To note the progress report on the implementation of activities under the UNEP components associated with stage I of the HCFC phase-out management plan (HPMP) for Honduras, submitted by UNEP and contained in document UNEP/Ozl.Pro/ExCom/83/11; and

(b) To request UNEP to continue submitting at each meeting, until the submission of the fifth and final tranche of stage I of the HPMP, a progress report on the implementation of all the activities under the UNEP components associated with stage I of the HPMP, including the disbursements achieved.

<u>India: HCFC phase-out management plan (stage I – final financial report)</u> (UNDP, UNEP, and the Government of Germany)

Background

97. At the 82nd meeting, UNDP submitted on behalf of the Government of India the final progress report on the implementation of the work programme associated with the third and final tranche of stage I of the

HPMP[18] in line with decision 75/29(a). Stage I was operationally completed by 31 December 2017, the PCR was submitted on 27 September 2018, and the financial completion of the project was expected by 31 December 2018.

98. Upon consideration of the submission, the Executive Committee decided *inter alia* to request the Government of India, UNDP, UNEP and the Government of Germany to report to the Secretariat the final disbursement to beneficiaries at 31 December 2018 and to return, at the 83rd meeting, any balances remaining from stage I of the HPMP as at the same date (decision 82/39).

99. Accordingly, UNDP submitted to the 83rd meeting the final financial report for stage I of the HPMP for India, indicating an unspent balance of US $83,405, plus agency support costs of US $5,838, to be returned to the Fund. Out of this, US $3,556, plus agency support costs of US $249, are associated with the second tranche approved to UNDP at the 71st meeting, and US $79,849, plus agency support costs of US $5,589, are associated with the third tranche approved to UNDP at the 75th meeting.

100. With this report, stage I of the HPMP for India has been financially completed and no further reporting is required.

Secretariat's recommendation

101. The Executive Committee may wish to note:

(a) The final financial report for stage I of the HCFC phase-out management plan (HPMP) for India, submitted by UNDP, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) That US $3,556, plus agency support costs of US $249, and US $79,849, plus agency support costs of US $5,589, associated with unspent balance from the second and third tranches, respectively, of stage I of the HPMP for India, had already been returned by UNDP at the 83rd meeting.

India: HCFC phase-out management plan (stage II – second tranche) (UNDP, UNEP, and the Government of Germany)

102. At the 82nd meeting, UNDP submitted on behalf of the Government of India, the request for the second tranche of stage II of the HPMP. The proposal indicated that the Government of India had introduced a ban on the use of HCFCs, including HCFC-141b, pure and contained in pre-blended polyols, in the manufacturing of domestic refrigerators and continuous sandwich panels as of 1 January 2015. However, three continuous-sandwich-panel manufacturers were planned to be included in the first tranche, of which two had signed MOAs with the Government. In view of that, UNDP clarified that the Government was assessing whether those enterprises complied with the ban. Should it be found that they were not in compliance, the MOAs would be terminated and any funding disbursed to the two enterprises would be returned to the project.

103. Accordingly, the Executive Committee *inter alia* requested the Government of India, through UNDP, to provide, at the 83rd meeting, an update on 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 (decision 82/74(b)(i)), noting that, if the Government of India were to determine that a

[18] The third and final tranche of stage I of the HPMP was approved at the 75th meeting at a total cost of US $1,858,200, consisting of US $1,438,490, plus agency support costs of US $100,694 for UNDP, US $86,160, plus agency support costs of US $10,478 for UNEP, and US $199,440, plus agency support costs of US $22,938 for the Government of Germany.

continuous-foam-panel-manufacturing enterprise was not in compliance with the ban referred to, the MOA with that enterprise would be terminated, and any funding disbursed would be returned to the project, in line with decision 77/43(d)(ii). The Committee 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 (decision 82/74(c)).

104. As of the time of writing this document, UNDP reported that the assessment, in line with decision 82/74(b)(i), was still underway and that, as soon as the status of adherence to the ban by the enterprises was determined, it would be communicated. It was expected that the assessment could be completed before the 83rd meeting.

Secretariat's comments

105. Upon a request for a clarification, while no specific reason was provided on why the assessment could not be completed prior to the deadline of submission of documents, UNDP indicated that the assessment might be completed before the 83rd meeting. As agreed at the 82nd meeting, no further disbursement had been made to these enterprises. UNDP also reassured that the Government was committed to implement decision 82/74(b)(i); should it be determined that the two continuous lines had breached the 1 January 2015 phase-out targets in the continuous panel sector, the funds would be returned to the project.

Secretariat's recommendation

106. The Executive Committee may wish to request the Government of India, through UNDP, to provide at the 84th 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).

<u>Indonesia: HCFC phase-out management plan (stage I) – Status of conversion of the refrigeration and air-conditioning manufacturing enterprises and of PT. TSG Chemical</u> (UNDP and World Bank)

107. On behalf of the Government of Indonesia, UNDP as the lead implementing agency, has submitted a report on the status of enterprises that received funding to convert to low-GWP alternatives but temporarily manufacture high-GWP-based RAC equipment, in line with decision 81/11(c), and a report on the status of the participation of the systems house PT. TSG Chemical, in line with decision 82/30(e).

RAC manufacturing sector

108. 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 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.

109. Of the remaining 20 enterprises, only one (Panasonic) is currently manufacturing air conditioners based on HFC-32 technology. Eight large- and medium-sized enterprises have manufactured HFC-32-based prototype equipment, while eight small-sized enterprises are assemblers that work based on custom-made orders; to date, no orders for HFC-32-based equipment have been received. Three additional manufacturing enterprises were still waiting for the market for HFC-32-based equipment to improve before undertaking their conversion. Currently, the 19 enterprises are manufacturing equipment based on high-GWP (principally R-410A, R-404A, and HFC-134a) refrigerants.

110. The reasons for the delay in the conversion and manufacturing of RAC equipment with the agreed technology by the 19 enterprises are: limited commercial availability of HFC-32-based compressors and components at affordable prices; lack of demand in the local market for HFC-32-based equipment; and higher cost of HFC-32-based equipment compared to other equipment available in the country (e.g. based on R-407C refrigerant).

Report and discussions at the 82nd meeting

111. As reported at the 82nd meeting, the compressor manufacturers in China were currently unable to provide HFC-32 compressors to Indonesia, while the compressor manufacturer in Thailand had only tested its first prototype in February 2019. Accordingly, the supply-chain scenario for HFC-32 compressors of the required size, upon which RAC manufacturers depend on, was still unclear. Therefore, the Executive Committee decided to extend the completion of the RAC manufacturing sector plan to 31 December 2019 to allow manufacturers to test the recently developed HFC-32 compressor, to initiate commercial manufacturing of the HFC-32 equipment, and to allow the payment of incremental operating costs to the manufacturers (decision 82/30).

Progress since the 82nd meeting

112. Chinese compressor manufacturers are still not able to supply the (relatively low) quantities required for Indonesian manufacturers at a price that can be competitive to R-407C compressors currently being used. The compressor manufacturer in Thailand has not yet been able to supply HFC-32 compressors in Indonesia as it is still internally testing those units. Accordingly, no further funding to the enterprises was disbursed since the last financial status reported to the 82nd meeting.

PU foam sector

113. At the 82nd meeting, it was reported that one systems house (PT. Sutindo Chemical Indonesia) completed its conversion, while the other systems house (PT. TSG Chemical, with a funding allocation of US $301,539, plus agency support costs of US $22,615 for the World Bank), was still considering whether to withdraw from the project. Due to a fire at the systems house (unrelated to the project), PT. TSG Chemical has now decided to withdraw from the project; the funding allocation associated with the project would be returned to the 83rd meeting.

Secretariat's comments

114. Despite the efforts made by the Government of Indonesia, with the support of UNDP, the industry and other stakeholders, there has been limited progress in introducing the HFC-32 technology, mainly due to the lack of availability of competitively priced compressors of the capacity required for the Indonesian market. While noting the efforts of the Government and UNDP in this regard, the Secretariat considers it unlikely that these two factors will by themselves be able to transform the market, particularly one with considerable global influence. In order to generate the economies-of-scale that may be necessary to enable compressor manufacturers to compete with high-GWP-based equipment, substantial market demand for HFC-32-based equipment would likely be required, such as through the conversions planned under the stage II of the HPMP in China. On this basis, it could be expected that a further extension of stage I of the HPMP for Indonesia may be submitted to the 84th meeting, in line with decision 82/30(g)(i).

Secretariat's recommendation

115. Executive Committee may wish to:

(a) Note the report, submitted by UNDP and the World Bank, on the status of conversion of the refrigeration and air-conditioning manufacturing enterprises and of PT. TSG Chemical of stage I of the HCFC phase-out management plan (HPMP) for Indonesia, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) Note that PT. TSG Chemical had decided to withdraw from stage I of the HPMP for Indonesia, and that US $301,539, plus agency support costs of US $22,615 for the World Bank, associated with the enterprise had already been returned at the 83rd meeting.

Iran (Islamic Republic of): HCFC phase-out management plan (stage I - final progress report) (UNDP, UNEP, UNIDO, and the Government of Germany)

Background

116. On behalf of the Government of the Islamic Republic of Iran, UNDP as the lead implementing agency has submitted the final progress report on the implementation of the work programme associated with the fourth and final tranche of stage I of the HPMP[19] for the country, in line with decision 74/43(b), and the associated online PCR.

HCFC consumption

117. In 2018, in its CP implementation report, the Islamic Republic of Iran reported consumption of 2,386.76 mt (162.95 ODP tonnes) of HCFCs. This consumption was 52 per cent below the Montreal Protocol HCFC consumption target for 2018 and 39 per cent below the annual consumption target for 2018 (266.35 ODP tonnes) stipulated in the Agreement between the Government and the Executive Committee. The licensing and quota system for HCFC imports and exports continues to operate effectively.

Progress report

118. All activities under stage I of the HPMP for the Islamic Republic or Iran have been successfully completed, as reported below.

Regulatory measures

119. The NOU continued to issue licenses for imports of ODS and ODS-containing equipment. A new online system introduced by the customs department has expedited the import request process, increased the accuracy and reliability of the data and prevented illegal trade. The ban on imports of HCFC-22-based residential air conditioners was established in 2018.

Manufacturing sector

120. The following activities were completed:

(a) Conversion of seven PU foam enterprises in the continuous panel sector to hydrocarbon (HC)

[19] The fourth and final tranche of stage I of the HPMP was approved at the 74th meeting at a total cost of US $885,977, consisting of US $250,430, plus agency support costs of US $18,872 for UNDP, US $274,827, plus agency support costs of US $20,612 for UNIDO and US $288,582, plus agency support costs of US $32,744 for the Government of Germany.

technology, phasing out 27.8 ODP tonnes of HCFC-141b (Government of Germany);[20]

(b) Conversion of 11 rigid PU foam enterprises in domestic refrigeration and discontinuous panels to HC technology, phasing out 88.1 ODP tonnes of HCFC-141b (UNIDO); and

(c) Conversion of one AC manufacturing enterprise to R-410A, phasing out 29.3 ODP tonnes of HCFC-22 (UNDP).

Activities in the RAC servicing sector (Government of Germany and UNEP)

121. The following activities in the RAC servicing sector have been completed: training and awareness workshops on HCFC regulations and enforcement for more than 400 customs and enforcement officers; training on good servicing practices in several provinces provided to over 750 technicians; awareness workshops on energy efficiency and good practices for more than 150 technicians; modification of refrigeration systems to sealed-leakage-free systems; commissioning and installation of the said systems; training and monitoring of the results in two supermarket chains; introductory training in managing log books for servicing enterprises and supermarkets; and production and distribution of technical publications to stakeholders.

Level of fund disbursement

122. As at December 2018, of the US $9,994,338 approved, US $9,760,317 had been disbursed, as shown in Table 5. The balance is related to the last conversion completed by UNIDO. Once the last payment is released in 2019, any unspent balance will be returned to the Fund.

Table 5. Financial report of stage I of the HPMP for the Islamic Republic of Iran

Agency	Approved (US $)	Disbursed (US $)	Disbursement rate (%)
UNDP	4,340,246	4,340,246	100
UNIDO	2,506,277	2,272,256	91
Government of Germany	2,885,815	2,885,815	100
UNEP	262,000	262,000	100
Total	**9,994,338**	**9,760,317**	**98**

Secretariat's comments

123. The Secretariat notes that the remaining stage I activities have been completed and that the licensing and quota system has been enforced and strengthened through the online system. As the commissioning of the last enterprise (Emersun) was only completed in February 2019, this should be considered the date of completion of stage I, rather than 31 December 2018.

124. In reviewing the PCR, the Secretariat noted that a revised report would need to be submitted once UNIDO finalized the remaining payments related to the conversion of Emersun. UNIDO estimated that these payments would be done within the next two months. The Secretariat also noted that the PCR did not include sufficient information on actions taken to ensure that the specific equipment or components which were replaced had in fact been destroyed or rendered unusable, in line with decision 22/38(c). Accordingly, the Secretariat requested that the revised PCR include this information for all completed investment projects.

[20] One additional enterprise stopped, on its own, using 2.9 ODP tonnes of HCFC-141b, and the associated funding will be returned to the Multilateral Fund by deducting it from the second tranche of stage II of the HPMP, in line with decision 80/21.

Secretariat's recommendation

125. The Executive Committee may wish:

(a) To note the final progress report on the implementation of the work programme associated with the fourth tranche of stage I of the HCFC phase-out management plan (HPMP) for the Islamic Republic of Iran, submitted by UNDP, and contained in document UNEP/OzL.Pro/ExCom/83/11;

(b) To request the Government of the Islamic Republic of Iran, UNDP, UNIDO, UNEP and the Government of Germany to submit a revised project completion report, including:

(i) The final disbursement for stage I of the HPMP and any balance to be returned to the Fund; and

(ii) Detailed information on the actions taken to ensure that specific equipment or components replaced had in fact been destroyed or rendered unusable, in line with decision 22/38(c).

Jordan: HCFC phase-out management plan (stage II) – Change in technology at five enterprises from HFO-1233zd(E) to cyclopentane-based foam blowing agent (World Bank and UNIDO)

Background

126. At the 77th meeting, the Executive Committee approved in principle, stage II of the HPMP for Jordan[21] for the period of 2017 to 2022, to reduce HCFC consumption by 50 per cent of the baseline, in the amount of US $3,289,919, consisting of US $2,075,236, plus agency support costs of US $145,267 for the World Bank, and US $999,455, plus agency supports costs of US $69,961 for UNIDO. In approving the stage II, the Executive Committee *inter alia* noted that the Government of Jordan would have flexibility in using the funds approved for the PU foam sector to achieve a smooth and efficient HCFC-141b phase-out in line with its Agreement with the Executive Committee (decision 77/45(b)(iii)).

127. The PU foam sector plan of stage II of the HPMP includes the conversion of three large enterprises, Jordan Pioneer for Metal Industry (Jordan Pioneer), Al Safa for Sheet Metal Industry and Panel Co (Al Safa) and Jordan Manufacturing and Services Solutions (JMSS), 43 small- and medium-sized enterprises (SMEs) and six enterprises in spray foam applications. The total phase-out approved in the foam sector plan was 33.07 ODP tonnes.[22] Of these enterprises, Jordan Pioneer agreed to convert to cyclopentane as the blowing agent; the remaining foam enterprises agreed to convert to HFOs as this would involve minimum incremental capital costs; it was expected that reduced HFO-based formulations would be available in the near future at a competitive price, given the reduction in HCFC-141b availability and the corresponding increase in prices. Table 6 presents a summary of the approved funds and associated phase-out of HCFC-141b for these enterprises.

[21] UNEP/OzL.Pro/ExCom/77/51.

[22] Stage II of the HPMP would result in the total phase-out of HCFC-141b of 38.91 ODP tonnes in all applications (including domestic and commercial refrigeration); this consists of 27.6 ODP tonnes of HCFC-141b in bulk and 11.31 ODP tonnes of HCFC-141b contained in imported pre-blended polyols.

Table 6. Incremental costs approved for HCFC phase-out in the foam sector in stage II for Jordan

Particulars	Incremental costs approved in US $	Phase-out in ODP tonnes
PU foam (three large enterprises)	480,889	9.77
PU foam (43 SMEs[23])	799,794	14.61
Spray foam (six enterprises)	411,212	8.69
Total	1,691,895	33.07

128. During the implementation of the project, five[24] out of the 51 PU foam enterprises producing panels and other products, namely Al Safa, Shams Al-ram Tri, Yousef Workshop for Metal Industries, Al-Qanadeel, and Prefabricated Building (Maani) have requested for technology change from the originally proposed HFO-1233zd(E) to cyclopentane. This technology change is requested as the enterprises consider cyclopentane technology as mature and having a lower operating cost as compared to HFO formulations. The representatives from the enterprises had discussions with systems houses, equipment suppliers and foam producers during the study tour to Egypt undertaken in February 2019 as a part of technology information outreach and experience sharing. During the study tour, the enterprises developed a better understanding of the supply situation of HFO-based polyol systems and safety aspects associated with the use of cyclopentane as a blowing agent, and decided to adopt cyclopentane due to the high cost and shorter shelf life of HFO-based formulations. These enterprises were also committed to invest additional funds as required for implementing conversion to cyclopentane in a safe manner.

129. Subsequently, in accordance with paragraph 7(a)(vii) of the Agreement between the Government of Jordan and the Executive Committee, the Government, through the World Bank, has submitted a request to change the technology for the five enterprises from HFO-based to cyclopentane-based foam blowing agents.

Incremental costs

130. The estimated incremental costs for conversion of the five enterprises to cyclopentane, as submitted, is shown in Table 7. The conversion costs to HFOs as approved include incremental capital costs relating to technical assistance, trials and testing, and incremental operating costs based on costs of formulations using HFOs. Capital costs for conversion to cyclopentane are higher mainly due to investments in additional storage equipment, replacement of foam dispensers, installation of safety systems in the manufacturing facility, and safety audit and training of staff. The use of cyclopentane results in operating savings due to the low cost of cyclopentane formulations compared to those of HCFC-141b.

Table 7. Revised incremental cost of the conversion to cyclopentane-based blowing agents (US $)

Enterprises	HFO-1233zd(E)	Cyclopentane*
Al Safa	205,000	383,283
Shams Al-ram Tri	130,077	391,063
Yousef Workshop for Metal Industries	112,844	392,207
Al-Qanadeel	88,718	393,810
Prefabricated Buildings (Maani)	87,539	393,886
Total	**624,178**	**1,954,249**

*As given in the proposal by the World Bank.

[23] One enterprise out of the 43 SMEs, Enjaz Jordan for Steel Structure, is ineligible.

[24] Letters confirming this technology change from the Ministry of Environment of Jordan as well as from the five enterprises, all dated 4 April 2019, were provided. Originally, six enterprises expressed their interest in adopting cylcopentane in place of HFOs; however, after consultations between the World Bank, the Government and the enterprises, only five enterprises decided to adopt cyclopentane.

Secretariat's comments

131. The Secretariat noted that the Agreement between the Government of Jordan and the World Bank had been signed and that the project implementation activities for stage II commenced in January 2018.

132. The Secretariat requested clarifications on how this change would affect the remaining conversion projects in the industry. The World Bank clarified that in the foam sector, HCFC-141b consumption of the remaining enterprises was small and that they were not proposing any technology change at this stage. They would continue to implement the conversion project at a future date.

133. On availability of cyclopentane, the World Bank informed that cyclopentane was available from local suppliers and could be imported from Egypt and other countries; equipment for using cyclopentane was also available from suppliers in neighbouring countries like Egypt and the United Arab Emirates.

134. The Secretariat reviewed the costs for conversion based on the project costs that were agreed in stage II of the HPMP for conversion to cyclopentane for Jordan Pioneer which converted to cyclopentane and is comparable in size with these enterprises; the revised incremental costs are shown in Table 8. The change in technology would result in a revised incremental cost of US $768,652; the five enterprises have confirmed through individual letters that they would bear additional costs for the change in technology to cyclopentane. Since both HFO and cyclopentane blowing agents are low-GWP technologies, the greenhouse gas impact is expected to be negligible.

Table 8. Revised incremental cost of the conversion to cyclopentane-based blowing agents (US $)

Enterprises	HFO-1233zd(E)	Cyclopentane	Difference
Al Safa	205,000	221,283	16,283
Shams Al-ram Tri	130,077	237,951	107,874
Yousef Workshop for Metal Industries	112,844	240,402	127,558
Al-Qanadeel	88,718	243,834	155,116
Prefabricated Building (Maani)	87,539	244,002	156,463
Total	**624,178**	**1,187,472**	**563,294**

135. Finally, the Secretariat notes that the technology change would result in sustained adoption of low-GWP technologies in foam applications in these enterprises and will facilitate the achievement of compliance targets of Jordan.

Secretariat's recommendation

136. The Executive Committee may wish:

(a) To note the request submitted by the World Bank on behalf of the Government of Jordan for the change of technology in the conversion of the five enterprises from HFO-1233zd(E) to cyclopentane-based foam blowing agent in stage II of the HCFC phase-out management plan (HPMP) for Jordan as contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To approve the change of technology mentioned in sub-paragraph (a) above, noting that the enterprises would bear any additional costs for this change in technology for conversion from HCFC-141b to cyclopentane.

Maldives: HCFC phase-out management plan (demonstration project for HCFC-free low-GWP alternatives in refrigeration in the fisheries sector) (UNEP and UNDP)

Background

137. At its 76th meeting, the Executive Committee approved the demonstration project on HCFC-free, low-GWP alternatives in refrigeration in the fisheries sector in Maldives,[25] in the amount of US $141,000, plus agency support costs of US $12,690 (decision 76/34).

138. The project was approved to identify, *inter alia*, low-GWP alternative technologies to HCFCs for use in refrigeration equipment with a charge of 150 kg to 200 kg of refrigerant in the fisheries sector, and to convert the HCFC-22-based refrigeration equipment in three fishing vessels to low-GWP technologies.

139. At the 80th meeting,[26] UNDP as the implementing agency for the demonstration project, reported that the Government had selected R-448A, a non-flammable HFO-HFC blend[27] with a GWP of 1,386 as the replacement alternative. UNDP sought guidance on whether the country could proceed with the demonstration project using this alternative. The Executive Committee requested UNDP to continue exploring other low-GWP alternatives and to report to the 81st meeting.

140. At the 81st meeting,[28] UNDP presented the final report on the demonstration project. That report concluded that R-448A remained as the best drop-in refrigerant for replacing HCFC-22 used in fishing vessels in Maldives. The Executive Committee noted the report on the demonstration project, and requested UNDP to include in the progress report on the implementation of stage I of the HPMP for the country, detailed information on the activities undertaken when retrofitting the HCFC-22-based refrigeration systems in three fishing vessels and to continue exploring other low-GWP alternatives.

141. UNEP, as the lead agency for the HPMP, submitted to the 83rd meeting a progress report on the implementation of the demonstration project for conversion of three fishing vessels.

142. As of March 2019, R-448A refrigerant, compressor oil and other miscellaneous materials were procured and retrofitting was undertaken following the guidelines provided by the supplier of R-448A refrigerant. No significant modification was made to the refrigeration system except for the change of compressor oil, gasket, seals, and filter drier prior to replacing HCFC-22 with R-448A. One fishing vessel has been successfully retrofitted to R-448A.

143. Retrofitting can be performed by a regular RAC technician and completed within a reasonable timeframe without major disruption to the operation of the vessel. The retrofitted fishing vessels have been observed to have an enhanced performance, as it takes a slightly shorter time for the retrofitted refrigeration system to bring temperature down to zero than that prior to retrofitting.

144. The report also highlighted that the R-448A refrigerant was currently not commercially available in the market in Maldives. The small quantity of R-448A purchased specifically for the demonstration project had a price of US $55.31/kg, compared to US $9/kg for HCFC-22. This might create a barrier for adopting the new technology in the fishery sector.

[25] UNEP/OzL.Pro/ExCom/76/40.
[26] UNEP/OzL.Pro/ExCom/80/12.
[27] HFO-1234yf, HFO-1234ze, HFC-32, HFC-125 and HFC-134a; 20/7/26/26/21 per cent.
[28] UNEP/OzL.Pro/ExCom/81/10.

Secretariat's comments

145. Upon a request for clarification, UNDP informed that detailed measurements of performance, including pressure and temperature on both suction and discharge sides, had been carried out. The data shows a slightly improved performance of the retrofitted vessel, as well as a slight (not significant) improvement with regard to energy efficiency. These data will be continuously collected in the other two retrofitted vessels. The remaining two vessels will be retrofitted by May 2019, and the final report on all the results achieved, as well as the financial information on retrofitting the three fishing vessels will be submitted to the 84th meeting.

146. The Secretariat noted that R-448A refrigerant was not commercially available in the market in Maldives, and that the price of the amounts imported for the project was high. UNEP explained that once the supply of R-448A became available in sufficient amounts in the Asia market, the cost of the refrigerant would decrease.

147. The Secretariat further inquired about the consumption in the fishery sector and whether the Government anticipated any challenges in meeting the 97.5 per cent reduction by 2020 as planned under its HPMP. UNEP advised that most of the existing fishing vessels were still using HCFC-22, with the fisheries sector accounting for approximately 10 to 20 per cent of the HCFC-22 consumption. However, the demand in the fisheries sector seems to be decreasing with the ban of HCFC-based equipment starting from 2016. The Government of Maldives focuses strongly on the development of solutions with low-GWP alternatives and energy-efficient systems; therefore, the new fishing vessels imported and facilities established will use low-GWP refrigerants, which will help the country achieve its 97.5 per cent reduction target by 2020.

148. A financial report indicated that, out of the US $141,000 approved for the demonstration project, US $94,378 (67 per cent) had been disbursed and the remaining US $46,622 had all been committed.

Secretariat's recommendation

149. The Executive Committee may wish:

(a) To note with appreciation, the progress report on the demonstration project for HCFC-free low-GWP alternatives in refrigeration in the fisheries sector implemented in Maldives submitted by UNDP; and

(b) To request UNDP to submit the progress report on the implementation of stage I of the HCFC phase-out management plan for Maldives.

<u>North Macedonia: HCFC phase-out management plan (stage I – update on the conversion of the foam enterprise Sileks)</u> (UNIDO)

Background

150. At its 82nd meeting, the Executive Committee considered the eighth tranche of the HPMP for North Macedonia. UNIDO explained that a fire destroyed the facility of the foam enterprise Sileks in 2016, prior to initiating the conversion, yet UNIDO was informed about it only in September 2018 during a visit to the country. No decision was made on whether the enterprise would continue with its planned conversion or whether the funds would be returned. Subsequently, the Committee approved the eighth tranche, on the understanding that an update on the conversion of the foam enterprise Sileks would be provided to the 83rd meeting under reports on projects with specific reporting requirements (decision 82/53(a)).

151. UNIDO, on behalf of the Government of North Macedonia, submitted an update on the conversion of Sileks, in line with decision 82/53(a).

Update

152. UNIDO continued its discussions with the Government and undertook a mission to Sileks. The fire caused complete destruction of the enterprise, which is not in a position to take on additional financial investments. Accordingly, UNIDO and the Government of North Macedonia agreed to cancel the project and return the associated funds of US $30,000, plus agency support costs of US $2,250, to the Multilateral Fund.

Secretariat's recommendation

153. The Executive Committee may wish to:

(a) Note the update, provided by UNIDO, on the conversion of the foam enterprise Sileks, funded under the stage I of the HCFC phase-out management plan (HPMP) for North Macedonia, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) Note that the foam enterprise Sileks had decided to withdraw from the HPMP for North Macedonia, and that US $30,000, plus agency support costs of US $2,250 for UNIDO, associated with the enterprise had already been returned at the 83rd meeting.

Suriname: HCFC phase-out management plan (stage I – third tranche) (UNEP)

Background

154. At its 81st meeting, the Executive Committee considered the request for the third tranche of stage I of the HPMP for Suriname and noted the concerns raised by the Secretariat regarding licensing and monitoring systems in the country relating to the process of clearance of imports of HCFCs, recording of HCFCs under different harmonized system (HS) codes and absence of penalties or incentives encouraging importers to follow correct procedures for reporting imports of HCFCs. Subsequently, the Executive Committee requested UNEP, *inter alia*, to provide an update at the 83rd meeting on the steps taken by the Government of Suriname to strengthen the HCFC licensing and monitoring system, addressing the issues identified in the review of the HCFC verification report by the Secretariat (decision 81/51(b)). The Committee also decided that funding under the last tranche of stage I of the HPMP for Suriname would be considered only after the Government of Suriname had addressed all the issues identified in the verification report and implemented relevant actions, thereby strengthening the import/export licensing and quota systems (decision 81/51(c)(i)).

155. In response to decision 81/51(b), UNEP, on behalf of the Government of Suriname, provided a report on the efforts undertaken by the Government to strengthen the HCFC licensing and monitoring system, which is summarized below:

(a) The NOU initiated discussions in January 2019 on the implementation of the mandatory requirement of no-objection letters[29] for imports of HCFCs, with institutions such as Customs, Ministry of Trade, Industry and Tourism (MoTIT), and the Bureau of Public Health, which are involved in the processing and monitoring of import-export transactions. As an interim measure, Government entities agreed that shipments of ODS would not be released from Customs without the no-objection letter. The no-objection letter has been made mandatory for importers to submit

[29] No-objection letter is a pre-requisite for import of HCFCs under the quota system; this is issued by the NOU to importers prior to imports of HCFCs.

an application to MoTIT for imports. The inspection of shipment can be done only by the Bureau of Public Health as per the national legislation;

(b) The NOU has been in consultations with Customs authorities for the training of Customs brokers and officers in product descriptions for HCFCs and HS codes. It is anticipated that training will be conducted between April and September 2019. Partners for this training will include the Air-conditioning, Refrigeration and Ventilation Association of Suriname (ARVAS) and at least one importer;

(c) Since November 2018, the NOU has initiated the process of operationalising an online system, to be established by June 2019, for processing import permit applications. The MoTIT is also establishing a national electronic licensing system which will include ODS; this will allow for the online exchange of data on imports and independent verification of reported refrigerant imports. For monitoring trade and use of HCFCs, the NOU is working closely with the MoTIT and ARVAS to establish a system of registration for all purchases of refrigerants, which will be included as part of the online system of MoTIT;

(e) The Customs and the MoTIT are sharing data on imports of all refrigerants and RAC equipment with the NOU bi-annually since 2018.

Secretariat's comments

156. The Secretariat noted with appreciation the efforts taken by the Government of Suriname on strengthening the licensing system, noting that these efforts needed to be closely monitored during the HCFC phase-out.

157. Upon request for clarification on the role of the NOU in the verification process of imports, UNEP informed that inspection of shipments was the responsibility of the Bureau of Public Health as per the national legislation; no-objection letters on imports issued by the NOU are necessary for allowing HCFC imports and thus, the NOU operationally controls the import process prior to the import being effected.

158. UNEP informed that, to ensure accuracy of HS codes and product descriptions in single administrative documents (SADs)[30] for imports, training of Customs officers and brokers, ARVAS, and other relevant stakeholders was proposed to be undertaken on data inputs in SAD; a quick reference tool would also be provided for assisting the brokers in filling correct data in the SADs.

159. On the issue of periodic data reporting and data upkeep, UNEP informed that the importers were submitting the data annually based on no-objection letters; discussions are underway for requiring importers to report data twice a year. Further, the NOU is planning to discuss a bi-annual sales reporting process with retailers, with the support from ARVAS.

160. Upon request for clarifications on penalties or incentives for encouraging importers to follow correct procedures for accurately reporting HCFC imports, UNEP explained that if procedural violation was observed, import requests would not be processed until necessary corrective measures were undertaken by the importers, in accordance with MoTIT and Customs rules.

161. UNEP also mentioned that its CAP supported the Government of Suriname in policy and regulations design, review and implementation on issues relating to detection and prevention on illegal trade; training

[30] A single administrative document (SAD) needs to be filled by importers for imports of HCFCs to clear goods through customs.

was also provided to the National Ozone Officer on Montreal Protocol implementation procedures, including monitoring and reporting data.

Secretariat's recommendation

162. The Executive Committee may wish:

(a) To note the report on the efforts undertaken by the Government of Suriname to strengthen the HCFC licensing and monitoring system, submitted by UNEP, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To reiterate decision 81/51(c)(i) that funding under the last tranche of stage I of the HCFC phase-out management plan for Suriname would be considered by the Executive Committee only after the Government of Suriname had addressed all the issues identified in the verification report and implemented the relevant actions, thereby strengthening the import/export licensing and quota systems.

Tunisia: HCFC phase-out management plan (stage II) – Request for the cancellation of the air-conditioning sector plan and updating of the Agreement (UNIDO, UNEP and the Government of France)

163. On behalf of the Government of Tunisia, UNIDO, as the lead implementing agency and in charge of the residential AC sector plan in stage I of the HPMP,[31] has submitted a request to cancel the AC sector plan of the HPMP, and to update the Agreement between the Government and the Executive Committee for the reduction in consumption of HCFCs.

164. In its letter[32] to UNIDO, the Government of Tunisia reported that after evaluation of the current situation in the AC sector, it had found that the beneficiary enterprises had technical and financial difficulties in converting to the agreed alternative technology (i.e., R-290). Accordingly, it authorised UNIDO to cancel the US $1,108,275, plus agency support costs approved in principle for the implementation of the sector plan, and to return balances associated with the sector plan. The Government further requested that the HPMP implementation period be extended from 2018 to 2020 to complete the remaining activities under stage I.

165. UNIDO indicated that the Government of Tunisia agreed that the consumption associated with the AC manufacturing sector of 79.3 mt (4.36 ODP tonnes) would be considered as fully phased out, and would be deducted from the remaining eligible consumption, in addition to the consumption related to the servicing sector as per the original Agreement. Table 9 shows the current consumption of HCFCs in Tunisia.

Table 9. HCFC consumption in Tunisia (2014-2017 Article 7 data, 2018 CP data)

HCFC	2014	2015	2016	2017	2018	Baseline
Metric tonnes						
HCFC-22	610.43	629.75	463.562	501.535	471.13	709.34
HCFC-141b	8.46	8.46	0	8.25	0	14.57
Total (mt)	618.89	638.21	464.062*	509.785	471.13	723.91
ODP tonnes						
HCFC-22	33.57	34.63	25.50	25.78	25.91	39.01
HCFC-141b	0.93	0.93	0	0.91	0	1.61

[31] Stage I of the HPMP for Tunisia for the period 2014 to 2018 to reduce HCFC consumption by 15 per cent of the baseline, was approved in principle at the 72nd meeting, in the amount of US $1,966,209, consisting of US $1,100,195, plus agency support costs of US $77,014 for UNIDO, US $100,000, plus agency support costs of US $13,000 for UNEP, and US $600,000, plus agency support costs of US $76,000 for the Government of France (decision 72/36(a)).
[32] Letter of 15 March 2019 from the National Agency for Environmental Protection of Tunisia to UNIDO.

HCFC	2014	2015	2016	2017	2018	Baseline
Total (ODP tonnes)	34.5	35.56	25.50	28.49	25.91	40.62

*HFC-123 (0.5 mt) reported in 2016.

166. UNIDO further indicated that the balance from the AC sector plan of US $900,489, consisting of US $340,237 and the associated project management unit (PMU) costs of US $21,792, plus agency support costs of US $25,342 for UNIDO, and US $454,087, plus agency support costs of US $59,031 for the Government of France, approved as part of the first and second tranches of stage I of the HPMP, would be returned to the 84th meeting.

167. UNIDO provided a revised plan for the implementation of the remaining components of stage I of the HPMP, to be finalized in 2020, as follows:

(a) Finalize the adoption of subsidiary legislation to align the new certification system with the requirements of the European F-Gas Regulation;

(b) Complete the conversion of the remaining enterprise in the solvent sector, and preparation of the completion reports;

(c) Continue the training for Customs authorities and other stakeholders, jointly with trainers from the servicing sector, on the topic of identification of refrigerants;

(d) Continue the training activities for trainers in vocational schools to include the required elements of the updated practical training modules to be used for upcoming training of technicians, and continue technicians' training;

(e) Continue the implementation of the incentive programme for equipment replacement to encourage the use of new alternative refrigerants, for selected end users; and

(f) Continue the ongoing public awareness campaign programmes addressing good and safe servicing practices and skills in the use of alternative refrigerants.

168. UNIDO is proposing to distribute the funding of stage I, after deducting the funding for the AC sector plan and extending the Agreement from 2018 to 2020, as presented in Table 10.

Table 10. Revised tranche distribution for stage I of the HPMP for Tunisia

ORIGINAL						
Particulars	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Lead IA (UNIDO) agreed funding (US $)	512,885	478,896	0	108,414	0	1,100,195
Support costs for lead IA (US $)	35,902	33,523	0	7,589	0	77,014
Cooperating IA (UNEP) agreed funding (US $)	30,000	55,000	0	15,000	0	100,000
Support costs for cooperating IA (UNEP) (US $)	3,900	7,150	0	1,950	0	13,000
Cooperating IA (France) agreed funding (US $)	135,690	394,397	0	69,913	0	600,000
Support costs for cooperating IA (France) (US $)*	17,187	49,957	0	8,856	0	76,000
Total agreed funding (US $)	678,575	928,293	0	193,327	0	1,800,195
Total agency support costs (US $)	56,989	90,630	0	18,395	0	166,014
Total agreed costs (US $)	735,564	1,018,923	0	211,722	0	1,966,209
REVISED						

	2014	2016	2018	2019	2020	Total
Lead IA (UNIDO) agreed funding (US $)	376,920	71,038	0	57,500	0	505,458
Support costs for lead IA (US $)	26,384	4,973	0	4,025	0	35,382
Cooperating IA (UNEP) agreed funding (US $)	30,000	55,000	0	15,000	0	100,000
Support costs for cooperating IA (UNEP) (US $)	3,900	7,150	0	1,950	0	13,000
Cooperating IA (France) agreed funding (US $)	38,000	38,000		19,000		95,000
Support costs for cooperating IA (France) (US $)**	4,940	4,940	0	2,470	0	12,350
Total agreed funding (US $)	444,920	164,038		91,500		700,458
Total agency support costs (US $)	35,224	17,063		8,445		60,732
Total agreed costs (US $)	480,144	181,101		99,945		761,190

* Calculated based on the original total project cost of US $600,000
** Calculated as 13 per cent based on the revised funding of US $95,000 after the return.

Secretariat's comments

Removal of the AC sector plan from stage I

169. In reviewing this request, the Secretariat noted that during the project review of stage I of the HPMP, the lack of available low-GWP completely knocked down (CKD) kits on the market required that these projects commence only in 2016, i.e., two years after the approval of the HPMP. As CKD kits were not available at the time of the 76th meeting, when the request for the second tranche was approved, the implementation of the AC sector plan was further deferred. After further consideration of the availability of these kits, the four AC enterprises converted their operations using R-410A-based CKD kits since 2017, with their own resources, and had requested the cancellation of the AC sector plan.

Revised plan of action and funding distribution for stage I of the HPMP and submission of the third tranche

170. The Secretariat noted that the action plan provided by UNIDO was a continuation of the activities that were approved as part of the second tranche, and included those that will be implemented for the last tranche. These activities will support the country in maintaining the reduction in HCFC consumption through the application of good servicing practices. UNIDO will submit the request for the third tranche of stage I jointly with stage II of the HPMP to the 84th meeting. UNIDO assured that activities in the solvent and refrigeration servicing sectors were being implemented; the progress of these activities will be further reviewed when the request for the third and final tranche is submitted.

Revision to the HPMP Agreement

171. In view of the removal of the AC sector plan from stage I of the HPMP and the revised funding schedule, Appendix 2-A and Appendix 8-A of the Agreement between the Government of Tunisia and the Executive Committee has been updated, and a new paragraph 16 has been added to indicate that the updated Agreement supersedes that reached at the 72nd meeting, as contained in Annex III to the present document. The full updated Agreement will be appended to the final report of the 83rd meeting.

Secretariat's recommendation

172. The Executive Committee may wish:

(a) To note the request from the Government of Tunisia to remove the residential air-conditioning (AC) sector plan, implemented by UNIDO and the Government of France, from stage I of the HCFC phase-out management plan (HPMP) contained in document UNEP/OzL.Pro/ExCom/72/36, noting that all enterprises included in the sector plan had phased out their consumption of HCFC-22 (4.36 ODP tonnes);

(b) To further note:

(i) That the amount of US $1,206,919, comprising US $513,275, and the associated project management unit (PMU) costs of US $81,462, plus agency support costs of US $41,632 for UNIDO, and US $505,000, plus agency support costs of US $65,550 for the Government of France, approved in principle for the AC sector plan of stage I of the HPMP, would be removed from the Agreement between the Government of Tunisia and the Executive Committee;

(ii) The revised plan for of the refrigeration servicing sector included in stage I of the HPMP;

(iii) That the Fund Secretariat had updated Appendix 2-A of the Agreement between the Government of Tunisia and the Executive Committee, contained in Annex III to document UNEP/OzL.Pro/ExCom/83/11, to reflect the removal of the residential AC sector plan implemented by UNIDO and the Government of France and the revised funding schedule, and that a new paragraph 16 had been added to indicate that the updated Agreement supersedes that reached at the 72nd meeting, and that Appendix 8-A had been removed; and

(c) To request UNIDO and the Government of France to return to the Multilateral Fund US $900,489 consisting of US $340,237 and the associated PMU costs of US $21,792, plus agency support costs of US $25,342 for UNIDO, and US $454,087, plus agency support costs of US $59,031 for the Government of France, associated with the AC sector plan approved as part of the first and second tranches of stage I of the HPMP, to the 84th meeting.

PART V: DEMONSTRATION PROJECTS FOR LOW-GLOBAL-WARMING-POTENTIAL ALTERNATIVES TO HCFCs AND FEASIBILITY STUDIES FOR DISTRICT COOLING (DECISION 72/40)

Background

173. At the 74th, 75th and 76th meetings, the Executive Committee approved three feasibility studies for district cooling (the Dominican Republic, Egypt, and Kuwait) and 17 projects to demonstrate low-GWP technologies pursuant to decision XXV/5 and decision 72/40, including: seven projects in the refrigeration and air-conditioning and assembly sub-sector (China, Colombia, Costa Rica, Kuwait, Saudi Arabia (two), a global (Argentina and Tunisia) and a regional (West Asia[33]) projects; five in the foam sector (Colombia, Egypt, Morocco, Saudi Arabia, South Africa, and Thailand); and three in the refrigeration servicing sector (Maldives, Europe and Central Asia region, and a global project for Eastern Africa and Caribbean regions).

174. As of the 82nd meeting two (out of three) feasibility studies in the Dominican Republic and Egypt, as well as six (out of 17) demonstration projects in China, Colombia (2), Costa Rica, Maldives and South Africa had been completed and their final reports had been presented to the Executive Committee. The final reports

[33] The demonstration project in West Asia on promoting refrigerant alternatives for high ambient temperature countries referred to as PRAHA-II.

for the one remaining feasibility study and seven out of the 11 ongoing demonstration projects are due at the 83rd meeting.

175. Bilateral and implementing agencies submitted for consideration at the 83rd meeting:

(a) Final reports for the demonstration projects in Saudi Arabia (AC by the World Bank) and Thailand, and for the feasibility study for district cooling in Kuwait (full reports are attached as Annexes IV, V and VI to the present document); and

(b) Progress reports on the implementation of nine demonstration projects.

176. For the progress reports on demonstration projects presented to the 83rd meeting, the Secretariat is recommending the cancellation of one project (Kuwait), and an extension of the date of completion for six projects in Egypt, Europe and Central Asia, Morocco, Saudi Arabia (2) and West Asia, given the progress reported and the advanced stage of implementation achieved.

177. The description of each report, and the corresponding Secretariat's comments and recommendations are presented below.

Egypt: Demonstration of low-cost options for the conversion to non-ODS technologies in the polyurethane foam sector at very small users (UNDP)

Background

178. At the 76th meeting, the Executive Committee approved a demonstration project to optimize non-ODS technologies in the PU foam sector in Egypt. The project was expected to contribute to the greater availability of said technologies and to present cost-effective phase-out options for very small users (VSUs), at the amount of US $295,000, plus agency support costs of US $20,650 for UNDP. The Government of Egypt and UNDP were requested to complete the project within 12 months of its approval and to submit a comprehensive final report soon after project completion (decision 76/30).

179. At the 80th meeting, the Executive Committee extended the project completion date to 31 December 2018, on the understanding that no further extension would be requested, and requested UNDP to submit the final report no later than the 83rd meeting (decision 80/26(e)).

Progress report

180. In line with decision 80/26(e), on behalf of the Government of Egypt, UNDP has submitted a preliminary final report of the demonstration project. Although most of the activities in the project have been completed, the final report will be submitted to the 84th meeting, once testing of the equipment at the systems house and with selected small users is finalized.

181. The project was implemented in two parts: the first part involved equipment selection (i.e., developing specifications for the equipment, bidding, review of bids, and procurement), and the second part was the optimization of pre-packaged foaming systems (i.e., selection of a systems house willing to work with these systems, sourcing the pre-packaged systems from suppliers, and field testing the system with the selected equipment with small foam users).

182. The equipment selection component involved a procurement process, where distinct specifications for small, mobile equipment to be used by VSUs were developed for bidding. After a review of the offers received, three types of foaming machines were selected and purchased: one high-pressure, one low-pressure,

and another low-pressure machine for integral skin foam (ISF). These were distributed to three systems houses for evaluation; however, this aspect of the project had not yet been completed.

183. Results obtained from the bidding process for the equipment selection component showed that a basic sole pour-in-place (PIP) foam dispenser could be purchased for US $5,350 rather than US $10,000; a basic spray/PIP dispenser could be purchased for US $6,600 rather than US $10,000; and a basic ISF dispenser could be purchased for US $18,480 instead of US $25,000-30,000.

184. The objective of the chemical component of the project was to make available the pre-packaged foam systems with long shelf life for infrequent VSUs. This was undertaken by identifying and visiting at least one supplier of such systems, and local systems houses that would be interested in distributing or developing similar products. The systems houses showed little interest, as the systems in question were very expensive.

185. UNDP indicated that the results of the project showed the following:

(a) Basic foam dispensers might be available at lower prices where specifications are clearly identified, therefore potentially reducing equipment costs of future foam projects funded by the Multilateral Fund for small and very small foam manufacturers; and

(b) No interest was shown in the use of pre-packaged chemicals, as these were designed for narrowly specialized applications (i.e., back fill around electrical posts) which were not common in Article 5 countries, and as the related investment cost was very high.

Secretariat's comments

186. The Secretariat sought clarification on how the selected equipment was evaluated, noting that the equipment had not yet been tested by the systems house nor by the selected small foam users. UNDP explained that this testing would be completed by the end of May 2019, due to a delay in the delivery. The specifications of the dispensers have been provided to the systems houses so that the trials could proceed efficiently. Once the systems houses have completed this phase, the equipment will be further evaluated in a selected small user. These activities are expected to be completed by June 2019.

187. The Secretariat noted the following based on the report submitted:

(a) While it appears that after a bidding process, UNDP was able to identify equipment suppliers who could provide low-cost mobile foaming machines, the utility and efficiency of these machines have not been demonstrated through testing with VSUs; and

(b) The pre-packaged PU systems are not a commercially viable option for Article 5 countries as these systems are for applications that are not common in these countries, and as their cost is very high for small users.

188. The Secretariat noted that the project was not completed by December 2018 according to the extended project completion date (decision 80/26(e)). However, achieving the completion of testing and evaluation of the low-cost equipment is important, as it will provide technical conclusions on the usefulness of such equipment for small users. UNDP had indicated that field testing of the equipment with three systems houses and some downstream foam users will be completed by June 2019.

189. Noting that field testing of the equipment is the only remaining activity, the Secretariat recommends an extension of this project with the view of receiving the detailed final report at the 84th meeting. This report should contain details on the comparison of the specifications of the original equipment vis-à-vis the

optimized low-cost equipment units, the performance of the equipment during testing, and recommendations on its utility for small users. The report should also include information on what foam systems were used during the testing, and the results of using the new low-cost equipment. Based on the remaining activities for the project, the project should be extended to no later than 31 July 2019.

Secretariat's recommendation

190. The Executive Committee may wish:

(a) To note the preliminary final report on the demonstration of low-cost options for the conversion to non-ODS technologies in the polyurethane foam sector at very small users in Egypt, submitted by UNDP, contained in document UNEP/OzL.Pro/ExCom/83/11;

(b) On an exceptional basis, noting the substantial progress so far achieved, to further extend the project completion date of the project referred to in sub-paragraph (a) above to 31 July 2019, on the understanding that no further extension of project implementation would be requested, and to request UNDP to submit the final report no later than the 84th meeting;

(c) To request UNDP to ensure that the final report of the project indicated in sub-paragraph (a) above would be submitted to the 84th meeting and would include details on the comparison of the specifications of the original equipment vis-à-vis the optimized low-cost units, the performance of the equipment during testing, including the foam systems used during the testing, the results of using the new equipment, and recommendations on its utility for small users.

Europe and Central Asia (ECA) Region: Development of a regional centre of excellence for training and certification and demonstration of low-global-warming-potential alternative refrigerants – progress report (Russian Federation)

Background

191. On behalf of countries in the Europe and Central Asia (ECA) region, the Government of the Russian Federation submitted the progress report on the development of a regional centre of excellence for training and certification and demonstration of low-GWP alternative refrigerants,[34] in line with decision 82/22(f).

192. The overall objective of the project was to improve the technical capacity of the RAC sectors of the countries in Eastern Europe and Central Asia (ECA)[35] to overcome barriers to the adoption of low-GWP refrigerants; improve servicing practices; reduce the levels of F-gas emissions from existing RAC equipment; and provide technicians and equipment manufacturers with understanding of energy efficient design and operation of domestic, commercial and industrial RAC equipment. The Government of the Russian Federation requested the assistance of UNIDO to implement this project.

[34] At the 76th meeting, the Executive Committee approved the project in the amount of US $591,600, plus agency support costs of US $75,076 for the Government of the Russian Federation, in line with decision 72/40 and requested the Government of the Russian Federation to complete the project within 36 months of its approval, and to submit a comprehensive final report soon after project completion (decision 76/35).

[35] Albania, Armenia, Bosnia and Herzegovina, Georgia, the Kyrgyz Republic, Montenegro, North Macedonia, the Republic of Moldova, Serbia, Turkey and Turkmenistan.

Progress report

193. The regional centre of excellence is being established in Armenia, through the Ministry of Nature Protection and will be opened in September 2019. This centre will provide training and advisory services for countries in the ECA region once it is fully operational.

194. The following activities are being implemented:

(a) Creation of a website (http://hvaccenter.am/) to broadcast the centre's services and provide a setting for remote online training;

(b) Development of training programmes, certification schemes, and training of instructors;

(c) Development of a common curriculum for vocational and academic studies covering RAC for implementation by individual countries as part of their HCFC phase-out management plan activities (completed); and

(d) 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 (completed).

195. The Government of the Russian Federation, through UNIDO, had initiated tender procedures for the implementation of the demonstration project on the use of low-GWP refrigerants and energy efficient designs.

Level of fund disbursement

196. As at April 2019, of the US $591,600 approved, US $366,596 had been disbursed (62 per cent).

Secretariat's comments

197. The Secretariat clarified the date for completion of the project, noting that the report included activities to be completed by November 2019 while the project completion date was June 2019. It was explained that, whereas the project was approved in 2016, funds were transferred from the Government of the Russian Federation to UNIDO only in September 2017. The project is expected to be completed in December 2019.

198. In response to the Secretariat's clarification on technical assistance that had been carried out through the project, the Government of the Russian Federation indicated that the following were initiated: a regional council of national refrigeration associations from the beneficiary countries had been established; e-learning modules on the use of natural refrigerants and safe operation of ammonia-, CO_2- and HC-based systems were being developed to support online education and training; and guides for the use of the e-learning modules including translated versions would be displayed online.

199. The Secretariat noted the substantive progress in the implementation of this project despite initial delays experienced, and further noted that the centre would contribute to strengthening the RAC sector in the ECA region.

Secretariat's recommendation

200. The Executive Committee may wish:

(a) To note the progress report on the development of a regional centre of excellence for training and certification and demonstration of low-global-warming-potential (GWP) alternative refrigerants in Europe and Central Asia, submitted by the Government of the Russian Federation and contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To extend the project completion date to 31 December 2019, on an exceptional basis, noting the substantial progress so far achieved, on the understanding that no further extension of project implementation would be requested, and to request the Government of the Russian Federation to submit the final report on the project referred to in sub-paragraph (a) above no later than the 85th meeting.

<u>Kuwait: Report on the demonstration project to evaluate HCFC-free and low-global-warming-potential technology performance in air-conditioning applications</u> (UNDP)

Background

201. At its 76th meeting, the Executive Committee approved a demonstration project to evaluate HCFC-free and low-GWP technology performance in AC applications in Kuwait[36] in the amount of US $293,000, plus agency support costs of US $20,510, in line with decision 72/40.

202. The objective of the project was to demonstrate the performance of two types of AC equipment currently available for high ambient temperature (HAT) conditions: an 8-tonne capacity HFC-32-based AC system; and a 40-tonne capacity mini-chiller using R-290 refrigerant to be installed in four selected locations in Kuwait. The performance of the equipment would be monitored and evaluated taking into consideration the performance of compressors, condensers, evaporators, energy efficiency and power consumption, and would be compared with HCFC-22-based and R-410a-based equipment of similar size and capacity.

203. On behalf of the Government of Kuwait, UNDP has submitted a report of the demonstration project. The report indicated that UNDP was unable to implement the project despite an active search for suppliers of the proposed R-290 and HFC-32 equipment, as the bidding process resulted in costs which were three times the approved amount. As a result, UNDP and the Government of Kuwait are requesting for a cancellation of the project, and for the balances to be returned to the 84th meeting.

Secretariat's comments

204. In seeking clarification on the actions taken by UNDP upon receipt of initial high bids for the equipment, UNDP explained that in consultation with the NOU and the Kuwait Institute of Scientific Research (KISR), it was decided to reduce the project sites to two instead of four, and conduct a second bidding process. This second bidding was cancelled as only one offer was received with the equipment cost quoted at US $650,000. UNDP indicated that they were bound by the organization's financial rules and regulations which required the bidding process to be followed, and could not find options for sourcing this equipment from the sole supplier, despite requiring only few units.

[36] UNEP/OzL.Pro/ExCom/76/38.

205. The Secretariat expressed its concern on the request for cancellation, noting that the project proposal was reviewed rigorously; and UNDP had provided assurances that the equipment to be evaluated was available. UNDP explained that during implementation, the price of the proposed equipment became a challenge, in addition to potential concerns on the safety of the operation of larger-capacity equipment in countries where such equipment had not been used before, and where standards were not in place. For these reasons, the project could not be completed and had to be cancelled and remaining balances returned. The provisional financial report submitted revealed that no disbursements were made for the project; UNDP had also clarified that the return could be done only at the 84th meeting as procedures on the project closure would require signatures from UNDP and the Government of Kuwait.

Secretariat's recommendation

206. The Executive Committee may wish to cancel the demonstration project to evaluate HCFC-free and low-global-warming-potential (GWP) technology performance in air-conditioning applications in Kuwait, and to request UNDP to return, to the 84th meeting, the amount of US $293,000, plus agency support costs of US $20,510.

Morocco: Demonstration project on the use of low-cost pentane foaming technology for the conversion to non-ODS technologies in the polyurethane foam manufacturing sector at small and medium-sized enterprises (UNIDO)

207. At its 75th meeting, the Executive Committee approved the demonstration project on the use of low-cost pentane foaming technology for the conversion to non-ODS technologies in PU foams at SMEs in Morocco,[37] in the amount of US $280,500, plus agency support costs of US $19,635 for UNIDO (decision 75/41).

208. The objective of the project was to explore the possibility of reducing the initial capital cost by designing a simple, standardized, easy-to-handle and compact foaming machine capable of operating with flammable pentane, equipment and movable ventilation systems serving several products. The project was to be completed in 16 months.

209. 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(f)).

210. UNIDO, on behalf of the Government of Morocco, has submitted to the 83rd meeting a brief progress report of the demonstration project. The submission informed that suppliers for both foaming machines and chemicals had been identified; that chemicals and equipment had been purchased, delivered, and equipment installed; and that production commissioning, start-up, test and training were to be completed by the end of 2019.

Secretariat's comments

211. UNIDO explained that the significant delay in the implementation of the project was due to the unavailability of the NOU to participate in the study tour to identify the potential suppliers for pre-blended HC-based polyols and foaming equipment. In addition, the equipment had to be installed in the newly built premises, in an industrial zone which was not ready when equipment was delivered in 2018. The Secretariat noted that significant efforts had been invested, the majority of the activities planned under the demonstration project had been completed and expenditures occurred. It would be beneficial to complete the project and

[37] UNEP/OzL.Pro/ExCom/75/58.

share the results of the demonstration with all other Article 5 countries. After discussion with UNIDO, it was agreed that the project would be completed by September 2019 and that UNIDO would submit the final report of the demonstration project to the 84th meeting.

Secretariat's recommendation

212. The Executive Committee may wish to:

(a) Note the progress report on the demonstration project on the use of low-cost pentane foaming technology for the conversion to non-ODS technologies in the polyurethane foam manufacturing sector at small and medium-sized enterprises in Morocco, submitted by UNIDO and contained in document UNEP/OzL.Pro/ExCom/83/11;

(b) Extend the completion date of the project referred to in sub-paragraph (a) above to 30 September 2019, noting the advanced progress in implementation and the potential replicability of the results in several Article 5 countries; and

(c) To request UNIDO to submit the final report of the project referred to in sub-paragraph (a) above to the 84th meeting and to return all remaining balances by the 85th meeting.

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

Background

213. On behalf of the Government of Saudi Arabia, UNIDO submitted to the 83rd meeting a progress report on the demonstration project on promoting HFO-based low-GWP refrigerants for the AC sector in high ambient temperatures.

214. 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.

215. 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.

Progress report

216. While production equipment was delivered, installation is still pending as the enterprise has decided to move the production line. The enterprise is planning to nonetheless preliminarily install the equipment so that a test run can be undertaken and personnel trained; the line would be moved by September 2019. Further testing and optimization of the units are required. Completion of those activities, as well as a workshop to disseminate the project results, is expected by December 2019. Based on the testing by the enterprise, as well as results from PRAHA-II, the enterprise decided to focus its production on R-290-based equipment, though future use of HFO and HFO blends cannot be excluded.

Secretariat's comments

217. Equipment has been purchased and delivered to the enterprise; however, a few remaining activities are required for project completion by December 2019. Given the advanced stage of implementation of the project, and the potential implication of the results in several Article 5 countries, the Secretariat recommends extending the project to 31 December 2019, requesting that the final report be submitted to the 85th meeting, and that all remaining balances be returned by the 86th meeting.

Secretariat's recommendation

218. The Executive Committee may wish to:

(a) Note the progress report on the demonstration project on promoting HFO-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/83/11;

(b) Extend the completion date of the project referred to in sub-paragraph (a) above to 31 December 2019, noting the advanced progress in implementation and the potential replicability of the results in several Article 5 countries; and

(c) To request UNIDO to submit the final report of the project referred to in sub-paragraph (a) above no later than the 85th meeting and to return all remaining balances by the 86th meeting.

Saudi Arabia: Demonstration project at air-conditioning manufacturers to develop window and packaged air conditioners using low-global-warming-potential refrigerants – final report (World Bank)

Background

219. At its 76th meeting, the Executive Committee approved the demonstration project at two enterprises manufacturing air conditioners in Saudi Arabia: Saudi Factory for Electrical Appliances Co. Ltd ("SFEA") and Petra Engineering Industries Co. Ltd. ("Petra"), in the amount of US $796,400, plus agency support costs of US $55,748 for the World Bank. In approving the project, the Executive Committee had requested the Government of Saudi Arabia and the World Bank to complete the project by May 2017, and to submit a comprehensive final report soon after project completion (decision 76/26(c)).

220. SFEA was to develop two sizes of window air conditioners (1.5 to 2 tonnes of refrigeration (TR)[38]) based on HFC-32 and R-290, while Petra would develop packaged AC systems that combine chiller and air-handling (11.4 to 28.4 TR), using the same refrigerants. Subsequent to the approval of the project, the World Bank reported that SFEA decided to withdraw from the project given difficulty with the supply of 60-hertz compressors and the decreasing market for window air conditioners in Saudi Arabia. Accordingly, US $220,000, plus agency support costs of US $15,400 for the World Bank were returned to the 82nd meeting (decision 82/22(b)(i)).

221. Following an update provided during the 80th meeting, the Executive Committee agreed to extend the project completion date to 30 September 2018, on the understanding that no further extension of project implementation would be requested, and to request the World Bank to submit the final report no later than the 82nd meeting (decision 80/26(h)). At the 82nd meeting, the Executive Committee urged the World Bank to

[38] 1 TR is equivalent to 12,000 Btu/hr or 3.5 kW.

submit the final report for the project as soon as possible so that it could be presented at the 83rd meeting (decision 82/22(b)(ii)).

222. In line with decision 82/22(b)(ii), on behalf of the Government of Saudi Arabia, the World Bank submitted the final report on the demonstration project at AC manufacturers to develop window and packaged air conditioners using refrigerants with low GWP (attached as Annex IV to the present document).

Progress report

223. Petra designed, manufactured, and tested six prototype commercial air-cooled chillers using HFC-32 and R-290 refrigerants with cooling capacities of 40 kW, 70 kW and 100 kW. The design of the equipment was in accordance with the safety requirements of ISO-5149[39] and IEC-60335-2-40.[40] Testing was conducted at 35 °C, 46 °C and 52 °C. Results were compared to R-410A, which was tested as a drop-in to HFC-32. In all cases, both HFC-32 and R-290 units showed similar or better performance (efficiency and cooling capacity) than R-410A. However, design changes necessary to mitigate the risk of using R-290 resulted in a significant increase in the cost of the equipment. The cost increase was minimal in the case of HFC-32.

224. The project demonstrated that commercial air-cooled chillers can be designed and operated with low-GWP refrigerants such as HFC-32 and R-290 for a variety of cooling capacities and operating conditions, including high ambient temperatures. Requirements of current international safety standards did not limit the amount of flammable refrigerants used for this project because of the application and location of the chillers. However, the use of flammable refrigerants such as R-290 would be severely restricted by current safety standards for most commercial applications, which is not the case for mildly flammable refrigerants like HFC-32.

Secretariat's comments

Scope and methodology

225. Regarding the scope of the project, the World Bank clarified that the performance, quantity of charge, and prices were compared to those of R-410A-based equipment rather than HCFC-22-based equipment as had been expected for the project, as the former is the market standard. As the project had been completed, a comparison based on HCFC-22 equipment could not be provided. The Secretariat recalls that the project was approved under the window for demonstration projects for low-GWP alternatives to HCFCs, but agrees that R-410A-based equipment is the predominant technology choice in the market at present. As such, the results of the demonstration project may be useful for the HFC phase-down in Article 5 countries.

226. The methodology used in the project did not compare the performance of R-410A-based equipment to the performance of the prototypes manufactured for this project. Rather, the performance of the HFC-32- and R-290-based prototypes was compared to the performance of the HFC-32-based prototype that had been charged with R-410A. This may introduce a potential performance bias toward HFC-32 as the reference model is optimized for HFC-32.

227. The World Bank provided additional information to compare the performance of a standard AC unit that was optimized for R-410A and used two compressors identical to those used on the HFC-32 prototype, with the performance of the HFC-32 prototype with R-410A as a drop-in, and with HFC-32. As shown in

[39] International Organization for Standards (ISO) 5149: Refrigerating systems and heat pumps – safety and environmental requirements. Available at https://www.iso.org/standard/54979.html.
[40] International Electrotechnical Commission (IEC) 60335-2-40: Household and similar electrical appliances – safety. Available at https://webstore.iec.ch/publication/31169.

Table 11, the performance of both the R-410A standard AC unit and the HFC-32 prototype with R-410A drop-in were below that of the HFC-32 prototype at both 35 °C (T1) and 46 °C (T3) conditions. While the difference at T1 was relatively small, both the energy efficiency ratio (EER) and cooling capacity with R-410A degraded significantly at T3 condition when compared with HFC-32. The HFC-32 prototype with R-410A drop-in performed better than the R-410A standard unit at both conditions.

Table 11. Performance of the R-410A standard air-conditioning unit and the HFC-32 prototype

Equipment	EER (Btu/Whr)		Cooling capacity (Btu/hr)	
	T1	T3	T1	T3
R-410A standard unit	9.43	6.46	96.6	75.6
HFC-32 prototype with R-410A drop-in	9.57	6.55	97.8	79.9
HFC-32 prototype with HFC-32	9.96	7.90	105.4	99.7

228. Regarding whether the results of the project might affect the choice of technology for the stand-alone HFC investment project in Jordan[41] for the conversion of similar equipment to R-290 that was approved at the 81st meeting (decision 81/62), the World Bank clarified that while Petra Jordan and Petra Saudi Arabia had the same owner, the two were independent enterprises in all aspects: financial, design, staff, production and scope of work; the latter mainly served the Saudi Arabia market, and the refrigerant technology choice depended on different applications by the users, while the former exported to 52 countries with different specifications and demands. Petra Jordan and Petra Saudi Arabia plan to continue the research and development in different R-290 products and to make those available in the market.

229. The main difference between prototypes of a particular capacity was the selection of the compressor: for R-410A and HFC-32 these were the same fixed-speed scroll compressors, while a fixed-speed semi-hermetic compressor was used for R-290, as no compressor supplier at the capacity needed for the project (i.e., 40 kW and above) could be found. The World Bank noted that differences in the performance of R-290 could be attributed in part to the semi-hermetic compressor which, in general, is less efficient than the scroll compressors used with HFC-32 and R-410A.

230. The project found that the use of flammable refrigerants such as R-290 would be severely restricted by current safety standards for most commercial applications. The project in Jordan foresaw that equipment would comprise multiple, independent circuits to stay within the 5 kg/circuit charge limitation while still maintaining energy efficiency; such an approach was not considered under the present project. The use of multiple, independent circuits is likely to increase manufacturing costs relative to equipment that uses a single, larger refrigerant circuit; however, estimates on how large such an increase would be are unavailable. Refrigerant charge may also be reduced through the use of microchannel heat exchangers, as was the case in the demonstration project at Industrias Thermotar Ltda.[42] Petra, however, prefers to develop its own fin-and-tube heat exchangers in-house.

231. Depending on the equipment capacity, the conversion to both HFC-32 and R-290 saw a reduction in the refrigerant charge between 15 and 25 per cent and 23 and 33 per cent, respectively, relative to R-410A. Notwithstanding that reduction in charge, the cost of the condenser and evaporator did not change between the three refrigerants, contrary to a previous study on this matter.[43] In particular, given the reduction in charge, one would expect that there would be reductions in the materials used to manufacture the condenser and evaporator. Moreover, given the lower operating pressure of R-290 relative to R-410A and HFC-32, thinner tubing might be used in R-290 heat exchangers, which could generate additional material savings. The World Bank clarified that cost also depended on sales volumes, which were currently lower for the larger-diameter

[41] UNEP/OzL.Pro/ExCom/81/40.
[42] http://www.multilateralfund.org/Our%20Work/DemonProject/Document%20Library/8110p2-4Colombia%20RAC%201.pdf.
[43] UNEP/OzL.Pro/ExCom/77/69.

copper tubes used by Petra. Furthermore, additional investment is needed for new tooling and machinery and, therefore, fabrication costs for the smaller tube diameter would be also higher. Thus, the total cost is comparable for condensers with standard and smaller diameter tubing.

232. Given the reduction in refrigerant charge and price of refrigerant relative to R-410A, the cost of charging the units was 50 to 57 per cent less with HFC-32 and 25 to 44 per cent higher with R-290. The reason for the increased cost with R-290 is the high price of the refrigerant (US $12.25/kg) relative to R-410A (US $6.55/kg). There was a small increase in the cost of major components when transitioning from R-410A to HFC-32, resulting in an increase between 11 and 13 per cent, depending on the size of the unit. The difference in cost between HFC-32 and R-290 for most major components was minor, except for the compressor, which was approximately a factor of three more expensive, and resulted in substantial increases in the cost of a unit relative to HFC-32. A leak detector, required for R-290 but apparently not required for HFC-32, also contributed to that difference.

233. The World Bank also provided the costs of a R-290 unit with ATEX[44] components, which were approximately twice of those for the HFC-32 units. However, the Secretariat is not clear that this substantial difference in cost is relevant for most applications. In particular, the ATEX equipment directive is applicable to equipment that is used in potentially explosive atmospheres. Industrial and commercial air-conditioning and refrigeration (ICR) systems located in hazardous areas where potentially explosive atmospheres exist have to fulfil ATEX requirements, irrespective of whether the refrigerant used in the equipment is flammable. The World Bank suggested that there could be instances where ICR systems using HC refrigerants may be classified as hazardous areas in the event of a refrigerant leak and, therefore, would be required to comply with the ATEX directive. This situation could also apply to systems using A2L refrigerants; however, due to the lower flammability limit of those refrigerants, such instances would be less frequent.

234. Petra also made minor modifications to its laboratory to safely handle and test flammable refrigerants; those modifications cost between US $15,000 and US $20,000.

Secretariat's recommendation

235. The Executive Committee may wish:

(a) To note, with appreciation, the final report, submitted by the World Bank, of the demonstration project at air-conditioning manufacturers to develop window and packaged air conditioners using refrigerants with low global-warming potential (GWP) in Saudi Arabia contained in document UNEP/OzL.Pro/ExCom/83/11; 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 projects for manufacturing packaged air conditioners using refrigerants with low GWP.

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

Background

236. At its 76th meeting, the Executive Committee approved the demonstration project for the phase-out

[44] Appareils destinés à être utilisés en ATmosphères EXplosibles (ATEX) *inter alia* specifies equipment allowed in an environment with an explosive atmosphere.

of HCFCs using HFO as foam blowing agent in the 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).

237. At its 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)).

238. 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 foam applications in high ambient temperatures (PU foam sector), and to assess capital and operating cost reductions compared with other alternatives through the use of an optimized water/physical foam blowing agent, lower foam density and lower thermal conductivity.

Progress report

239. On behalf of the Government of Saudi Arabia, UNIDO has submitted a detailed progress report of the demonstration project. Although most of the activities in the project have been completed, the final report will be submitted to the 84th meeting, once field-scale testing and a dissemination workshop are completed.

240. The project was implemented at Sham Najd International, a local producer of sprayed rigid polyurethane (PUR) and polyisocyanurate foam (PIR) for insulating and waterproofing walls, ceilings, roofs, suspended ceilings and floors at construction sites and industrial sites. The only blowing agent tested was HFO-1233zd(E), because it was not possible to procure HFO-1336mzz(Z) in the quantities required for a full-scale demonstration project as it was not commercially available.

241. Based on the test results, the spray foam formulation with HFO-1233zd(E) appears to have considerable potential 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 so far are the following:

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

(b) Compared to baseline foam formulation, the sprayed surface of the PU as a product displayed more pinholes. Nevertheless, it still met customer expectations;

(c) The alternative blowing agent did not require new foaming equipment. All testing was performed with Sham Najd’s existing equipment (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-blown foam;

(f) The 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. The HFO-1233zd(E)-based foam 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;

(g) The cost of the HFO-1233zd(E)-based system is higher than that of HCFC-141b: based on prices provided, the incremental operational cost was US $4.30/kg. However, including the lower thermal conductivity (better insulation) and lower density of the foam produced with HFO-1233zd(E), the incremental operational cost obtained was US $0.52/kg. 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.

Secretariat's comments

Additional tests

242. Given that the report is to be used by other Article 5 countries as reference when formulating and implementing projects, the Secretariat discussed with UNIDO additional details to be included. UNIDO agreed to include in the field testing, several tests that could not be done in the first part of the project, such as adhesion strength, water absorption, closed cell content, durability of thermal resistance and compression strength against ageing/degradation, among others. All of the above tests will be conducted according to EN-14315 (Thermal insulating products for buildings – *in-situ* formed sprayed PUR and PIR foam products). The final report will also include an independent technical review, as per existing policies.

Availability of formulations used in the demonstration

243. In clarifying the origin of the foam system formulations being used to test HFO-1233zd(E) and whether those formulations were available to any systems house, UNIDO indicated that the formulation used for the first tests was fully developed by Covestro, and was not available to any other systems house. All foam formulation details are systems houses' own developments, which are generally secret. However, the additive suppliers (i.e., Evonik and Momentive) and the blowing agent suppliers (i.e., Honeywell and Chemours) actively provide support to the formulators at systems houses. This will allow local systems houses to develop their own formulations.

Project duration extension and final report

244. The Secretariat noted that the project was not completed by December 2018 as per the extended project completion date agreed by the Executive Committee (decision 80/26(i)). However, substantial progress had been achieved with all of the lab-scale tests completed and a comprehensive set of results had been made available. On the two remaining activities (i.e., field-scale testing and dissemination workshop) UNIDO clarified that the latter would take place in May 2019, while the field testing would take place upon delivery in May of additional materials procured. The tests will be done at Sham Najd with three foam system formulations. The final report including the results from these tests will be available by October 2019.

245. Noting the considerable progress achieved, the results already obtained from the testing of the technology, and the additional valuable information that can be obtained from field tests in high ambient temperature conditions, the Secretariat supports an extension of this project with the view of receiving the detailed final report at the 84th meeting. Based on the estimated time to produce the report, the Secretariat recommends the extension of the project to 31 October 2019.

Secretariat's recommendation

246. The Executive Committee may wish:

(a) To note the progress report on the implementation of 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, contained in document UNEP/Ozl.Pro/ExCom/83/11; and

(b) On an exceptional basis, noting the substantial progress so far achieved, to further extend the project completion date of the project referred to in sub-paragraph (a) above to 31 October 2019, 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 84th meeting.

Thailand: Demonstration project at foam system houses in Thailand to formulate pre-blended polyols for spray polyurethane foam applications using a low-GWP blowing agent (World Bank)

Background

247. At its 76th meeting, the Executive Committee approved a demonstration project at two foam systems houses in Thailand to formulate pre-blended polyols for spray PU foam applications using a low-GWP blowing agent, at a total cost of US $352,550, plus agency support costs of US $24,679 for the World Bank (decision 76/33).

248. The objectives of the project were:

(a) To strengthen the capacity of the two local systems houses to formulate, test, and produce pre-blended polyol using HFOs (namely, HFO-1233zd(E) and HFO-1336mzz(Z)) for SMEs in the PU spray foam sector;

(b) To validate and optimize the use of HFOs co-blown with CO_2 for spray foam applications to achieve a similar thermal performance to that of HCFC-141b with minimum incremental operating costs (to optimize the HFO ratio to 10 per cent);

(c) To prepare a cost analysis of the different HFO-reduced formulations versus the HCFC-141b-based formulations; and

(d) To disseminate the results of the assessment to system houses in Thailand and other countries.

249. The project was implemented at two system houses, namely Bangkok Integrated Trading Co., Ltd (BIT) and South City Polychem Co., Ltd. (SCP) which supply polyols (mostly using HCFC-141b) to customers in a range of PU foam applications including spray foam.

250. On behalf of the Government of Thailand, the World Bank has submitted the final report of the demonstration project (attached in Annex V to the present document). The conclusions of the demonstration project are the following:

(a) BIT and SPC conducted evaluation of five and two different reduced formulations for each HFO (i.e., HFO-1233zd(E) and HFO-1336mzz(Z), respectively) and identified final formulation for detailed evaluation based on reactivity time, adhesion and shrinkage. The details of formulations used for final testing at BIT and SCP including additives and other components are given in Table 12:[45]

Table 12. Formulations used for evaluation as a percentage of total system (%)

	BIT			SCP		
Particulars	HCFC-141b	HFO-1233zd(E)	HFO-1336mzz(Z)	HCFC-141b	HFO-1233zd(E)	HFO-1336mzz(Z)
Polyol blend	24.9	35.7	35.4	24.9	35.7	35.4
Additives and catalysts	1.3	4.6	5.7	1.3	4.6	5.7
Other additives	6.0	6.7	5.4	6.0	6.7	5.4
Blowing agent	10.0	4.7	4.7	10.0	4.7	4.7
Isocyanate	57.8	48.3	48.8	57.8	48.3	48.8
Total	100	100	100	100	100	100

(b) Spray foam formulations with HFO blowing agents amounting to 10 per cent of the polyol with adjustments on the choice of polyol and the catalyst package could yield the foam properties that were acceptable to the Thai spray foam market. While the HFO-1233zd(E) formulation demonstrated instability in the formulation, the report indicates that the stability issue could be solved by introducing a new catalyst package;

(c) In terms of adhesion and reactivity time, spray foams blown with HFOs exhibited adhesion performance and reactivity time that was acceptable to the market. Density of spray foam made from the reduced HFO formulations was slightly higher than the baseline HCFC-141b formulation. A slight increase in the compressive strength was also observed;

(d) The initial K-factors of the reduced HFO formulations were higher than the HCFC-141b formulation. All properties of HFO-blown foams were quite stable over time. The report also indicates that the increase in K-factor was within the acceptable range in Thailand's market;

(e) Both HFO formulations passed the fire performance tests using ASTM[46] – 568 and 635;

(f) Under hot summer climatic conditions up to above 35 °C, the HFO-1233zd(E)-based systems could require a storage conditioned to cool the formulated polyol storage;

(g) Based on the formulations, the price of reduced HFO formulations (i.e., HFO-1233zd(E) and HFO-1336mzz(Z)) is about 22 to 38 per cent, respectively, above HCFC-141b formulations in case of BIT, and 42 to 46 per cent, respectively, above HCFC-141b formulations in case of SCP. HCFC-141b-based systems in case of BIT is US $1.93/kg and in case of SCP is US $2.15/kg and the percentage increase in price of HFO-based formulations for SCP was higher than BIT only by about five per cent; and

(h) The downstream spray foam users that participated in the demonstration were satisfied with overall performance of the formulations in terms of processing time, adherence properties and other physical properties associated with the spray foam.

[45] The main parameters considered for choosing the formulations are reactivity, shrinkage and adhesion properties.
[46] American Society for Testing and Materials.

251. Table 13 below presents the actual costs for the thermal conductivity tester and spray foam equipment procured for the systems houses against the budgets. The price of foaming machine and thermal conductivity tester were negotiated by each of the enterprises and hence, there was a difference in the equipment supplied to the enterprises. The financial report for the project including all the elements would be available along with the PCR.

Table 13. Costs for spray foam equipment and thermal conductivity tester

Equipment	BIT		SCP	
	Approved (US $)	Actual (US $)	Approved (US $)	Actual (US $)
Spray foam machine	40,000	43,675	40,000	41,692
Thermal conductivity tester	5,000	29,821	5,000	22,253

252. The preliminary findings from the two demonstration projects were presented at the 12th Regional ODS Workshop in Bangkok organized by the World Bank in February 2018, and the final results were presented at the 13th Regional ODS Workshop in Bangkok held in February 2019. At each of these workshops, there were more than 80 participants from the national ozone offices and foam industries from China, Indonesia, Jordan, Malaysia, the Philippines, Thailand and Viet Nam. Moreover, three additional workshops were organized in Thailand for disseminating the results among Government officials, spray foam enterprises, chemical suppliers, and equipment suppliers. Some of the countries participating in the workshops expressed interest in using these results and developing the formulations using HFOs in their markets.

Secretariat's comments

253. The Secretariat noted that the initial project plan was to submit the findings of the demonstration project by the 79th meeting so that results of this project could also be used while assessing stage II of the HCFC phase-out management plan for Thailand; however, the results were not available on time. The World Bank informed that the main reasons for the initial delay were relating to obtaining supply of HFOs and administrative modalities relating to the project agreement process with the beneficiary enterprises.

254. The Secretariat requested additional information on technical capacity of the systems houses in developing low-cost reduced HFO formulations. The World Bank informed that due to limited technical capability of BIT, the formulation development process with HFOs took longer than expected; both the systems houses were satisfied with the overall performance of HFO-based systems for spray foam applications. Through this project, they gained confidence in using HFO-based systems for spray foam, noting that the formulation development and adjustment is an ongoing process. The World Bank also informed that the enterprises did not experience major challenges in procuring HFOs for the project and would not expect constraints on commercial availability of the HFOs.

255. The Secretariat requested additional information on why the isocyanate to polyol ratio in SCP is different compared to BIT for HCFC-based and HFO-based formulations. The World Bank clarified that BIT and SCP use different additives in their formulations; as a result, the ratios of polyol to isocyanate are different; both enterprises were able to sell these formulations to their customers and were in use in the market. The Secretariat also notes that SCP that has better technical capabilities is able to produce lower cost formulations for the market; also, in this project, technical support was provided through an international expert who trained the staff in the enterprises on the theory of the PU foam technology, and the testing process related procedures. On the higher thermal conductivity of reduced HFO formulations, the World Bank informed that it is due to higher percentage on CO_2 in the cells; further, the increase in thermal conductivity levels were acceptable to the consumers in the spray foam market in Thailand.

256. On the price difference between blowing agent, polyol, other additives and isocyanate in each enterprise, the World Bank informed that this is due to individual enterprise negotiations between the systems houses and the suppliers, and type of additives procured from the suppliers; they also clarified that being small systems houses, preferential prices of different chemicals are not available as of date.

257. Regarding the big difference between the proposed and the actual costs for the thermal conductivity tester, the World Bank clarified that the cost of K-value tester in the original proposal was underestimated, and as a result, the actual price was much higher than the budgeted level. There is no change in the specifications of the equipment needed for testing the foam.

258. The Secretariat notes that recent trends suggest the price of HCFC-141b is increasing and with regulatory factors decreasing availability of HCFC-141b, the price of HCFC-141b is expected to continue to increase; this trend is already observed in some countries. Further, the reported price of HFOs could vary and with increasing production of HFOs, there could be a reduction in price of HFOs, though the timing of this reduction is uncertain. In addition, significant price drop of HFOs coupled with price increase of HCFC-141b could make the costs of HFO-based formulations comparable with HCFC-141b formulations.

Secretariat's recommendation

259. The Executive Committee may wish:

(a) To note, with appreciation, the final report, submitted by the World Bank, of the demonstration project at two foam system houses in Thailand to formulate pre-blended polyols for spray polyurethane foam applications using a blowing agent with low global-warming potential, contained in document UNEP/Ozl.Pro/ExCom/83/11; and

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

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

260. On behalf of the West Asia countries[47] that took part in the project, UNEP and UNIDO submitted a progress report on the demonstration project on promoting alternative refrigerants in AC for high-ambient countries in West Asia better known as PRAHA-II.

261. The project was approved at the 76th meeting and aimed to build on the progress of the demonstration project to promote low-GWP alternatives for the AC industry in high-ambient countries in West Asia (PRAHA-I)[48] by advancing the capacity of stakeholders to use low-GWP refrigerants in the AC sector in countries with high-ambient temperature.

262. At its 80th meeting, the Executive Committee agreed to extend the project, originally expected to be completed by November 2017, to 31 December 2018, on the understanding that no further extension of project implementation would be requested, and to request the implementing agencies to submit the final report no later than the 83rd meeting (decision 80/26(l)). A succinct progress report was submitted to the

[47] 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.
[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.

82nd meeting documenting substantial progress on many activities; outstanding activities included developing the risk assessment model suitable for use patterns and high ambient temperature operating conditions, expected to be completed by October 2018, and testing and optimization using prototypes that were developed under the project PRAHA-I, expected to be completed by November 2018.

263. Participating countries in West Asia, UNEP and UNIDO have made substantial progress and completed many but not all of the projects planned activities. In particular, the project's first component, building the capacity of the local industry in designing and testing products using efficient lower-GWP flammable refrigerants, has been completed. There has also been substantial progress in the second and third components, to evaluate and optimize the prototype built for PRAHA-I, and to build a risk assessment model for the high ambient temperature countries. For the former, an initial optimization of the PRAHA-I prototypes has been completed, and their performance evaluated. Based on the results, three prototypes were selected for additional testing and evaluation; one has been built, and the other two will be completed by April and May 2019, respectively. Testing of those units will be completed by June 2019, including analysis of system performance of leak-recharge of high-glide alternatives. For the latter, the necessary data for the model has been collected; testing and validating the model are in progress and will be completed by September 2019.

264. Due to difficulties in finalizing the contract with a testing facility, the outstanding activities could not be completed in the expected timeframe and, therefore, only a preliminary progress report could be submitted to the 83rd meeting. Therefore, UNEP and UNIDO are requesting a further extension of the project until 15 November 2019.

Secretariat's comments

265. Notwithstanding the progress achieved, the project has not been completed in line with decisions 80/26(l) and 82/22(g). In particular, remaining activities include completing the testing of prototypes, reviewing and validating the test optimization results and data collected for the risk assessment model, and a symposium to disseminate the project results. The former is expected to be completed by June 2019, and the latter is planned for September or October of 2019.

266. Based on the progress achieved so far, and the likely benefits to high ambient temperature countries that the completed project would provide, the Secretariat recommends extending the project to 15 November 2019, requesting that the final report be submitted to the 84th meeting, and that all remaining balances be returned by the 85th meeting.

Secretariat's recommendation

267. The Executive Committee may wish:

(a) To note the progress report on the demonstration project on promoting alternative refrigerants in air-conditioning for high-ambient countries in West Asia (PRAHA-II) submitted by UNEP and UNIDO, contained in document UNEP/OzL.Pro/ExCom/83/11; and

(b) To extend the date of completion of the project referred to in sub-paragraph (a) above to 15 November 2019 in order to complete the testing of prototypes, validating the test optimization results and risk assessment model and disseminate the project results, and to request UNEP and UNIDO to submit the final report no later than the 84th meeting and to return all remaining balances by the 85th meeting.

Feasibility study for district cooling

Kuwait: Feasibility study comparing three not-in-kind technologies for use in central air-conditioning - final report (UNEP and UNIDO)

268. On behalf of the Government of Kuwait, UNEP and UNIDO submitted the final report on the feasibility study, in line with decision 82/24(b). The full report is attached as Annex VI to this document.

269. The study demonstrated the technical feasibility of a chilled water system combined with evaporative cooling for central air-conditioning systems in two locations, a school and a mosque, using two-stage[49] "direct/indirect" evaporative cooling (TSDI). This technology was the best option suitable for Kuwait's climatic conditions. The technical and financial studies were based on the required installed capacity of 800 TR for the school, and 81 TR for the mosque.

270. The following findings were summarized in the final report:

(a) The capital cost required for the installation of the hybrid not-in-kind (NIK) technology for both locations was approximately 50 per cent higher than the currently used in-kind technology (i.e., the cost was US $1,600/TR for the NIK technology as compared to US $750/TR for the current in-kind technology);

(b) The use of the NIK technologies demonstrated savings in energy consumption of around 46 per cent for both locations compared to the current in-kind technology;

(c) Based on a comparative analysis of capital and operating costs for both technologies, the study showed an internal rate of return (IRR) of 31 per cent with a payback period of four years to recover the additional capital cost (i.e., US $680,000) of installing the NIK system for the school; and an IRR of 35 per cent with a payback period of two years to recover the additional capital cost (US $68,850) for the mosque;

(d) The study concluded that there are savings of about 52 per cent overall for the NIK assisted by in-kind technology system when compared to simply the traditional electric in-kind system, and that this might possibly be adopted in other applications using central systems in the country.

Secretariat's comments

271. In reviewing the final report, the Secretariat compared it with the preliminary one submitted to the 82nd meeting and observed that it contained more detailed information on those activities that were to be completed, in particular progress on the pilot phase of the project. The report presented data gathered from the two pilot locations, which had shown promising outcomes. The report also provided the results of the evaluation of the technical and financial viability of the approach which was not provided at the 82nd meeting as the pilot phase was not yet completed, and concluded that this is a promising alternative in the country.

272. Based on the results from the two pilot sites, the Kuwait Public Authority for Housing Welfare (KPAHW) would consider adjusting its bidding process for future public buildings to move towards TSDI

[49] In the first stage, hot outside air passes inside a heat exchanger that is cooled by evaporation on the outside. During this initial cooling phase, the incoming air stream is cooled without raising its humidity. In the second stage, the same air stream passes through a water-soaked pad where the additional cooling takes place and the air picks up some additional humidity.

evaporative cooling systems. Future development plans would include investing in and implementing this NIK technology in other selected sites, at the earliest by 2020.

273. UNIDO and UNEP also reiterated that the Government of Kuwait will provide an update, even after project completion, on how implementation in other sites in Kuwait was done.

Secretariat's recommendation

274. The Executive Committee may wish:

(a) To note, with appreciation, the final report for the feasibility study comparing three not-in-kind technologies for use in central air-conditioning in Kuwait, submitted by UNEP and UNIDO and contained in document UNEP/OzL.Pro/ExCom/83/11;

(b) To reiterate that UNEP and UNIDO would submit the project completion report for the feasibility study referred to in sub-paragraph (a) above and return any balances to the 84th meeting; and

(c) To encourage the Government of Kuwait, through UNEP and UNIDO, to provide updated information on the actions taken as a result of the feasibility studies to a future meeting of the Executive Committee.

PART VI: CHANGE OF IMPLEMENTING AGENCY FOR STAGE II OF THE HCFC PHASE-OUT MANAGEMENT (HPMP) AND ENABLING ACTIVITIES FOR HFC PHASE-DOWN FOR THE PHILIPPINES

Philippines: Stage II of the HCFC phase-out management plan and enabling activities – request for a change in implementing agency (World Bank)

Background

275. At its 80th meeting, the Executive Committee approved, in principle, stage II of the HPMP for the Philippines in the amount of US $2,750,057, plus agency support costs of US $192,504,[50, 51] and the enabling activities for HFC phase-down in the amount of US $250,000, plus agency support costs of US $17,500,[52] both to be implemented with the assistance of the World Bank.

276. The Secretariat has received a request from the Government of the Philippines[53] to transfer from the World Bank to UNIDO the stage II of the HPMP for the Philippines and the enabling activities for HFC phase-down.

Secretariat's comments

277. In response to the letter from the Government of the Philippines, the Secretariat consulted with the World Bank and requested the value of unspent funds from the projects that would need to be returned to the Multilateral Fund and transferred to UNIDO at the 83rd meeting. The World Bank informed the Secretariat

[50] Decision 80/60.
[51] The first tranche of stage II of the HPMP was approved in the amount of US $1,010,023, plus agency support costs of US $70,701 for the World Bank (decision 80/60(f)).
[52] Decision 80/52.
[53] Letter of 3 April 2019 from the Environmental Management Bureau of the Philippines to the Secretariat.

that the Agreement between the World Bank and the Government of the Philippines for stage II of the HPMP had not been signed; therefore, the full amount as approved would be returned. With regard to the enabling activities approved under the additional contributions to the Multilateral Fund, the World Bank reported disbursements of US $24,008, plus agency support costs.

278. The funds to be returned to the Multilateral Fund for subsequent transfer to UNIDO are presented in Table 14.

Table 14. Approved funds and funds approved in principle to be transferred from the World Bank to UNIDO

Project	Code	Approved at the 80th meeting (US $)	Balance as of April 2019 (US $)		
			Project cost	Support costs	Total
HCFC phase-out management plan (stage II, first tranche	PHI/PHA/80/INV/103	736,129	736,129	51,528	787,657
	PHI/PHA/80/TAS/102	273,894	273,894	19,173	293,067
Enabling activities for HFC phase-down	PHI/SEV/80/TAS/01+	250,000	225,992	15,819	241,811
Balance			**1,236,015**	**86,520**	**1,322,535**
Stage II funding tranches approved in principle			**1,740,034**	**121,802**	**1,861,836**
Grand total			**2,976,049**	**208,322**	**3,184,371**

279. The Secretariat noted that the change of implementing agency in stage II of the HPMP would require an update of the Agreement between the Government and the Executive Committee, as presented in Annex VII to the present document. The full Agreement will be appended to the final report of the 83rd meeting.

Secretariat's recommendation

280. The Executive Committee may wish:

(a) To note the request by the Government of the Philippines to transfer to UNIDO all the phase-out activities included in stage II of the HCFC phase-out management plan (HPMP), and the enabling activities for HFC phase-down, initially planned for implementation by the World Bank;

(b) With regard to stage II of the HPMP for the Philippines:

(i) To note that the World Bank had already returned to the Multilateral Fund at the 83rd meeting US $1,010,023, plus agency support costs of US $70,701, associated with the first tranche (PHI/PHA/80/INV/103 and PHI/PHA/80/TAS/102);

(ii) To approve:

a. The transfer to UNIDO of US $1,010,023, plus agency support costs of US $70,701 approved for the World Bank, associated with the first tranche (PHI/PHA/80/INV/103 and PHI/PHA/80/TAS/102);

b. The transfer from the World Bank to UNIDO of the funding of US $1,740,034, plus agency support costs of US $121,802, approved in principle, associated with the second and third funding tranches;

(iii) To note that the Fund Secretariat had updated the Agreement between the Government of the Philippines and the Executive Committee for stage II of the HPMP, as contained in Annex VII to the present document, specifically: paragraph 9 and Appendix 2-A, on the basis of the transfer of the World Bank's components to UNIDO; and paragraph 17, which had been added to indicate that the World Bank had stopped being the lead implementing agency as of the 83rd meeting and that the updated Agreement superseded that reached at the 80th meeting;

(c) With regard to the enabling activities for HFC phase-down approved under the additional contributions to the Multilateral Fund (PHI/SEV/80/TAS/01+):

(i) To note that the World Bank had already returned at the 83rd meeting the remaining balance of US $225,992, plus agency support costs of US $15,819; and

(ii) To approve the transfer to UNIDO of the remaining balance of US $225,992, plus agency support costs of US $15,819 approved for the World Bank.

PART VII: REQUESTS FOR EXTENSION OF ENABLING ACTIVITIES

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

281. At the 80th meeting, the Executive Committee approved enabling activities for HFC phase-down for 59 Article 5 countries;[54] with a project duration of 18 months from the time of approval. At the 81st meeting, the Executive Committee decided to maintain the 18-month implementation period for such projects in line with decision 79/46(d)(iii) 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.[55]

282. In line with decision 81/32(a), on behalf of 51 Article 5 countries the four implementing agencies, have submitted official requests for extension of enabling activities which have an expected completion date of June 2019, as shown in Table 15.

Table 15. Requests for extension of enabling activities for HFC phase-down submitted to 83rd meeting

Country	Lead implementing agency	Extension requested
Angola	UNEP	12 months
Armenia	UNIDO	12 months
Bhutan	UNEP	12 months
Bosnia and Herzegovina	UNIDO	12 months

[54] Decision 80/41.
[55] Decision 81/32(a).

Country	Lead implementing agency	Extension requested
Burkina Faso	UNIDO	12 months
Cameroon	UNIDO	12 months
Chile*	UNDP	12 months
China**	UNDP	12 months
Colombia	UNDP	12 months
Congo (the)	UNIDO	12 months
Costa Rica	UNDP	12 months
Dominica	UNEP	12 months
Dominican Republic (the)	UNEP	12 months
Ecuador	UNEP	12 months
Eritrea	UNEP	12 months
Fiji	UNDP	12 months
Gabon	UNEP	12 months
Gambia (the)	UNIDO	12 months
Ghana	UNEP	6 months
Guatemala	UNEP	12 months
Jamaica	UNDP	12 months
Kyrgyzstan	UNEP	12 months
Lebanon	UNDP	12 months
Lesotho****	UNEP	6 months
Malaysia	World Bank	12 months
Maldives****	UNEP	12 months
Mexico**	UNIDO	12 months
Mongolia	UNEP	12 months
Namibia	UNEP	12 months
Nigeria	UNEP	12 months
North Macedonia	UNIDO	12 months
Palau	UNEP	12 months
Peru	UNDP	12 months
Philippines (the)	UNIDO	12 months
Rwanda****	UNEP	12 months
Saint Lucia	UNEP	12 months
Saint Vincent and the Grenadines	UNEP	12 months
Senegal	UNEP	12 months
Serbia	UNIDO	12 months
Somalia	UNIDO	12 months
Sudan***	UNEP	12 months
Suriname	UNEP	12 months
Thailand	World Bank	12 months
Togo	UNEP	12 months
Trinidad and Tobago	UNDP	12 months
Tunisia****	UNIDO	12 months
Turkey	UNIDO	12 months
Turkmenistan	UNEP	12 months
Uruguay***	UNDP	12 months
Zambia	UNEP	12 months
Zimbabwe	UNEP	6 months

* UNEP and UNIDO as cooperating implementing agencies
** UNEP as cooperating implementing agency
*** UNIDO as cooperating implementing agency
**** Government of Italy as cooperating implementing agency

Secretariat's comments

283. The Secretariat noted that all requests for extension of enabling activities were approved at the 80th meeting which were expected to be completed by June 2019. The main reasons cited for the extension included *inter alia*, the need to complete planned activities; delayed start of implementation; and difficulties in coordination between NOUs and the implementing agencies. Most countries requested for a 12-month extension, while Ghana, Lesotho and Zimbabwe indicated that they needed six months to complete all planned activities.

Secretariat's recommendation

284. The Executive Committee may wish:

(a) To note and consider the requests for extension of enabling activities for HFC phase-down, submitted by the respective implementing agencies for the 51 Article 5 countries listed in Table 15 of document UNEP/OzL.Pro/ExCom/83/11; and

(b) To extend the completion date for the enabling activities for HFC phase-down to December 2019 for Ghana, Lesotho and Zimbabwe, and to June 2020 for Angola, Armenia, Bhutan, Bosnia and Herzegovina, Burkina Faso, Cameroon, Chile, China, Colombia, the Congo, Costa Rica, Dominica, the Dominican Republic, Ecuador, Eritrea, Fiji, Gabon, the Gambia, Guatemala, Jamaica, Kyrgyzstan, Lebanon, Malaysia, Maldives, Mexico, Mongolia, Namibia, Nigeria, North Macedonia, Palau, Peru, the Philippines, Rwanda, Saint Lucia, Saint Vincent and the Grenadines, Senegal, Serbia, Somalia, Sudan, Suriname, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uruguay and Zambia, on the understanding that no further extension would be requested, and that bilateral and 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).

Annex I

PROJECTS FOR WHICH ADDITIONAL STATUS REPORTS TO THE 84TH MEETING ARE REQUESTED

Country	Code	Agency	Project Title	Recommendations
Antigua and Barbuda	ANT/PHA/73/PRP/17	UNEP	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on implementation
Antigua and Barbuda	ANT/SEV/73/INS/16	UNEP	Extension of institutional strengthening project (phase V: 1/2015-12/2016)	To request a status report to the 84th meeting on implementation
Bahrain	BAH/PHA/68/INV/27	UNIDO	HCFC phase-out management plan (stage I, first tranche) (phase-out of HCFC-22 from the manufacturing of central air-conditioning and window air-conditioning at Awal Gulf manufacturing enterprise)	To request a status report to the 84th meeting on implementation
Central African Republic (the)	CAF/SEV/68/INS/23	UNEP	Extension of the institutional strengthening project (phase VI: 1/2013-12/2014)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Chile	CHI/PHA/76/TAS/191	UNEP	HCFC phase-out management plan (stage II, first tranche) (refrigeration servicing sector)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Democratic People's Republic of Korea (the)	DRK/PHA/73/INV/59	UNIDO	HCFC phase-out management plan (stage I, first tranche) (phase-out of HCFC-141b in polyurethane foam sector at Pyongyang Sonbong and Puhung Building Materials)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic People's Republic of Korea (the)	DRK/PHA/73/TAS/60	UNIDO	HCFC phase-out management plan (stage I, first tranche) (refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic People's Republic of Korea (the)	DRK/PHA/75/INV/62	UNIDO	HCFC phase-out management plan (stage I, second tranche) (phase-out of HCFC-141b in polyurethane foam sector at Pyongyang Sonbong and Puhung Building Materials)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic People's Republic of Korea (the)	DRK/PHA/75/TAS/63	UNIDO	HCFC phase-out management plan (stage I, second tranche) (policy, refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic People's Republic of Korea (the)	DRK/PHA/77/INV/64	UNIDO	HCFC phase-out management plan (stage I, third tranche) (policy, refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic People's Republic of Korea (the)	DRK/SEV/68/INS/57	UNEP	Extension of institutional strengthening project (phases VI and VII: 1/2010-12/2013)	To request a status report to the 84th meeting on implementation including updates on the resumption of activities
Democratic Republic of the Congo (the)	DRC/PHA/79/PRP/42	UNDP	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on the level of funds disbursement, including an update on the submission of stage II

Country	Code	Agency	Project Title	Recommendations
Democratic Republic of the Congo (the)	DRC/PHA/79/PRP/43	UNEP	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on the level of funds disbursement, including an update on the submission of stage II
Dominica	DMI/SEV/80/INS/23	UNEP	Additional emergency assistance for institutional strengthening	To request a status report to the 84th meeting on implementation of the strategy and action plan noted by decision 81/36
Ethiopia	ETH/PHA/77/INV/28	UNIDO	HCFC phase-out management plan (stage I, second tranche)	To request a status report to the 84th meeting on progress achieved and the level of funds disbursement
Ethiopia	ETH/PHA/77/TAS/27	UNEP	HCFC phase-out management plan (stage I, second tranche)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Ethiopia	ETH/SEV/77/INS/26	UNEP	Extension of the institutional strengthening project (phase VII 1/2017-12/2018)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Guatemala	GUA/PHA/75/TAS/50	UNEP	HCFC phase-out management plan (stage I, third tranche)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Haiti	HAI/PHA/76/INV/22	UNDP	HCFC phase-out management plan (stage I, second tranche)	To request a status report to the 84th meeting on the level of funds disbursement and finalization of the agreement with UNDP; and UNEP CAP to provide assistance for expedited implementation of project activities
Haiti	HAI/SEV/75/INS/20	UNEP	Extension of the institutional strengthening project (phase IV: 11/2015-10/2017)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
India	IND/SEV/76/INS/467	UNDP	Extension of institutional strengthening project (phase X: 4/2016-3/2018)	To request a status report to the 84th meeting on the level of funds disbursement
Iran (Islamic Republic of)	IRA/PHA/77/INV/226	UNDP	HCFC phase-out management plan (stage II, first tranche) (foam sector)	To request a status report to the 84th meeting on the level of funds disbursement
Iraq	IRQ/PHA/74/INV/23	UNIDO	HCFC phase-out management plan (stage I, second tranche) (refrigeration servicing sector)	To request a status report to the 84th meeting on the level of funds disbursement
Qatar	QAT/PHA/65/INV/18	UNIDO	HCFC phase-out management plan (stage I, first tranche) (refrigeration servicing sector)	To request a status report on project implementation to the 84th meeting noting project completion by 1 July 2019 and return of remaining balances by 31 December 2019
Qatar	QAT/PHA/65/TAS/17	UNEP	HCFC phase-out management plan (stage I, first tranche) (refrigeration servicing sector)	To request a status report on project implementation to the 84th meeting noting project completion by 1 July 2019 and return of remaining balances by 31 December 2019

Country	Code	Agency	Project Title	Recommendations
Qatar	QAT/PHA/73/PRP/20	UNEP	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on submission of stage II, noting that the submission is delayed
Qatar	QAT/PHA/73/PRP/21	UNIDO	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on submission of stage II, noting that the submission is delayed
Qatar	QAT/SEV/79/INS/22	UNIDO	Renewal of institutional strengthening project (phase IV: 8/2017-7/2019)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Saudi Arabia	SAU/FOA/62/INV/13	UNIDO	Phase-out of HCFC-22 and HCFC-142b from the manufacture of extruded polystyrene panel at Al-Watania Plastics	To request a status report to the 84th meeting on implementation, including update on auctioning of the equipment that was procured and needs to be sold
Saudi Arabia	SAU/PHA/68/INV/17	UNIDO	HCFC phase-out management plan (stage I, first tranche) (refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation
Saudi Arabia	SAU/PHA/72/INV/20	UNIDO	HCFC phase-out management plan (stage I, second tranche) (refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation
Saudi Arabia	SAU/PHA/75/INV/24	UNIDO	HCFC phase-out management plan (stage I, third tranche) (polyurethane foam sector plan)	To request a status report to the 84th meeting on implementation
Saudi Arabia	SAU/PHA/75/INV/25	UNIDO	HCFC phase-out management plan (stage I, third tranche) (refrigeration servicing and monitoring)	To request a status report to the 84th meeting on implementation
Saudi Arabia	SAU/PHA/77/INV/31	UNIDO	HCFC phase-out management plan (stage I, fourth tranche) (polyurethane foam sector plan)	To request a status report to the 84th meeting on implementation and levels of funds disbursed
Saudi Arabia	SAU/PHA/77/TAS/32	UNEP	HCFC phase-out management plan (stage I, fourth tranche) (refrigeration servicing, custom training and monitoring)	To request a status report to the 84th meeting on implementation and levels of funds disbursement
Saudi Arabia	SAU/SEV/67/INS/15	UNEP	Extension of the institutional strengthening project (phase II: 7/2012-6/2014)	To request a status report to the 84th meeting on implementation
Somalia	SOM/PHA/77/INV/12	UNIDO	HCFC phase-out management plan (stage I, second tranche) (refrigeration servicing sector)	To request a status report to the 84th meeting on implementation
Somalia	SOM/PHA/77/TAS/13	UNIDO	HCFC phase-out management plan (stage I, second tranche) (additional security)	To request a status report to the 84th meeting on implementation
South Sudan	SSD/PHA/77/TAS/04	UNEP	HCFC phase-out management plan (stage I, first tranche)	To request a status report to the 84th meeting on implementation and levels of funds disbursement
South Sudan	SSD/SEV/76/INS/03	UNEP	Institutional strengthening project (phase I: 5/2016-4/2018)	To request a status report to the 84th meeting on implementation and levels of funds disbursement
Suriname	SUR/PHA/74/TAS/22	UNEP	HCFC phase-out management plan (stage I, second tranche)	To request a status report to the 84th meeting on levels of funds disbursement

Country	**Code**	**Agency**	**Project Title**	**Recommendations**
Suriname	SUR/SEV/77/INS/25	UNEP	Extension of the institutional strengthening project (phase VI: 12/2016-11/2018)	To request a status report to the 84th meeting on implementation and levels of funds disbursement
Syrian Arab Republic (the)	SYR/FOA/61/PRP/102	UNIDO	Preparation for HCFC phase-out investment activities (foam sector)	To request a status report to the 84th meeting on implementation and monitor submission of stage I
Syrian Arab Republic (the)	SYR/PHA/55/PRP/97	UNIDO	Preparation of a HCFC phase-out management plan	To request a status report to the 84th meeting on implementation and monitor submission of stage I
Syrian Arab Republic (the)	SYR/REF/62/INV/103	UNIDO	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	To request a status report to the 84th meeting on implementation
Syrian Arab Republic (the)	SYR/SEV/73/INS/104	UNIDO	Extension of institutional strengthening (phase V: 1/2015-12/2016)	To request a status report to the 84th meeting on implementation
Tunisia	TUN/FOA/77/PRP/72	UNIDO	Preparation for HCFC phase-out investment activities (stage II) (polyurethane foam sector)	To request a status report to the 84th meeting on the level of funds disbursement including an update on the submission of stage II
Tunisia	TUN/PHA/77/PRP/71	UNIDO	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on the level of funds disbursement including an update on the submission of stage II
Turkey	TUR/PHA/74/PRP/105	UNIDO	Preparation of a HCFC phase-out management plan (stage II)	To request a status report to the 84th meeting on the level of funds disbursement including an update on the submission of stage II
Yemen	YEM/SEV/73/INS/43	UNEP	Extension of the institutional strengthening project (phase VIII: 1/2015-12/2016)	To request a status report to the 84th meeting on implementation and the level of funds disbursement
Zambia	ZAM/PHA/77/INV/33	UNIDO	HCFC phase-out management plan (stage I, third tranche)	To request a status report to the 84th meeting on implementation and the level of funds disbursement

Annex II

Government of Cuba

Pilot Demonstration Project on ODS-Waste Management and Disposal

Final report

Prepared by
Ozone Technical Office (OTOZ)

Implemented with assistance of the United Nations Development Programme - UNDP

Funded by the Multilateral Fund (MLF) for the Implementation of the Montreal Protocol

December 2nd, 2018

Contents

1. **Summary of the project details as per the approval.**

COUNTRY:	Cuba
IMPLEMENTING AGENCY:	UNDP
PROJECT TITLE:	Pilot Demonstration Project on ODS-Waste Management and Disposal
SECTOR:	ODS-Waste
Sub-Sector:	Refrigeration Servicing Sector
Date of Approval:	April 2011
PROJECT IMPACT:	8.8 Metric Tons of CFC-12
PROJECT DURATION:	36 months
LOCAL OWNERSHIP:	100 %
EXPORT COMPONENT:	0 %
REQUESTED MLF GRANT:	US$ 525,200
IMPLEMENTING AGENCY SUPPORT COST:	US$ 39,390 (7.5 %)
TOTAL COST OF PROJECT TO MLF:	US$ 564,590
COST-EFFECTIVENESS:	US$ 3.95/kg ODS (metric) based on complete destruction of recovered ODS Waste in Cuba. Not all will be destroyed during the 3-year demonstration project.
NATIONAL COORDINATING AGENCY:	Technical Ozone Office: Ministry of Science, Technology and the Environment.

2. **Background**

In 2006, Cuba introduced the *Energy Revolution Year* where one important component was to promote the complete substitution of old energy inefficient domestic refrigerators and air-conditioning units. The programme was actively supported by the National Ozone Unit (NOU) to ensure that the Ozone depleting substances (ODS) contained in those refrigerators were properly recovered, following best refrigeration practices. With this Energy Programme, between 2005 and 2010 over 2.757 million refrigerators and 276,000 air-conditioning units, on average 20 to 60 years old, were de-manufactured and replaced with energy efficient units at a cost of over 700 million US dollars to the government of Cuba which funded the complete recollection, substitution and de-manufacturing programme.

At the 62nd meeting of the Executive Committee of the Multilateral fund, a Pilot demonstration project on ODS waste management and disposal, with UNDP as implementing agency; The funds provided by the Multilateral Fund were US$ 525,200. The project sought to demonstrate a cost-effective way for the collection, storage and disposal unwanted ODS using a cement kiln.

3. Implementation of the project

The project worked in two aspects, 1) Strengthening the national system for refrigerant collection, and 2) Design and construction of a refrigerant disposal facility.

The project started in March 2011 with participation of the Ministry of Science, Technology and Environment (CITMA), Ministry of Construction (MINCON), Ministry of Internal Commerce (MINCIN), led by the Ozone Technical Office (OTOZ). Each of the involved entities designate a participant that supported the implementation of the project.

4. Description of the collection, storage and destruction

4.1 Recovery and collection of ODS

All refrigeration servicing workshops and maintenance brigades in the country, belonging to any of the organisms (OACE – Organismo de Administracion Central del Estado) are required to avoid the release to the atmosphere of refrigerant from equipment being serviced, repaired, substituted or dismantled and must recover this, store it in equipment loaned to them, and hand it over to the municipal workshops of the Ministry of Interior Commerce (MINCIN), Industrial Equipment and Services Enterprise (Empresa Industrial de Equipos y Servicios - EIESA) or others as previously agreed with the MINCIN. EIASA's workshops as well as the municipal MINCIN approved workshops are responsible for adequate handling and storage of ODS received.

The system is structured around 1,000 local level workshops. As there are 169 municipalities, one of the above mentioned 1,000 workshops acts as a municipal level center. The ODS recovered by the 1,000 workshops thus feeds into 169 municipal level workshops. There are 6 territorial workshops that serve as collection centers which cover the entire country, located in the main cities and provinces: Havana, Villa Clara, Santi Espíritu, Camagüey, Holguín and Santiago de Cuba.

The ODS refrigerants comes from all the service workshops regardless of the governmental sector where it comes from. The service workshops are responsible for taking and delivering the gas to the municipal collection centers, which inform the collection centers when they have significant quantities.

In the territorial workshops (collection centers), the cylinders brought by the service workshops are weighted, the gas they contain is then identified, and transferred to cylinders of greater capacity that exists in every collection center.

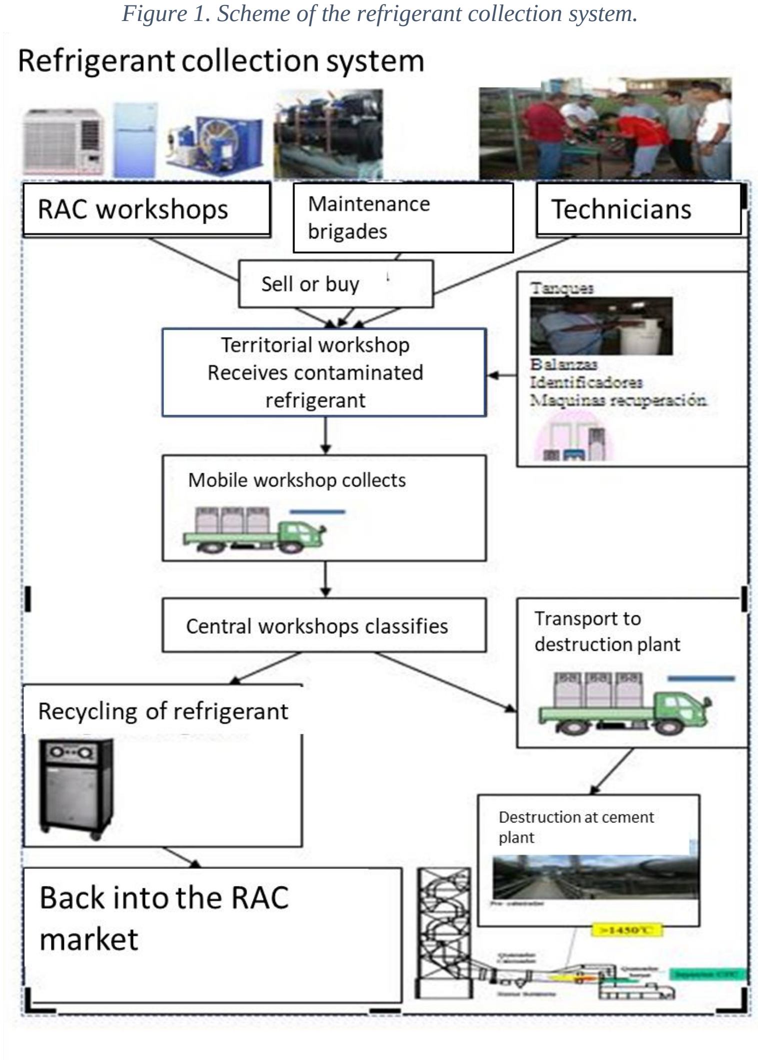
Once the recovered refrigerant is in the collection center, it is identified and its concentration measured, if its reading yields more than 98%, it is further recycled and cleaned in a refrigerant recycling machine, otherwise it will be destroyed in the cement plant.

All this process is registered in authorization books kept for this purpose where type of gas, quantity, origin and destination are registered.

All gases are transported independently of the origin and destination in a specialized vehicle designed for this purpose. The workshops inform the central warehouse when they have significant quantities for the change to collect the stored material.

A scheme of the refrigerant collection system is show below in figure 1.

Figure 1. Scheme of the refrigerant collection system.



4.2 Transport of the recovered refrigerant

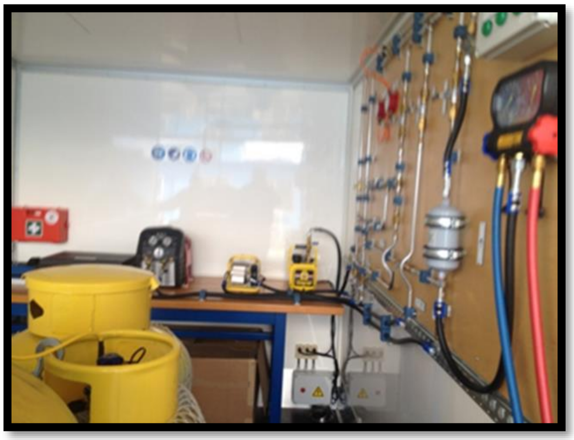
One of the main challenges identified during the design of the project was the transport of the recovered refrigerant to the collection centers and to the destruction facility. To overcome this challenge the project team, led by OTOZ, and with support of the Spanish firm in charge of the design and installation of the destruction facility, MIESA EXPORTACIÓN SL, designed and acquire a specialized vehicle (mobile workshop).

The description and main characteristics of the vehicle for transfer of refrigerants are:

- Type of truck: Single cabin and short bed, closed, adjusted to the size of the equipment that is mounted, without free spaces or storage area.
- There has a rigid structure where the machines for transferring and recovering refrigerants, hose adapters and all electrical connections are mounted.
- Three (3) tanks: a) One (1) of 1-tonne for contaminated refrigerant, b) One (1) of 500 kg and c) One of 200 kg for recovered refrigerants are incorporated into the truck, with safety valve, pressure gauges, manhole for cleaning, oil drain valve, level of volumetric liquid and two (2) half-inch valves of liquid and steam with a maximum working pressure 30 Bar.
- Digital Balance 115v. Heavy, robust, anti-vibration work incorporated into the truck for weighing tanks and cylinders in transport equipment with capacity. 0-150 Kg Precision 0.1 kg.
- High capacity refrigerant transfer machine; Liquid 300 l/min, 110-volt, 3/8-inch sockets. Electric connection.
- High capacity Recovery Machine: Vapor 300 g/min. Liquid 7,500 g/min. 110-volt, 3/8-inch intakes. Electric connection.
- 8 flexible 3m hoses for extra strong high-pressure coolant and 3/8-inch ball valves on one end, SAE 1/2.
- 8 flexible hoses of 3/8 inch alternating red and blue specialized for refrigerants. Maximum operating pressure 600 PSIG.
- 3 flexible hoses of 15 cm. for extra strong high-pressure refrigerant and ½-inch ball valves on one male end and female connection, SAE 3/8.
- 3 flexible hoses of 15 cm. for extra strong high-pressure refrigerant and 3/8-inch ball valves on one end, and both female connections, SAE 1/2.
- With ample space to handle tanks from which the refrigerant is extracted or filled: 30 lb (13.6 Kg); 50 lb (22.5 Kg) and 60 Kg.
- Specifications standards: European standard for the transport and storage of refrigerants.

In the pictures below, an interior view of the mobile workshop can be seen.

Picture 1. Interior of the mobile workshop.



Picture 2. General view of the mobile workshop (Source: OTOZ).

Picture 3. Instruments inside the mobile workshop. (Source: OTOZ).

5. Description of the destruction process

5.1 Selection of the destruction technology

The technology chosen for the destruction of ODS in the demonstration project in Cuba was rotary cement kilns, this is one of the destruction and disposal technologies approved by the parties of the Montreal Protocol (Decision XIV/6, Annex VI: Approved destruction processes)[1].

During the initial phase of the project, a technical team of Cuba visited the Akoh cement plant, part of the group Sumitomo Osaka Cement Co. Ltd. in Japan to analyze the technology. This plant uses as feedstock waste and fuel alternative such as waste plastics, wood, sludge waste treatment plants, urban waste, waste oil, coal ash, used tires and CFCs.

After the visit, the technical team found that it was suitable for the country to adopt this approach for the disposal of ODS, as there were several cement kilns with dry and humid process, and that other technologies were not present in the country requiring high capital costs to set them up.

Rotary cement kilns provide an excellent technical option for the destruction of ODS given specific characteristics such as:

- High flame temperatures which can reach 1800-2000 Cº;
- Long residence times, as a consequence of large kiln size and volumes, which can reach 6 seconds in the kiln per-se;
- No residues are generated in the form of either ashes or scoria.

Given the high temperatures and long residence times, these kilns are ideal media to destroy organic compounds of a high chemical stability such as CFCs and HCFCs. One of the main problems with their destruction is the emissions of acid gases, such as HCl and HF, but they can react with the calcium salts present in the feedstock, coming to form $CaCl_2$ and CaF_2 which become part of the clinker.

On the other hand, chlorine contained in these gases constitutes the main problem given that it can, not only affect the quality of the cement, but also the kiln itself. It is important to have a control ratio to avoid excesses of this gas in the hot gas flux of the kiln, as it could contribute to the unlimited thickening of the crust that adheres to the refractory coating, affecting the interior of the kiln, which can lead to reduced productivity. This effect is significantly more marked in dry process kilns, as they require installations for the development of the calcination stages and synthesis, which contribute to the gases recirculation inside the kiln and therefore they spend more time in direct contact with the solid and cause the volatile elements to increase their concentration as time passes; therefore, the negative effect created by the presence of Cl- and F- becomes increasingly marked.

So, to minimize this effect a cement kiln with a humid process was chosen for the demonstration project.

[1] https://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/976

5.2 Designated local facility

In Cuba there is just one (1) cement plant that uses humid process in its manufacture. This facility, known as the Siguaney Cement Plant of the Grupo Empresarial del Cemento (Cement Business Group) under the Ministry of Construction, is located in the town of Siguaney located in the province of Sancti Spiritus, approximately 300 km to the South-East of Havana.

The cement kiln is 126 m long by 4 m diameter. With a production capacity of 500 ton of Clinker/day, using oil as fuel. The temperatures of operation are 1800-2000 °C in the freeboard and 6 seconds of gasses residence time, under alkaline atmosphere. Chlorine contents are present in the fuel and raw materials. Kiln has not an emission control. Other wastes processed at the kiln are used oils, sludge and obsolete medicines.

6. Construction of the destruction facility

6.1 Selection process of technology supplier

The acquisition of the equipment was contracted to a Spanish company and the assembly was executed by the Cuban part; the start-up was conducted by the Cuban part with support of the Spanish company.

The Company MIESA EXPORTACIÓN SL with address C / San Vicente, 8-48001 Bilbao (BIZKAIA), Spain, was hire as supplier of the project, with the objective of providing engineering, assembly and maintenance services of the equipment and automatic systems needed for the ODS destruction in the cement kiln.

The selection process was conducted by the Cuban Importing Company (EMED) according to the local regulations and processes. During the bidding process, EMED selected the Spanish company as it was the only one that comply with the technical requirements, offered the automatic system requested and agreed to adjust the automation of the gas burning line with the existing kiln in a joint work with designers from the Cuban counterparts as this one was a requirement made by the authorities.

The supplier provided the control panel (automatic cabinets, brand Siemens) and the PLC for the kiln with the whole installation and its accessories, automation of the gas burning line, supply lines (water, energy, air) and sanitary material for the swimming pool area.

In addition, all the necessary equipment for the transfer of stored gas, recovery machines, refrigerant gas identifiers, gas cylinder to recover, scales for weighing the gas and other supplies and accessories, were provided by the supplier.

6.2 Civil work at the cement plant.

It was necessary a building annexed to the area of the kiln automatic controls to locate the acquired equipment, the pool area of the cylinders, and a reception and storage area for the full and empty refrigerant cylinders.

It is also necessary to point out that in Cuba, the Environmental Law 81 of the Ministry of Science, Technology and Environment (CITMA) requires for this type of project the request for an environmental license during its execution, start-up and operation. This license mentions actions and activities of mandatory compliance.

It was also necessary to install a fire prevention system and certify it according to the Cuban norms for this type of installation; it is also part of the aforementioned conditions of the environmental license granted.

The construction process of the civil work is show in the pictures below.

Picture 4.Project team during the construction of the ODS disposal plant. (Source: OTOZ)

Picture 5. Construction of the ODS disposal plant (Source: OTOZ).

Picture 6. Installation of the control panels. (Source: OTOZ)

Picture 7. Assembly of supply lines (Source: OTOZ)

Picture 8. Storage area for cylinders (Source: OTOZ).

Picture 9. General view of the civil works of the disposal plant. (Source: OTOZ).

7. Description of the destruction process

7.1 Reception, storage and handling of ODS cylinders.

The cylinders with unwanted ODS arrive at the plant from two points:

- The stored ones of the Energy Program in Havana City.
- From the collection centers of the different part of the country.

The cylinders of CFCs and HCFCs are received in the plant and stored in a covered area destined for this purpose, at room temperature. There is a scale for the weighing of the same is identified the substance contained, as well as wheelbarrow to transport them.

All these processes are enabled in a registry to keep track of the amount and kind of ODS destroyed.

7.2 Station for preparing and injecting the ODS from the cylinders to the cement kilns.

As mentioned before, it is very important to control the injection ration of ODS into the cement kiln. The injection is control through an automatic process that was designed for the destruction of CFC and HCFC and its parameters are adjusted automatically in the control cabinet after deciding the destruction of one or the other.

In ODS dosing station, the cylinders are placed inside a pool at a temperature of 30°C, in order to facilitate the extraction of the vapor phase from the cylinder; then the cylinders are connected by threaded hoses and their corresponding valves to a manifold that allows the simultaneous coupling of several bullets to the kiln feeding system, to achieve the strict control of the dosing of the gas to the kiln. There is a regulating valve for pressure and flow. It also has an emergency valve for the automatic disconnection of the supply to the kiln in case of unexpected stops or failures in the operation.

In the case of CFC-11 (which is liquid at room temperature), air is injected into the cylinders and heated at its base to achieve evaporation and in this phase (gas) is introduced into the kiln.

The installation is equipped with a vacuum pump that is used sporadically to extract the gases from

the cylinders when they have little content. There is a filter to separate the oil that may come with the gas, with the aim of not embedding in the pipes, the latter are coated with insulating material to maintain the temperature. In addition, it consists of a vaporizer to heat the water of the pool when the temperature is below 30°C, controlled by a temperature sensor facilitating the gas output of the cylinders.

The gas injection system has a complex system of valves to ensure that the quantities that are injected into the kiln are correct. The CFCs or HCFCs are injected at the entrance of the primary air fan of the kiln burner, by means of a 0.5-inch pipe. It is important to bear in mind that the feeding of CFCs, or HCFCs to the kiln, is only done when the cement is being produced and when this process is stable.

For each type of refrigerant, a kiln dosage is guaranteed, as it is key to maintain the quality of the cement so the quantities of ODS to be destroyed are according to the calculation of the production load of the cement kiln. Due to the age of the kiln a maximum amount of 0.1 kg per tonne of cement is injected, which guarantees the complete destruction of the gases.

The installed system has a nominal destruction capacity of 10 tons/year, being the destruction capacity related to the production of cement.

8. Start-up and operation of the destruction plant

The destruction plant in Siguaney cement plant started in October 2015, but even before the commissioning of the disposal plant, it has faced different challenges that has delayed its start-up and limited its operation which has impacted the CFC and HCFC destroyed.

Among the challenges faced were:

a) Delay in the approval of the environmental license: CFC and HCFC were two new type of waste to be treated in the cement kiln.
b) Delay in the commissioning of the civil works and importation process of the system.
c) Requirement to wait for a maintenance window in the kiln to conduct the trials and start the system.
d) Breakage of parts of the technological process of cement manufacturing, such as valves, the mills, refractory bricks from the kilns. This goes through lengthy import procedures into the country.
e) Problems with the supply chain of the raw material, for the types of cement that it produces.
f) Problems in the country with the supply of fuel.
g) Problems with the supply of water to the factory, due to the drought in that area of the country.
h) Extension of technological breaks more than the time foreseen by the schedule.

9. Amount of ODS destroyed

The amount of ODS destroyed is presented in the next table; The low quantities destroyed respond to problems listed before and to the low production level of the plant, which is in line with the economic activity of the country.

Table 1. Amount destroyed by the ODS disposal plant.

Year	ODS destroyed	Amount (ton)
2015	R-12	0.308
	R-22	0.215

Year	ODS destroyed	Amount (ton)
2016	R-11	0.268
	R-12	0.259
2017		0.000
2018	R-12	0.695
total		**1.745**

During the end of 2016 and 2017, there were a severe drought in the area, so the complete operation of the cement plant stopped as it is based in a humid process; as the destruction of ODS is linked to the manufacture of cement, there was not destruction of ODS in 2017.

Currently the disposal plant is in operation and it is expected that continues destroying the collected ODS under Energy Programme and the implementation of the HCFC phase out management plan. OTOZ estimates that more than 80 tonnes of refrigerant are stored in a warehouse in Havana, guarded by the Ministry of Internal Trade (MINCIN), who is responsible for its storage, transportation and destruction in the factory.

10. Operation of the collection system

A refrigerant recovery and collection systems is in place, it is in charge of the Ministry of Internal Commerce (MINCIN), which coordinates the operation of the municipal and territorial workshops that conform the system. The MINCIN is also in charge of the mobile workshop used to transport the collected refrigerants between the different centers and the disposal plant.

In Cuba, transportation is a challenge, so the mobile workshops designed and acquired by the project is a key tool to complete the sound management of refrigerant within the country.

However, the collection system faces some challenges, such as:

- The smaller workshops do not deliver the amounts collected to the provincial centers.
- Many of the smaller workshops do not have the appropriate equipment for the collection of refrigerants.
- Limit the mixture of refrigerants at the time of recovery.
- The destruction of refrigerant involves a payment for its disposal to the cement plant. The cement company calculated the cost of destruction of $ 6 per kilo.

11. Challenges and lesson learnt during project implementation

11.1 Challenges

Some of the challenges faced by the project during its implementation were:

- Lack of installed capacity in the smaller workshops to collect refrigerant.

- The installed controls of the cement kiln were quite old, so it was required additional training to kiln operators and to adapt solutions to make it work between the obsolete technology of the cement plant and the state-of-the-art technology of the automatic controls of the assembled disposal system.
- Breakage of parts of the plant that was necessary to import during the project that stopped the start-up process extending the project implementation time.
- Times of delay in the fuel supply of the plant due to country problems.
- Delay caused by the water supply in the territory caused by a severe drought. Other sectors of the industry and the population were prioritized for the water supply.
- Delay in the hiring and importation of resources by the Importing Company, resulting in delays in the physical and financial execution of the project not foreseen in the work plan.
- Delay by the Entity responsible for the recovery and transportation of refrigerant gases in implementing its technical and financial execution plan.
- Difficulties in the identification of laboratories available in Cuba for conducting a dioxins and furans analysis and difficulties in identifying laboratories abroad for contracting the analysis of these samples (There is no laboratory in Cuba for the analysis of this type). There are not the necessary sample collection points in the discharge chimney for the collection of the sample.

11.2 Lesson learnt.

The implementation of the project left some valuable lessons, such as:

- The selected technology of destruction of gases in cement plant depends on industrial processes, (these gases are injected into the kiln in the process of making cement, when this process is stopped, the destruction of gases is stopped and the scheduled schedule.
- It takes time for the necessary training of the specialists who receive the new technology.
- The coordination between the different parties or institutions involved in the project is complex and requires a lot of time. It is needed to be systematically checked, to resolve the difficulties that arise during execution and to monitor the progress of the tasks.
- The part that receives the new technology, in this case the cement plant, sometimes due to breakage, due to the non-existence of raw material in time and/or due to an increase in the number of unplanned technological breaks, lengthens the project implementation schedule, resulting in delays of the planned activities.
- Even if there is collected ODS waste in the country, the logistical arrangements for its transportation to the destruction plant are as important as the destruction plan itself.
- To adapt new controls and devises to an existing plant, especially to one with several years in operation, carries difficulties and delays. It is important to consider this parameter when selecting the location of a destruction facility.

Annex III

TEXT TO BE INCLUDED IN THE UPDATED AGREEMENT BETWEEN THE GOVERNMENT OF TUNISIA AND THE EXECUTIVE COMMITTEE OF THE MULTILATERAL FUND FOR THE REDUCTION IN CONSUMPTION OF HYDROCHLOROFLUOROCARBONS (Relevant changes are in bold font for ease of reference)

16. This updated Agreement supersedes the Agreement reached between the Government of Tunisia and the Executive Committee at the 72nd meeting of the Executive Committee.

APPENDIX 2-A: THE TARGETS, AND FUNDING

Row	Particulars	2014	2015	2016	2017	2018	2019	2020	Total
1.1	Montreal Protocol reduction schedule of Annex C, Group I substances (ODP tonnes)	40.70	36.63	36.63	36.63	36.63	36.63	36.63	n/a
1.2	Maximum allowable total consumption of Annex C, Group I substances (ODP tonnes)	40.70	36.63	36.63	36.63	34.60	34.60	34.60	n/a
2.1	Lead IA (UNIDO) agreed funding (US $)	**376,920**	**0**	**71,038**	**0**	**0**	**57,500**	**0**	**505,458**
2.2	Support costs for Lead IA (US $)	**26,384**	**0**	**4,973**	**0**	**0**	**4,025**	**0**	**35,382**
2.3	Cooperating IA (UNEP) agreed funding (US $)	**30,000**	**0**	**55,000**	**0**	**0**	**15,000**	**0**	**100,000**
2.4	Support costs for Cooperating IA (UNEP,US $)	**3,900**	**0**	**7,150**	**0**	**0**	**1,950**	**0**	**13,000**
2.5	Cooperating IA (France) agreed funding (US $)	**38,000**	**0**	**38,000**	**0**	**0**	**19,000**	**0**	**95,000**
2.6	Support costs for Cooperating IA (France, US $)	**4,940**	**0**	**4,940**	**0**	**0**	**2,470**	**0**	**12,350**
3.1	Total agreed funding (US $)	**444,920**	**0**	**164,038**	**0**	**0**	**91,500**	**0**	**700,458**
3.2	Total support costs (US $)	**35,224**	**0**	**17,063**	**0**	**0**	**8,445**	**0**	**60,732**
3.3	Total agreed costs (US $)*	**480,144**	**0**	**181,101**	**0**	**0**	**99,945**	**0**	**761,190**
4.1.1	Total phase-out of HCFC-22 agreed to be achieved under this Agreement (ODP tonnes)								9.26
4.1.2	Phase-out of HCFC-22 to be achieved in previously approved projects (ODP tonnes)								0
4.1.3	Remaining eligible consumption for HCFC-22 (ODP tonnes)								29.75
4.2.1	Total phase-out of HCFC-141b agreed to be achieved under this Agreement (ODP tonnes)								1.34
4.2.2	Phase-out of HCFC-141b to be achieved in previously approved projects (ODP tonnes)								0
4.2.3	Remaining eligible consumption for HCFC-141b (ODP tonnes)								0.27
4.3.1	Total phase-out of HCFC-142b agreed to be achieved under this Agreement (ODP tonnes)								0
4.3.2	Phase-out of HCFC-142b to be achieved in previously approved projects (ODP tonnes)								0
4.3.3	Remaining eligible consumption for HCFC-142b (ODP tonnes)								0.04
4.4.1	Total phase-out of HCFC-141b contained in imported pre-blended polyols agreed to be achieved under this Agreement (ODP tonnes)								0
4.4.2	Phase-out of HCFC-141b contained in imported pre-blended polyols to be achieved in previously approved projects (ODP tonnes)								0
4.4.3	Remaining eligible consumption for HCFC-141b contained in imported pre-blended polyols (ODP tonnes)								5.02

* Revised at the 83rd meeting following cancellation of the AC sector plan and the associated project management and agency support costs (US $1,206,919 including agency support costs)

Annex IV

DEMONSTRATION PROJECT TO DEVELOP WINDOW AND PACKAGED AIR-CONDITIONERS USING LOWER-GWP REFRIGERANT IN SAUDI ARABIA

FINAL REPORT

Submitted by:

The World Bank

February 2019

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Executive Summary

This demonstration project was conducted in response to decision 76/26 of the Executive Committee of the Multilateral Fund (May 2016 meeting), asking for the development of window and packaged air-conditioners in Saudi Arabia using alternative refrigerants with lower global warming potential (GWP). The Multilateral Fund allocated US $796,400 to two companies: Saudi Factory for Electrical Appliances Co. Ltd. would develop window AC prototypes while PETRA Engineering Industries (KSA) Co., Ltd would develop packaged air-conditioners. The window AC component was later withdrawn from the project after approval.

The project was carried out at PETRA Engineering Industries Company Saudi Arabia and consisted of designing, manufacturing and testing commercial air-cooled chillers using low GWP refrigerants R-32 and R-290. A total of six units were built (3 for R-290 and 3 for R-32) with cooling capacities of 40 kW, 70 kW and 100 kW. The design of the products was in accordance with the safety requirements of ISO-5149 and IEC-60335-2-40, given that both R-32 and R-290 are flammable refrigerants.

The air-cooled chillers were tested at a standard ambient condition of 35^{o}C as well as at high ambient temperatures of 46^{o}C and 52^{o}C. Results were compared to the baseline refrigerant R-410A, which for this project was tested as a drop-in to R-32. In all cases, both R-32 and R-290 units showed similar or better performance (efficiency and cooling capacity) than R-410A. However, design changes necessary to mitigate the risk of using R-290 (highly flammable refrigerant) resulted in a significant increase in the cost of the chillers. The cost increase was minimal in the case of the mildly flammable refrigerant R-32.

The project demonstrated that commercial air-cooled chillers can be successfully designed and operated with low GWP alternative refrigerants such as R-32 and R-290 for a variety of cooling capacities and operating conditions (including high ambient temperatures). Requirements of current international safety standards did not limit the amount of flammable refrigerants used for this particular project because of the specific application and location of the chillers. However, it should be noted that in most commercial applications, the use of highly flammable refrigerants such as R-290 is severely restricted by current safety standards, which is not the case for mildly flammable refrigerants like R-32.

It is believed that findings from this project will help developing countries with high ambient temperature conditions accelerate their adoption and implementation of the Kigali Amendment.

I. Introduction

In 2007, the Parties to the Montreal Protocol agreed to accelerate the phase-out schedule for hydrocholorofluorocarbons (HCFCs) in developing countries. More specifically, the Parties agreed to a freeze consumption in 2013 (based on average consumption of 2009-2010) followed by reductions of the baseline by 10%, 35%, 67.5% and 97.5% for years 2015, 2020, 2025 and 2030 respectively allowing 2.5% to continue during the period 2030 - 2040 as a service tail and a complete phase out by 2040.

The Article 5 parties, especially those in high-ambient conditions, face serious challenges in finding out suitable lower-GWP alternatives to replace HCFC-22 in air-conditioning applications while maintaining minimum energy performance standards. Although the Executive Committee has funded demonstration project to promote low-GWP alternatives for the A/C industry in high-ambient countries, there are gaps in testing lower-GWP refrigerants: R-32 and R-290 in window and packaged air-conditioners.

To address this gap, the Executive Committee of the Multilateral Fund (MLF)[1] at its 76th meeting in May 2016 approved a demonstration project in Saudi Arabia to develop window and packaged air-conditioners using low GWP alternative refrigerants. The MLF allocated US $796,400, plus agency support costs of US $55,748 for the World Bank. Funding from the Multilateral Fund has been specifically allocated to the two air-conditioning manufacturers in Saudi Arabia. Saudi Factory for Electrical Appliances Co. Ltd. would develop window AC prototypes while PETRA Engineering Industries (KSA) Co., Ltd would develop packaged air-conditioners.

After the approval of the project, Saudi Factory for Electrical Appliances Co. Ltd. did not participate in the development of window AC prototypes without providing any official explanation. The fund[2] related to the development cost of window AC prototypes has been returned to MLF at the 82nd meeting. The development of window AC using lower GWP refrigerant is expected to be covered by one of AC manufacturers as indicated by UNIDO at the 76th meeting.

PETRA Engineering Industries Company Saudi Arabia (hereinafter referred to as "PETRA") confirmed its commitment to develop the packaged air-conditioners.

Objectives

The main objective of the demonstration project was to design, develop and test the performance of air-cooled chillers (integrated chiller and air-handling unit) using low GWP refrigerants R-32 and R-290 at 3 cooling capacities: 40 kW, 70kW, and 100 kW.

Both R-32 and R-290 are environmentally friendly refrigerants, with zero ozone depletion potential (ODP) and low GWP. Both refrigerants have excellent thermophysical properties and are considered good alternatives to R-410A (and R-22). However, both are flammable and

[1] Decision 76/26, May 24, 2016

[2] US $220,000 plus agency support costs of US $15,400

necessitate design modifications of the baseline R-410A product. Some properties of R-32, R-290 and R-410A are summarized in Table 1 below.

In order to achieve the project's objectives, PETRA conducted the following tasks:

- Review R-32 and R-290 refrigerant properties.
- Integrate the refrigerant properties in the design software simulation model.
- Use the software simulation model to design the evaporator and condenser coils including circuiting, number of rows, tube diameters and fin spacing.
- Validate the simulation results through actual tests, before producing the prototypes.
- Select the main components (evaporator, condenser, fans and compressor) to achieve similar or better performance than the baseline R-410A unit. The design took into account specific characteristics of each refrigerant such as higher operating pressures and discharge temperatures of R-32.
- Address safety measures by considering the risk associated with the flammability of both R-32 (mildly flammable) and R-290 (highly flammable). The design of the units was consistent with the requirements of ISO-5149 for refrigerant quantities and IEC-60335-2-40 for electrical components and markings.

Table 1: Properties of R-32, R-290 and R-410A

Parameters	R-32	R-290	R-410A
Chemical name	Difluoromethane	Propane	-
Chemical formula or mass composition	CH_2F_2	$CH_3CH_2CH_3$	R-32/R-125 (50%/50%)
Safety group (ASHRAE 34)	A2L	A3	A1
Lower Flammability Limit (Kg/m^3)	0.307	0.038	-
Boiling point (ºC)	-51.65	-42.11	-51.44
Critical Temperature (ºC)	78.11	96.74	71.36
ODP	0	0	0
GWP $_{(AR4)}$	675	3	2,088

In total, six prototype units were manufactured: three with R-32 (at cooling capacities of 40 kW, 70 kW and 100 kW), and three with R-290. The units were tested at a standard ambient condition of 35ºC as well as at high ambient temperatures of 46ºC and 52ºC. The results were compared to the baseline R-410A which was tested as a drop-in refrigerant to R-32.

II. Project Implementation

The project consisted of three phases: (1) software development; (2) design and fabrication of the prototypes; and (3) testing.

1. Software Development

New software was developed to simulate the performance of the R-32 and R-290 units. PETRA developed the software in 6 different stages as described below:

a. **Data acquisition** – This stage consisted of acquiring scientific information by reviewing the latest scientific research papers, case studies, etc.
b. **Design** – This is the most critical stage where the evaporator and condenser heat exchanger models are developed. The system's coefficient of performance can be evaluated as a function of the heat exchanger design and various two-phase flow heat transfer and pressure drop for both R-32 and R-290 are investigated.
c. **Implementation** – After the completion of the design phase, the algorithms are developed and translated into programming code language.
d. **Testing** – This is a critical stage in the software development stage. The software is tested to assess if it meets its intended purpose and does what it is supposed to do. Errors are identified and corrected until the software is ready for operational use.
e. **Deployment** – After completing the testing phase, the software is deployed to the technical/application team where it is used by engineers to design products. Any problem when operating the software is recorded and passed on to the support and maintenance team for appropriate action.
f. **Support and Maintenance** – This is the last stage in the life cycle process where modifications are made to the software to correct faults, improve performance or adapt the software to a modified environment.

Finally, the software makes use of a user-friendly interface as shown in Figure 1.

2. Design and Manufacturing of Prototypes

The design of the prototype units presented unique challenges as both R-32 and R-290 are flammable refrigerants. According to ASHRAE 34 [1] or ISO 817 [2], the group safety classification for R-32 is A2L, where "A" stands for lower toxicity and "2L" for lower flammability (i.e. refrigerants with a burning velocity less or equal than 10 cm/s). On the other hand, R-290 has a safety classification A3, where "3" stands for higher flammability.

Several safety features had to be taken into consideration to limit the risk of using flammable refrigerants as described below.

ISO 5149

First, the refrigerant quantities used in the chillers had to be consistent with the requirements of ISO 5149 [3]. This refrigerant charge limit depends on the type of occupancy where the chillers will be installed (i.e. general, supervised or authorized occupancy), the safety classification of the refrigerant, the air conditioning system classification (direct, indirect etc.) and where the refrigerant containing components (i.e. compressors, heat exchangers etc.) are located (outdoor, mechanical room etc.).

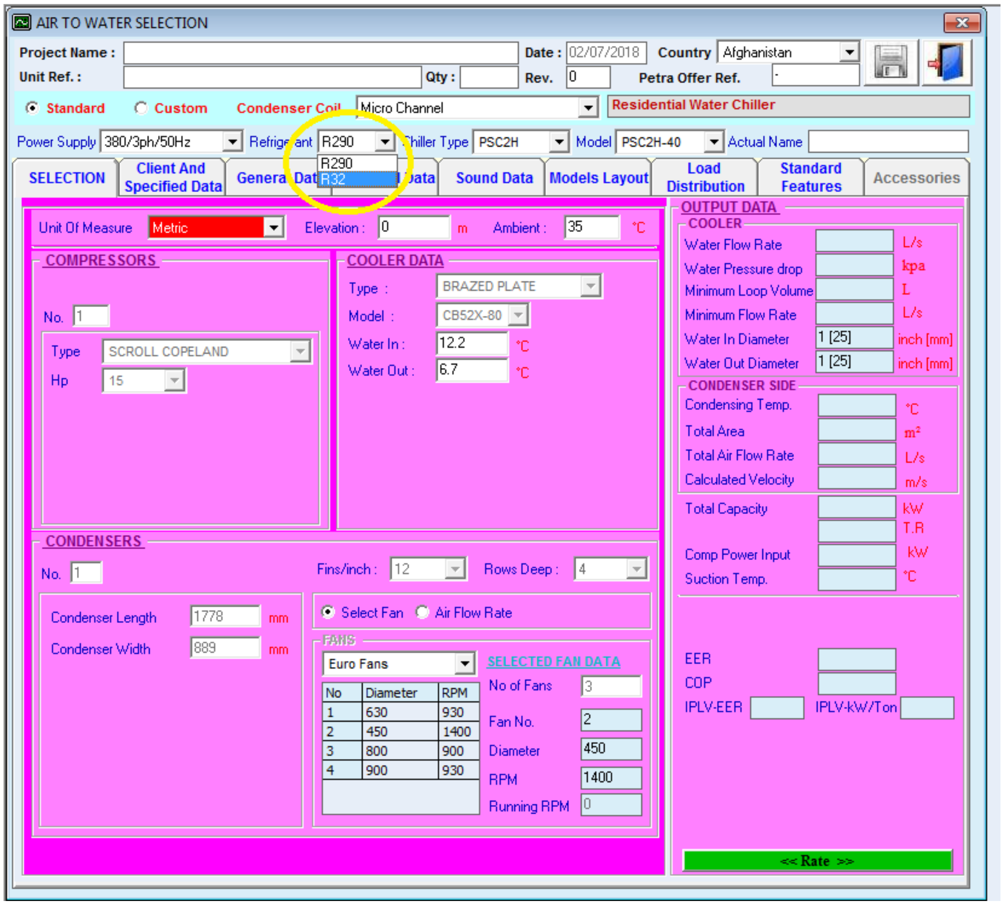

Figure 1: Software User Interface

During product development and testing, the air-cooled chillers were located in PETRA's manufacturing facility (i.e. authorized occupancy). Consequently, according to ISO 5149 there were no refrigerant charge restrictions for both R-32 and R-290. However, had the intended use of the chillers be for general occupancies (such as hospitals, schools etc.), or supervised occupancies (such as office buildings etc.), the amount of flammable refrigerant would have been severely restricted for R-290 because of its highly flammable classification (i.e. "3"), to a point where the chillers would not be able to operate properly.

Based on ISO 5149 and refrigerant charges ranging from 4 – 5.5 kg per circuit (Table 4), the R-290 air-cooled chiller could be used for applications other than human comfort in supervised or authorized occupancies and when the equipment is located in an above ground machinery room. If the charge could be reduced to less than 5 kg per refrigeration circuit, they could be also used in all occupancy categories if the equipment is located in open air such as on the roof top.

On the other hand, the charge limit restriction would have been less constraining for R-32 because of its mildly flammable classification (i.e. "2L"). The following tables show possible applications for each occupancy category and location classification.

Table 2: Possible Applications of R-290 Prototypes

Occupancy category			**Location classification**			
			I[3]	**II**[4]	**III**[5]	**IV**[6]
General occupancy "a": hotels, schools, restaurant	Human comfort		No (charge > 1 kg)		No[7]	Yes[8] (charge < 5 kg)
	Other applications	Below ground	No (charge > 1 kg)		No (charge > 1 kg)	
		Above ground	No (charge > 1.5 kg)		Yes[8] (charge < 5 kg)	
Supervised occupancy "b": Offices	Human comfort		No (charge > 1 kg)		No[9]	
	Other applications	Below ground	No (charge > 1.5 kg)		No (charge > 1 kg)	
		Above ground	No (charge > 2.5 kg)		Yes (charge < 10 kg)	
Authorized occupancy "c": manufacturing facilities	Human comfort		No (charge > 1 kg)		Yes[10]	
	Other applications	Below ground	No (charge > 1.5 kg)		No (charge > 1 kg)	
		Above ground	Yes[11] (charge < 10 kg)	Yes[11] (charge < 25 kg)	Yes (no charge restriction)	

Table 3: Possible Applications of R-32 Prototypes

Occupancy category		**Location classification**			
		I	**II**	**III**	**IV**
General occupancy "a": hotels, schools, restaurant	Human comfort	Yes[12] (charge < 12 kg)		Yes (no charge restriction)	Yes (charge < 60 kg)
	Other applications	Yes[13] (charge < 12 kg)			
Supervised occupancy "b": Offices	Human comfort	Yes[12] (charge < 12 kg)			
	Other applications	Yes[13] (charge < 12 kg)	Yes[13] (charge < 25 kg)		
Authorized occupancy "c": manufacturing facilities	Human comfort	Yes[12] (charge < 12 kg)			
	Other applications	Yes[13] (charge < 12 kg)	Yes[13] (charge < 25 kg)		

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[3] The refrigerating system or refrigerant-containing parts are located in the occupied space
[4] All compressors and pressure vessels are either located in a machinery room or in the open air; coil-type heat exchangers and pipework, including valves, can be located in an occupied space
[5] All refrigerant-containing parts are located in a machinery room or open air
[6] All refrigerant-containing parts are located in the ventilated enclosures
[7] In accordance with occupancy "a" other applications
[8] Only for 40 kW and 70 kW unit with charge not more than 5 kg
[9] In accordance with occupancy "b" other applications
[10] In accordance with occupancy "c" other applications
[11] Room volume larger than 526 m^3 for 70 kW unit, 658 m^3 for 40 kW unit, and 724 m^3 for 100 kW unit
[12] Floor area larger than 19 m^2 for 70 kW unit, 29 m^2 for 40 kW unit, and 34m^2 for 100 kW unit and height of supply vent at 1.8m
[13] Room volume larger than 73 m^3 for 70 kW unit, 90 m^3 for 40 kW unit, and 97 m^3 for 100 kW unit

Occupancy category		Location classification			
		I	II	III	IV
	< 1 person per 10 m^2	Yes[13] (charge < 50 kg)	Yes (no charge restriction)		

Tables 2 and 3 show possible applications of R-290 and R-32 that are germane to the chillers designed for this project. As such, the tables should not be viewed as universally applicable. Designers should always refer to ISO 5149 to ensure compliance with safety requirements.

<u>IEC 60335-2-40</u>

The prototype units were also designed to comply with the marking requirements of IEC 60335-2-40 [4]. These requirements are necessary to warn about the flammability hazard of both R-32 and R-290.

It should be noted that IEC 60335-2-40-2018 has also requirements on refrigerant charge limits, which in some instances may be different than the requirements of ISO 5149. However, given that the IEC standard was published in the first quarter of 2018 when the preliminary design of the units was well underway and almost complete, it was decided to stick with the refrigerant charge limit requirements of ISO 5149 instead.

<u>Prototype Unit Design</u>

A schematic of the 100 kW air-cooled chiller is shown in Figures 2 (general view) and 3 (top and side views). Both R-32 and R-290 units are the same except that scroll compressors were used for R-32 while semi-hermetic compressors were used for R-290 as scroll compressors were not yet available for this refrigerant. All components selected (expansion valves, solenoid valves etc.) were compatible with both R-32 and R-290.

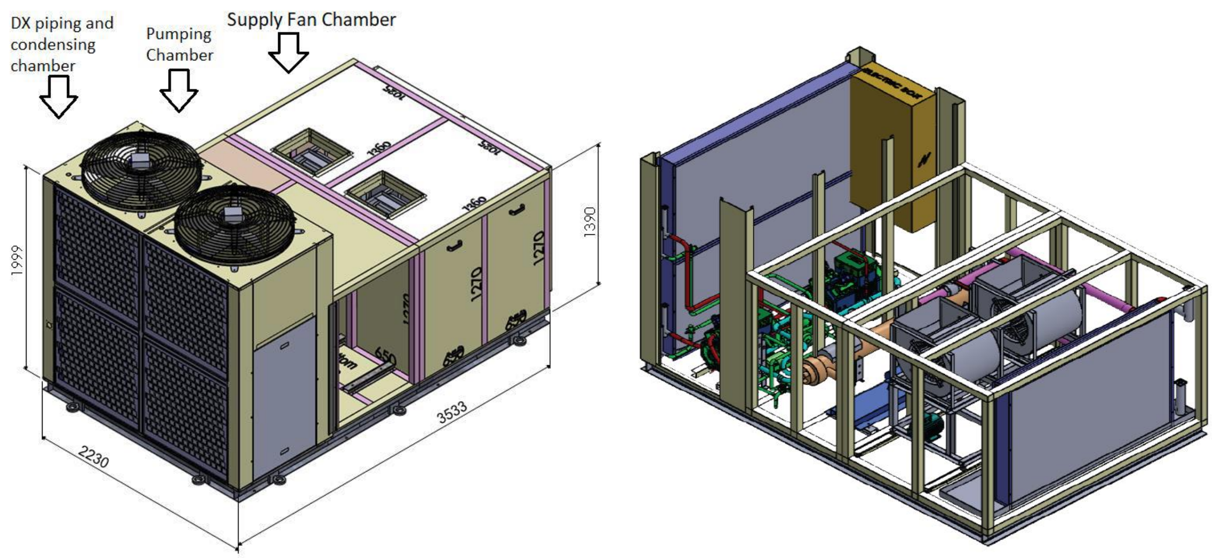


Figure 2: Schematic of 100 kW Prototype Air-Cooled Chiller

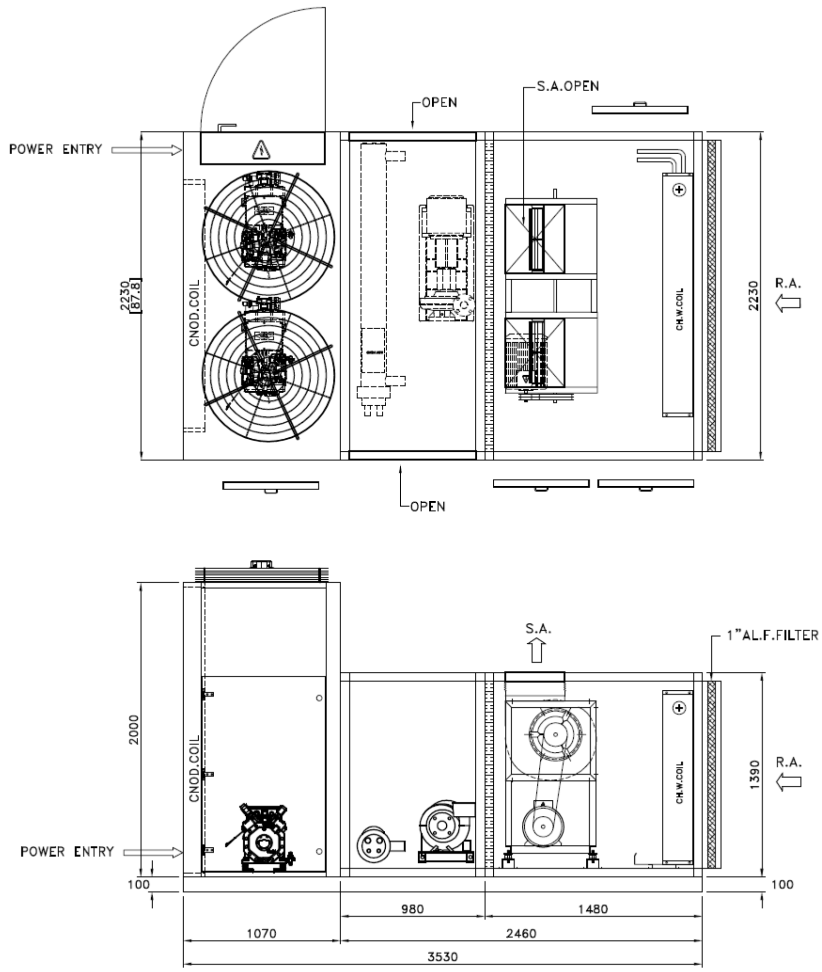


Figure 3: Top and Side Views of 100 kW Prototype Air-Cooled Chiller

As can be seen in the figures, the prototype units are of a hybrid design where the air-cooled chiller is connected with the air handlers in the same cabinet. By using an air-cooled chiller to generate chilled water and circulate it to the air handling unit via a water pump, any refrigerant leakage will be contained in the shell and tube heat exchanger and/or the finned tube cooling coil in the air handling unit so the main supply air stream will be safe from any flammable refrigerant leakage. Furthermore, PETRA separated the compressor and condenser in one chamber and shell and tube heat exchanger in another chamber to further minimize gas leakage to the air handling unit.

A schematic of the 70 kW air-cooled chiller is shown in Figures 4 (general view) and 5 (top and side views). The 40 kW units have the same dimensions but are equipped with only one compressor.

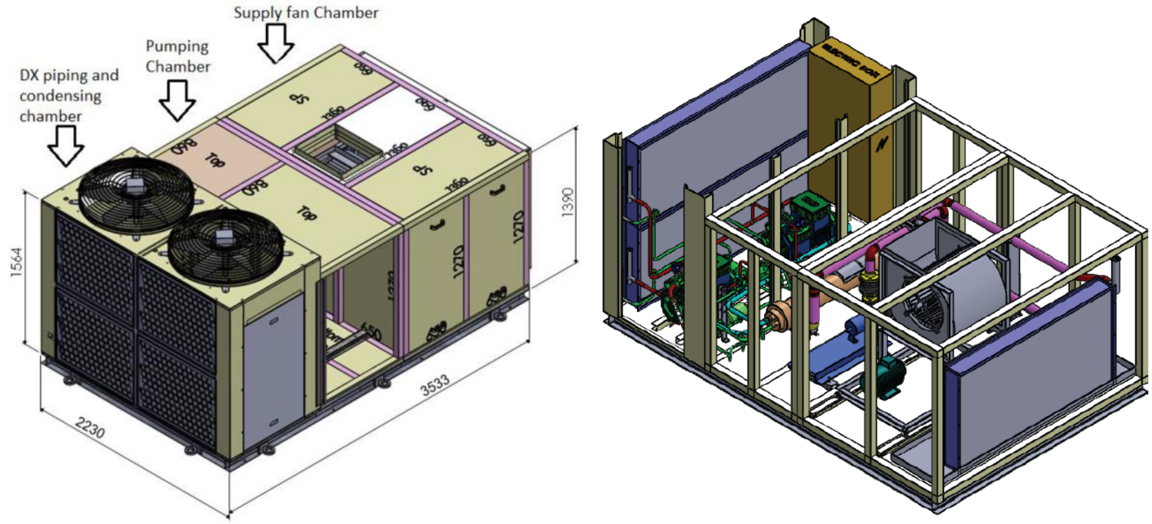


Figure 4: Schematic of 70 kW Prototype Air-Cooled Chiller

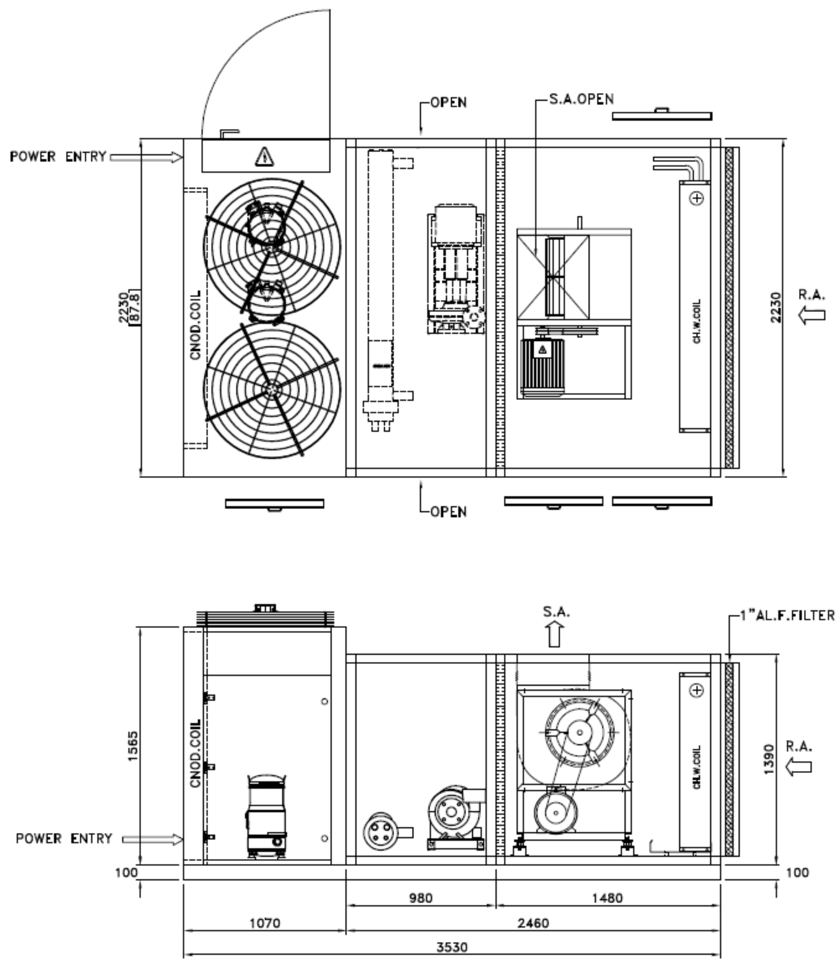


Figure 5: Top and Side Views of 70 kW Prototype Air-Cooled Chiller

Specific Design Features for Flammable Refrigerants

DX piping and condensing chamber

- Reduce number of junction boxes inside the chamber to reduce ignition source.
- Reduce number of welding joints as much as possible to prevent leakage.
- Use of automatic shut-off valves (liquid solenoid valves) to isolate parts of the refrigeration circuit when a leak occurs.
- Use of more than one independent refrigerant circuit on high capacity units to reduce refrigerant losses in case of a major leak.
- For R-290 units, installation of leak detector sensors to detect, in the event of a leak, the concentration of flammable refrigerants and immediately shut off the unit while operating the axial fans only to move the refrigerant out of the unit.

Electrical enclosure

- The electrical enclosure is located on the opposite end of the welding joints of the condenser
- NEMA 4X electrical enclosure is used to provide a degree of protection to unauthorized access and a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects.
- Installation of air flow switches insider the electrical panel to ensure that the panel always has a positive pressure.
- Emergency push button switch on the electrical panel door to immediate disconnect the power.
- Electrical conduits sealed with silicone to prevent flammable refrigerant to enter the enclosure in case of leakage.
- For the location classification and requirement according ATEX such as Class 1, Division 1, Group A, B, C, or D as defined in NFPA 70, the prototype can be fitted with NEMA 7 enclosure.

Other Design Features

- Electrical safety capsule on both discharge and suctions side of the compressor to protect the compressor and refrigeration system from unsafe high and low pressure conditions. A pressure relief valve is installed as mechanical protection to control high excessive pressure as additional protection to electrical mechanical capsule. This is particularly important for high ambient temperature countries like Saudi Arabia.

Finally, all prototype units were designed to meet the minimum energy efficiency standards currently in place in Saudi Arabia [5].

Prototype Units

Petra manufactured 6 prototype units, 3 units using R-32 at cooling capacities of 40 kW, 70 kW and 100 kW, and 3 other units using R-290 (same cooling capacities), some are shown in the following figures.

Figure 6: Prototypes

Figure 7: R-32 Prototype with Markings

Figure 8: R-32 Unit with Scroll Compressor

Figure 9: R-290 Unit with Semi-Hermetic Compressor

Figure 10: R-290 Leak Sensor

Figure 11: NEMA 7 Electrical Panel Upgrade

Refrigerant Charge Amounts

Each prototype unit was charged with the amount of refrigerant needed to achieve suitable superheat and sub-cooling temperatures. Table 4 shows the refrigerant charge amounts for each unit including the baseline R-410A.

Table 4: Total Refrigerant Charge Amounts (kg) per Unit

Capacity	No. of refrigeration circuit	R-410A	R-32	R-290
100 kW	2	16	12	11
70 kW	2	12	9	8
40 kW	1	6.5	5.5	5

3. Testing

After completing the production of the six prototype units, they were installed and tested one by one in PETRA's testing facility. PETRA's testing facility has a total area of more than 840 m^2 and is fully equipped to accurately test the units according to AHRI and ASHRAE industry standards. The facility has a thermal room capable of testing air-cooled chillers at various water flow rates and ambient temperatures. The facility has also a sound room equipped with instruments capable of measuring sound pressure levels.

Test Procedure

The test setup was prepared according to AHRI 550/590 [6] as shown in Figure 12, with air flow measurement station to measure air flow rate and air sampler tree to measure ambient, return and supply air dry and wet bulb temperatures.

Figure 12: Unit Test Setup

The tests involved measurements of net capacity (kW or Btu/h) and efficiency (COP in W/W or EER in Btu/W.h) when operating under specified design conditions according to AHRI 550/590, and were carried out under steady state conditions within the tolerances specified in the procedure.

All tests were conducted in the calorimeter laboratory to enable ambient and return air temperatures at conditions shown in Table 5 below.

Table 5: Testing Temperature Conditions (°C)

Rating conditions	Indoor section		Outdoor section	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
T_1	27.0	19.0	35.0	24.0
T_3	29.0	19.0	46.0	24.0
T_3^+	29.0	19.0	52.0	24.0

<u>Laboratory Modifications for Flammable Refrigerants</u>

PETRA made minor modifications to its laboratory to safely handle and test flammable refrigerants. More specifically, PETRA added an alarm panel to detect R-290 (Figure 13) and control the exhaust fan in case the concentration of the refrigerant in the laboratory suddenly increases.

Figure 13: Control Alarm Panel and R-290 Sensors

III. Performance Results

Figure 14 to Figure 16 show variations in Energy Efficiency Ratio (EER) and cooling capacity for the 40 kW, 70 kW and 100 kW prototypes for refrigerants R-290, R-32 and R-410A at three ambient temperatures of 35ºC, 46ºC and 52ºC.

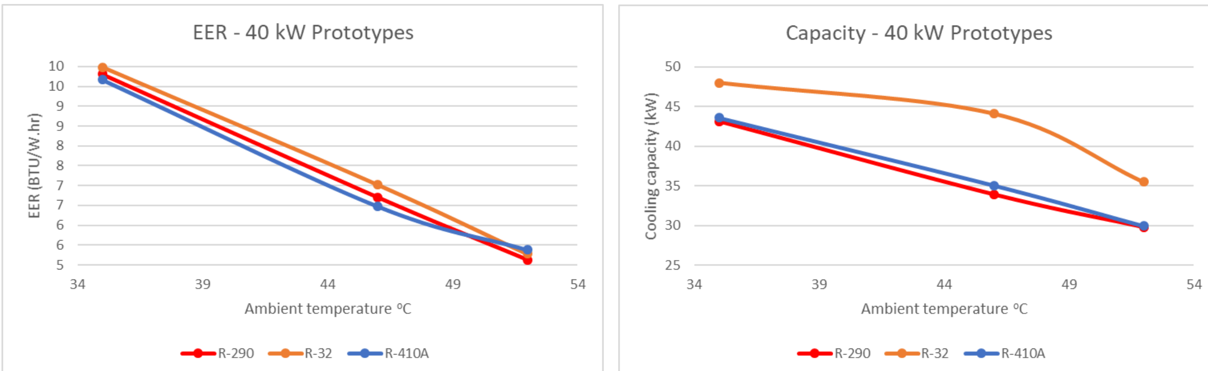


Figure 14: EER and Cooling Capacity at Various Ambient Temperatures – 40 kW Prototypes

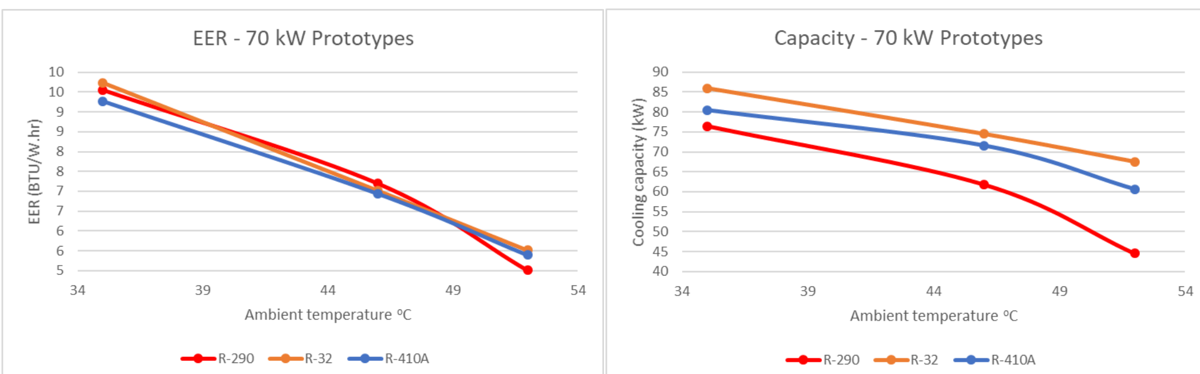


Figure 15: EER and Cooling Capacity at Various Ambient Temperatures – 70 kW Prototypes

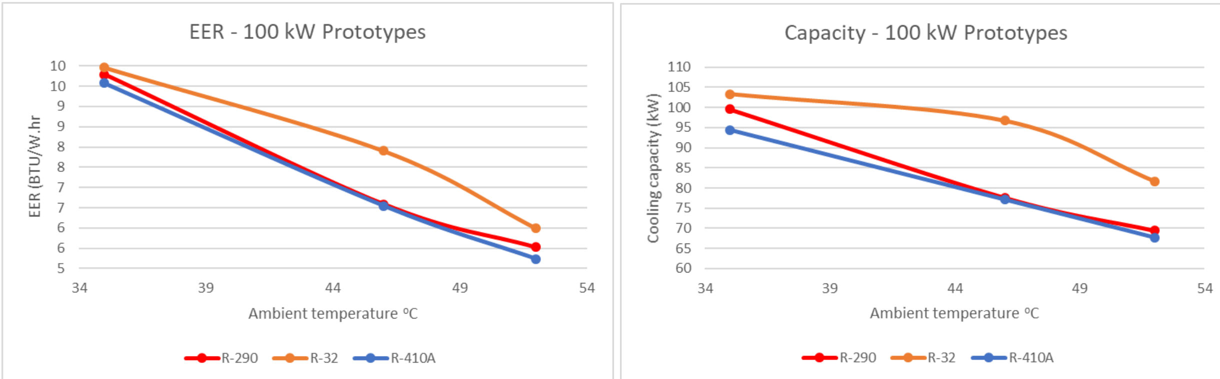


Figure 16: EER and Cooling Capacity at Various Ambient Temperatures – 100 kW Prototypes

As expected, all refrigerants experienced degradation in Energy Efficiency Ratio (EER) and cooling capacity when the ambient temperature increases. When comparing EER, both R-32 and R-290 had slightly better performance than the baseline R-410A at T1 and T3 condition but R-32 EER is lower than R-290 and R-410A at 52°C condition. The only exception is the 100 kW prototype where R-32 has better EER than both R-290 and R-410A at all testing conditions. In terms of cooling capacity, all R-32 prototypes have higher capacity than both R-290 and R-410A at each testing conditions. Comparing cooling capacity of R-410A and R-290 prototypes, the 40 kW and 100 kW have similar cooling capacity while the 70 kW R-410A has higher capacity than R-290 prototype. It should be noted that the performance of R-290 could be attributed to the semi-hermetic compressors which, in general, are less efficient than the scroll compressors used with R-32 and R-410A.

Figures 17, 18 and 19 illustrate the low GWP refrigerants' relative performance to the baseline R-410A for the 100 kW prototypes at the ambient temperatures of 35°C, 46ºC and 52ºC respectively. These figures give a better visualization of the performance of R-32 and R-290 relative to the baseline R-410A. Results in the upper right quadrant of the chart indicate a better efficiency and a better cooling capacity than R-410A. As can be seen from the figures, R-32 experienced a higher capacity and efficiency than R-410A for all three ambient temperatures. On the other hand, the R-290 prototype's performance was very similar to R-410A. As mentioned before, with better compressors, R-290 would have performed better. It should be stressed again that R-410A was tested as a drop in to R-32 and that the unit was not optimized for that refrigerant. Detailed test reports are included in Appendix A.

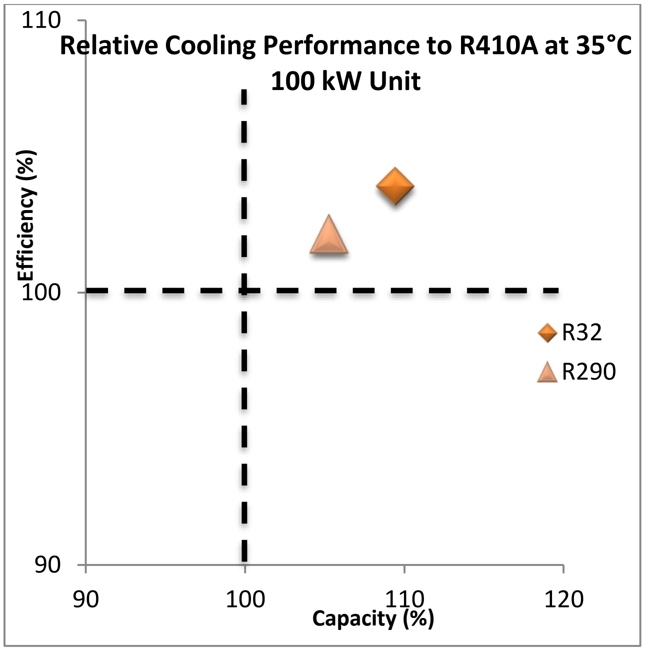


Figure 17: Low GWP refrigerants relative performance to R-410A at 35°C – 100 kW Prototypes

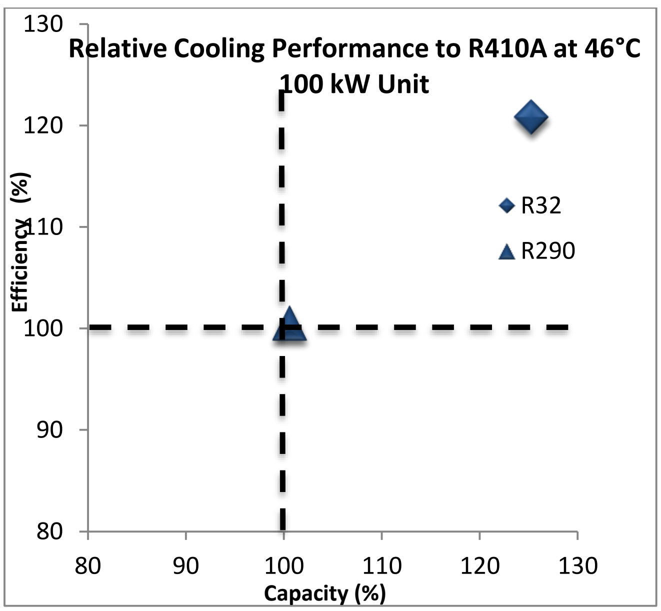


Figure 18: Low GWP refrigerants relative performance to R-410A at 46°C – 100 kW Prototypes

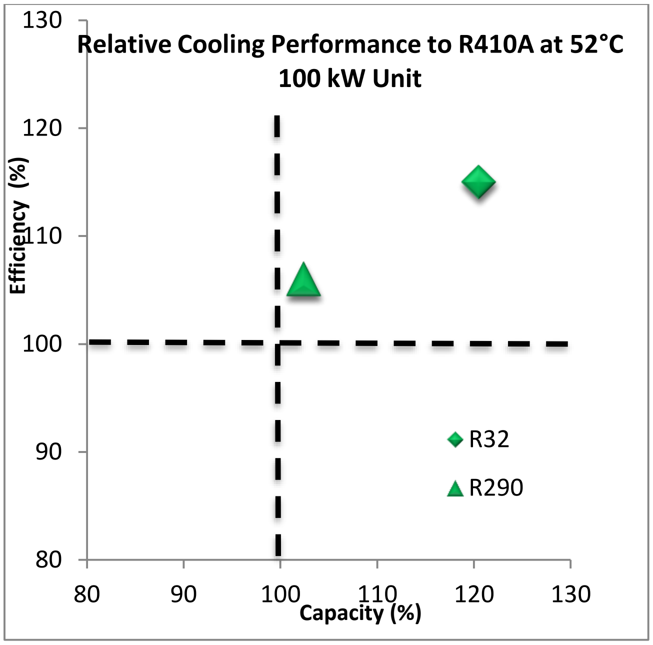


Figure 19: Low GWP refrigerants relative performance to R-410A at 52°C – 100 kW Prototypes

IV. Cost Analysis

An analysis was conducted to compare the cost of the low GWP alternative refrigerants and the major components of the chillers to the baseline R-410A. Tables 6, 7 and 8 indicate that the cost of charging the units with R-290 is 25 to 44% higher than R-410A. On the other hand, the cost of charging R-32 is about 50 to 57% less. The higher cost of R-290 is attributed to a weak demand for this refrigerant in the GCC countries and in particular Saudi Arabia.

Table 6: Cost Comparison of Refrigerant – 100 kW Unit

	R-410A	**R-32**	**R-290**
Refrigerant charge (kg)	16	12	11
Charge ratio to R-410A (%)		75%	68.8%
Unit cost ($/kg)	6.55	4.44	12.25
Cost of Refrigerant ($)	104.8	53.33	134.75
Cost ratio to R-410A (%)		50.88%	128.58%

Table 7: Cost Comparison of Refrigerant – 70 kW Unit

	R-410A	**R-32**	**R-290**
Refrigerant charge (kg)	12	9	8
Charge ratio to R-410A (%)		75%	66.7%
Unit cost ($/kg)	6.55	4.44	12.25
Cost of Refrigerant ($)	78.6	40.0	98.0
Cost ratio to R-410A (%)		50.89%	124.68%

Table 8: Cost Comparison of Refrigerant – 40 kW Unit

	R-410A	R-32	R-290
Refrigerant charge (kg)	6.5	5.5	5
Charge ratio to R-410A (%)		84.6%	76.9%
Unit cost ($/kg)	6.55	4.44	12.25
Cost of Refrigerant ($)	42.58	24.42	61.25
Cost ratio to R-410A (%)		57.35%	143.85%

Table 9 compares the cost of major components of the 100 kW chiller using R-32 and R-290 to the baseline R-410A. The last column in the table reflects the cost of the components designed to meet the European Directive 2014/34/EU also known as "ATEX Equipment Directive" [7]. The ATEX Directive covers equipment and protective systems intended for use in potentially explosive atmospheres. It specifies safety requirements and conformity assessment procedures that are to be applied before products are sold on the EU market.

Table 9: Cost Comparison of Major Components - 100 kW Unit (US $)

Major Components – 100 kW Unit	R-410A Unit (baseline)	R-32 Unit	R-290 Unit	R-290 Unit with ATEX Components
Compressor (2)	1,821	1,821	6,286	10,686
Condenser coil	2,560	2,560	2,560	2,560
Evaporator heat exchanger	1,829	1,829	1,829	1,829
Water Pump, water coil and supply fan	6,691	6,691	6,691	10,036
Expansion valve (2)	123	123	196	196
Electrical panel and cables	2,054	4,414	4,414	13,242
Piping (2)	693	640	693	693
Pressure relief valve (2)	275	275	246	246
Filter drier (2)	275	275	275	275
Solenoid valve (2)	156	156	156	467
Leak detector R-290 (2)	0	0	544	1,632
TOTAL (US $)	16,477	18,784	23,890	41,862
Percentage increase to R-410A unit	0%	14%	45%	154%

Results from Table 9 show that the exception of the electrical panel, the cost of R-32 components is very similar to R-410A. Overall, the cost is 14% higher than R-410A, mainly due to upgrade electrical panel. On the other hand, R-290 components are more expensive resulting in an overall cost increase of 45% over R-410A. This increase is mainly due to the high cost of the R-290 semi-hermetic compressor. The ATEX requirements increase significantly the cost of R-290 components; more than 150% over the cost of R-410A. However, while the cost of R-290 components is relatively high today, this cost could decrease if production increases in the future.

Cost comparisons for the 70 and 40 kW chillers can be found in Tables 10 and 11 respectively.

Table 10: Cost Comparison of Major Components - 70 kW Unit (US $)

Major Components – 70 kW Unit	R-410A Unit (baseline)	R-32 Unit	R-290 Unit	R-290 Unit with ATEX Components
Compressor (2)	1,493	1,493	5,155	8,763
Condenser coil	2,099	2,099	2,099	2,099
Evaporator heat exchanger	1,500	1,500	1,500	1,500
Water Pump, water coil and supply fan	6,259	6,259	6,259	9,389
Expansion valve (2)	101	101	161	161
Electrical panel and cables	1,684	3,619	3,619	10,858
Piping (2)	568	525	568	568
Pressure relief valve (2)	275	275	246	246
Filter drier (2)	275	275	275	275
Solenoid valve (2)	156	156	156	467
Leak detector R-290 (2)	0	0	544	1,632
TOTAL (US $)	14,411	16,302	20,582	32,828
Percentage increase to R-410A unit	0%	13%	43%	128%

Table 11: Cost Comparison of Major Components - 40 kW Unit (US $)

Major Components – 40 kW Unit	R-410A Unit (baseline)	R-32 Unit	R-290 Unit	R-290 Unit with ATEX Components
Compressor	911	911	3,143	5,343
Condenser coil	1,280	1,280	1,280	1,280
Evaporator heat exchanger	915	915	915	915
Water Pump, water coil and supply fan	5,896	5,896	5,896	8,844
Expansion valve (2)	62	62	98	98
Electrical panel and cables	1,027	2,207	2,207	6,621
Piping (2)	347	320	347	347
Pressure relief valve (2)	138	138	123	123
Filter drier (2)	138	138	138	138
Solenoid valve (2)	78	78	78	234
Leak detector R-290 (2)	0	0	544	1,632
TOTAL (US $)	10,789	11,943	14,768	25,573
Percentage increase to R-410A unit	0%	11%	37%	137%

V. Conclusions

This project successfully demonstrated that commercial air-cooled chillers can be designed and operated with flammable low GWP alternative refrigerants for a variety of cooling capacities and operating conditions, including high ambient temperatures. A total of six units were built with cooling capacities of 40 kW, 70 kW and 100 kW. The design of the products was in accordance with the safety requirements of ISO-5149 and IEC-60335-2-40.

The air-cooled chillers were tested at a standard ambient condition of 35ºC as well as at high ambient temperatures of 46ºC and 52ºC. In all cases, both R-32 and R-290 units showed similar or better performance (efficiency and cooling capacity) than the baseline R-410A chiller. The design changes necessary to mitigate the risk of using R-32 resulted in a marginal increase in the cost of the chillers. However, the cost increase was significantly higher in the case of the highly flammable refrigerant R-290. It is expected that both the cost of the R-32 and R-290 chillers will decrease in the future as production increases.

Requirements of current international safety standards did not limit the amount of flammable refrigerants used for this particular project because of the specific application and location of the chillers. However, it should be noted that in most commercial applications, the use of highly flammable refrigerants such as R-290 is severely restricted by current safety standards, which is not the case for mildly flammable refrigerants like R-32.

Finally, it is believed that findings from this project will help developing countries with high ambient temperature conditions accelerate their adoption and implementation of the Kigali Amendment.

VI. References

1- ANSI/ASHRAE 34, 2016, *Designation and Safety Classification of Refrigerants*, ASHRAE, Atlanta, Georgia, USA.

2- ISO 817, 2014, *Refrigerants -- Designation and safety classification*, International Organization for Standardization, Geneva, Switzerland.

3- ISO 5149, 2014, *Refrigerating systems and heat pumps — Safety and environmental requirements —Part 1: Definitions, classification and selection criteria*, International Organization for Standardization, Geneva, Switzerland.

4- IEC 60335-2-40, 2018, *Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers*, International Electrotechnical Commission, Geneva, Switzerland.

5- SASO 2874, 2016, *Air-Conditioners – Minimum Energy Performance Requirements and Testing Requirements*, Saudi Standards, Metrology and Quality Organization, Riyadh, Saudi Arabia.

6- AHRI 550/590, 2018, *Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle*, Air-Conditioning, Heating, and Refrigeration Institute, Arlington, Virginia, USA.

7- Directive 2014/34/EU, 2014, *Harmonization of the laws of the Member States Relating to Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres,* European Union, Brussels, Belgium.

VII. Appendix A

Test reports for all prototypes and low GWP alternatives as well as the baseline R-410A are shown in the following tables.

Test Results: 100 kW Prototype (R-32) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.51
		S-T	Volts	453.95
		R-T	Volts	456.45
	Current	R	Amps	58.83
		S	Amps	61.75
		T	Amps	59.39
	Watts	R	KW	13.27
		S	KW	13.77
		T	KW	12.97
		Total KW	KW	40.00
	Power Factor		---	0.85
	Total Power Exclude pump & fan		KW	35.40
	Frequency		Hz	60.49
COOLER	Water In		°C	10.42
	Water Out		°C	4.99
	Temperature Drop 1		°C	5.43
	Flow Rate		GPM	72.90
Air condition	Return Air Dry Bulb		°C	26.80
	Return Air Wet Bulb		°C	19.28
	Supply Air Dry Bulb		°C	15.04
	Supply Wet Bulb		°C	13.17
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	35.33
Compressor Data 1	Discharge Temp.		°C	92.90
	Liquid Temp.		°C	45.34
	Suction Temp.		°C	7.08
	Discharge Pressure		[psi]	407.70
	Liquid Pressure		[psi]	402.87
	Suction Pressure		[psi]	104.67
Compressor Data 2	Discharge Temp.		°C	91.04
	Liquid Temp.		°C	47.06
	Suction Temp.		°C	7.77
	Discharge Pressure		[psi]	423.66
	Liquid Pressure		[psi]	413.93
	Suction Pressure		[psi]	105.54

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	7.71
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.436
	water Flow Rate	ft^3/hr	584.86
Air Side	Enthalpy in	KJ/KG	54.87
	Enthalpy out	KJ/KG	37.110
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	359767
		KW	105.4
		TR	30.0
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	352556
		KW	103.3
		TR	29.4
Unit Eff.	UNIT EER	Btu/W.hr	9.96
	COP	W/W	2.92
Energy Balance	Heat Balance	Energy Balance Different Percentage	2%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-32) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.12
		S-T	Volts	452.52
		R-T	Volts	454.64
	Current	R	Amps	66.85
		S	Amps	70.64
		T	Amps	67.33
	Watts	R	KW	15.38
		S	KW	16.03
		T	KW	14.95
		Total KW	KW	46.35
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	41.75
	Frequency		Hz	60.46
COOLER	Water In		°C	12.03
	Water Out		°C	6.88
	Temperature Drop 1		°C	5.15
	Flow Rate		GPM	72.70
Air condition	Return Air Dry Bulb		°C	29.15
	Return Air Wet Bulb		°C	19.00
	Supply Air Dry Bulb		°C	16.21
	Supply Wet Bulb		°C	13.23
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	45.92
Compressor Data 1	Discharge Temp.		°C	109.84
	Liquid Temp.		°C	55.17
	Suction Temp.		°C	9.48
	Discharge Pressure		[psi]	501.27
	Liquid Pressure		[psi]	501.17
	Suction Pressure		[psi]	111.34
Compressor Data 2	Discharge Temp.		°C	107.70
	Liquid Temp.		°C	56.78
	Suction Temp.		°C	10.20
	Discharge Pressure		[psi]	520.35
	Liquid Pressure		[psi]	511.27
	Suction Pressure		[psi]	111.05

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	9.45
	Specific Heat	Btu/lbm·°F	1.008
	Density	Ibm/ft^3	62.428
	water Flow Rate	ft^3/hr	583.26
Air Side	Enthalpy in	KJ/KG	53.87
	Enthalpy out	KJ/KG	37.250
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	340037
		KW	99.7
		TR	28.3
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	329926
		KW	96.7
		TR	27.5
Unit Eff.	UNIT EER	Btu/W.hr	7.90
	COP	W/W	2.32
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-32) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.31
		S-T	Volts	452.72
		R-T	Volts	454.74
	Current	R	Amps	72.89
		S	Amps	77.31
		T	Amps	73.49
	Watts	R	KW	16.92
		S	KW	17.71
		T	KW	16.46
		Total KW	KW	51.09
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	46.49
	Frequency		Hz	60.51
COOLER	Water In		°C	13.59
	Water Out		°C	9.22
	Temperature Drop 1		°C	4.37
	Flow Rate		GPM	72.80
Air condition	Return Air Dry Bulb		°C	29.23
	Return Air Wet Bulb		°C	18.82
	Supply Air Dry Bulb		°C	17.91
	Supply Wet Bulb		°C	13.99
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	51.80
Compressor Data 1	Discharge Temp.		°C	117.99
	Liquid Temp.		°C	60.76
	Suction Temp.		°C	11.94
	Discharge Pressure		[psi]	561.23
	Liquid Pressure		[psi]	562.55
	Suction Pressure		[psi]	119.86
Compressor Data 2	Discharge Temp.		°C	117.60
	Liquid Temp.		°C	62.68
	Suction Temp.		°C	12.77
	Discharge Pressure		[psi]	588.42
	Liquid Pressure		[psi]	578.44
	Suction Pressure		[psi]	119.05

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	11.41
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.417
	water Flow Rate	ft^3/hr	584.06
Air Side	Enthalpy in	KJ/KG	53.28
	Enthalpy out	KJ/KG	39.240
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	289310
		KW	84.8
		TR	24.1
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	278710
		KW	81.7
		TR	23.2
Unit Eff.	UNIT EER	Btu/W.hr	6.00
	COP	W/W	1.76
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-410A) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.89
		S-T	Volts	454.27
		R-T	Volts	456.57
	Current	R	Amps	56.74
		S	Amps	59.45
		T	Amps	57.05
	Watts	R	KW	12.73
		S	KW	13.15
		T	KW	12.37
		Total KW	KW	38.25
	Power Factor		---	0.84
	Total Power Exclude pump & fan		KW	33.65
	Frequency		Hz	60.50
COOLER	Water In		°C	10.71
	Water Out		°C	5.66
	Temperature Drop 1		°C	5.05
	Flow Rate		GPM	72.70
Air condition	Return Air Dry Bulb		°C	26.85
	Return Air Wet Bulb		°C	19.51
	Supply Air Dry Bulb		°C	15.59
	Supply Wet Bulb		°C	14.02
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	35.16
Compressor Data 1	Discharge Temp.		°C	72.55
	Liquid Temp.		°C	43.96
	Suction Temp.		°C	7.77
	Discharge Pressure		[psi]	388.76
	Liquid Pressure		[psi]	382.02
	Suction Pressure		[psi]	102.71
Compressor Data 2	Discharge Temp.		°C	70.08
	Liquid Temp.		°C	44.37
	Suction Temp.		°C	7.17
	Discharge Pressure		[psi]	417.69
	Liquid Pressure		[psi]	406.09
	Suction Pressure		[psi]	104.40

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	8.19
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.434
	water Flow Rate	ft^3/hr	583.26
Air Side	Enthalpy in	KJ/KG	55.61
	Enthalpy out	KJ/KG	39.380
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	333695
		KW	97.8
		TR	27.8
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	322184
		KW	94.4
		TR	26.8
Unit Eff.	UNIT EER	Btu/W.hr	9.57
	COP	W/W	2.81
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-410A) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.58
		S-T	Volts	452.98
		R-T	Volts	455.35
	Current	R	Amps	65.44
		S	Amps	67.84
		T	Amps	63.36
	Watts	R	KW	14.88
		S	KW	15.44
		T	KW	14.49
		Total KW	KW	44.81
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	40.21
	Frequency		Hz	60.48
COOLER	Water In		°C	13.19
	Water Out		°C	9.06
	Temperature Drop 1		°C	4.13
	Flow Rate		GPM	72.60
Air condition	Return Air Dry Bulb		°C	26.26
	Return Air Wet Bulb		°C	19.20
	Supply Air Dry Bulb		°C	17.69
	Supply Wet Bulb		°C	14.76
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	45.92
Compressor Data 1	Discharge Temp.		°C	86.68
	Liquid Temp.		°C	54.65
	Suction Temp.		°C	11.33
	Discharge Pressure		[psi]	488.66
	Liquid Pressure		[psi]	486.04
	Suction Pressure		[psi]	114.86
Compressor Data 2	Discharge Temp.		°C	83.82
	Liquid Temp.		°C	55.91
	Suction Temp.		°C	10.03
	Discharge Pressure		[psi]	529.55
	Liquid Pressure		[psi]	517.50
	Suction Pressure		[psi]	113.26

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	11.13
	Specific Heat	Btu/lbm·°F	1.009
	Density	lbm/ft^3	62.418
	water Flow Rate	ft^3/hr	582.46
Air Side	Enthalpy in	KJ/KG	54.62
	Enthalpy out	KJ/KG	41.360
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	272656
		KW	79.9
		TR	22.7
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	263226
		KW	77.1
		TR	21.9
Unit Eff.	UNIT EER	Btu/W.hr	6.55
	COP	W/W	1.92
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-410A) @52°C Condition

TEST Results

Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.48
		S-T	Volts	452.77
		R-T	Volts	455.18
	Current	R	Amps	70.34
		S	Amps	73.13
		T	Amps	68.09
	Watts	R	KW	16.17
		S	KW	16.82
		T	KW	15.75
		Total KW	KW	48.74
	Power Factor		---	0.88
	Total Power Exclude pump & fan		KW	44.14
	Frequency		Hz	60.50
COOLER	Water In		°C	14.47
	Water Out		°C	10.85
	Temperature Drop 1		°C	3.62
	Flow Rate		GPM	72.80
Air condition	Return Air Dry Bulb		°C	29.15
	Return Air Wet Bulb		°C	18.90
	Supply Air Dry Bulb		°C	18.74
	Supply Wet Bulb		°C	14.96
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	51.50
Compressor Data 1	Discharge Temp.		°C	95.85
	Liquid Temp.		°C	60.43
	Suction Temp.		°C	13.03
	Discharge Pressure		[psi]	552.17
	Liquid Pressure		[psi]	550.15
	Suction Pressure		[psi]	117.73
Compressor Data 2	Discharge Temp.		°C	91.89
	Liquid Temp.		°C	60.72
	Suction Temp.		°C	11.14
	Discharge Pressure		[psi]	584.35
	Liquid Pressure		[psi]	572.26
	Suction Pressure		[psi]	114.22

Unit Performance Calculations

Parameter		Unit	READING
Water Prop	Mean Temp.	°C	12.66
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.408
	water Flow Rate	ft^3/hr	584.06
Air Side	Enthalpy in	KJ/KG	53.54
	Enthalpy out	KJ/KG	41.900
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	239717
		KW	70.3
		TR	20.0
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	231067
		KW	67.7
		TR	19.3
Unit Eff.	UNIT EER	Btu/W.hr	5.23
	COP	W/W	1.53
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-290) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.27
		S-T	Volts	453.94
		R-T	Volts	455.94
	Current	R	Amps	60.79
		S	Amps	62.70
		T	Amps	61.80
	Watts	R	KW	12.97
		S	KW	13.38
		T	KW	12.94
		Total KW	KW	39.29
	Power Factor		---	0.81
	Total Power Exclude pump & fan		KW	34.69
	Frequency		Hz	60.52
COOLER	Water In		°C	10.35
	Water Out		°C	5.06
	Temperature Drop 1		°C	5.29
	Flow Rate		GPM	72.90
Air condition	Return Air Dry Bulb		°C	27.00
	Return Air Wet Bulb		°C	19.40
	Supply Air Dry Bulb		°C	14.90
	Supply Wet Bulb		°C	13.56
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	35.46
Compressor Data 1	Discharge Temp.		°C	69.99
	Liquid Temp.		°C	39.41
	Suction Temp.		°C	8.57
	Discharge Pressure		[psi]	248.14
	Liquid Pressure		[psi]	241.92
	Suction Pressure		[psi]	56.25
Compressor Data 2	Discharge Temp.		°C	67.94
	Liquid Temp.		°C	39.52
	Suction Temp.		°C	6.73
	Discharge Pressure		[psi]	243.09
	Liquid Pressure		[psi]	237.48
	Suction Pressure		[psi]	59.74

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	7.71
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.436
	water Flow Rate	ft^3/hr	584.86
Air Side	Enthalpy in	KJ/KG	55.27
	Enthalpy out	KJ/KG	38.160
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	350492
		KW	102.7
		TR	29.2
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	339653
		KW	99.5
		TR	28.3
Unit Eff.	UNIT EER	Btu/W.hr	9.79
	COP	W/W	2.87
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-290) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.73
		S-T	Volts	453.36
		R-T	Volts	455.51
	Current	R	Amps	67.29
		S	Amps	69.78
		T	Amps	68.94
	Watts	R	KW	14.70
		S	KW	15.30
		T	KW	14.78
		Total KW	KW	44.78
	Power Factor		---	0.83
	Total Power Exclude pump & fan		KW	40.18
	Frequency		Hz	60.48
COOLER	Water In		°C	12.27
	Water Out		°C	8.15
	Temperature Drop 1		°C	4.12
	Flow Rate		GPM	72.60
Air condition	Return Air Dry Bulb		°C	28.89
	Return Air Wet Bulb		°C	19.30
	Supply Air Dry Bulb		°C	16.74
	Supply Wet Bulb		°C	14.81
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	45.50
Compressor Data 1	Discharge Temp.		°C	74.11
	Liquid Temp.		°C	48.42
	Suction Temp.		°C	8.18
	Discharge Pressure		[psi]	297.17
	Liquid Pressure		[psi]	290.70
	Suction Pressure		[psi]	62.75
Compressor Data 2	Discharge Temp.		°C	74.74
	Liquid Temp.		°C	47.59
	Suction Temp.		°C	10.98
	Discharge Pressure		[psi]	334.14
	Liquid Pressure		[psi]	330.71
	Suction Pressure		[psi]	62.28

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	10.21
	Specific Heat	Btu/lbm·°F	1.009
	Density	lbm/ft^3	62.424
	water Flow Rate	ft^3/hr	582.46
Air Side	Enthalpy in	KJ/KG	54.87
	Enthalpy out	KJ/KG	41.530
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	271953
		KW	79.7
		TR	22.7
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	264814
		KW	77.6
		TR	22.1
Unit Eff.	UNIT EER	Btu/W.hr	6.59
	COP	W/W	1.93
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 100 kW Prototype (R-290) @52°C Condition

TEST Results

Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.93
		S-T	Volts	453.33
		R-T	Volts	455.33
	Current	R	Amps	70.63
		S	Amps	73.46
		T	Amps	72.33
	Watts	R	KW	15.58
		S	KW	16.25
		T	KW	15.62
		Total KW	KW	47.45
	Power Factor		---	0.84
	Total Power Exclude pump & fan		KW	42.85
	Frequency		Hz	60.45
COOLER	Water In		°C	13.69
	Water Out		°C	9.98
	Temperature Drop 1		°C	3.71
	Flow Rate		GPM	72.90
Air condition	Return Air Dry Bulb		°C	29.42
	Return Air Wet Bulb		°C	19.52
	Supply Air Dry Bulb		°C	17.87
	Supply Wet Bulb		°C	15.57
	Air Flow rate		CFM	10256
Condenser	Ambient		°C	52.01
Compressor Data 1	Discharge Temp.		°C	81.24
	Liquid Temp.		°C	54.74
	Suction Temp.		°C	10.61
	Discharge Pressure		[psi]	341.76
	Liquid Pressure		[psi]	335.48
	Suction Pressure		[psi]	67.78
Compressor Data 2	Discharge Temp.		°C	80.26
	Liquid Temp.		°C	53.74
	Suction Temp.		°C	13.19
	Discharge Pressure		[psi]	367.74
	Liquid Pressure		[psi]	366.24
	Suction Pressure		[psi]	69.00

Unit Performance Calculations

Parameter		Unit	READING
Water Prop	Mean Temp.	°C	11.84
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.414
	water Flow Rate	ft^3/hr	584.86
Air Side	Enthalpy in	KJ/KG	55.59
	Enthalpy out	KJ/KG	43.660
	Air Flow Rate	ft^3/min	10256
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	245973
		KW	72.1
		TR	20.5
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	236824
		KW	69.4
		TR	19.7
Unit Eff.	UNIT EER	Btu/W.hr	5.53
	COP	W/W	1.62
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-32) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.51
		S-T	Volts	454.20
		R-T	Volts	455.71
	Current	R	Amps	50.46
		S	Amps	48.12
		T	Amps	49.84
	Watts	R	KW	11.04
		S	KW	10.62
		T	KW	11.24
		Total KW	KW	32.90
	Power Factor		---	0.84
	Total Power Exclude pump & fan		KW	30.10
	Frequency		Hz	60.49
COOLER	Water In		°C	9.87
	Water Out		°C	4.62
	Temperature Drop 1		°C	5.26
	Flow Rate		GPM	62.90
Air condition	Return Air Dry Bulb		°C	26.49
	Return Air Wet Bulb		°C	19.60
	Supply Air Dry Bulb		°C	14.25
	Supply Wet Bulb		°C	13.06
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	35.22
Compressor Data 1	Discharge Temp.		°C	99.27
	Liquid Temp.		°C	45.23
	Suction Temp.		°C	11.48
	Discharge Pressure		[psi]	427.41
	Liquid Pressure		[psi]	421.68
	Suction Pressure		[psi]	104.60
Compressor Data 2	Discharge Temp.		°C	100.02
	Liquid Temp.		°C	44.11
	Suction Temp.		°C	12.73
	Discharge Pressure		[psi]	440.95
	Liquid Pressure		[psi]	434.95
	Suction Pressure		[psi]	100.67

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	7.24
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.438
	water Flow Rate	ft^3/hr	504.63
Air Side	Enthalpy in	KJ/KG	55.62
	Enthalpy out	KJ/KG	36.850
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	300394
		KW	88.0
		TR	25.0
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	293114
		KW	85.9
		TR	24.4
Unit Eff.	UNIT EER	Btu/W.hr	9.74
	COP	W/W	2.85
Energy Balance	Heat Balance	Energy Balance Different Percentage	2%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-32) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	452.34
		S-T	Volts	453.20
		R-T	Volts	454.63
	Current	R	Amps	58.69
		S	Amps	55.72
		T	Amps	58.08
	Watts	R	KW	13.07
		S	KW	12.55
		T	KW	13.35
		Total KW	KW	38.97
	Power Factor		---	0.86
	Total Power Exclude pump & fan		KW	36.17
	Frequency		Hz	60.48
COOLER	Water In		°C	10.92
	Water Out		°C	6.32
	Temperature Drop 1		°C	4.60
	Flow Rate		GPM	62.80
Air condition	Return Air Dry Bulb		°C	28.61
	Return Air Wet Bulb		°C	19.13
	Supply Air Dry Bulb		°C	15.17
	Supply Wet Bulb		°C	13.52
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	45.87
Compressor Data 1	Discharge Temp.		°C	120.56
	Liquid Temp.		°C	56.10
	Suction Temp.		°C	12.32
	Discharge Pressure		[psi]	551.61
	Liquid Pressure		[psi]	546.27
	Suction Pressure		[psi]	111.01
Compressor Data 2	Discharge Temp.		°C	119.90
	Liquid Temp.		°C	54.58
	Suction Temp.		°C	15.30
	Discharge Pressure		[psi]	557.59
	Liquid Pressure		[psi]	551.59
	Suction Pressure		[psi]	107.53

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	8.62
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.432
	water Flow Rate	ft^3/hr	503.83
Air Side	Enthalpy in	KJ/KG	54.31
	Enthalpy out	KJ/KG	38.040
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	262584
		KW	77.0
		TR	21.9
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	254074
		KW	74.5
		TR	21.2
Unit Eff.	UNIT EER	Btu/W.hr	7.02
	COP	W/W	2.06
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-32) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	450.93
		S-T	Volts	452.00
		R-T	Volts	453.08
	Current	R	Amps	65.67
		S	Amps	63.94
		T	Amps	66.46
	Watts	R	KW	14.88
		S	KW	14.52
		T	KW	15.12
		Total KW	KW	44.52
	Power Factor		---	0.86
	Total Power Exclude pump & fan		KW	41.72
	Frequency		Hz	60.50
COOLER	Water In		°C	11.64
	Water Out		°C	7.44
	Temperature Drop 1		°C	4.20
	Flow Rate		GPM	62.60
Air condition	Return Air Dry Bulb		°C	29.19
	Return Air Wet Bulb		°C	19.42
	Supply Air Dry Bulb		°C	16.51
	Supply Wet Bulb		°C	14.45
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	51.80
Compressor Data 1	Discharge Temp.		°C	126.40
	Liquid Temp.		°C	59.38
	Suction Temp.		°C	14.60
	Discharge Pressure		[psi]	595.49
	Liquid Pressure		[psi]	590.33
	Suction Pressure		[psi]	114.02
Compressor Data 2	Discharge Temp.		°C	125.17
	Liquid Temp.		°C	58.14
	Suction Temp.		°C	16.77
	Discharge Pressure		[psi]	602.08
	Liquid Pressure		[psi]	596.08
	Suction Pressure		[psi]	111.98

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	9.54
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.428
	water Flow Rate	ft^3/hr	502.23
Air Side	Enthalpy in	KJ/KG	55.25
	Enthalpy out	KJ/KG	40.500
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	239021
		KW	70.1
		TR	19.9
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	230338
		KW	67.5
		TR	19.2
Unit Eff.	UNIT EER	Btu/W.hr	5.52
	COP	W/W	1.62
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-410A) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.48
		S-T	Volts	454.27
		R-T	Volts	456.10
	Current	R	Amps	49.79
		S	Amps	47.44
		T	Amps	49.37
	Watts	R	KW	10.85
		S	KW	10.46
		T	KW	11.11
		Total KW	KW	32.41
	Power Factor		---	0.84
	Total Power Exclude pump & fan		KW	29.61
	Frequency		Hz	60.43
COOLER	Water In		°C	10.41
	Water Out		°C	5.50
	Temperature Drop 1		°C	4.91
	Flow Rate		GPM	63.20
Air condition	Return Air Dry Bulb		°C	26.68
	Return Air Wet Bulb		°C	19.50
	Supply Air Dry Bulb		°C	14.78
	Supply Wet Bulb		°C	13.51
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	35.53
Compressor Data 1	Discharge Temp.		°C	82.12
	Liquid Temp.		°C	41.82
	Suction Temp.		°C	10.19
	Discharge Pressure		[psi]	433.96
	Liquid Pressure		[psi]	425.77
	Suction Pressure		[psi]	106.13
Compressor Data 2	Discharge Temp.		°C	80.68
	Liquid Temp.		°C	43.33
	Suction Temp.		°C	11.73
	Discharge Pressure		[psi]	437.66
	Liquid Pressure		[psi]	431.56
	Suction Pressure		[psi]	103.46

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	7.96
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.435
	water Flow Rate	ft^3/hr	507.04
Air Side	Enthalpy in	KJ/KG	55.61
	Enthalpy out	KJ/KG	38.030
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	282038
		KW	82.7
		TR	23.5
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	274531
		KW	80.5
		TR	22.9
Unit Eff.	UNIT EER	Btu/W.hr	9.27
	COP	W/W	2.72
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-410A) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.11
		S-T	Volts	453.94
		R-T	Volts	455.70
	Current	R	Amps	57.22
		S	Amps	54.32
		T	Amps	56.79
	Watts	R	KW	12.71
		S	KW	12.22
		T	KW	13.04
		Total KW	KW	37.97
	Power Factor		---	0.86
	Total Power Exclude pump & fan		KW	35.17
	Frequency		Hz	60.45
COOLER	Water In		°C	11.92
	Water Out		°C	7.49
	Temperature Drop 1		°C	4.43
	Flow Rate		GPM	62.80
Air condition	Return Air Dry Bulb		°C	29.05
	Return Air Wet Bulb		°C	19.24
	Supply Air Dry Bulb		°C	15.73
	Supply Wet Bulb		°C	13.89
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	46.49
Compressor Data 1	Discharge Temp.		°C	99.08
	Liquid Temp.		°C	53.25
	Suction Temp.		°C	13.02
	Discharge Pressure		[psi]	556.60
	Liquid Pressure		[psi]	549.79
	Suction Pressure		[psi]	113.13
Compressor Data 2	Discharge Temp.		°C	97.21
	Liquid Temp.		°C	53.82
	Suction Temp.		°C	15.03
	Discharge Pressure		[psi]	551.21
	Liquid Pressure		[psi]	545.21
	Suction Pressure		[psi]	109.28

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	9.70
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.427
	water Flow Rate	ft^3/hr	503.83
Air Side	Enthalpy in	KJ/KG	54.66
	Enthalpy out	KJ/KG	39.020
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	252808
		KW	74.1
		TR	21.1
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	244236
		KW	71.6
		TR	20.4
Unit Eff.	UNIT EER	Btu/W.hr	6.94
	COP	W/W	2.04
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-410A) @52°C Condition

TEST Results

Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.72
		S-T	Volts	454.68
		R-T	Volts	456.08
	Current	R	Amps	61.51
		S	Amps	58.40
		T	Amps	61.05
	Watts	R	KW	13.78
		S	KW	13.25
		T	KW	14.12
		Total KW	KW	41.15
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	38.35
	Frequency		Hz	60.49
COOLER	Water In		°C	14.71
	Water Out		°C	10.93
	Temperature Drop 1		°C	3.78
	Flow Rate		GPM	62.70
Air condition	Return Air Dry Bulb		°C	29.42
	Return Air Wet Bulb		°C	19.02
	Supply Air Dry Bulb		°C	18.66
	Supply Wet Bulb		°C	14.52
	Air Flow rate		CFM	8068
Condenser	Ambient		°C	51.53
Compressor Data 1	Discharge Temp.		°C	106.99
	Liquid Temp.		°C	60.66
	Suction Temp.		°C	21.52
	Discharge Pressure		[psi]	607.20
	Liquid Pressure		[psi]	599.55
	Suction Pressure		[psi]	121.60
Compressor Data 2	Discharge Temp.		°C	105.13
	Liquid Temp.		°C	60.04
	Suction Temp.		°C	19.31
	Discharge Pressure		[psi]	609.40
	Liquid Pressure		[psi]	603.40
	Suction Pressure		[psi]	118.00

Unit Performance Calculations

Parameter		Unit	READING
Water Prop	Mean Temp.	°C	12.82
	Specific Heat	Btu/lbm·°F	1.009
	Density	lbm/ft^3	62.406
	water Flow Rate	ft^3/hr	503.03
Air Side	Enthalpy in	KJ/KG	53.92
	Enthalpy out	KJ/KG	40.670
	Air Flow Rate	ft^3/min	8068
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	215592
		KW	63.2
		TR	18.0
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	206914
		KW	60.6
		TR	17.2
Unit Eff.	UNIT EER	Btu/W.hr	5.40
	COP	W/W	1.58
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-290) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.74
		S-T	Volts	455.01
		R-T	Volts	457.20
	Current	R	Amps	47.37
		S	Amps	48.60
		T	Amps	47.95
	Watts	R	KW	9.97
		S	KW	10.22
		T	KW	9.92
		Total KW	KW	30.12
	Power Factor		---	0.80
	Total Power Exclude pump & fan		KW	27.32
	Frequency		Hz	60.49
COOLER	Water In		°C	11.63
	Water Out		°C	6.86
	Temperature Drop 1		°C	4.77
	Flow Rate		GPM	62.10
Air condition	Return Air Dry Bulb		°C	27.31
	Return Air Wet Bulb		°C	19.50
	Supply Air Dry Bulb		°C	15.02
	Supply Wet Bulb		°C	13.85
	Air Flow rate		CFM	8085
Condenser	Ambient		°C	35.56
Compressor Data 1	Discharge Temp.		°C	67.71
	Liquid Temp.		°C	40.63
	Suction Temp.		°C	15.76
	Discharge Pressure		[psi]	244.23
	Liquid Pressure		[psi]	236.60
	Suction Pressure		[psi]	56.83
Compressor Data 2	Discharge Temp.		°C	65.42
	Liquid Temp.		°C	44.40
	Suction Temp.		°C	11.55
	Discharge Pressure		[psi]	222.11
	Liquid Pressure		[psi]	213.44
	Suction Pressure		[psi]	50.49

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	9.24
	Specific Heat	Btu/lbm·°F	1.008
	Density	lbm/ft^3	62.429
	water Flow Rate	ft^3/hr	498.22
Air Side	Enthalpy in	KJ/KG	55.60
	Enthalpy out	KJ/KG	38.930
	Air Flow Rate	ft^3/min	8085
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	269448
		KW	79.0
		TR	22.5
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	260869
		KW	76.5
		TR	21.7
Unit Eff.	UNIT EER	Btu/W.hr	9.55
	COP	W/W	2.80
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-290) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.32
		S-T	Volts	454.74
		R-T	Volts	456.76
	Current	R	Amps	49.67
		S	Amps	51.15
		T	Amps	50.32
	Watts	R	KW	10.62
		S	KW	10.92
		T	KW	10.56
		Total KW	KW	32.10
	Power Factor		---	0.81
	Total Power Exclude pump & fan		KW	29.30
	Frequency		Hz	60.47
COOLER	Water In		°C	12.85
	Water Out		°C	8.96
	Temperature Drop 1		°C	3.89
	Flow Rate		GPM	62.10
Air condition	Return Air Dry Bulb		°C	29.16
	Return Air Wet Bulb		°C	19.77
	Supply Air Dry Bulb		°C	16.13
	Supply Wet Bulb		°C	15.31
	Air Flow rate		CFM	8085
Condenser	Ambient		°C	46.04
Compressor Data 1	Discharge Temp.		°C	76.31
	Liquid Temp.		°C	48.40
	Suction Temp.		°C	18.28
	Discharge Pressure		[psi]	286.08
	Liquid Pressure		[psi]	279.37
	Suction Pressure		[psi]	60.23
Compressor Data 2	Discharge Temp.		°C	75.40
	Liquid Temp.		°C	52.47
	Suction Temp.		°C	13.60
	Discharge Pressure		[psi]	282.87
	Liquid Pressure		[psi]	275.00
	Suction Pressure		[psi]	58.84

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	10.91
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.420
	water Flow Rate	ft^3/hr	498.22
Air Side	Enthalpy in	KJ/KG	56.44
	Enthalpy out	KJ/KG	42.960
	Air Flow Rate	ft^3/min	8085
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	219661
		KW	64.4
		TR	18.3
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	210949
		KW	61.8
		TR	17.6
Unit Eff.	UNIT EER	Btu/W.hr	7.20
	COP	W/W	2.11
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 70 kW Prototype (R-290) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	453.97
		S-T	Volts	454.18
		R-T	Volts	456.43
	Current	R	Amps	50.93
		S	Amps	52.44
		T	Amps	51.57
	Watts	R	KW	10.96
		S	KW	11.26
		T	KW	10.89
		Total KW	KW	33.11
	Power Factor		---	81.00
	Total Power Exclude pump & fan		KW	30.31
	Frequency		Hz	60.49
COOLER	Water In		°C	13.01
	Water Out		°C	10.20
	Temperature Drop 1		°C	2.81
	Flow Rate		GPM	62.30
Air condition	Return Air Dry Bulb		°C	29.24
	Return Air Wet Bulb		°C	19.58
	Supply Air Dry Bulb		°C	17.06
	Supply Wet Bulb		°C	16.39
	Air Flow rate		CFM	8085
Condenser	Ambient		°C	51.68
Compressor Data 1	Discharge Temp.		°C	80.83
	Liquid Temp.		°C	53.24
	Suction Temp.		°C	19.80
	Discharge Pressure		[psi]	334.11
	Liquid Pressure		[psi]	327.98
	Suction Pressure		[psi]	62.66
Compressor Data 2	Discharge Temp.		°C	80.10
	Liquid Temp.		°C	57.17
	Suction Temp.		°C	15.06
	Discharge Pressure		[psi]	327.32
	Liquid Pressure		[psi]	319.75
	Suction Pressure		[psi]	60.31

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	11.61
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.415
	water Flow Rate	ft^3/hr	499.82
Air Side	Enthalpy in	KJ/KG	55.79
	Enthalpy out	KJ/KG	46.080
	Air Flow Rate	ft^3/min	8085
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	159207
		KW	46.7
		TR	13.3
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	151952
		KW	44.5
		TR	12.7
Unit Eff.	UNIT EER	Btu/W.hr	5.01
	COP	W/W	1.47
Energy Balance	Heat Balance	Energy Balance Different Percentage	5%
		Allowable tolerance as AHRI 550/590	5%

Test Results: 40 kW Prototype (R-32) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.31
		S-T	Volts	454.64
		R-T	Volts	457.21
	Current	R	Amps	26.89
		S	Amps	28.17
		T	Amps	27.29
	Watts	R	KW	6.18
		S	KW	6.43
		T	KW	6.10
		Total KW	KW	18.71
	Power Factor		---	0.86
	Total Power Exclude pump & fan		KW	16.41
	Frequency		Hz	60.48
COOLER	Water In		°C	14.71
	Water Out		°C	10.17
	Temperature Drop 1		°C	4.54
	Flow Rate		GPM	39.90
Air condition	Return Air Dry Bulb		°C	26.22
	Return Air Wet Bulb		°C	19.40
	Supply Air Dry Bulb		°C	15.90
	Supply Wet Bulb		°C	14.60
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	35.24
Compressor Data	Discharge Temp.		°C	100.63
	Liquid Temp.		°C	47.48
	Suction Temp.		°C	11.29
	Discharge Pressure		[psi]	492.93
	Liquid Pressure		[psi]	489.31
	Suction Pressure		[psi]	126.38

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	12.44
	Specific Heat	Btu/lbm·°F	1.009
	Density	lbm/ft^3	62.409
	water Flow Rate	ft^3/hr	320.11
Air Side	Enthalpy in	KJ/KG	55.30
	Enthalpy out	KJ/KG	40.960
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	164766
		KW	48.3
		TR	13.7
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	163760
		KW	48.0
		TR	13.6
Unit Eff.	UNIT EER	Btu/W.hr	9.98
	COP	W/W	2.93
Energy Balance	Heat Balance	Energy Balance Different Percentage	1%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-32) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	455.49
		S-T	Volts	455.93
		R-T	Volts	458.14
	Current	R	Amps	33.25
		S	Amps	35.20
		T	Amps	33.79
	Watts	R	KW	7.82
		S	KW	8.21
		T	KW	7.70
		Total KW	KW	23.72
	Power Factor		---	0.88
	Total Power Exclude pump & fan		KW	21.42
	Frequency		Hz	60.51
COOLER	Water In		°C	16.09
	Water Out		°C	11.81
	Temperature Drop 1		°C	4.28
	Flow Rate		GPM	39.70
Air condition	Return Air Dry Bulb		°C	29.42
	Return Air Wet Bulb		°C	19.49
	Supply Air Dry Bulb		°C	17.20
	Supply Wet Bulb		°C	15.09
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	45.19
Compressor Data	Discharge Temp.		°C	119.92
	Liquid Temp.		°C	57.99
	Suction Temp.		°C	15.67
	Discharge Pressure		[psi]	628.25
	Liquid Pressure		[psi]	626.47
	Suction Pressure		[psi]	134.72

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	13.95
	Specific Heat	Btu/lbm·°F	1.010
	Density	lbm/ft^3	62.397
	water Flow Rate	ft^3/hr	318.51
Air Side	Enthalpy in	KJ/KG	55.48
	Enthalpy out	KJ/KG	42.300
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	154747
		KW	45.4
		TR	12.9
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	150513
		KW	44.1
		TR	12.5
Unit Eff.	UNIT EER	Btu/W.hr	7.03
	COP	W/W	2.06
Energy Balance	Heat Balance	Energy Balance Different Percentage	3%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-32) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	455.43
		S-T	Volts	455.90
		R-T	Volts	458.06
	Current	R	Amps	36.41
		S	Amps	36.77
		T	Amps	35.65
	Watts	R	KW	8.42
		S	KW	8.52
		T	KW	8.30
		Total KW	KW	25.24
	Power Factor		---	0.88
	Total Power Exclude pump & fan		KW	22.94
	Frequency		Hz	60.51
COOLER	Water In		°C	16.91
	Water Out		°C	13.42
	Temperature Drop 1		°C	3.49
	Flow Rate		GPM	39.80
Air condition	Return Air Dry Bulb		°C	29.49
	Return Air Wet Bulb		°C	19.07
	Supply Air Dry Bulb		°C	18.16
	Supply Wet Bulb		°C	15.51
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	51.90
Compressor Data	Discharge Temp.		°C	126.40
	Liquid Temp.		°C	63.10
	Suction Temp.		°C	16.10
	Discharge Pressure		[psi]	635.10
	Liquid Pressure		[psi]	632.20
	Suction Pressure		[psi]	142.40

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	15.17
	Specific Heat	Btu/lbm·°F	1.010
	Density	Ibm/ft^3	62.386
	water Flow Rate	ft^3/hr	319.31
Air Side	Enthalpy in	KJ/KG	54.09
	Enthalpy out	KJ/KG	43.480
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	126422
		KW	37.1
		TR	10.5
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	121164
		KW	35.5
		TR	10.1
Unit Eff.	UNIT EER	Btu/W.hr	5.28
	COP	W/W	1.55
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-410A) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.94
		S-T	Volts	455.19
		R-T	Volts	457.85
	Current	R	Amps	25.62
		S	Amps	26.78
		T	Amps	25.96
	Watts	R	KW	5.85
		S	KW	6.06
		T	KW	5.76
		Total KW	KW	17.67
	Power Factor		---	0.86
	Total Power Exclude pump & fan		KW	15.37
	Frequency		Hz	60.46
COOLER	Water In		°C	14.32
	Water Out		°C	10.18
	Temperature Drop 1		°C	4.14
	Flow Rate		GPM	40.10
Air condition	Return Air Dry Bulb		°C	26.44
	Return Air Wet Bulb		°C	19.47
	Supply Air Dry Bulb		°C	16.50
	Supply Wet Bulb		°C	15.10
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	35.56
Compressor Data	Discharge Temp.		°C	83.36
	Liquid Temp.		°C	47.93
	Suction Temp.		°C	14.27
	Discharge Pressure		[psi]	474.30
	Liquid Pressure		[psi]	470.11
	Suction Pressure		[psi]	124.16

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	12.25
	Specific Heat	Btu/lbm·°F	1.009
	Density	lbm/ft^3	62.411
	water Flow Rate	ft^3/hr	321.71
Air Side	Enthalpy in	KJ/KG	55.52
	Enthalpy out	KJ/KG	42.500
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	150997
		KW	44.3
		TR	12.6
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	148686
		KW	43.6
		TR	12.4
Unit Eff.	UNIT EER	Btu/W.hr	9.67
	COP	W/W	2.83
Energy Balance	Heat Balance	Energy Balance Different Percentage	2%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-410A) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.61
		S-T	Volts	455.00
		R-T	Volts	457.51
	Current	R	Amps	29.46
		S	Amps	30.96
		T	Amps	29.91
	Watts	R	KW	6.85
		S	KW	7.15
		T	KW	6.76
		Total KW	KW	20.75
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	18.45
	Frequency		Hz	60.48
COOLER	Water In		°C	16.96
	Water Out		°C	13.59
	Temperature Drop 1		°C	3.37
	Flow Rate		GPM	39.90
Air condition	Return Air Dry Bulb		°C	28.92
	Return Air Wet Bulb		°C	19.32
	Supply Air Dry Bulb		°C	19.28
	Supply Wet Bulb		°C	15.86
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	46.16
Compressor Data	Discharge Temp.		°C	100.66
	Liquid Temp.		°C	57.25
	Suction Temp.		°C	18.50
	Discharge Pressure		[psi]	589.98
	Liquid Pressure		[psi]	586.74
	Suction Pressure		[psi]	128.13

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	15.28
	Specific Heat	Btu/lbm·°F	1.010
	Density	lbm/ft^3	62.385
	water Flow Rate	ft^3/hr	320.11
Air Side	Enthalpy in	KJ/KG	54.93
	Enthalpy out	KJ/KG	44.460
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	122386
		KW	35.9
		TR	10.2
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	119565
		KW	35.0
		TR	10.0
Unit Eff.	UNIT EER	Btu/W.hr	6.48
	COP	W/W	1.90
Energy Balance	Heat Balance	Energy Balance Different Percentage	2%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-410A) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	455.99
		S-T	Volts	456.58
		R-T	Volts	458.73
	Current	R	Amps	30.08
		S	Amps	31.72
		T	Amps	30.56
	Watts	R	KW	7.02
		S	KW	7.35
		T	KW	6.92
		Total KW	KW	21.29
	Power Factor		---	0.87
	Total Power Exclude pump & fan		KW	18.99
	Frequency		Hz	60.50
COOLER	Water In		°C	17.42
	Water Out		°C	14.48
	Temperature Drop 1		°C	2.94
	Flow Rate		GPM	39.80
Air condition	Return Air Dry Bulb		°C	29.14
	Return Air Wet Bulb		°C	19.16
	Supply Air Dry Bulb		°C	20.08
	Supply Wet Bulb		°C	16.21
	Air Flow rate		CFM	5900
Condenser	Ambient		°C	51.90
Compressor Data	Discharge Temp.		°C	103.74
	Liquid Temp.		°C	58.78
	Suction Temp.		°C	19.38
	Discharge Pressure		[psi]	606.45
	Liquid Pressure		[psi]	604.02
	Suction Pressure		[psi]	134.49

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	15.95
	Specific Heat	Btu/lbm·°F	1.011
	Density	lbm/ft^3	62.379
	water Flow Rate	ft^3/hr	319.31
Air Side	Enthalpy in	KJ/KG	54.40
	Enthalpy out	KJ/KG	45.460
	Air Flow Rate	ft^3/min	5900
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	106522
		KW	31.2
		TR	8.9
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	102093
		KW	29.9
		TR	8.5
Unit Eff.	UNIT EER	Btu/W.hr	5.38
	COP	W/W	1.58
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-290) @T1 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	454.85
		S-T	Volts	455.10
		R-T	Volts	457.35
	Current	R	Amps	26.84
		S	Amps	27.55
		T	Amps	27.18
	Watts	R	KW	5.72
		S	KW	5.87
		T	KW	5.70
		Total KW	KW	17.29
	Power Factor		---	0.81
	Total Power Exclude pump & fan		KW	14.99
	Frequency		Hz	60.48
COOLER	Water In		°C	14.64
	Water Out		°C	10.50
	Temperature Drop 1		°C	4.14
	Flow Rate		GPM	39.70
Air condition	Return Air Dry Bulb		°C	26.47
	Return Air Wet Bulb		°C	18.95
	Supply Air Dry Bulb		°C	15.66
	Supply Wet Bulb		°C	14.66
	Air Flow rate		CFM	6008
Condenser	Ambient		°C	35.44
Compressor Data	Discharge Temp.		°C	78.36
	Liquid Temp.		°C	42.21
	Suction Temp.		°C	13.90
	Discharge Pressure		[psi]	289.01
	Liquid Pressure		[psi]	286.76
	Suction Pressure		[psi]	62.87

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	12.57
	Specific Heat	Btu/lbm·°F	1.009
	Density	Ibm/ft^3	62.408
	water Flow Rate	ft^3/hr	318.51
Air Side	Enthalpy in	KJ/KG	53.79
	Enthalpy out	KJ/KG	41.140
	Air Flow Rate	ft^3/min	6008
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	149645
		KW	43.9
		TR	12.5
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	147105
		KW	43.1
		TR	12.3
Unit Eff.	UNIT EER	Btu/W.hr	9.82
	COP	W/W	2.88
Energy Balance	Heat Balance	Energy Balance Different Percentage	2%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-290) @T3 Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	455.44
		S-T	Volts	455.54
		R-T	Volts	457.93
	Current	R	Amps	29.77
		S	Amps	30.48
		T	Amps	30.23
	Watts	R	KW	6.45
		S	KW	6.63
		T	KW	6.47
		Total KW	KW	19.55
	Power Factor		---	0.82
	Total Power Exclude pump & fan		KW	17.25
	Frequency		Hz	60.48
COOLER	Water In		°C	16.96
	Water Out		°C	13.64
	Temperature Drop 1		°C	3.32
	Flow Rate		GPM	39.70
Air condition	Return Air Dry Bulb		°C	29.28
	Return Air Wet Bulb		°C	18.99
	Supply Air Dry Bulb		°C	18.17
	Supply Wet Bulb		°C	15.65
	Air Flow rate		CFM	6008
Condenser	Ambient		°C	45.06
Compressor Data	Discharge Temp.		°C	89.97
	Liquid Temp.		°C	54.49
	Suction Temp.		°C	18.18
	Discharge Pressure		[psi]	364.19
	Liquid Pressure		[psi]	363.75
	Suction Pressure		[psi]	71.22

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	15.30
	Specific Heat	Btu/lbm·°F	1.010
	Density	lbm/ft^3	62.385
	water Flow Rate	ft^3/hr	318.51
Air Side	Enthalpy in	KJ/KG	53.83
	Enthalpy out	KJ/KG	43.880
	Air Flow Rate	ft^3/min	6008
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	119966
		KW	35.2
		TR	10.0
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	115707
		KW	33.9
		TR	9.6
Unit Eff.	UNIT EER	Btu/W.hr	6.71
	COP	W/W	1.97
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Test Results: 40 kW Prototype (R-290) @52°C Condition

TEST Results				
Parameter			Unit	Reading
Electrical Data	Voltage	R-S	Volts	455.23
		S-T	Volts	455.36
		R-T	Volts	457.73
	Current	R	Amps	33.83
		S	Amps	34.05
		T	Amps	33.43
	Watts	R	KW	7.38
		S	KW	7.43
		T	KW	7.33
		Total KW	KW	22.14
	Power Factor		---	0.83
	Total Power Exclude pump & fan		KW	19.84
	Frequency		Hz	60.49
COOLER	Water In		°C	17.68
	Water Out		°C	14.74
	Temperature Drop 1		°C	2.94
	Flow Rate		GPM	39.80
Air condition	Return Air Dry Bulb		°C	29.43
	Return Air Wet Bulb		°C	19.10
	Supply Air Dry Bulb		°C	19.23
	Supply Wet Bulb		°C	16.20
	Air Flow rate		CFM	6008
Condenser	Ambient		°C	52.10
Compressor Data	Discharge Temp.		°C	94.90
	Liquid Temp.		°C	59.21
	Suction Temp.		°C	20.37
	Discharge Pressure		[psi]	404.13
	Liquid Pressure		[psi]	401.00
	Suction Pressure		[psi]	74.77

Unit Performance Calculations			
Parameter		Unit	READING
Water Prop	Mean Temp.	°C	16.21
	Specific Heat	Btu/lbm·°F	1.011
	Density	Ibm/ft^3	62.376
	water Flow Rate	ft^3/hr	319.31
Air Side	Enthalpy in	KJ/KG	54.19
	Enthalpy out	KJ/KG	45.450
	Air Flow Rate	ft^3/min	6008
Water Capacity & EER	Water Side Cooling Capacity	Btu/hr	106385
		KW	31.2
		TR	8.9
Air Capacity & EER	Air Side Cooling Capacity	Btu/hr	101636
		KW	29.8
		TR	8.5
Unit Eff.	UNIT EER	Btu/W.hr	5.12
	COP	W/W	1.50
Energy Balance	Heat Balance	Energy Balance Different Percentage	4%
		Allowable tolerance as AHRI 550/590	4%

Annex V

DEMONSTRATION PROJECT AT FOAM SYSTEM HOUSES IN THAILAND TO FORMULATE PRE-BLENDED POLYOL FOR SPRAY POLYURETHANE FOAM APPLICATIONS USING LOW-GWP BLOWING AGENTS

WORLD BANK REPORT
SUBMITTED ON BEHALF OF THE ROYAL GOVERNMENT OF THAILAND

April 22, 2019

Introduction

1. The demonstration project at two foam system houses to formulate pre-blended polyol for spray polyurethane (PU) foam applications using low-global warming potential (GWP) blowing agent was submitted by the World Bank on behalf of the Royal Thai Government to the 75th meeting of the Executive Committee (ExCom) and resubmitted for the ExCom's approval at the 76th meeting. At the 76th meeting, the ExCom approved the project at a total cost of US $355,905.

2. The project was prepared consistent with the decision of the Meeting of the Parties (Dec. XIX/6) whereby there was a concern of the availability of validated cost effective and environmentally sound technologies to phase out HCFC-141b in the different foam applications in Article 5 countries.

3. The PU foam sector in Thailand comprises of 215 enterprises using 1,723 metric tons (MT) of HCFC-141b, in the manufacturing of rigid PU foam, including spray foam applications. Stage I of the HCFC Phase-out Management Plan (HPMP) of Thailand addressed 1,517 MT of HCFC-141b using in all PU foam applications, excluding consumption in the spray foam sub-sector due to the absence of low-GWP alternatives for this sub-sector. According to Stage II HPMP, the current HCFC-141b consumption in the spray foam sub-sector reduces from 349.1 MT in 2010 to 286.65 MT in 2017. The total HCFC-141b consumption is distributed among 102 spray foam enterprises of which, 71 enterprises were established prior to September 2007. Existing spray foam companies and their consumption is shown in Table 1.

Table 1: Summary of Spray Foam Companies and their Average HCFC-141b Consumption

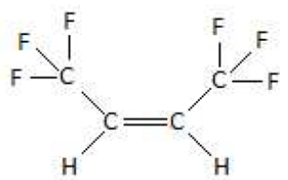
	No. of Companies	**No. of Eligible Companies**	**Total HCFC-141b Consumption**
Companies consume more than 10 MT	5	5	216.34
Companies consume more than 2 but less than 10 MT	10	8	52.41
Companies consume less than 2 MT	87	58	17.90
Total	**102**	**71**	**286.65**

4. The Stage II HPMP including funding for phasing out HCFC-141b in the spray foam was approved at the 82nd ExCom Meeting. The total funding provided for the spray foam sector, which is the only PU foam applications using HCFC-141b in Thailand, under the Stage II HPMP is US $1,732,597 to be released to Thailand from 2018 – 2022.

Background

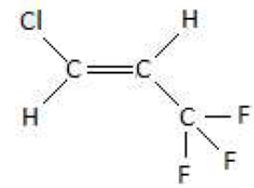
5. For developing countries, the proven technical options to replace HCFC-141b as a blowing agent for PU rigid foam are mainly limited to high GWP HFCs as HFC-245fa or HFC-365mfc/HFC-227ea blend, which have GWP values of 1030 and 965, respectively (100 years ITH, IPCC 4th Assessment Report 2008). Recent publications show promising results with the new unsaturated HFC/HCFC blowing agents, commonly known as HFOs, that exhibit GWP values lower than 10 (Bodgan, 2011; Costa, 2011). These options present themselves as viable alternatives not only their low GWP but also their better safety performance in comparison with hydrocarbon technology. Flammability is the critical barrier to the spray foam applications where most foam applicators are small and medium scale enterprise and the nature of the applications where significant leakage of blowing agents make hydrocarbon unacceptable.

6. The project was designed to evaluate two HFO molecules as co-blowing agents with CO2 generated from the water-isocyanate reaction: HFO-1336mzz(Z) and HFO-1233zd(E) as per the project proposal that was approved by the ExCom. Figures 1 and 2 show the chemical formulas of the blowing agents evaluated in this project. The physical properties of the two HFO molecules are summarized in Table 2.



cis-1,1,1,4,4,4-hexafluoro-2-butene

Figure 1. HFO-1336mzz(Z)



(E) 1-chloro-3,3,3-trifluoropropene

Figure 2. HFO-1233zd(E)

Table 2: Physical Properties of HCFC-141b and HFOs

Property	**HCFC-141b**	**HFO-1336mzz(Z)**	**HFO-1233zd(E)**
Suppliers	-	Chemours	Arkema
Boiling Point (°C)	32	33	19
Thermal Conductivity of Gas (Mw/m.K) at 25oC	9.5	10.7	10
ODP	0.11	0	0
GWP	782	2	1

Project Objectives

(a) To strengthen the capacity of two local system houses to formulate, test and produce pre-blended polyol using HFOs (namely, HFO-1336mzz(Z) and HFO-1233zd(E)) for small and medium-sized enterprises (SMEs) in the PU spray foam sector;
(b) To validate and optimize the use of HFOs co-blown with CO2 for spray foam applications to achieve a similar thermal performance to that of HCFC-141b with minimum incremental operating costs (to optimize the HFO ratio to 10 per cent);
(c) To prepare a cost analysis of the different HFO-reduced formulations versus HCFC-141b-based formulations; and
(d) To disseminate the results of the assessment to system houses in Thailand and other countries.

7. The approved demonstration project selected Bangkok Integrated Trading (BIT) and South City Petroleum, which are the two major suppliers of HCFC-141b pre-blended polyol to spray foam enterprises in Thailand. The two companies have different baseline technical capacities. BIT is a small-scaled system house with one chemist in its research team, while South City Petroleum is a much larger chemical company with a variety of products in addition to polyol systems. South City Petroleum has more than 4 chemists in their research and development team.

8. The project started on November 13, 2017 after the sub-grant agreements were signed by the enterprises and Government Savings Bank (GSB), the financial agent for the Multilateral Fund supported projects in Thailand. The implementation of the project was completed on December 15, 2018.

Project Implementation

Table 3. Project Implementation Timeframe

Activities	Actual Date
Planning for system development and verification testing	December 2017
Specification of foaming equipment and site preparation	July 2018
Procurement and installation of equipment at the system houses	July 2018
Raw materials acquisition	September 2018
Trials/testing/analysis	December 2018
Report and Review meeting.	December 2018
Technology dissemination workshop	December 2018
End of formula development	Mid of December 2018
Project completion (External testing completion)	Mid of January 2019
Submission of PCR	February 2019

Experimental

Experimental Design

9. At the beginning of the project, an international expert on foam formulations visited the two companies and provided them with technical training on the theory of the PU foam technology, and the basic concept for conducting the experiments. However, the actual design and implementation of the experiment was the responsibility of each system house. Therefore, the actual research and development process was varied from one company to another depending on the baseline technical capacity and the final formulations could be different as they were designed to meet the need of the different groups of clients.

10. In general, the experiments were conducted in three stages. The first stage was to determine blend stability of different formulations. The second stage was to determine the lowest percentages of the blowing agents in the blended polyol that provide desirable reactivity including cream time, gel time, and tact-free time. Once these percentages were determined, additional tests were done to determine physical properties of the foam products. These physical properties were density, K-factor, compressive strength, and dimension stability. The properties of new formulations were compared with the baseline HCFC-141b formulations.

Bangkok Integrated Trading

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11. To determine the optimum percentage of the new blowing agents, reactivity tests were carried out for 5 different percentages by weight of blowing agent to polyol (i.e., 5%, 10%, 15%, 20% and 25%). Compositions of raw materials are shown in Tables 4 and 5.

Table 4: Compositions of raw materials in HFO-1233zd(E) blended polyol formulation

Percentage of Blowing Agent	5%	10%	15%	20%	25%
Polyol (kg)	18	18	18	18	18
Water (kg)	0.558	0.486	0.414	0.342	0.27
Blowing Agent: 1233zd(E) (kg)	0.9	1.8	2.7	3.6	4.5

Table 5: Compositions of raw materials in HFO-1336mzz(Z) blended polyol formulation

Percentage of Blowing Agent	5%	10%	15%	20%	25%
Polyol (kg)	18	18	18	18	18
Water (kg)	0.63	0.54	0.45	0.36	0.27
Blowing Agent: 1336mzz(Z) (kg)	0.9	1.8	2.7	3.6	4.5

12. The detailed foam formulations for HFO-1233zd(E) and HFO-1336mzz(Z) developed by BIT for this demonstration project are summarized in Tables 6 and 7. Each formulation consisted of polyol, blowing agent, catalyst and additive, and isocyanate. For this demonstration project, BIT used a blend of sucrose-initiated polyol, Mannich-initiated polyol and polyester-initiated polyol. In addition, a combination of at least three catalysts were used to achieve desirable blowing, gelling and trimerization reactions. The test results provided initial indications on the optimal percentages of the blowing agents which did not severely affect the reactivity of the formulation. Once the optimal percentages were determined, further refinement of formulations were carried out to address other foam properties. The final percentage of the blowing agents may be slightly different from these initial tests.

Table 6: Foam system formulation for various percentage of HFO-1233zd(E) blowing agent and cost impact

Ingredients/HFO-1233zd(E)	5%	10%	15%	20%	25%	HCFC-141b
Blend of polyols, parts by weight	100	100	100	100	100	100
Catalyst package, parts by weight	5.30	5.30	5.30	5.30	5.30	5.44
HFO-1233zd(E), parts by weight	5.97	11.93	17.90	23.86	29.83	30.14
Iso/polyol index	1.15	1.15	1.15	1.15	1.15	1.15
HFO mole fraction in cell gas	0.18	0.34	0.47	0.59	0.70	0.85
HFO percent in foam, %	2.01	4.06	6.15	8.28	10.45	9.88
Cost of PU system, US$/kg*	2.18	2.39	2.61	2.83	3.06	2.15
Reduction percent, %	79.64	58.85	37.70	16.15	-5.80	

*Best estimates based on the initial formulations provided by the enterprise.

Table 7: Foam system formulation for various percentage of HFO-1336mzz(Z) blowing agent and cost impact

Ingredients/HFO-1336mzz(Z)	5%	10%	15%	20%	25%	HCFC-141b
Blend of polyols, parts by weight	100	100	100	100	100	100
Catalyst package, parts by weight	7.46	7.46	7.46	7.46	7.46	5.44

HFO-1336mzz(Z), parts by weight	6.33	12.65	18.98	25.30	31.63	30.14
Iso/polyol index	1.15	1.15	1.15	1.15	1.15	1.15
HFO mole fraction in cell gas	0.14	0.27	0.40	0.52	0.65	0.85
HFO percent in foam, %	2.01	4.09	6.24	8.46	10.76	9.88
Cost of PU system, US$/kg*	2.22	2.60	3.00	3.41	3.83	2.15
Reduction percent, %	79.64	58.60	36.85	14.34	-8.95	

*Best estimates based on the initial formulations provided by the enterprise.

13. Reactivities of all the formulations shown in Tables 6 and 7 were conducted by using cup tests. The following parameters were measured: (i) cream time; (ii) gel time; (iii) tact-free time; and (iv) free-rise density. The results of these tests are shown in Table 8.

Table 8: Results of Reactivity Tests for both blowing agents

Blowing Agent	**HFO-1233zd(E)**					**HFO-1336mzz(Z)**				
Percentage	5%	10%	15%	20%	25%	5%	10%	15%	20%	25%
Cream time (sec)	4	4	4	4	4	5	5	5	5	5
Gel time (sec)	9	9	10	10	10	9	9	9	9	9
Tact-free-time (sec)	15	16	16	16	16	15	16	15	16	15
Free-rise Density (Kg/m3)	35.5	35.5	35.5	35.6	35.6	36.7	36.7	36.75	36.7	36.7

14. Based on the results of the reactivity tests, all foam formulations exhibited similar and acceptable cream time, gel time, tact-free-time and free-rise density for both HFO-1233zd(E) and HFO-1336mzz(Z). Additional tests on adhesion and foam shrinkage were conducted. The 5% formulations for both HFO-1233zd(E) and HFO-1336mzz(Z) provided poor performance on the adhesion and shrinkage. At the 10% level and higher, the HFO-1336mzz(Z) blown foam rendered acceptable adhesion performance, and shrinkage was found to be limited. Through the evaluation of foam adhesion and shrinkage, the final percentages of blowing agent of 13% and 10% were selected for HFO-1233zd(E) and HFO-1336mzz(Z) formulations, respectively.

Table 9. Experimental Design

Factors (Independent Variables)	**Levels**
	Bangkok Integrated Trading
Type of HFO	HFO-1336mzz(Z)
	HFO-1233zd(E)
Mole fraction of HFO into the gas cells (reduction percent of HFO compared to HCFC-141b formulation)	0.85 (0%)
	0.35 (59%) HFO-1336mzz(Z)
	0.45 (47%) HFO-1233zd(E)

15. BIT's baseline HCFC-141b foam formulation having 0.85 mole fraction in the gas cells was used as a reference standard. Three specimens for each blowing agents were produced. The objective of BIT is to reduce HFO in the formulation in order to maintain price competitiveness to the extent possible when comparing with HCFC-141b formulation. The 10% HFO-1336mzz(Z) formulation results in the reduction of the mole fraction of the blowing agent in the gas cells to 0.35, which is equivalent to 59% reduction compared to HCFC-141b. Similarly, the 13% HFO-1233zd(E) formulation reduces the mole fraction of the blowing agent in the gas cells to 0.45, which is equivalent to 47% reduction compared to HCFC-141b formulation.

16. The isocyanate/polyol index is 115/100 for HFO-1336mzz(Z) and 115/100 for HFO-1233zd(E). The gel time and the free rise density are kept constant for all the experiments.

Responses and Test Methods

17. Table 10 summarizes the responses and associated test methods employed for determining the respective responses.

Table 10. Responses and Test Methods Employed by Bangkok Integrated Trading

<table>
<tr><th colspan="4">Table 8 Responses and Test Methods: Bangkok Integrated Trading</th></tr>
<tr><th colspan="2">Property</th><th>Test</th><th>Testing Laboratory</th></tr>
<tr><td colspan="2">Reactivity at machine</td><td>Visual</td><td>In-house</td></tr>
<tr><td colspan="2">Density</td><td>ASTM D-1622</td><td>In-house</td></tr>
<tr><td colspan="2">K-Factor</td><td>ASTM C-518</td><td>In-house</td></tr>
<tr><td colspan="2">Compressive strength</td><td>ASTM D-1621</td><td>In-house</td></tr>
<tr><td colspan="2">Adhesion strength</td><td>Metal Sheet and Roof Tile</td><td>In-house</td></tr>
<tr><td colspan="2">Dimensional stability</td><td>ASTM D-2126</td><td>In-house</td></tr>
<tr><td rowspan="2">Aging (*)</td><td>K-Factor</td><td>ASTM C-518</td><td>In-house</td></tr>
<tr><td>Compressive Strength</td><td>ASTM D-1621</td><td>In-house</td></tr>
<tr><td colspan="2">Fire Performance</td><td>ASTM D-568-77,
ASTM D-635-03</td><td>KMUTT</td></tr>
</table>

(*) K-Factor and Compressive Strength: 2 weeks, 3 weeks, 1 month

Preparation of Foam Samples

18. After blending the fully formulated polyol, the fully formulated polyol and isocyanate were applied by using a high-pressure machine GRACO Reactor H-VR sprayer (financed by the Project) at the conditions shown in Table 11. The final spray foam sheet was made by spraying the mixture of formulated polyol and isocyanate horizontally back-and-fort on a large cardboard paper at a rate of 3 – 4 passes per one inch of thickness. The final foam sheet has a thickness of 4 – 5 inches. Three foam sheets were made (one for each blowing agent: standard HCFC-141b; 13% HFO-1233zd(E) formulation; and 10% HFO-1336mzz(Z) formulation). All foam samples/specimens for different blowing agents were made from the respective foam sheets by cutting the sheets into a number of pieces with specific dimensions conforming with testing standards summarized in Table 10.

Table 11. Spray Foam Conditions

Spray machine	GRACO Reactor H-VR Sprayer
Spray gun	Air Purge Spray Gun
Percentage by weight of CO_2, %	Not applicable
Ambient Temperature, ºC	28º – 32ºC
Relative Humidity, %	52% - 62%
Substrate Temperature, ºC	40ºC
Iso Temperature, ºC	50ºC
Polyol Temperature, ºC	50ºC
Primary Heater	Off

Hose length, m	15
Hose Temperature, ºC	50ºC
Static Pressure, psi	1,700
Dynamic Pressure, psi	1,700

Stability of Polyol Blend

19. Polyol blended with HFO-1336mzz(Z) using regular catalysts demonstrates excellent stability. To achieve the same results with HFO-1233zd(E), special catalysts are required. Polyol with catalysts and additives were mixed and retained in test tubes from 1 – 3 weeks. All formulations showed good stability. There was no precipitation observed after three weeks. Table 12 summarizes the reaction times of the three different foam formulations.

Table 12. Reactivities of Baseline Foam Formulations and those with New Blowing Agents

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Mole fraction in the gas cells	0.85	0.45	0.35
Weight of blowing agent in formulation (%)	9.88	4.32	5.43
Reduction by weight (%)	0	56.25	44.99
Cream time (sec)	4	4	5
Tack free time (sec)	14	16	16
Cream time (sec) after 1 week	4	4	5
Tack free time (sec) after 1 week	14	16	16

20. The stability tests on foam reactivity and physical properties such as dimensional stability, K-factor, and compressive strength were conducted and the results of three different blowing agent formulations are shown in Tables 13 - 15. It was found that reactivity times of new foam formulations (with 13% of HFO-1233zd(E) are similar to reactivity times of HCFC-141b blown foam.

Table 13. Dimensional Stability

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Foam density (kg/m^3)	38.04	38.77	39.07
Dimension stability 70ºC (%ΔV), 24 hrs	0.30	0.59	0.47
1st week	0.40	0.68	0.58
2nd week	0.46	0.73	0.63
Dimension stability -30ºC (%ΔV), 24 hrs	-0.64	-0.57	-0.70
1st week	-0.87	-0.77	-0.83
2nd week	-0.90	-0.82	-0.92
Dimension stability 70ºC+95% RH (%ΔV), 24 hrs	0.47	2.03	1.82
1st week	0.71	2.06	1.86

2nd week	0.94	2.13	2.02

21. The density of the foam blown with HFO-1233zd(E) an HFO-1336mzz(Z) was slightly higher than the density of the HCFC-141b blown foam. The density increase was less than 3% in comparison with the HCFC-141b blown foam. Dimension stability of foam produced with new HFO formulation was comparable to HCFC-141b blown foam. After two weeks, the foam dimension changes were within 1 - 2% for the three testing conditions (-30°C, 70°C, and 70°C with high humidity level).

Table 14. Comparison of K-Value of HFCF-141b with K-Factor of HFOs Blown Foam

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Initial K-Factor (mW/m.K)	21.40	24.20	26.10
2nd week	22.00	24.90	27.00
3rd week	22.40	25.40	27.30
4th week	22.70	26.00	27.80

Note: The variance in densities of foam samples from unevenly spraying makes comparison a challenge.

22. The initial K-values of 13% HFO-1233zd(E) and 10% HFO-1336mzz(Z) blown foam were higher than the K-value of HCFC-141b blown foam. The increase is about 10% for the HFO-1233zd(E) formulation and about 20% for the HFO-1336mzz(Z) formulation). The insulation property gradually deteriorated over time. While the K-value of the HFO-1336mzz(Z) formulation was the highest; however, it showed a slower rate of increase after four weeks in comparison with the HFO-1233zd(E) formulation.

23. The 10% increase in the K-value was acceptable to BIT's spray foam customers. Hence, the HFO-1233zd(E) formulation was more desirable. To make the insulation performance of the HFO-1336mzz(Z) formulation comparable to the HFO-1233zd(E) formulation, BIT could have increased the amount of the blowing agent; however, such increase would result in a higher cost which was not desirable.

Table 15. Compressive Strength

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Initial Compressive Strength (kPa)	184.80	188.20	190.59
2nd week	185.97	187.38	189.34
3rd week	183.94	188.75	191.49

Note: Compressive strength of test samples vary depending on quality of the foam cells which affects the compressive strength of the test samples.

24. The experiment showed that the compressive strength of spray foams produced by three different formulations were comparable and stable over the experiment period of three weeks.

Fire Performance

Table 16. Results of Fire Performance Tests Based on ASTM Standards

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
ASTM D568-77	-	Extinguished	Extinguished
ASTM D635-03	-	Extinguished	Extinguished

Note: Tests were conducted at KMUTT

25. The foam specimens based on the two HFO formulations were subject to fire safety tests which were conducted by King Mongkut University of Technology Thonburi's (KMUTT) laboratory. The testing procedures of ASTM D568-77 and ASTM D635-03 were employed. The test results confirmed that HFO-1233zd(E) blown foam and HFO-1336mzz(Z) foam met the fire safety standards.

Field Test

26. Two field tests were conducted at Bangkok Integrated Trading's facility. Two of its major customers were invited to witness the field test. The test simulates applying spray foam on the wall by spraying two new foam formulations against a metal sheet and roof tiles. Visual inspection and simple tests were conducted at the sites. Based on this set-up, the customers are satisfied with the basic properties of the spray foam made from both HFO-1233zd(E) and HFO-1336mzz(Z) formulations. These properties include cell size appearance, reaction time, adhesion and foam strength. The costs of the two formulations are similar. The customers preferred the spray foam made from HFO-1233zd(E) blowing agent due to its foam appearance.

Fig. 3 Field Demonstration of HFO blown foam (HFO-1233zd(E)) at BIT

Fig. 4 Field Demonstration of HFO blown foam (HFO-1336mzz(Z)) at BIT

Incremental Capital Cost

27. The demonstration project as approved by the ExCom also provided financial supports to BIT to acquire one spray foam machine and thermal conductivity testing machine. These pieces of equipment were critical to the development of new foam formulations and for demonstration of the final products. As described in the project proposal, the enterprise anticipated that reduction of the blowing agent in the formulation would require additional water content in the polyol system and that consequently led to the increasing ratio of isocyanate and polyol (different foam index). Therefore, the spray foam machine with adjustable ratios of isocyanate and polyol was acquired by the project. To facilitate development and testing of new formulation, the thermal conductivity testing machine was provided.

28. The spray foam machine purchased by BIT was made by a Graco machine (Model: Reactor H-VR). The injection rates of isocyanate and polyol could be varied within the range from 1:1 to 2.5:1. The thermal conductivity tester purchased by BIT are Thermtest Model HFM-100. The approved funding levels for the spray foam machine and thermal conductivity tester were US $40,000 and US $5,000, respectively. The actual costs paid by BIT were US $43,675 and US $29,821, respectively. Detailed financial information will be provided in the Project Completion Report.

Cost Effectiveness of BIT's HFO Based Formulations

29. Cost comparison and cost effectiveness of the two new foam formulations were calculate based on the chemical costs purchased by BIT. Table 17 was developed based on the following costs of the following chemicals: US $3.20/kg of HCFC-141b; US $16/kg of HFO-1233zd(E); and US $22/kg of HFO-1336mzz(Z).

Table 17. Cost of Foam Production and Incremental Operating Cost of HFO Formulations

BIT	141b system			1233zd(E) system			1336mzz(Z) system		
	Parts	Unit Cost (US$/kg)	Price	Parts	Unit Cost (US$/kg)	Price	Parts	Unit Cost (US$/kg)	Price
Polyol Blend	100.00	1.86	186.00	100.00	1.71	171.00	100.00	1.69	169.00
Additives & Catalysts	5.44	10.50	57.12	5.30	12.50	66.27	13.26	3.98	52.74
Other Additives	15.13	2.50	37.83	16.00	2.26	36.20	16.57	1.90	31.48
Blowing Agent	30.14	3.20	96.45	12.00	16.00	192.00	16.57	22.00	364.54
Sub-total	150.71		377.39	133.30		465.47	146.40		617.76
Isocyanate	154.48	1.80	278.06	144.41	1.80	259.94	158.60	1.80	285.48
Sub-total	154.48		278.06	144.41		259.94	158.60		285.48
Total	305.19		655.46	277.71		725.41	305.00		903.24
Price of foam (US$/kg)			2.15			2.61			2.96
IOC (US$/kg 141b)						4.72			8.24

30. While the cost of producing on kg of foam increased by 20% - 40% in comparison with the cost of the baseline foam produced with HCFC-141b. The incremental operating costs of the new HFOs formulations were about US $4.72 – US $8.24/kg of HCFC-141b.

South City Petroleum

31. Almost all spray foams in Thailand prefer to purchase polyol systems pre-mixed with a blowing agent. The objective is to replace HCFC-141b with HFO-1233zd(E) and HFO-1336mzz(Z) without significantly increasing the price of the pre-blended polyol since the spray foam market is extremely price sensitive. Because of this constraint, the company aims to develop new HFO formulations with the HFO content not exceeding 10% of the weight of the polyol without significantly compromising the foam performance. Reactivity tests were conducted for two different percentages of the blowing agents (both HFO-1233zd(E) and HFO-1336mzz(Z)) at 5% and 10% of the weight of the polyol. At the five percent of both blowing agents, the amount of the water content to compensate the lower amount of blowing agents exceeded 4.5% in the formulations. The higher water content demonstrates adverse effects on the foam stability. Hence, only the 10 percent blowing agent formulation was further developed. The isocyanate/polyol index of at least 120 was employed to reduce friability problems and increase the catalyst to enhance trimerization in order to improve flam retardant property and foam strength.

Table 18. Experimental Design

Factors	Levels		
Blowing Agent	**% Usage in Blended Polyol**	**Mole Fraction in Gas Cell**	**% Reduction**
HCFC-141b	30	0.84	
HFO-1336mzz(Z)	10	0.34	59.52
HFO-1233zd(E)	10	0.37	55.95
HFO-1336mzz(Z)	5	0.17	79.76
HFO-1233zd(E)	5	0.16	80.95

Type	HCFC-141b	HFO-1233zd(E)	HFO-1336mzz(Z)	HFO-1233zd(E)	HFO-1336mzz(Z)
	30%	10%		5%	
Initial mole fraction, CO_2	0.16	0.63	0.66	0.64	0.83
Initial mole fraction, blowing agent	0.84	0.37	0.34	0.16	0.17

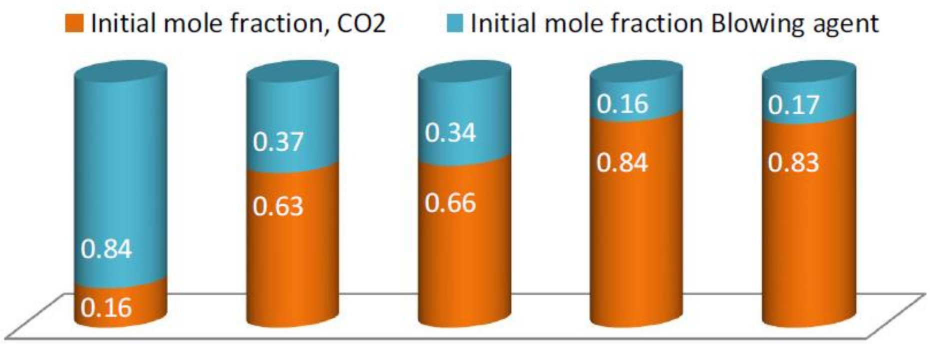

Fig. 5 Initial mole fractions of two co-blowing agents

Fig. 6 Cup tests for the two new HFO formulations

32. As mentioned above, the 5% HFO formulations contained more than 4.5% of water in the formulations. The high-water content could adversely affect chemical stability of polyester initiated polyols and some water-sensitive catalysts, which could result in formation of more opened cells, higher K factors and friability of the final foam products.

33. The characteristics of foam blown with 10% of HFO-1233zd(E) and HFO-1336mzz(Z) are summarized in Table 19. With 10% of the blowing agents, both formulations require an additional amount of water in order to maintain the free rise density at the same level as the HCFC-141b formulations.

Table 19. Characteristics of Foam with Alternative Glowing Agents

Type	HCFC-141b	HFO1233zd(E)	HFO-1336mzz(Z)
CO_2 moles/kg of polymer	0.23	0.63	0.68
Blowing agent moles/kg of polymer	1.24	0.36	0.34
Total gas moles/kg of polymer	1.47	0.99	1.02
Initial mole fraction, CO_2	0.16	0.63	0.66
Initial mole fraction, Blowing agent	0.84	0.37	0.34
Blowing agent in foam (%)	12.66	4.49	5.28
Reduction percent (%)	-	64.56	58.29

Preparation of Foam Samples

34. After blending the fully formulated polyol, the fully formulated polyol and isocyanate were applied by using a high-pressure machine GRACO Reactor H-VR sprayer (financed by the Project) at the conditions shown in Table 20.

Table 20. Spray Conditions

Spray Gun	Fusion AP
Injection pressure, psi	1200
Isocyanate temperature, ^{o}C	Room temperature
Polyol temperature, ^{o}C	40 - 45
Substrate (metal sheet and roof tile) temperature* ^{o}C	Room temperature (28^{o}C)

*Samples for adhesion tests

35. The final spray foam sheet was made by spraying the mixture of formulated polyol and isocyanate horizontally back-and-fort on a large cardboard paper at a rate of 3 – 4 passes per one inch of thickness. The final foam sheet has a thickness of 4 – 5 inches. Three foam sheets were made (one for each blowing agent: standard HCFC-141b; 10% HFO-1233zd(E) formulation; and 10% HFO-1336mzz(Z) formulation). All foam samples/specimens for different blowing agents were made from the respective foam sheets by cutting the sheets into several pieces with specific dimensions conforming with testing standards summarized in Table 21.

Table 21. Test Methods Employed by South City Petroleum

<table>
<tr><th colspan="5">Table X. Test Methods: South City Petroleum</th></tr>
<tr><th colspan="2">Property</th><th>Test</th><th>Testing Laboratory</th><th>Specimen Dimension</th></tr>
<tr><td colspan="2">Reactivity at machine</td><td>Visual</td><td></td><td></td></tr>
<tr><td colspan="2">Density</td><td>ASTM D-1622</td><td>In-house</td><td>10 cm * 10 cm * 10 cm</td></tr>
<tr><td colspan="2">K Factor</td><td>ASTM C-518</td><td>HFM-100 Heat flow meter from Thermtest, Canada and Eko Japan</td><td>30 cm * 30 cm * 2.54 cm</td></tr>
<tr><td colspan="2">Compressive Strength</td><td>ASTM D-1621</td><td>In-house</td><td>3 cm * 3 cm * 3 cm</td></tr>
<tr><td colspan="2">Adhesion Strength</td><td>Hand Peeling</td><td>In-house</td><td>Roof tile and netal sheet</td></tr>
<tr><td colspan="2">Dimension Stability</td><td>ASTM D-2126</td><td>In-house</td><td>10 cm * 10 cm * 10 cm</td></tr>
<tr><td colspan="2">Water Absorbent*</td><td>Volume (%)</td><td>In-house</td><td>10 cm * 10 cm * 2.54 cm</td></tr>
<tr><td rowspan="2">Aging*</td><td>K Factor</td><td>ASTM C-518</td><td>HFM-100 Heat flow meter from Thermtest, Canada and Eko Japan</td><td>30 cm * 30 cm * 2.54 cm</td></tr>
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<tr><td colspan="2" rowspan="2">Fire Performance</td><td>UL94</td><td>National Metal and Materials Technology Center (MTEC)</td><td>1.3 cm * 12.5 cm * 1.3 cm</td></tr>
<tr><td>ASTM D-568 and ASTM D-635</td><td>Institute for Scientific and Technological Research and Services (ISTRS), King Mongkut University of Technology Thonburi (KMUTT)</td><td>50 cm * 10 cm * 3 cm</td></tr>
</table>

*K factor: 1 week and 1 month; compressive strength: initial and 1 month; and water absorbent: 2 hours and 24 hours.

Stability of Polyol Blend

36. The stability of fully formulated polyol was evaluated by monitoring the hand-mixed reactivity in the laboratory. The results are summarized in Table 22.

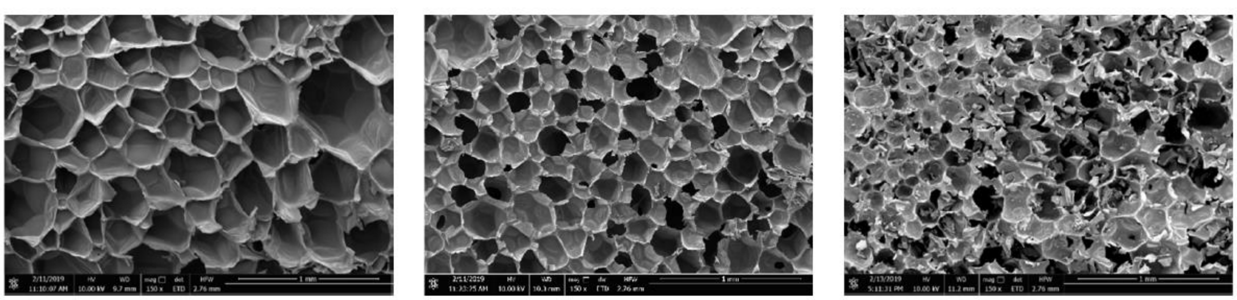
Table 22. Stability of Polyol Blends

Blowing Agent	HCFC-141b	HFO-1233zd(E)			HFO-1336mzz(Z)		
Mole fraction in gas cells	0.84	0.37			0.34		
Weight percent of blowing agent in formulation (%)	30.00	10.00			10.00		
Mole fraction different percent (%)	-	55.95			59.52		
Chemical characteristics	initial	initial	2nd Week	4th Week	initial	2nd Week	4th Week
Cream time (sec)	3	4	4	4	4	4	4
Gel time (sec)	5	6	6	6	6	7	6
Track free time (sec)	8	7	7	7	7	8	7
End of rise (sec)	12	13	13	14	14	14	15
Cup density (kg/m^3)	30.63	32.98	34.45	34.96	35.14	35.68	36.55
Upper cup density (kg/m^3)	26.09	26.29	25.59	26.86	27.23	28.13	26.26

37. All samples were kept at the normal room temperature which is the industry practice for storing the raw materials. The results confirmed that reaction activities of both HFO formulations are quite stable. However, it was still advisable that the HFO-1233zd(E) pre-blended polyol be stored in air-conditioned room as the temperature of the storage rooms could become much higher in summer.

Cell Structure Appearance

38. Cell structures of foams produced by different blowing agents are showed in Fig. X. The test results confirmed that foams produced by the three formulations (30% HCFC-141b; 10% HFO-1233zd(E); and 10% HFO-1336mzz(Z) contained mostly spherical shapes resulting in higher compressive strength and good dimension stability. However, the test results also showed that due to a higher water level in the formulations, the foam structures contained more opened cells.



(a) 30% HCFC-141b (b) 10% HFO-1233zd(E) (c) 10% HFO-1336mmz(Z)

Fig. 7 Cell Structures of Foam Produced from Three Different Blowing Agents

Compressive Strength

39. Comprehensive strength of foam produced with three different blowing agents: (i) 30% HCFC-141b formulation; (ii) 10% HFO-1233zd(E) formulation; and (iii) 10% HFO-1336mzz(Z) formulations was measured immediately after the production and one month later. For each formulation, separate sets of samples were tested for the initial compressive strength and the compressive strength after 1 month. Since the foam samples were made from larger foam sheets that were sprayed manually, the property of the foams may not be consistent, and it may affect the accuracy of the results.

Table 23. Compressive Strength (kPa)

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Initial	194.00	256.00	206.00
1 month later	189.73	204.77	244.37

40. In spite of the above imperfection, the test results suggested that the new HFO formulations provided the final foam products with higher compressive strength than the foam products made with the HCFC-141b formulation. This improvement may be attributed to the use of different combinations of polyol types to compensate with the counter effect from the higher level of water in the formulations.

Dimension Stability

41. The dimension stability tests were conducted at two different temperature levels at two different occasions. The first tests were undertaken one week after the foam samples were made, and the second tests were done another week later. At both temperature levels, the foam products made by the new formulations exhibited acceptable dimension stability. That is, the volumes of the samples changed less than 2% during the first two weeks after the samples were made. The results are shown in Table 24.

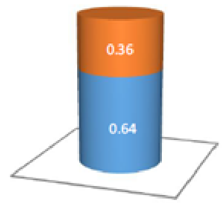
Table 24. Results of Dimension Stability Tests

Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Foam Density (kg/m^3)	38.18	39.51	34.64
Dimension Stability at 70 ºC (%ΔV)			
1st Week	1.96	0.43	-0.56
2nd Week	1.90	0.37	-0.71
Dimension Stability at -30 ºC (%ΔV)			
1st Week	-0.34	-0.46	-0.48
2nd Week	-1.39	-0.46	-0.31

K-Factor

42. The test results confirmed that the new HFO formulations had higher thermal conductivity than the HCFC-141b formulation. This was anticipated since the HFO formulations resulted in foam products with a higher mole fraction of CO_2 in the foam cells.

Table 25. K-Factors (mW/mK)*

Blowing Agent	HCFC-141b		HFO-1233zd(E)		HFO-1336mzz(Z)	
Mole Fraction in Gas Cell Blowing Agent CO_2						
Foam Density (kg/m^3)	38.57	40.67	47.82	44.38	43.86	47.24
1st Week	20.00	21.94	24.74	22.19	26.88	21.58
4th Week	23.40	23.70	28.56	29.50	31.16	30.70

*Upper temperature: 35ºC; Lower temperature: 15ºC; Mean temperature: 25ºC

43. Because of the expected ununiform foam structure due to the manual spray operations, two samples were used for each test condition. The variance densities of the foam samples were the outcome of the unevenly spraying process.

44. In general, it was still reasonable to draw a conclusion that the foam products manufactured from the two HFO formulations had higher thermal conductivity that those produced with the HCFC-141b formulations. This was the direct implication of having a higher mole fraction of CO2 in the gas cells. However, the increase was slightly higher, which was around 21.58 – 26.88 mW/mK, when the foam products were kept at the room conditions for one week. This range was acceptable to the industry. The thermal conductivity continued to change over the course of one month.

Hand Peeling Adhesion Tests

45. Since most spray foam applications in Thailand were done on metal sheet roof and roof tile or concrete, the adhesion tests were made to demonstrate the adhesion strength of the spray foams against these two substrates. The samples were prepared by spraying three different fully blended polyols and isocyanate on the two substrates at 28ºC. The adhesion tests were done by peeling the foam out from the substrates. Three different failure types including the foam adhesive failure, thin layer cohesive failure, and cohesive failure, were observed. It was considered an adhesive failure if the foam could be removed completely from the surface. The thin layer cohesive failure was considered if it left a thin layer of foam on the surface of the substrates. Foams with a good adhesion property were those foams that could not be peeled off from the surface of the substrates. The peeling force applied to the samples would result in foam cracks. The test results are summarized in Table 26.

Table 26. Hand-Peeling Adhesion Test Results

Materials	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
Metal sheet roof	**100% Thin layer Failure**	**100% Thin Layer Failure**	**100% Thin Layer Failure**
Adhesion Performance	Good	Good	Good
Roof tile	**100% Cohesive Failure**	**100% Cohesive Failure**	**100% Cohesive Failure**
Adhesion Performance	Excellent	Excellent	Excellent

46. All foams adhered excellently on the roof tile. High peeling force was required and resulted in breaking the foam. This failure mode is shown in Fig. 8.

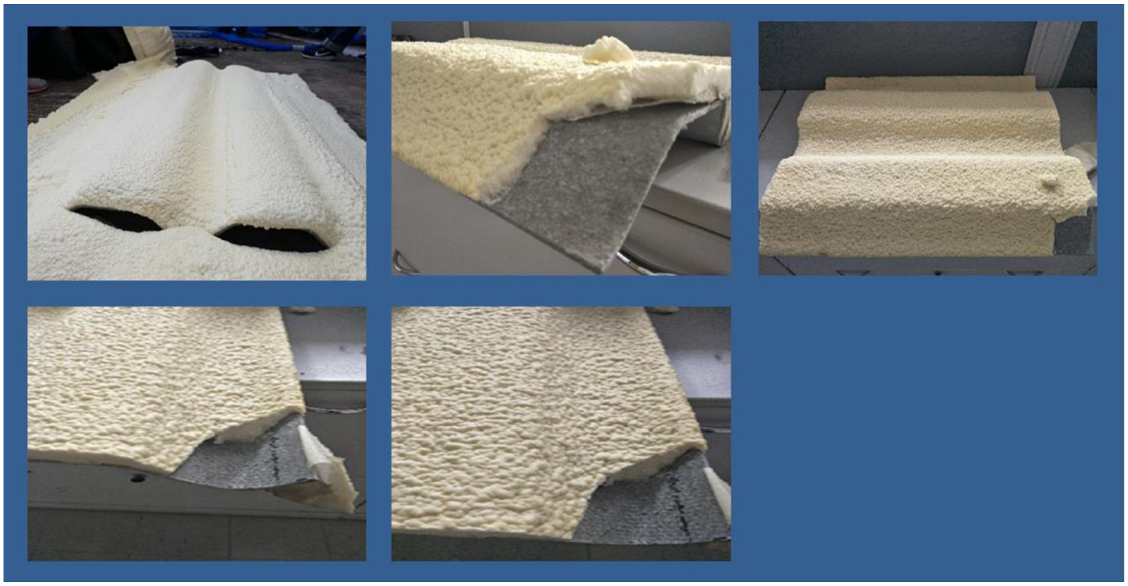


Fig. 8 Hand-peeling tests for spray foam with a roof tile as substrate

47. For the metal roof surface, all foams were peeled out of the surface of the substrate by high peeling force; however, there was thin skin of foam remaining on the metal surface as shown in Fig. 9.

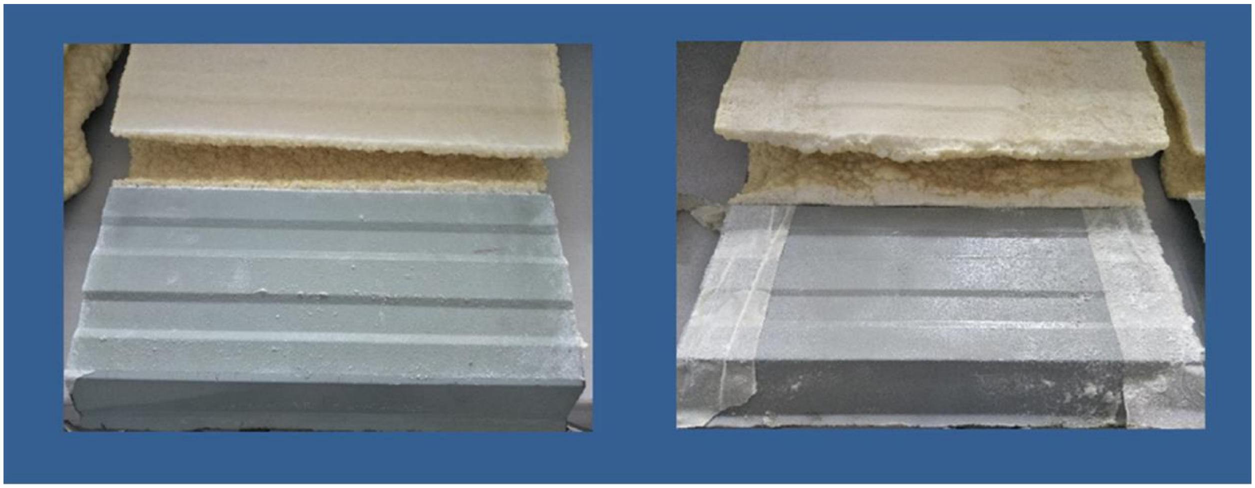


Fig. 9. Hand-Peeling Tests for spray foam with metal roof sheet as a substrate.

Water Absorbent

48. South City Petroleum also conducted water absorbent tests of their baseline and new HFO formulations because this property was considered as one of the key parameters in its product specifications. Four samples from each formulation were prepared. The four samples were divided into two groups. The first two were immerged into water for two hours. Another set of two samples for each formulation were immerged into water for four hours before the tests were taken.

49. The results of the water absorbent tests for a total of 12 samples produced with three different formulations were summarized in Table 27.

Table 27. Water Absorbent Test Results (%Volume)

Blowing Agent	**HCFC-141b**		**HFO-1233zd(E)**		**HFO-1336mzz(Z)**	
Dipping period	2 hrs.	24 hrs.	2 hrs.	24 hrs.	2 hrs.	24 hrs.
Sample 1	0.83	2.61	1.01	3.11	1.06	3.11
Sample 2	1	2.34	1.51	4.27	1.55	3.81

50. Foam samples made from the two new HFO formulations demonstrated higher percentage of water absorbent that the HCFC-141b formulated foam samples. The higher water absorbent in the HFO formulations was the results of more opened cells in the foam structure due to the increasing water content in the HFO formulations which was required to compensate for the lower quantity of the blowing agents.

Fire Performance

51. Flame retardant property of foams blown with different blowing agents was conducted by employing two different international standards: (i) UL 94; and (ii) ASTM -568 and ASTM D-635. Foam samples made from the two HFO formulations passed the UL 94 standard V-0 level tests. The foam samples that were subject to a vertical flame stopped within 10 seconds and the foam drips were not inflamed.

52. The ASTM D-568 standard tests confirmed that the foam samples made with the HFO formulations were self-extinguished within 1 – 2 seconds when they were subject to a vertical flame. Moreover, the burn propagated less than 3 mm. Similarly, the ASTM D-635 standard tests for a horizontal flame position also yielded the same results for the samples made from the two HFO formulations. Therefore, these foam samples were considered to meet ASTM D-568 and D-635 standards. The test results based on both standards are summarized in Table 28.

Table 28. Fire Performance Test Results

Table XX. Fire Performance Test Results			
Blowing Agent	**HCFC-141b**	**HFO-1233zd(E)**	**HFO-1336mzz(Z)**
UL 94	V-0	V-0	V-0
ASTM D-568 and ASTM D-635	Self-Extinguished	Self-Extinguished	Self-Extinguished

Field Tests

53. Because of a lower quantity of an HFO blowing agent in order to keep the product cost competitive, the rising of foam had to be compensated by generating CO2 as a co-blowing gas from the additional water content to enhance the water-isocyanate reaction. Therefore, the new HFO formulations, which had a higher water content, consumed more isocyanate. The ratio between the HFO blended polyol and isocyanate was adjusted to about 0.78:1 or 0.82:1 by volume. However, most Thai spray foamers only had spray machines with a fixed ratio at 1:1 by volume. As a result, the field tests were then operated at South City Petroleum's facility.

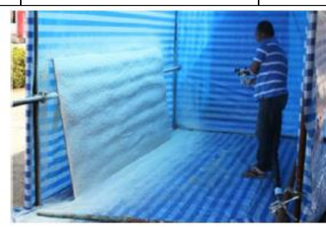
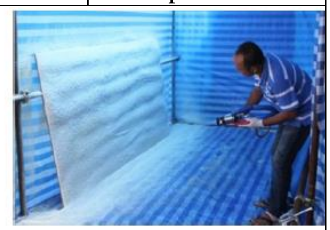
54. Two major spray foam companies in Thailand (Narongrit, and Lohr Trade and Consulting) were invited to participate in the field test on December 11, 2018. Both spray foam companies had opportunities to use South City Petroleum's spray machine funded by the MLF to spray the two new HFO formulations

and to inspect the final foam products. At the end of the field test, both enterprises were asked for their opinions on the following: chemical reaction, foam appearance, foam strength, adhesion performance, and the overall view of the two new HFO formulations. The results of the interviews were included in Table 29.

Table 29. Field Test Interview Results

Filed Test	**HFO-1233zd(E)**		**HFO-1336mzz(Z)**	
	Narongrit	**Lohr Trade and Consulting**	**Narongrit**	**Lohr Trade and Consulting**
Chemical reaction	Little slow	Appropriate	Appropriate	Little fast
Foam cell appearance	Appropriate	Appropriate	Appropriate	Appropriate
Foam strength	Appropriate	Appropriate	Appropriate	Appropriate
Adhesion on substrate	Fair	Good	Fair	Fair
Satisfaction	Reaction time to be improved	Appropriate	Appropriate	Reaction time to be improved



55. Both invited enterprises were confident that the HFO formulations could be used in the Thai industry as a replacement for the HCFC-141b formulation. They were satisfied with the cell size appearance, reaction time, adhesion and foam strength. The only area of improvement suggested by the enterprises was the reaction time. One suggested that the HFO-1233zd(E) formulation should be improved to have faster reaction, while another suggested to slow down the reaction time of the HFO-1336mzz(Z) formulation.

Incremental Capital Cost

56. The demonstration project as approved by the ExCom also provided financial supports to South City Petroleum to acquire one spray foam machine and thermal conductivity testing machine. These pieces of equipment were critical to the development of new foam formulations and for demonstration of the final products. As described in the project proposal, the enterprise anticipated that reduction of the blowing agent in the formulation would require additional water content in the polyol system and that consequently led to the increasing ratio of isocyanate and polyol (different foam index). Therefore, the spray foam machine with adjustable ratios of isocyanate and polyol was acquired by the project. To facilitate development and testing of new formulation, the thermal conductivity testing machine was provided.

57. The spray foam machine purchased by South City Petroleum was made by a Graco machine (Model: Reactor H-VR). The injection rates of isocyanate and polyol could be varied within the range from 1:1 to 2.5:1. The thermal conductivity tester purchased by South City Petroleum are Thermtest Model HFM-100. The approved funding levels for the spray foam machine and thermal conductivity tester were US $40,000 and US $5,000, respectively. The actual costs paid by South City Petroleum were US $41,692 and US $22,253, respectively. Detailed financial information will be provided in the Project Completion Report.

Cost Effectiveness of South City Petroleum's HFO Based Formulations

58. Cost is the major issues in this industry. The new HFO formulations must be price competitive in comparison with the current HCFC-141b formulations. Table 30 provides cost comparison between the HCFC-141b formulations and the two HFO formulations. The following costs of the blowing agents were use in the calculation: US $2.86/kg of HCFC-141b; US $14/kg of HFO-1233zd(E); and US $20/kg of HFO-1336mzz(Z).

Table 30. Cost of Foam Production and Incremental Operating Cost of HFO Formulations

South City Petroleum	141b system			1233zd(E) system			1336mzz(Z) system		
	Parts	Unit Cost (US$/kg)	Price	Parts	Unit Cost (US$/kg)	Price	Parts	Unit Cost (US$/kg)	Price
Polyol Blend	100.00	1.76	175.70	100.00	1.58	158.03	100.00	1.58	158.03
Additives & Catalysts	5.27	9.36	49.32	12.90	12.68	163.54	16.13	6.75	108.88
Other Additives	24.03	1.84	44.16	18.68	1.84	34.42	15.19	2.27	34.42
Blowing Agent	40.27	2.86	115.07	13.16	14.00	184.24	13.13	20.00	262.60
Sub-total	169.57		384.25	144.74		540.23	144.45		563.93
Isocyanate	231.80	1.68	390.44	135.40	1.68	228.07	137.72	1.68	231.97
Sub-total	231.80		390.44	135.40		228.07	137.72		231.97
Total	401.37		774.70	280.14		768.30	282.17		795.91
Price of foam (US$/kg)			1.93			2.74			2.82
IOC (US$/kg 141b)						8.10			8.88

59. For the HFO-1233zd(E) formulation, a new catalyst package was required to overcome the formulation stability. While the cost of HFO-1233zd(E) was significantly lower than the cost of HFO-1336mzz(Z), the cost of the new innovative catalyst package for HFO-1233zd(E) made the overall incremental operating cost of the HFO-1233zd(E) formulation only slightly less expensive than the HFO-1336mzz(Z) formulation.

Summary

60. The results of the demonstration project to develop reduced HFO polyol formulation systems at BIT and South City Petroleum confirmed that the spray foam formulations with HFO blowing agents of about 10% of the polyol weight and proper adjustments on the choice of polyol and the catalyst package could yield the foam properties that were still acceptable to the Thai spray foam market. While the HFO-1233zd(E) formulation demonstrated instability in the formulation, the issue could be solved by introducing a new catalyst package. Spray foams blown with HFOs exhibited adhesion performance that was acceptable to the market.

61. Reactivity time of the new reduced HFO formulations is similar to the HCFC-141b formulation. This was acceptable to the Thai market. Density of spray foam made from the reduced HFO formulations was slightly higher than the baseline HCFC-141b formulation. The slight increase in the compressive strength was also observed. Similarly, the initial K-factors of the reduced HFO formulations were 20 – 30% higher than the HCFC-141b formulation. All properties of HFO blown foams were quite stable over time. Both HFO formulations passed the fire performance tests.

Table 31. Summary of Key Performance of HFO Formulations of BIT and South City Petroleum

	BIT		South City Petroleum	
	-1233zd(E)	-1336mzz(Z)	-1233zd(E)	-1336mzz(Z)
Reactivity				
Cream time (sec)	4	5	4	4

Gel time (sec)	9	9	6	6
Tack-free time	16	16	7	7
Foam Properties				
Foam Density (kg/m^3)	38.77	39.07	39.51	34.64
K-Factor (mW/m.K)	24.20	26.10	24.74	26.88
Compressive Strength (kPa)	188.20	190.59	256.00	206.00
Cost				
Cost of PU System ($/kg foam)	2.61	2.96	2.74	2.82
Incremental Operating Cost ($/kg HCFC-141b)	4.72	8.24	8.10	8.88

62. Reduction of the blowing agents required an additional amount of water to generate CO2 from the water-isocyanate reaction. Consequently, an additional amount of isocyanate which made the polyol and isocyanate ratio by volume deviated from 1:1 was required. Most spray foam enterprises in Thailand would have to either retrofit or replace their existing spray machine to be able to apply these new formulations.

National Ozone Unit (NOU) at Environment Public Authority (EPA) of Kuwait

In cooperation with

UNIDO & UNEP

Comparative Study to Analyse NIK Technologies for Central Air Conditioning Applications in Kuwait

Final Report

October 2018

Project Coordinators:

UNIDO: Ole R. Nielsen & Fukuya IINO

UNEP: Ayman Eltalouny

Project Consultant:

Dr Alaa Olama

Comparative Study to Analyse NIK Technologies for Central Air Conditioning Applications in Kuwait

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Introduction

At the 75th EXCOM, UNIDO resubmitted requests for this proposal for feasibility studies, in line with decision 74/29 (originally 72/40), to develop a business model for district cooling in Kuwait and Egypt. UNIDO is the lead implementing agency and UNEP is the cooperating agency for both studies.

The feasibility study objective is to provide a detailed technical, financial as well as environmental and energy assessment / road map for the government of Kuwait, in the development of Central A/C systems. The focus of the feasibility study will be a full comparative analysis of three not-in-kind technologies namely:

I. Deep Sea Water free cooling.
II. Waste heat absorption and
III. Solar assisted chilled water absorption systems

Being considered the most promising for Kuwait.

The deliverables of the feasibility study will be:

1. Assessment of the most suitable not-in-kind technology for Central AC systems
2. Assessment of available renewable energy sources,
3. Assessment of legalization barriers,
4. Assessment of energy saving mechanisms,
5. Assessment of environmental benefits
6. Development of a financial structure and financial scheme for both, governmental co-financing mechanisms, including the possibility of providing incentives for private companies.

The project was approved by the 75th EXCOM in accordance to the following decision:

> *20. For Kuwait, the focus of the feasibility study will be a full comparative analysis of three not-in-kind technologies: deep sea water free cooling, waste heat absorption and solar assisted chilled water absorption systems, to determine which may be the most promising option for central air-conditioning systems.*
>
> *21. The following activities will be implemented:*
>
> *(a) A literature review on the current status of deep sea water free cooling, waste heat absorption, and solar assisted chilled water absorption systems;*
>
> *(b) Analysis of renewable energy sources, legal barriers, energy saving mechanisms, environmental benefits; and*
>
> *(c) Development of a financial structure and financial scheme for both the Government, co-financing mechanisms (including the possibility of reducing energy subsidies), and private energy providers.*

Project Objectives

The focus of the feasibility Study is to comparatively assess three not-in-kind technologies for central AC and DC; and provide technical and economical evidence to be disseminated to government officials as well as private investors. This feasibility study will address:

- Use of not-in-kind technologies
- Central A/C technology options;
- Legalization Barriers;
- Energy saving mechanisms;
- Governmental co-financing mechanism

Project Context

UNIDO and UNEP have been implementing a demonstration project for a detailed technical, financial as well as environmental and energy assessment / road map for the government for

Kuwait, in the development of Central A/C systems. The focus of the feasibility study will be a comparative analysis of three not-in-kind technologies namely deep-sea water free cooling, waste heat absorption and solar assisted chilled water absorption systems that are being considered the most promising for Kuwait.
In addition, the most suitable Not-In-Kind (NIK) cooling technology will be selected to air condition two sites, a school and a mosque. Conceptual designs are prepared, each design shall be governed by the principle of energy conservation, adopting together with conventional In-Kind (IK) cooling other suitable techniques NIK cooling techniques to provide substantial savings in operating costs.

1.0 Selection Criteria for the Two Sites

Questionnaires were prepared, see annex 1, based on a point system to help evaluate selection of the best sites/buildings suitable for application of NIK cooling technologies. Unfortunately, this selection process did not provide tangible results because the best sites selected were not assessable to a deep-seawater source, reject heat sources or downstream natural gas piping network (solar assisted absorption cooling). Eventually, general construction plans were obtained for candidate sites that are to be built by “Kuwait Public Authority for Housing Welfare (KPAHW)” and those satisfied one important NIK cooling technology; Two Stage Direct Indirect (TSDI) evaporative cooling.
Sites that are in the planning stage were preferred also buildings designs that are to be repetitively constructed in future at other sites.
In total four different candidate building sites were proposed by KPAHW.
Those are:

1. ***A school***. The school central air-conditioning system, utilising 5 air cooled chillers, each 200 TR refrigeration capacity, total capacity 1000 TR. The school air conditioning design IK design was provided.
2. ***A Medical Centre.*** Comprising small operating theatres, emergency units and other medical facilities. The Medical Centre has a designed IK central air conditioning system using DX units. Unfortunately, the design documents were not complete, and it proved impossible to obtain enough data to form an accurate idea on refrigeration loads, schedule of equipment and other vital design data on time to consider this selection seriously.
3. ***A small mosque.*** Although the mosque architectural and civil design data were complete, no central air conditioning system was provided. This excluded the use of this mosque because of the time needed to estimate cooling loads and create a central air conditioning design.
4. ***A large central mosque***. A complete central air conditioning IK design was provided. The air conditioning IK design documents were complete and were enough to get a complete and full picture on the IK design.

It was decided to select site 1 and 4 as the two designated sites for changing their air conditioning design from IK to NIK or NIK assisted by IK.
It is important to note that the selection of the sites fulfilled two important criteria:

I. Sites are important to the country's construction policy represented by Kuwait Public Authority for Housing Welfare (KPAHW) building program.
II. Construction plans are well developed but not too far developed that NIK cooling cannot be integrated into it.

The two buildings selected were ideally suited for Two Stage Direct Indirect (TSDI) evaporative cooling. This is especially important given the importance of the recommendations of increasing fresh air (outdoor air) in those applications of schools and public gathering areas.

2.0 Compilation of Technical Solutions

The relevant technical solutions chosen for the demonstration of cooling systems are examined such as fluorocarbon chillers (In- Kind cooling technology), non-fluorocarbon chillers (Not-In-Kind cooling technology), distribution piping network, load interface techniques and energy calculation methods. The compilation of technical information on relevant technical solutions chosen for the demonstration of NIK cooling systems encompass the following solutions compiled:

- Systems utilising In-Kind cooling technologies or fluorocarbon chillers.
- Systems using Not-In-Kind cooling technologies or non-fluorocarbon chillers.
    - Systems operating by deep sea cooling or cooling/heating.
    - Reject exhaust heat or flue gas streams fired absorption systems.
    - Solar assisted chilled water absorption systems.
    - Natural gas fired double effect absorption chillers/heaters systems.
    - Steam or hot water indirect fired absorption systems.
- Distribution piping networks pumping arrangements.
- District cooling for a city using reject heat in power stations
- Load interface techniques and energy calculation methods.
- Daily cooling load profile curves, diversity factors and Thermal Energy Storage (TES).

Details on each solution and suitability for the case is described in detail in annex-2.

3.0 Kuwait Climatological Conditions and the Concept of Two-stage Direct/Indirect (TSDI) evaporative cooling.

The two sites suggested by "Kuwait Public Authority for Housing Welfare (KPAHW)" were not within easy access to the Gulf for a Deep-Sea Cooling system use, nor were they near an exhaust heat source or a downstream natural gas pipeline to use with a solar assisted cooling system. The two sites were however most suited for using an NIK system, a two stage direct/indirect evaporation system. Kuwait being a low humidity country, especially in summer, makes it ideal for using the system at high efficiency when most needed. The system was adopted for both sites, as shown later.

3.1 Kuwait Climatological Conditions.

Kuwait enjoys remarkably low relative humidity conditions during summer, which makes it ideally suited for the use of TSDI evaporative cooling. Table 3.1 below shows basic Climatological readings in Kuwait, for 2002.

The year was arbitrally chosen according to information made available. The date stated is the one at which the highest dry bulb temperature occurred for the designated month. Coincident dew point, wet bulb and relative humidity are shown.

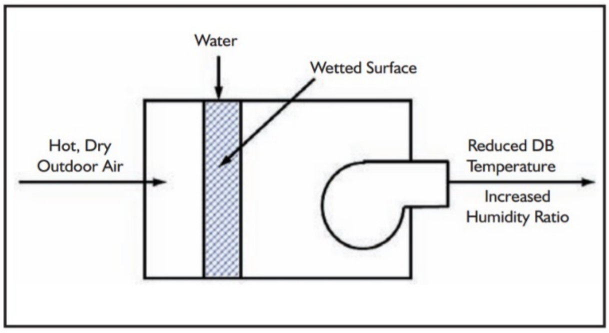
Table 3.1 Kuwait Highest monthly dry bulb, coincident dew point, wet bulb and relative humidity.

Kuwait Date, 2002	Hour	Highest T_{db}, °C	Coincident		
			Dew point, °C	T_{wb}, °C	Relative Humid. %
09.01	14:00	23.5	6.6	13.970	33.652
14.02	15:00	25.6	-0.3	12.499	18.154
31.03	15:00	31.8	3.5	15.975	16.691
22.04	15:00	36	13.8	21.298	26.537
22.05	15:00	44.2	1.8	19.663	7.56
29.06	15:00	47.9	4.7	21.513	7.684
06.07	16:00	45.7	3.8	20.624	8.066
14.08	15:00	49.7	4	21.851	6.686
02.09	14:00	46.6	4.5	21.079	8.093
01.10	15:00	38.8	11.2	20.997	19.213
06.11	15:00	32.5	14.3	20.492	33.302
14.12	15:00	21.9	10.3	14.983	47.663

The table shows that during November, December and January the high humidity ratio shall not provide enough TSDI cooling, if needed, and IK cooling may be needed. Otherwise, in March, April May, June, July, August, September and October TSDI cooling will operate well because of the low relative humidity (19.2 % to 6.7 %). This study is based on this criterion.
The two sites/buildings are redesigned to operate primarily on TSDI evaporative units with IK chilled water or DX units assisting in times when humidity is highest, providing the bulk of the cooling capacity needed during those eight months.
Furthermore, if Thermal Energy Storage (TES) tanks of the stratified type can be added to the system in order to reduce further the installed IK capacity. TES tanks stores cooling enthalpy at off-peak times and release it at on-peak time. This helps reducing installed capacity because energy is produced at night-time, when climatic temperatures are milder, saving energy further in the order of 10 to 20 %. However the scope of the study did not permit the exploration of this novel feature.

3.2 The Concept of Two Stages direct/Indirect (TSDI) evaporative cooling

Direct evaporative cooling is an old technology, useful in low wet bulb ambient temperature regions, since it relies on reducing the conditioned air temperature by evaporating water in the stream and using the water latent heat to reduce air temperature. Indirect evaporative cooling allows cooling the air stream without raising its humidity and allow using the system in hybrid arrangements with other cooling systems. This expands the use of indirect evaporative cooling; improving its efficiency while reducing water consumption



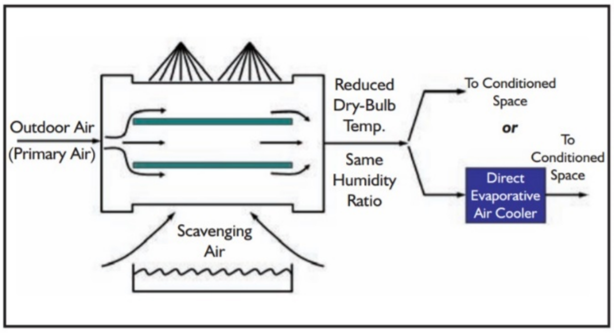


Figure 3.1: Basic direct evaporative cooler Indirect or indirect-direct evaporative cooler.

Figure 3.1 shows a schematic diagram of both systems. Indirect evaporative cooling using a secondary stream, not in directly contact with the primary stream, cools the outdoor air. The humidity of the primary stream thus does not rise. By combining both direct and indirect evaporative cooling air cooling quality improves.

In figure 3.1 the primary air is cooled in the first stage using an air heat exchanger. Primary air, which flows inside the heat exchanger, is cooled without raising its humidity. It is then cooled again by direct evaporative cooling in the second stage and its humidity is raised. Another direct/ indirect cooling system cools the water (not the primary air) in the first stage. The cooled water flows to a fin and tube heat exchanger cooling another stream of outdoor air reducing its temperature and humidity. The second stage cools the air by evaporative cooling.

Figure 3.2: An Indirect Evaporative Cooling module.

In Figure 3.2, shows a modular indirect evaporative cooling module comprising the heat exchanger section. Figure 3.3 shows the airflow pattern in and around the heat exchanger.

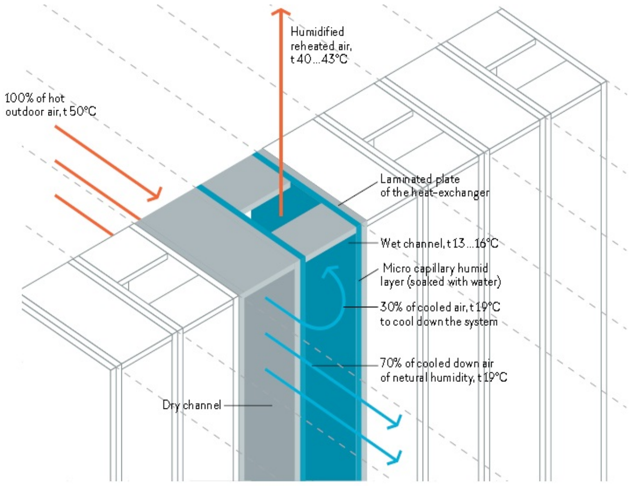


Figure 3.3: Details of air flow in and around an indirect evaporative cooling heat exchanger

Manufacturers of commercially available units claim to provide supply air at the following temperatures at 50º C conditions:

	Ambient Conditions	
	Condition 1 **50°C dry bulb/28°C wet bulb**	**Condition 2** **50°C dry bulb/19°C wet bulb**
Supply air		
Achieved conditions:		
Dry bulb, °C	25.7	13.8
Wet bulb, °C	21.7	3.8

The higher wet bulb temperature in the initial condition one (t db= 50 ºC, t wb=28 ºC), resulted in supply air at a higher t db (25.7 ºC) compared to initial condition 2 (t db= 50 ºC, t wb=19 ºC) where supply air t db dropped to 13.8 ºC.
Water consumption at those conditions is about 1.2 l/hr per kW. Water consumption may rise to about 2.5 l/hr per kW at maximum elevated dry bulb temperatures at Kuwait extreme summer conditions, when outdoor wet bulb temperatures are over 28°C, in certain climate zones, a hybrid system is used utilizing a mechanical vapour compression, an IK system, to assist until those harsh conditions are not prevailing. The system then switches back to Indirect Evaporative Cooling.

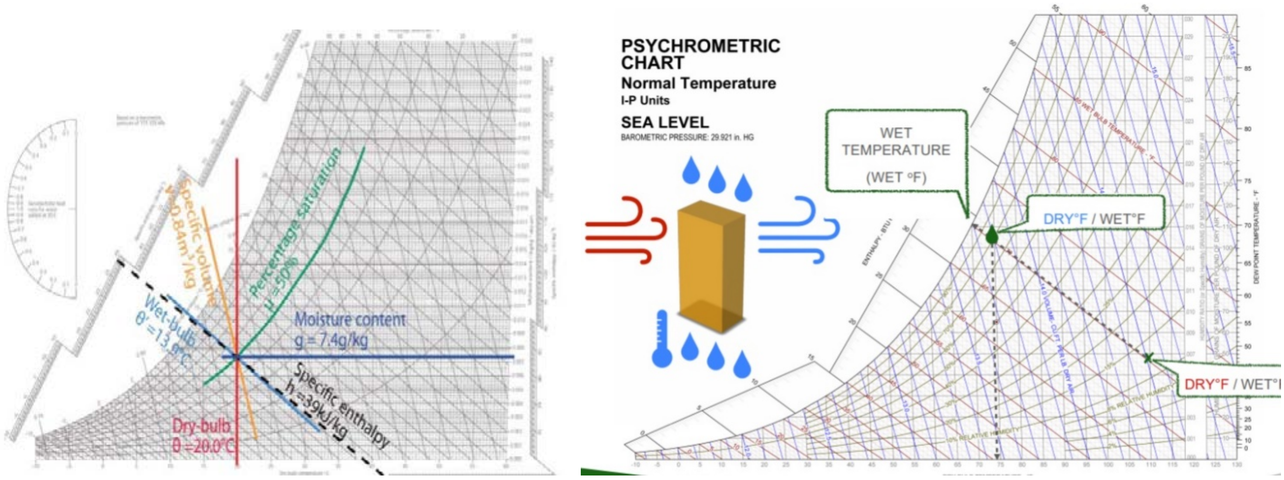
4.0 Energy Consumption comparison: TSDI evaporative cooling versus IK cooling.

4.1 Expected operational Savings of a 5000 cfm (30 TR, 106 kW) TSDI evaporative cooling unit

In sections 4.0 and 5.0 it is shown that the saving in operational cost for the two-sited selected. To demonstrate these savings, the following case study was made:

Two Stage Evaporative Cooling:

A 5000 cfm 100% outside air (Full Fresh Air) air handling unit is considered, the refrigeration capacity saving using a NIK evaporative system assisted by an IK system is calculated and compared to a full IK mechanical DX vapour compression system. Figures 4.1 and 4.2 shows the thermodynamic processes on a psychometric chart. Figure 4.3 and 4.4 shows an isometric view of the unit, a cross section plan and the thermodynamic processes on a psychometric chart. Figure 3.8 and 3.9 shows energy saving for Kuwait conditions in August, see table 3.1, the highest dry bulb temperature during the whole year.



Figures 4.1 and 4.2: Thermodynamic processes on psychometric chart.

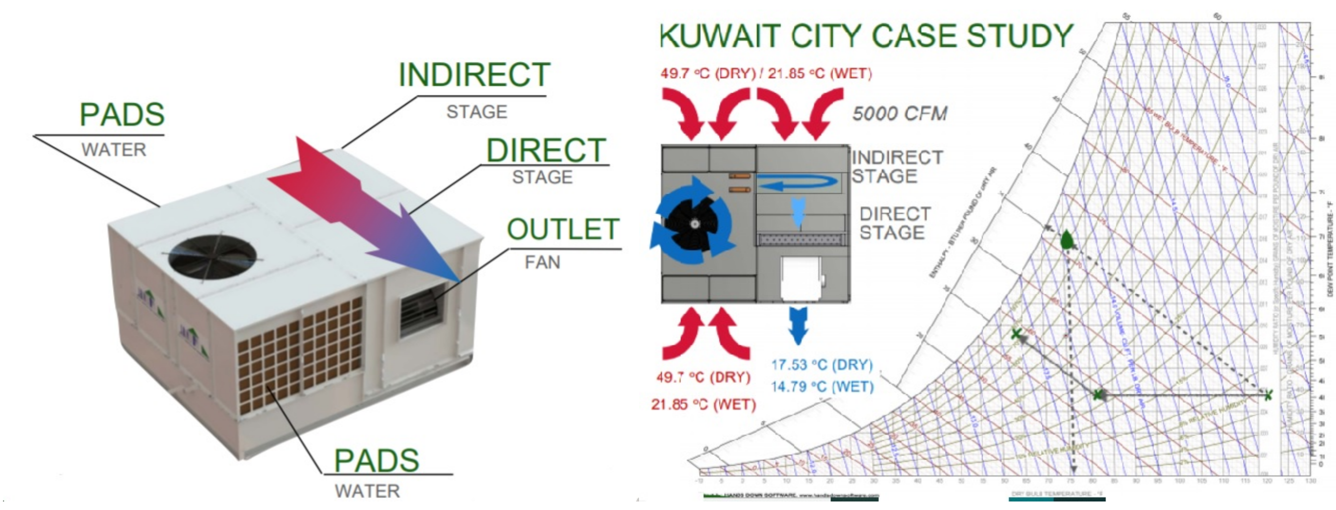


Figure 4.3 and 4.4: Isometric view of TSDI evaporative cooler and the thermodynamic processes on the psychometric chart

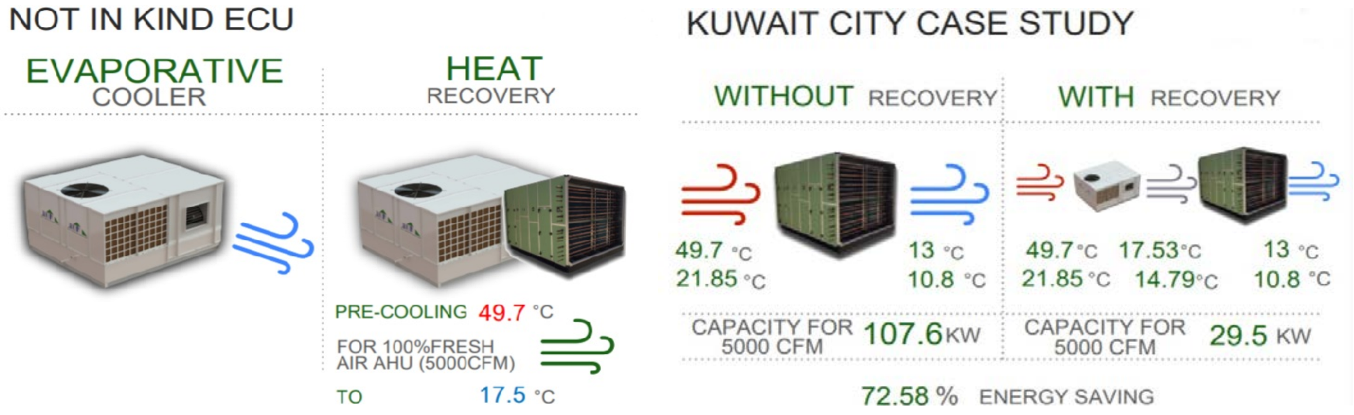


Figure 4.5 and 4.6: Energy saving for Kuwait maximum summer conditions, August 2002.

In this TSDI evaporative cooling system the first stage cools water located in the LHS of the unit in figure 3.6. Cooled water flows to the indirect stage, the RHS of the unit, in turn cools outdoor air passing through this second stage. Evaporative cooling then cools the air at the last stage. Figures 3.8 and 3.9 show the outdoor air conditions:

- Initial Kuwait conditions, August 14 th at 15:00: t db= 49.7 °C, t wb= 21.851 °C and RH= 6.686 %.
- Conditions exiting NIK TSDI unit : t db= 17.53 °C, t wb= 14.79 °C
- Conditions exiting IK DX unit : t db= 13 °C, t wb= 10.8 °C.
- Refrigeration capacity saved by using TSDI evap. Cooling: 78.1 kW or 72.58 % saving.

Savings for a 5000 cfm DX unit, with a refrigeration capacity of 107.6 kW (30.6 TR) are calculated to be about 73 % compared to a full IK cooling system. Refrigeration capacity of the IK DX unit drops to 29.5 kW (8.5 TR) or about 27.5 % of original IK capacity.
Total water Consumption is 178.16 l/hr total or 178.17/ 78.58 = 2.28 l/hr per kW at maximum dry bulb conditions of the year, 14th of August 2002.

4.2 Outdoor Air (Fresh Air) as opposed to Recirculated Air.

The IK central air conditioning design was based on limited fresh air requirements, about 15 % of air supply. This is to limit the necessity to cool outdoor air from design conditions (48 ^{0}C) to return air conditions, which can constitute a sizable load. This is specially so given the outdoor air requirements for a public assembly place where over 1000 worshipers may be attending at one time, during important religious occasions.
Alternatively, the advantages of air conditioning with full outdoor air for a public gathering place are several: outdoor air will provide better Indoor Air Quality (IAQ) and help reduce possible diseases cross contamination as well as help get rid of bacterial odour.
Given these conditions, it was thought that a full fresh air (outdoor air) TSDI evaporative cooling hybrid system would have an important advantage compared to a recirculated air system. This system was thus adopted.

4.3 Weather Data for Kuwait for the whole year, hour by hour.

Table 4.1 Supply air temperature spread chart for an entire year and Weather data.

Location: Kuwait City - Kuwait
Hourly Weather Data Source: EnergyPlus
Based on SAT Formulae for WBT Calculation on 27.11.2015

SUPPLY AIR TEMP IN °C	VENTILATION Ambient Air (No coooling) No of Hrs	in %	DIRECT EVAPORATIVE COOLING (DEC) Adiabatic Cooling No of Hrs	in %	INDIRECT EVAPORATIVE COOLING (IEC) Sensible Cooling No of Hrs	in %	INDIRECT - DIRECT EVAPORATIVE COOLING (IDEC) Two Stage Cooling No of Hrs	in %
S A Temp ≤ 14	1171	13%	2704	31%	2142	24%	5507	63%
S A Temp 14.01 - 16.00	474	5%	1068	12%	892	10%	1596	18%
S A Temp 16.01 - 18.00	618	7%	1038	12%	1040	12%	830	9%
S A Temp 18.01 - 20.00	576	7%	1224	14%	914	10%	401	5%
S A Temp 20.01 - 22.00	528	6%	1712	20%	1198	14%	226	3%
S A Temp 22.01 - 24.00	463	5%	770	9%	1535	18%	146	2%
S A Temp 24.01 - 26.00	480	5%	213	2%	857	10%	52	1%
S A Temp 26.01 - 28.00	545	6%	31	0%	166	2%	2	0%
S A Temp 28.01 - 30.00	524	6%	0	0%	16	0%	0	-----
S A Temp 30.01 - 32.00	514	6%	0	0%	0	0%	0	-----
S A Temp 32.01 - 34.00	518	6%	0	-----	0	0%	0	-----
S A Temp 34.01 - 36.00	482	6%	0	-----	0	-----	0	-----
S A Temp 36.01 - 38.00	429	5%	0	-----	0	-----	0	-----
S A Temp 38.01 - 40.00	368	4%	0		0		0	-----
S A Temp 40.01 - 42.00	333	4%	0		0		0	-----
S A Temp≥ 42.01	737	8%	0	-----	0	-----	0	-----
	8760		8760		8760		8760	

Table 4.1 shows the supply air temperature spread chart for an entire year weather data. These data were obtained from EnergyPlus™. The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) funds EnergyPlus. The National Renewable Energy Laboratory (NREL) manages it.
EnergyPlus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms. EnergyPlus™ is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.
To highlight the operational saving of a hybrid TSDI evaporative cooling unit compared to a DX unit for Kuwait, complete average hourly data for a whole year of IK cooling system and TSDI evaporative cooling system were calculated:

1- Complete average hourly daily data for Kuwait, for a whole year, compiled from 30 years period. These are:

- Ambient air conditions : T_{db}, T_{wb}, moisture, enthalpy.
- Conditions of air after TSDI evaporative cooler: WBD 9wet bulb depression), WBE (wet bulb efficiency- WBE= 13.63 ln (WBD) + 42), T db after Dry Air Moist Air heat exchanger.
- Load on cooling coil: with or without evaporate cooling per cfm for an entire year.

2- A worked example for energy consumption of a 5 TR TSDI evaporative cooling unit compared to a DX unit of the same capacity.

These data were obtained with the kind assistance of reference 9. References 10 and 11 offered data and assistance in producing this report.
Figure 4.7 shows a screen shot of the excel sheet showing the energy consumption results.

Date: 16.04.2017

Analysis of TR/CFM for Kuwait - only for AC hours, when IDEC can't meet comfort needs

Abbreviations:	
DBT	Dry Bulb Temp in °C
WBT	Wet Bulb Temp in °C
Moisture	Specific Humidity in [kgWater/kgDryAir]
Enthalpy	in kJ /kg

SUPPLY AIR - OFF COIL CONDITIONS	
DBT	14.57 °C
WBT	13.71 °C
Moisture	0.00946 kg/kg
Enthalpy	38.566 kJ/kg

WBD= wet bulb depression

WBE= wet bulb efficiency   WBE=13.63 ln(WBD)+42

S. No.	Month	Date	Time	Ambient Air conditions				Condition of Air after IEC					Load on cooling coil	
				DBT	WBT	Moisture	Enthalpy	WBD	WBE	DBT-DAMA	Moisture	Enthalpy	Without IEC or ERW	With IEC
8485	12/20 13:00:00			20.23	16.00	0.00960	44.722	4.23	50%	18.12	0.010	42.457	6.156	3.890
8486	12/20 14:00:00			20.46	15.57	0.00904	43.526	4.89	50%	18.02	0.009	40.931	4.960	2.364
8490	12/20 18:00:00			18.74	15.06	0.00917	42.096	3.68	50%	16.90	0.009	40.122	3.529	1.556
8491	12/20 19:00:00			17.27	15.15	0.00986	42.337	2.12	50%	16.21	0.010	41.165	3.770	2.598

	Without IEC or ERW	With IEC
Total: Load on Coil for 1 Year (kJ/kg)	61999.727	23867.147
Load on coil in Btu/lb	26655.11	10261.04
Load on coil in Btu/CFT	1996.12	768.42
Load on Coil in Btu/Hr	119767.27	46105.09
Load on coil per CFM for an entire year (TRH)	**9.98**	**3.84**
Savings by using IEC		**6.14**

DAMA= Dry Air-Wet Air= IEC

Notes:

Conversion: 1 kJ/kg = 0.429923 btu/lb   *For 1 CFM*   *3.84*

P.S: Density of air @ STP = 0.074887 lb/cft   *For 2500 CFM*   *9605.2*

Air flow rate taken as 1 CFM, hence per hour qty of air = 60 CFT

Figure 4.7: Screen shot of results.

4.4 Energy Consumption Comparison.

Table 4.2 shows the energy consumption comparison between two systems both nominally at 5 TR capacity: a DX system and a TSDI evaporative cooling system assisted by a DX cooling coil and condensing unit.
The reason this energy consumption is made is to demonstrate the energy savings given the operational conditions for Kuwait over a whole year.
The comparison shows a considerable saving when using a Hybrid TSDI unit compared to a DX unit, air-cooled. However, certain assumption were made.
Assumptions:

- The system operates on Full Fresh Air, except for 683 hrs. (Of 8670 hrs. - 7.8 % of total operational hrs.) when more cooling is needed than the nominal 5 TR DX coil installed, see note 1 and 2 below.

- If a Full fresh air model is used, during the 683 hrs. there will be a need for a larger DX coil- up to 16.9 TR. This system has not been contemplated. It was thought that reverting to a recirculated air during those 683 hrs. is justifiable, given the added expenses needed if a full fresh air system was used at all hrs.

- Even with a larger coil, 16.9 TR, there are some 5 hrs. when the refrigeration capacity is larger than 16.9 TR. Those five hours (0.057 % of the years) are not considered since we shifted to a recirculated system at the critical 683 hrs.
- The cost of the control system that switches to recirculated air for 683 hrs. is taken into consideration when comparing capital costs.

Table 4.2: Energy Consumption Comparison - 5 TR DX recirculated vs. A Hybrid TSDI evap. cooling

s. n	IK System	Cap., TR	Energy Consumption, kW.hr/yr.	NIK evaporative Hybrid System	Cap., TR	Energy Consumption, kW.hr/yr.
1	***System Description:*** System 1: Recirculated Air Re-circulation rooftop packaged AC unit. 2500 cfm.	5		***System Description:*** System 2: 100 % FA TSDI evaporative system with DX coil. DX hybrid operates when supply air temperature is above 14.6 ^{0}C and dew point is above 12.9 ^{0}C, to meet room conditions of 23.9 ^{0}C & 50 % RH.	Up to 16.9 TR	-16.9 TR for Full Fresh Air Or -5 TR and Recirculated DX air for 683 hrs per year.(2)
2	***Energy Consumption hours:*** - All year except 65 days (1560 hrs), winter season. 8760 – 1560 = 7200 hrs. - 300 operational days and 80 % diversity			***Energy Consumption hours:*** Hour's analysis shows: - 3892 hrs. needed with DX hybrid cooling. - 4868 hrs. with TSDI evap. Cooling will fulfil T_{db}= 14.6 ^{0}C and T_{dp} = 12.9 ^{0}C.	Note (1)	
3	***Unit's own energy consumption:*** Included in 1.5 Kw/TR			***Unit's own energy consumption:*** *For TSDI operation hours, without cooling, with* 0.6 kW/1000 CFM and 90% diversity -0.6 x (2500/1000) x 4868 x 0.9		6,572
4	***Energy consumption:*** 7200 x 5 x 1.5x 0.8 Hr x TR x kW/hr		43,200	***Energy consumption for DX Hybrid operating hours*** - 3.84 x 2500 x 1.5		14,400
5	***Total Energy Consumption:***		43,200	***Total Energy Consumption:*** 3 + 4		20,972
6	***Total Energy Saving:***		***22,228***	***(51.4 % saving)***		

Note (1): **Cooling Mode, Operational Hours and Tonnage.**

Operational Hours per Year.			
TSDI unit operational without cooling	TSDI unit operational & DX coil, max 5 TR	TSDI unit operational & DX coil, > 5 TR	Total
4868	3209	683 (2)	8760

Note (2): **Operational Hours and Tonnage over 5 TR**

Operational Hours per Year.				
16.0 – 16.9 TR	12.1 – 16.0 TR	8.1 – 12.0 TR	5.1 – 8.0 TR	Total
5	81	244	353	683

Table 4.3: Budgetary Cost, Electric and Water Consumption of all Air Handling Unit Types.

AHU Description			Utility requirement			Budgetary price CIF Kuwait Port / CFM
SN	Type	Cooling Description	Power (kW/ 1000 CFM)	Water (Annual average) LPH/ 1000 CFM	Water (Peak time consumption) LPH/ 1000 CFM	
1	TSDI evap. Cooling.	1. Indirect cooling stage 2. Direct (adiabatic) stage	0.6 kW	8 LPH	13 LPH	USD 2 / CFM
2	One Stage Indirect Evap. Cooling Only.	1. Indirect cooling stage	0.45 kW	6 LPH	11 LPH	USD 1.6 / CFM
3	TSDI evap. Cooling with cooling coil (CW or DX)	1. Indirect cooling stage 2. Cooling & dehumidification with CW/DX coil	0.8 kW (CW or DX coil press drop considered)	6 LPH	11 LPH	USD 3 / CFM
4	Typical AHU with cooling coil (CW or DX).	Cooling & dehumidification with CW/DX coil	0.6 kW (CW or DX coil press drop considered)	none	none	USD 1.5 / CFM

Table 4.4: Official Prices of Electricity and Water- Kuwait (Published in Arabic)

أولاً: تُحدد تعرفة وحدة الكهرباء على النحو الآتي:

سعر التعرفة لكل كيلو وات . ساعة (فلس)	القـــــطاع
(25) فلس	الحكومي
(5) فلس	الإستثماري و التجاري
(5) فلس	الصناعي و الزراعي
(3) فلس	الصناعي والزراعي المنتجين (المنشآت ذات العلاقة)
(12) فلس	الأخرى (باستثناء قطاع السكن الخاص)
(3) فلس لكل (ك.فار)	الطاقة غير الفاعلة للقطاعات الصناعية والتجارية والحكومية

ثانيـــــاً: تُحدد تعرفة وحدة المياه العذبة على النحو الآتي:

سعر التعرفة لكل الف جالون إمبراطوري شهرياً (دينار)	القـــــطاع
(4) د.ك	الحكومي
(2) د.ك	الإستثماري و التجاري
(2) د.ك	الأخرى (باستثناء قطاع السكن الخاص)
(1.250) د.ك	الصناعي و الزراعي
(750) فلس	الصناعي والزراعي المنتجين (المنشآت ذات العلاقة)
(500) فلس	محطات تعبئة المياه

The First Site

5.0 TSDI evaporative cooling system for a Direct Expansion (DX) central A.C. system of a Mosque

5.1 Estimated cooling load.

The Kuwait Public Authority for Housing Welfare (KPAHW) provided IK design drawings for a major mosque in the Capital, Kuwait City. The design provided, was a central air conditioning system made utilizing roof top DX air cooling packaged units.

In that original IK design, the nominal cooling load of the building is 81 TR. The hybrid system envisaged includes both two stage direct Indirect (TSDI) evaporative cooling assisted by a DX cooling coil to operate when the relative humidity is high to the extent that the TSDI system cannot reach the off coil design conditions.

Eventually the hybrid TSDI evaporative cooling system assisted by the DX system will provide much less energy consumption than a DX system. This is shown in the financial study.

There was no need to increase the installed DX coil capacity, to deal with the critical 683 hrs., when the TSDI system cannot deal with the load. In these hrs., the system reverted to a recirculated air system during those 683 hrs., as opposed to a full fresh air system for the all other operating hrs.

5.2 Modified Conceptual Design of the Plant Incorporating TSDI evaporative cooling system.

Figure 5.1 shows a schematic diagram of the Hybrid TSDI evaporative cooling system assisted by a DX cooling coil system.

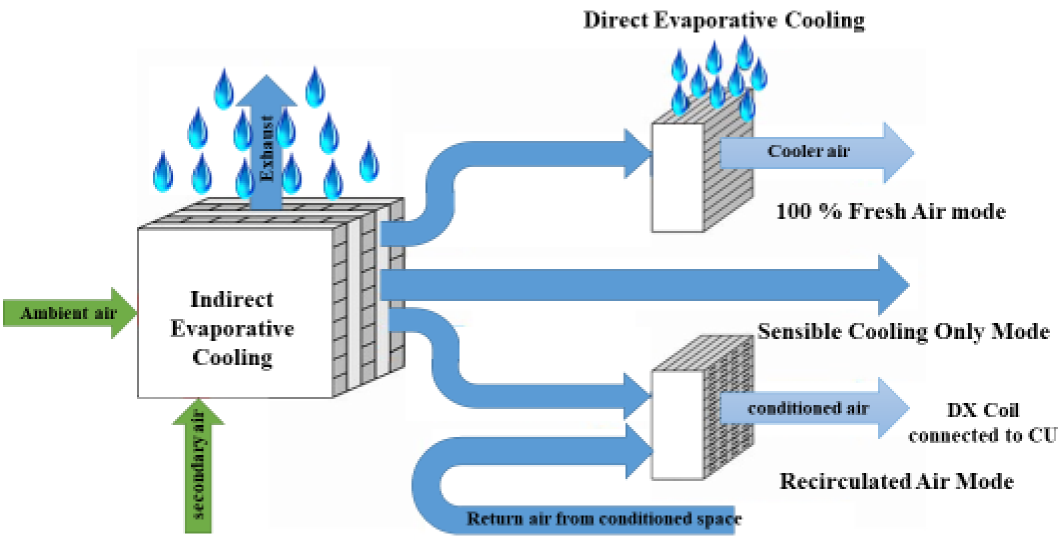


Figure 5.1: Schematic diagram of a hybrid TSDI evaporative cooling system assisted by a DX cooling coil

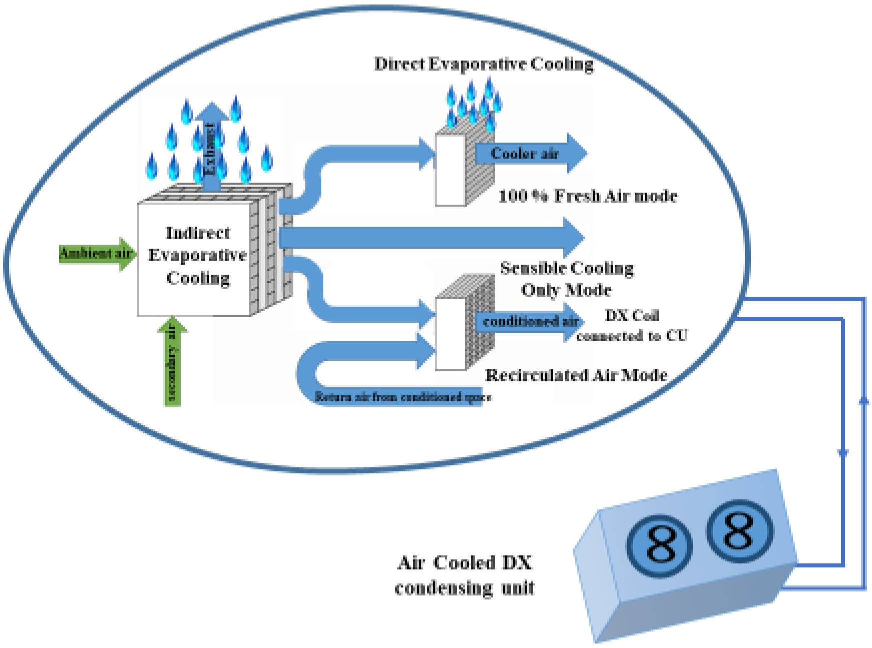


Figure 5.2: Schematic diagram of a hybrid TSDI evaporative cooling system with DX coil connected to air cooled condinsing unit

5.3 Operational savings of the Hybrid NIK assisted by IK system.

Table 5.1 for the mosque cooling energy comparison, compares both IK cooling system and NIK TSDI cooling system assisted by DX coils.
The reason energy consumption is made is to demonstrate the energy savings given the operational conditions for Kuwait over a whole year.

The comparison shows a considerable saving when using a Hybrid TSDI unit compared to a DX unit, air-cooled. However, certain assumptions were made.

Assumptions:

- The system operates on Full Fresh Air, except for 683 hrs. (Of 8670 hrs. - 7.8 % of all operating time) when more cooling is needed than the nominal 800 TR DX coil installed, see note 1 and 2 below.
- If a Full fresh air model is used, during the 683 hrs. Then a much larger need TSDI system would be needed - This system has not been contemplated because of its added unjustified extra expenses. It was assumed that air was recirculated during those 683 hrs. only.
- The cost of the control system that switches to recirculated air for the 683 hrs. is taken into consideration when comparing capital costs.

Table 5.1: Energy Consumption Comparison - 81 TR DX recirculated vs. A Hybrid TSDI evap. cooling for a mosque.

s. n	IK System	Cap., TR	Energy Consumption, kW.hr/yr.	NIK evaporative Hybrid System	Cap., TR	Energy Consumption, kW.hr/yr.
1	***System Description:*** System 1: Recirculated Air Re-circulation rooftop packaged AC unit. Total cfm 40,500.	81		***System Description:*** System 2: 100 % FA TSDI evaporative system with DX coil. DX hybrid operates when supply air temperature is above 14.6 ^{0}C and dew point is above 12.9 ^{0}C, to meet room conditions of 23.9 ^{0}C & 50 % RH.	81	- 81 TR and Recirculated DX air for 683 hrs per year.(2)
2	***Energy Consumption hours:*** - All year except 65 days (1560 hrs), winter season. 8760 – 1560 = 7200 hrs. - 300 operational days and 80 % diversity			***Energy Consumption hours:*** Hour's analysis shows: - 3892 hrs. needed with DX hybrid cooling. - 4868 hrs. with TSDI evap. Cooling will fulfil T_{db}= 14.6 ^{0}C and T_{dp} = 12.9 ^{0}C.	Note (1)	
3	***Unit's own energy consumption:*** Included in 1.5 Kw/TR			***Unit's own energy consumption:*** *For TSDI operation hours, without cooling, with* 0.6 kW/1000 CFM and 90% diversity -0.6 x {(500X 81)/1000} x 4868 x 0.9		106,463
4	***Energy consumption:*** 7200 x 81 x 1.5x 0.8 Hr x TR x kW/hr		699,840	***Energy consumption for DX Hybrid operating hours*** - 3.84 x 500 X 81 x 1.5		233,280
5	***Total Energy Consumption:***		699,840	***Total Energy Consumption:*** 3 + 4		339,743
6	***Total Energy Saving: kW.hrs/year***			***360,097 (51.5 % saving)***		

Note (1) & (2): **Cooling Mode, Operational Hours and Tonnage.**

Operational Hours per Year.			
TSDI unit operational without cooling	TSDI unit operational & DX coil, max 81 TR	TSDI unit operational & DX coil, > 81 TR	Total
4868	3209	683 (2)	8760

The Second Site

6.0 TSDI evaporative cooling system for a Chilled Water system air conditioning of a School.

The first site selected is a school. The school air conditioning original IK design was completed, and utilised an air cooled chilled water system connected to a chilled water-piping network to air handling units and fan coil units. The system incorporates a small number of split units (3) and one packaged unit

.

6.1 Estimated Cooling Load of the system.
About 800 TR (4 x 200 TR chillers + 1 x 200 TR stand-by chiller).

6.2 Modified Conceptual Design of the Plant Incorporating TSDI evaporative cooling system.

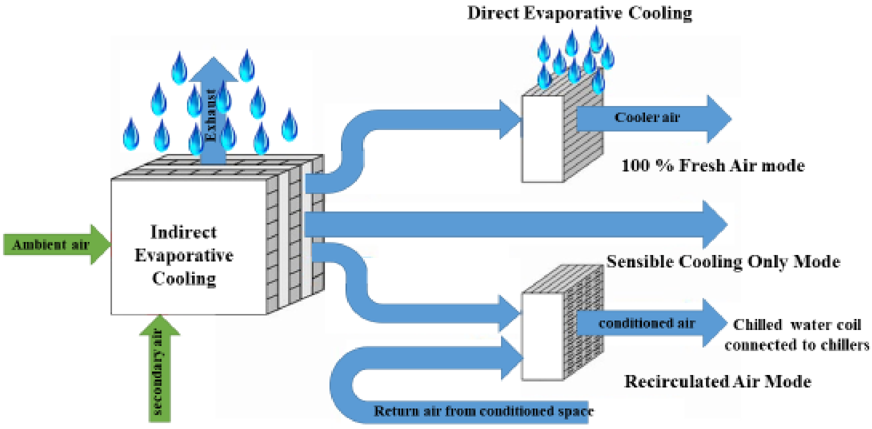


Figure 6.1: Schematic diagram of a hybrid TSDI evaporative cooling system assisted by a chilled water cooling coil

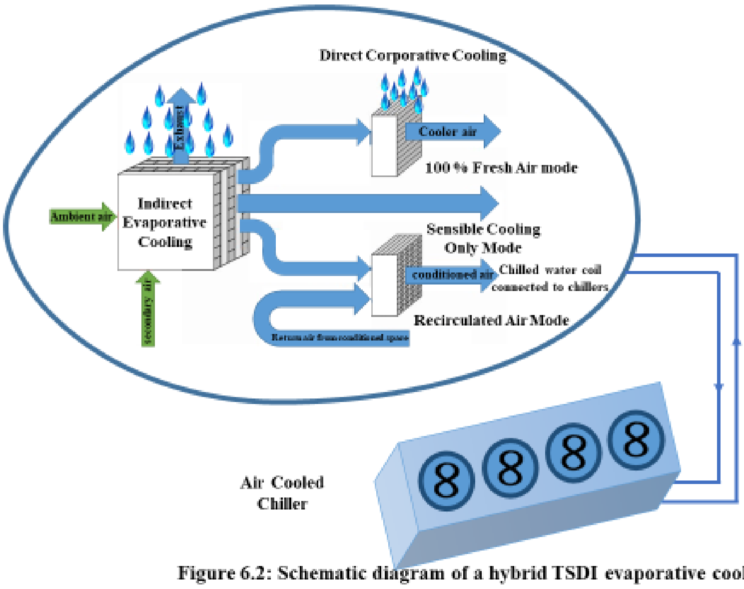


Figure 6.2: Schematic diagram of a hybrid TSDI evaporative cooling system assisted by chilled water coil connected to air cooled chiller

6.3. Operational savings of the Hybrid NIK assisted by IK system.

Table 6.1 for the energy consumption of the school air conditioning systems, compares both NIK cooling system assisted by the air cooled chilled water system IK cooling system with the original design of an IK air cooled chilled water system only.

The reason this energy consumption is made is to demonstrate the energy savings given the operational conditions for Kuwait over a whole year.

The comparison shows a considerable saving when using a Hybrid TSDI unit compared to a DX unit, air-cooled. The financial study shows these savings in detail. However, certain assumption were made.

Assumptions:

- The system operates on Full Fresh Air, except for 683 hrs. (Of 8670 hrs. - 7.8 % of the whole operating time) when more cooling is needed than the nominal 800 TR DX coil installed, see note 1 and 2 below.

- If a Full fresh air model is used, during the 683 hrs. Then a much larger need TSDI system would be needed - This system has not been contemplated because of its added unjustified extra expenses It was assumed that air was recirculated during those 683 hrs. only.

- The cost of the control system that switches to recirculated air for the 683 hrs. is taken into consideration when comparing capital costs.

Table 6.1: Energy Consumption Comparison - 800 TR CW recirculated vs. Full FA Hybrid TSDI evap. cooling for a school.

s. n	IK System	Cap., TR	Energy Consumption, kW.hr/yr.	NIK Evap. Hybrid System	Cap., TR	Energy Consumption, kW.hr/yr.
1	***System Description:*** System 1: Recirculated Air Re-circulation rooftop AHU, Chilled water unit. 500 X 800 cfm.	800		***System Description:*** System 2: 100 % FA TSDI evaporative system with DX coil. DX hybrid operates when supply air temperature is above 14.6 ^{0}C and dew point is above 12.9 ^{0}C, to meet room conditions of 23.9 ^{0}C & 50 % RH.	800	-800 TR and Recirculated DX air for 683 hrs per year.(2)
2	***Energy Consumption hours:*** - All year except 65 days (1560 hrs), winter season. 8760 – 1560 = 7200 hrs. - 300 operational days and 80 % diversity			***Energy Consumption hours:*** - Hour's analysis shows: -3892 hrs needed with DX cooling. - 4868 hrs with TSDI evap. Cooling will fulfil T_{db}= 14.6 ^{0}C and T_{dp} = 12.9 ^{0}C.		
3	***Unit's own energy consumption:*** Included in 1.5 Kw/TR Diversity 80 %			***Unit's own energy consumption:*** 0.6 kW/TR, Diversity 90 %. -0.6 x {(500 x 800)/1000)} x 4868 x 0.9		1,051,488
4	***Energy consumption:*** 7200 x 800 x 1.5x 0.8 Hr x TR x kW/hr		6,912,000	***Energy consumption for DX Hybrid operating hours:*** - 3.84 x 500 x 800 x 1.5		2,304,000
5	***Total Energy Consumption:***		6,912,000	***Total Energy Consumption:*** *3+4*		3,355,488
6	***Total Energy Saving: kW.hrs/year***			***3,556,512 (51.5 % saving)***		

Note (1) & (2): **Cooling Mode, Operational Hours and Tonnage.**

Operational Hours per Year.			
TSDI unit operational without cooling	TSDI unit operational & DX coil, max 800 TR	TSDI unit operational & DX coil, > 800 TR	Total
4868	3209	683 (2)	8760

7.0 Capital Costs, Operating Costs for the Financial Analysis and Summary Technical Results.

7.1 Assumptions for the breakdown of capital and operational costs of the Mosque and School.

This section is devoted to obtaining the following two items:

- Capital and operating parameters needed for the financial analysis part of the study in order to obtain the basic financial indicators to prove whether the system is viable or not for Kuwait, from a financial economic point of view.
- Provide an overall summary of technical results obtained, in order to simplify access to information regarding the technical part of the study.

In order to reach the first point, certain assumptions were made. Those are listed below:

The Mosque

- The IK central air conditioning system consists of seven packaged roof top direct expansion (DX) units. Those incorporate seven air handling unit section with a DX coil and a condensing unit section
- The capacities of the packaged units are between 5 and 20 TR.
- All packaged units are designed with 15 % fresh air and 85 % recirculated air.
- The packaged units are connected to a ductwork, both supply, return and an air distribution grilles and diffusers.
- The total installed capacity of the system is 81 TR.
- A small number of split units, exhaust fans and electric heaters will remain as they are in the NIK design.
- The proposed NIK design is to replace the packaged units with a Two Stage Direct Indirect (TSDI) evaporative cooling air handling units quipped with a DX coil connected to condensing units.
- The individual and aggregated capacity of the NIK system remains the same at 81 TR.
- The NIK system will be a full fresh air system to improve indoor air quality inside the mosque, except for 683 hrs. a year when humidity is too high, the system will then automatically shift to recirculated air with 15 % fresh air.

The School

- The IK central air conditioning system consists of several air handling unit sections equipped with a chilled water-cooling coil connected to five air-cooled chillers (4 +1 stand-by).
- The total aggregated capacities of the air-handling units is 800TR.
- All AHU are designed with 15 % fresh air and 85 % recirculated air.
- The AHUs are connected to a ductwork, both supply, return and an air distribution grilles and diffusers.
- The total installed capacity of the system is 1000 TR.
- A small number of split units, exhaust fans and electric heaters will remain as they are in the NIK design.
- The proposed NIK design is to replace the AHUs with a Two Stage Direct Indirect (TSDI) evaporative cooling air handling units quipped with a chilled water coils connected to the air cooled chillers.
- The individual and aggregated capacity of the NIK system remains the same at 800 TR.
- The NIK system will be a full fresh air system to improve indoor air quality inside the school, except for 683 hrs. a year when humidity is too high, the system will then automatically shift to recirculated air with 15 % fresh air.

7.2 Breakdown of Capital and Operating Costs of the Mosque.

Table 7.1: Breakdown of Capex and Opex for the Mosque-Kuwait.

Sn.	Item	As indicated	US $	Remarks
A	**Major Data for Not-In-Kind technology using TSDI evaporative cooling system.** **System Description:** 100 % FA, except 683 hrs when system shift to recirculated air. TSDI evaporative system with DX coil. DX hybrid operates when supply air temperature is above 14.6ºC and dew point is above 12.9 ºC, to meet room conditions of 23.9 ºC & 50 % RH			
	Total Aggregated AHUs Installed Capacity, TR	81		Comprises all AHUs capacities. According to table 4.5
	Unit's own electric energy consumption, kW.h/year: *For TSDI operation hours, without cooling, with* 0.8 kW/1000 CFM and 90% diversity -0.8 x {(500X 81)/1000} x 4868 x 0.9	141,950		500 cfm per TR. According to table 5.1
	Electric Energy consumption for DX Hybrid operating hours, kW.h/year: - 3.84 x 500 X 81 x 1.5	233,280		According to table 5.1
	Total Electric Energy consumption yearly: kW.h/yr.	375,230		
	Water Consumption, litre per year: 6 x { (500 x 81)/1000} x 3209	779, 787		Table 4.5
I	**Capital Costs Breakdown**:			
1	***Cost of AHUs with TSDI evaporative cooling and DX coils:*** 3 x 500 x 81		121,500	Table 4.5
2	***Automatic control system to switch to recirculated mode during hours when full fresh air will need for than 81 TR aggregated capacity-683 hr***. 81 x 500 x 0.2		8,100	See note (2), table 4.5 and USD 0.2 / cfm
	Total Capital Cost		**129,600**	
II	**Operating Costs**			
	Cost of Electric Energy Consumption per year: {(375,230 x 25)/1000} x 3.27		30, 675	Based on 1 kW.h= 25 Fils. 1 K.D= 1000 Fils

				1 K.D =1 USD3.27
	Cost of water consumption per year: {(779, 787 / 4.54609) /1000} x4x3.27		2,244	4 KD /1000 Imp. Gallon 1 Imp. Gallon= 4.54609 l.
	Total Yearly Operating Costs		**32,919**	
SN	**Item**	**As indicated**	**US $**	**Remarks**
B	**Major Data for In-Kind DX System.** **System Description:** Recirculated Air Re-circulation rooftop packaged AC unit. Total 40,500 cfm.			
	Total Aggregated AHUs Installed Capacity, TR:	81		
	Unit's own electric energy consumption, kW.h/year: - All year except 65 days (1560 hrs), winter season. 8760 – 1560 = 7200 hrs. - 300 operational days and 80 % diversity 7200 x 81 x 1.5x 0.8 Hr x TR x kW/hr	699,840		
I	**Capital Cost:**			
	Cost of AHUs with DX coils: 81 x 500 x 1.5		60,750	From Table 4.5
	Total Capital Costs		**60,750**	
II	**Operating Cost:**			
	Cost of electric energy consumption per year, hr x TR x kW/hr x diversity x rate and 80 % diversity : 7200 x 81 x 1.5x 0.8 x 25/1000 x 3.27		57,212	See Table 5.1
	Total yearly operating costs		**57,212**	

7.3 Breakdown of Capital and Operating Costs of the School.

Table 7.2: Breakdown of Capex and Opex for the School-Kuwait.

Sn.	Item	As indicated	US $	Remarks
A	**Major Data for Not-In-Kind technology using TSDI evaporative cooling system.** **System Description:** 100 % full fresh air TSDI evaporative system with chilled water coil. Chilled Water hybrid operates when supply air temperature is above 14.6 ^{0}C and dew point is above 12.9 ^{0}C, to meet room conditions of 23.9 ^{0}C & 50 % RH.			- 800 TR and Recirculated chilled water cooled air for 683 hrs per year.(2)
	Total Aggregated AHUs Installed Capacity, TR	800		Comprises all AHUs capacities. According to table 4.5
	Unit's own electric energy consumption, kW.h/year: 0.8 kW/TR, Diversity 90 %. -0.8 x {(500 x 800)/1000)} x 4868 x 0.9	1,401,984		500 cfm per TR. table 6.1 and table 4.5
	Electric Energy consumption for chilled water Hybrid operating hours, kW.h/year: -3.84 x 500 x 800 x 1.4	2,150,400		According to table 6.1
	Total Electric Energy consumption yearly: kW.h/yr.	3,552,384		
	Water Consumption, litre per year: 6 x { (500 x 800)/1000} x 3209	7,701,600		Without 682 hrs when CW coil operational. 3892-683=3209 Tables 4.5 and 6.1
I	**Capital Costs Breakdown**:			
1	***Cost of AHUs with TSDI evaporative cooling and chilled water coils:*** 3 x 500 x 800		1,200,000	Table 4.5
2	***Automatic control system to switch to recirculated mode during hours when full fresh air will need for than 81 TR aggregated capacity-683 hr***. 800 x 500 x 0.2		80,000	See note (2), table 4.5 and USD 0.2 / cfm
	Total Capital Cost		**1,280,000**	
II	**Operating Costs**			
	Cost of Electric Energy Consumption per year: {(3,552,384 x 25)/1000} x 3.27		290, 407	Based on 1 kW.h= 25 Fils. 1 K.D= 1000 Fils

				1 K.D =1 USD3.27
	Cost of water consumption per year: { (7,701,600 / 4.54609) /1000} x4x3.27		22,159	4 KD /1000 Imp. Gallon 1 Imp. Gallon= 4.54609 l.
	Total Yearly Operating Costs		**312,566**	
SN	**Item**	**As indicated**	**US $**	**Remarks**
B	**Major Data for In-Kind Chilled Water System.** **System Description:** Recirculated Air, Re-circulation rooftop AHU, Chilled water unit. 500 X 800 = 400,000 cfm.			
	Total Aggregated AHUs Installed Capacity, TR:	800		
	Unit's own electric energy consumption, kW.h/year: - All year except 65 days (1560 hrs), winter season. 8760 – 1560 = 7200 hrs. - 300 operational days and 80 % diversity (Hr x TR x kW/hr) 7200 x 800 x 1.4x 0.8	6,451,200		
I	**Capital Cost:**			
	Cost of AHUs with chilled water coils: 800 x 500 x 1.5		600,000	From Table 4.5
	Total Capital Costs		**600,000**	
II	**Operating Cost:**			
	Cost of electric energy consumption per year, hr x TR x kW/hr x diversity x rate and 80 % diversity ： 7200 x 800 x 1.4x 0.8 x 25/1000 x 3.27		527,386	See Table 6.1
	Total yearly operating costs		**527,386**	

7.4 Summary Technical Results.

The aim of the study is to analyse Not-In-Kind (NIK) cooling technologies for central air conditioning applications for Kuwait that have low GWP as well as provide significant energy efficiency savings.
Questionnaires were prepared to choose two sites where the air conditioning systems of buildings are designed for central system application by traditional electric system once for direct expansion (DX) and another for chilled water (CW) application.
The Kuwait EPA, the official entity that commissioned the study, has been providing guidance and assistance to us in filling questionnaires through information received from "Kuwait Public Authority for Housing Welfare" (KPAHW). General construction plans were obtained from KPAHW for candidate sites that are to be built by them and were to be centrally air conditioned by either a DX or a CW system. Four building sites were used to fill the questionnaires, those are:

1. ***A school.*** The school central air-conditioning system, utilising 5 air cooled chillers, each 200 TR refrigeration capacity, total capacity 1000 TR. The school air conditioning design IK design was provided.
2. ***A Medical Centre***. Comprising small operating theatres, emergency units and other medical facilities. The Medical Centre has a designed IK central air conditioning system using DX units. Unfortunately, the design documents were not complete, and it proved impossible to obtain enough data to form an accurate idea on refrigeration loads, schedule of equipment and other vital design data on time to consider this selection seriously.
3. ***A small mosque***. Although the mosque architectural and civil design data were complete, no central air conditioning system was provided. This excluded the use of this mosque because of the time needed to estimate cooling loads and create a central air conditioning design.
4. ***A large central mosque.*** Complete with central air conditioning IK design was provided. The air conditioning IK design documents were complete and were enough to get a complete and full picture on the IK design.

Selection number 1 and 4 proved best specially since their IK design was completed and could be modified to NIK as well as both were provided with either DX or CW systems design and were soon to be constructed.

Several NIK system were considered such as: deep sea cooling, cooling by the use of reject heat, natural gas fired absorption chiller and solar assisted absorption chiller cooling. Lastly Two Stage Direct Indirect (TSDI) evaporative cooling was considered. The latter NIK system was chosen because the unusual climatological conditions of Kuwait. Analysis of the climatological data over the last 30 years revealed that the relative humidity in Kuwait throughout summer is remarkably low. This dry summer ambient made TSDI evaporative ideally positioned for air conditioning. The system does not utilize refrigerants except water (no GWP) and is known for its low energy consumption.

The technical study looked at both sites and changed the original IK designs to a TSDI evaporative system assisted by the original IK system. Energy consumption was calculated throughout the year and design schematic diagram were made for the new systems.

The preliminary results made for the calculation of energy consumed by the technical study shows there are savings for the NIK assisted by IK system of about 52 % when compared to a traditional electric IK system.

The technical study shows also that the NIK system assisted by IK improves the Indoor Air Quality (IAQ) for occupants by using primarily full fresh air in both mosque and school thus enhancing greatly the way of life reducing cross contamination and renewing air reducing unwanted odours as well as reducing greatly the carbon footprint.
The technical study explains in detail the steps taken and justify the energy savings obtained. The study then made a cost breakdown of capital and operating cost to be used in the financial part of the study to calculate with a high degree of accuracy the energy savings and capital cost, cost break even, return on investment and other financial parameters.
The financial study justified the additional capital cost needed to adopt a TSDI evaporative system assisted by the original IK system and calculated more accurately those savings. In the financial study the system not only recoup its additional expenses in a limited short number of years but also shows the system can be adopted for other central system applications.
Further work will be needed to check empirically these results by building two prototypes: one DX and another CW, and monitor the operational results to disseminate the new technology in Kuwait.

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From the Industry:

9 Mr Sunil Tiwari, GM A.T.E. Enterprises.

10 Eng. Y. Barakat, DCM enterprises.

11 Eng. M. Manzalawi, Tiba enterprises.

Annex-1

Criteria and Questionnaire for sites locations -Kuwait NIK Project

No	Item	Criteria	Points	Score
1	New developed city/district.	New City = 20 New District in existing City = 15 Existing District = 5	20	
2	Minimum Cooling Capacity	< 5,000 TR = 5 5,000 – 10,000 TR = 7 10,000 – 30,000 TR = 8 > 30,000 TR = 10	10	
3	Proximity to: a. Sea side b. Waste Heat Source (elect. power station)	Within or less than 5Km = 30 5-10 Km = 20 More than 10 Km = 10	20	
4	Proximity to NG downstream line	Within connected proximity	10	
5	Current status of city/district development	Concept phase = 20 Design phase = 10 Contract phase = 5	20	
6	Type of application (residential, commercial, governmental, industrial, mixed)	Governmental = 20 Residential = 5 Commercial =15 Industrial = 15 Mixed Use = 20	20	
		Total	100	

Technical Information Survey

No.	Item	Details
1	Sites Parameters:	
A	Sites for District Cooling Plants under consideration.	- Name of sites: - Site 1: --------- - Site 2: ---------- - Site 3: ---------- - Site 4: ---------- (Chose two sites.)
B	Cost of Land: - Purchasing. - Renting.	Site 1: Site 2: Site 3: Site 4:
C	Cost of plant building construction:	For a masonry building: -----/square meter. For a steel structure building: ------/square meter.

No.	Item	Details
D	Additional Information you may think is important to list:	
2	Energy and Water.	
A	Electric Power Prices: - Low Voltage. - Medium Voltage. - High Voltage.	Residential: --- Commercial: ---- Industrial: ----- (Link to internet site- prices of electric power cost.)
B	Natural Gas Prices:	Site1: , Site 2: , Site3: , Site 4: Is it piped to site?
C	Is there a source of reject heat near the site? (Refinery, steel mill, glass factory, thermal desalination plant, electric power station, etc.…)	Site 1: Site 2: Site 3: Site 4:
D	- Is there a Refuse Processing Plant near the site? - Is there a Refuse Derive Fuel (RDF) available?	Site 1: Site 2: Site 3: Site 4:
E	Price of fresh water, brackish water and drain:	
F	Additional Information you may think is important to list:	
3	Salaries	
A	Salaries structure for: - Qualified Graduate engineers (5 to 10 years exp.): - Qualified Graduate engineers (1 to 5 years exp.): - Skilled Technician: - Technician: - Labourer:	
B	Additional Information you may think is important to list:	
4	Taxes and Custom Duties	
A	Rate of Income Taxes: - On individuals: - On Corporations:	
B	Taxes on Services: - On electric power supply: - On district Cooling Services. - Other.	
C	Custom Duties on imported Equipment:	

No.	Item	Details
D	Value Added taxes on Imported goods and services:	

Financial Information Survey

No.	Item	Details
1	Sites Parameters:	
A	Sites for District Cooling Plants under consideration.	- Name of sites: - Site 1: --------- - Site 2: ---------- - Site 3: ---------- - Site 4: ---------- (Chose two sites.)
B	Cost of Land: - Purchasing. - Renting.	Site 1: Site 2: Site 3: Site 4:
C	Cost of plant building construction:	For a masonry building: -----/square meter. For a steel structure building: ------/square meter.
D	Additional Information you may think is important to list:	
2	Energy and Water.	
A	Electric Power Prices: - Low Voltage. - Medium Voltage. - High Voltage.	Residential: --- Commercial: ---- Industrial: ----- (Link to internet site- prices of electric power cost.)
B	Natural Gas Prices:	Site1: , Site 2: , Site3: , Site 4: Is it piped to site?
C	Is there a source of reject heat near the site? (Refinery, steel mill, glass factory, thermal desalination plant, electric power station, etc.…)	Site 1: Site 2: Site 3: Site 4:
D	- Is there a Refuse Processing Plant near the site? - Is there a Refuse Derive Fuel (RDF) available?	Site 1: Site 2: Site 3: Site 4:
E	Price of fresh water, brackish water and drain:	
F	Additional Information you may think is important to list:	
3	Salaries	

No.	Item	Details
A	Salaries structure for: - Qualified Graduate engineers (5 to 10 years exp.): - Qualified Graduate engineers (1 to 5 years exp.): - Skilled Technician: - Technician: - Labourer:	
B	Additional Information you may think is important to list:	
4	Taxes and Custom Duties	
A	Rate of Income Taxes: - On individuals: - On Corporations:	
B	Taxes on Services: - On electric power supply: - On district Cooling Services. - Other.	
C	Custom Duties on imported Equipment:	
D	Value Added taxes on Imported goods and services:	

Annex-2

Compilation of Technical Solutions

The relevant technical solutions chosen for the demonstration of cooling systems are examined such as fluorocarbon chillers (In- Kind cooling technology), non-fluorocarbon chillers (Not-In-Kind cooling technology), distribution piping network, load interface techniques and energy calculation methods.
The compilation of technical information on relevant technical solutions chosen for the demonstration of NIK cooling systems encompass the following subjects:

1. Systems utilising In-Kind cooling technology or Fluorocarbon chillers

The definition of Not-In-Kind DC cooling technology is technology that mostly utilize electric power to produce cooling. Not-In-Kind DC cooling technology is technology that mostly do not utilize electric power to produce cooling. The aim of this study is the dissemination of Not-In-Kind cooling technologies, to help introducing these technologies in Kuwait.
Fluorocarbon chillers are In-Kind cooling technology, since they are mechanical vapour compression machine operated by electric power. Fluorocarbon chillers have real (not subsidized) operating costs relatively higher than these of Not-In-Kind cooling technologies. Therefore, they are not used in this study as the main producers of cooling capacity, but to assist in the cooling process when needed.
Sometimes Not-In-Kind technologies or non-fluorocarbon chillers are not able to bring down the chilled water supply temperature to low design levels efficiently and economically. In this case, In-Kind technologies may be needed to assist the cooling process. When design supply chilled water temperatures are set at 3 to 4 °C, In-Kind technology can be included. For this reason, sometimes electric chillers are included in the design of chilled water plants in-series arrangement with non-fluorocarbon chillers such as absorption chillers.
Distribution piping network designed with large delta T requires low supply chilled water temperature. This is to help reduce the diameter of the chilled water piping, thus reducing cost. This is especially important in large and long networks. Those temperatures are not reachable with current commercially available second-generation absorption chillers, since they can provide chilled water temperatures down to 5 to 6 ^{o}C safely. Lower chilled water temperatures, 3 to 4 ^{o}C, are available with new generation absorption chillers expected commercially in the near future. Thus, fluorocarbon chillers can be included in-series design arrangement to achieve those low temperatures.
This is also the case in applications when ice or ice-slurry are used for thermal energy storage system (TES), since negative chilled water supply design conditions are required to produce ice or ice- slurry and those temperatures are not achievable with current generations absorption chillers.
However, when used the major portion of cooling capacity will be borne by Not-In-Kind cooling technology resulting in low operating costs for the system, while fluorocarbon chillers, electrically operated, will provide a small fraction of the operating costs to achieve lower supply design chilled water temperatures, when needed.

2. Systems using Not-In-Kind cooling technologies or Non-fluorocarbon Chillers

The main NIK cooling technology systems are:

A. Systems operating by deep sea cooling (DSC) or cooling/heating

Deep Sea Cooling is a new technology that uses cold-water temperature of the seas, at great depths, to cool chilled water of a district cooling system. The main advantage of this technique is that may consumes down to a tenth energy consumption compared to In-Kind technologies.
This technique is well developed in Scandinavian countries and in island states such as Hawaii and others. Stockholm City has used its unique location on the shore of the Baltic Sea and at the mouth of Lake Malaren

(the largest lake in Sweden) to build a deep source cooling system for its downtown buildings. Another large project is planned for Dubai in the United Arab Emirates. Toronto City, Canada has the largest deep-source cooling project yet it is not the first city to plumb the depths of North America's glacial lakes.
Four years ago, Cornell University inaugurated a US $ 57 million lake-source cooling plant. The system cools university buildings and a nearby high school in Ithaca, New York.

The plant draws 3.9 ^{o}C (39 F) water from 70 meters (250 feet) below the surface of Cayuga Lake, a glacially carved lake that is 132.6 meters (435 feet) deep at its lowest point The Natural Energy Laboratory of Hawaii Authority (NELHA), a state research facility located on the Big Island of Hawaii, runs its own deep-source cooling plant. The system cools buildings on the agency's campus, which overlooks the Pacific Ocean. The plant draws 6 ^{o}C (42.8 F) seawater from depth of 610 meters (2,000 feet). "NELHA saves about US $3,000 a month in electrical costs by using the cold seawater air-conditioning process," said Jan War, an operations manager. Makai Ocean Engineering, a private company based in Honolulu, is also developing plans to cool all of the city's downtown using a similar system.

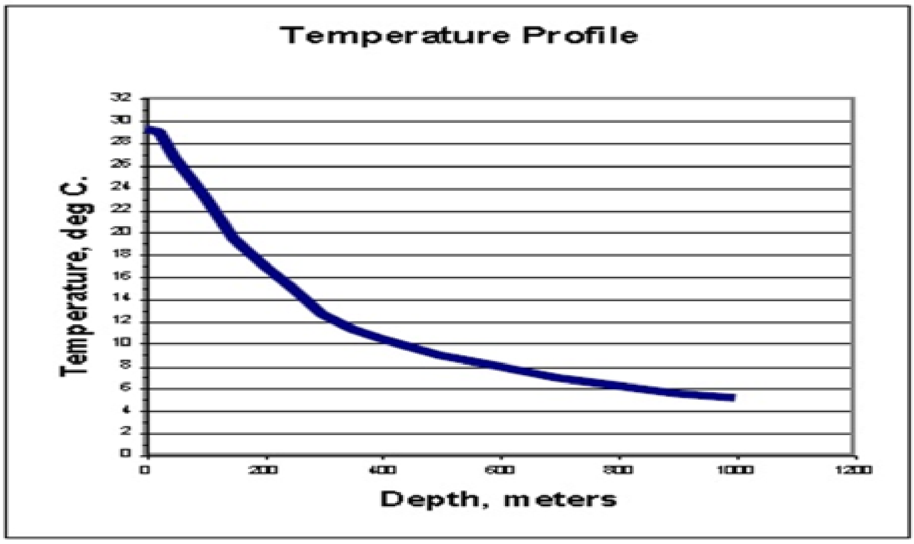

Figure 2.1: Seawater temperature drop versus depths of the Sea.

The graph shows the general trend of the downward decrease of seawater temperature as depth increase. This trend differs from summer to winter and with the location of the point where it is measured.
Oceanographers divide the ocean into categories by depth. The broadest category is the upper part of the ocean known as the —photical zone. This is generally regarded as the upper 200 meters of the ocean where sun light penetrates, and photosynthesis takes place. The bottom part of the ocean is called the —aphotical zone where sunlight does not add heat and cold temperatures are present. Bathymetry and oceanography studies suggest that at an ocean depth of at least 1000 meters, 4°C water temperature is assured. It should be noted that 4^{o}C temperature might also be available at depths of 500 to 900 meters. Diligent temperature studies for the Gulf need to be conducted as part of the study preceding a proposed project (1).
For a specific location, measurements that are more accurate are available at the US National Oceanic and Atmospheric Administration (NOAA). At NOAA, the National Centres for Environmental Information (NCEI) hosts and provides access to one of the most significant archives, with comprehensive oceanic, atmospheric, and geophysical data. NCEI is the US leading authority for environmental information (3). Once the Egyptian government approves the location of the plant, temperatures of the seawater at the location can be assessed.

Deep Sea Cooling and Horizontal Directional Drilling (HDD) Techniques

There are several problems associated with laying a pipe to access cold water from shore to the required depth. The tide action might dislodge anchoring blocks of the piping, especially with high seas. Coral Reefs and seabed marine life may also be affected. Because of that, environmental permits may be difficult to obtain. Returning seawater to the sea should be made so that it is returned to the depth strata where the seawater temperature is the same as that of the returning water. This assures conservation of the sea microorganisms without disruption.

Horizontal Directional Drilling (HDD) is a mature technology used in the Oil and Gas field. This technique enables directional drilling under the surface to access deep cold water with a horizontal displacement of up to eleven kilometres from shore. A rig could also drill a diagonal tunnel of suitable diameter to bring cold seawater to the surface. Using heat exchangers between the cold seawater and a chilled water system, temperatures of 5.5°C to 6.5°C could be achieved at the fresh chilled water network. Similarly, the rig would also drill suitable tunnel to return heated water to a suitable depth. This is the drilling technique suggested for the study.

Figure 2.2 shows the position of the supply and return tunnels and piping and the DC station.

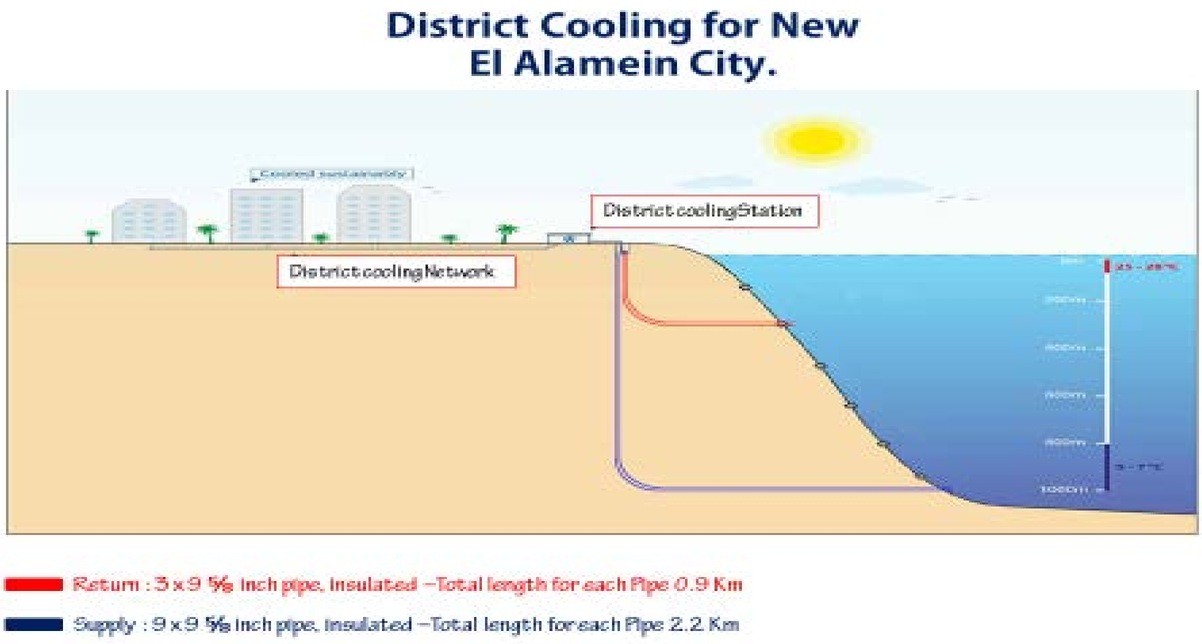

Figure 2.2: Example of Deep Sea Cooling or Free Cooling for a City.

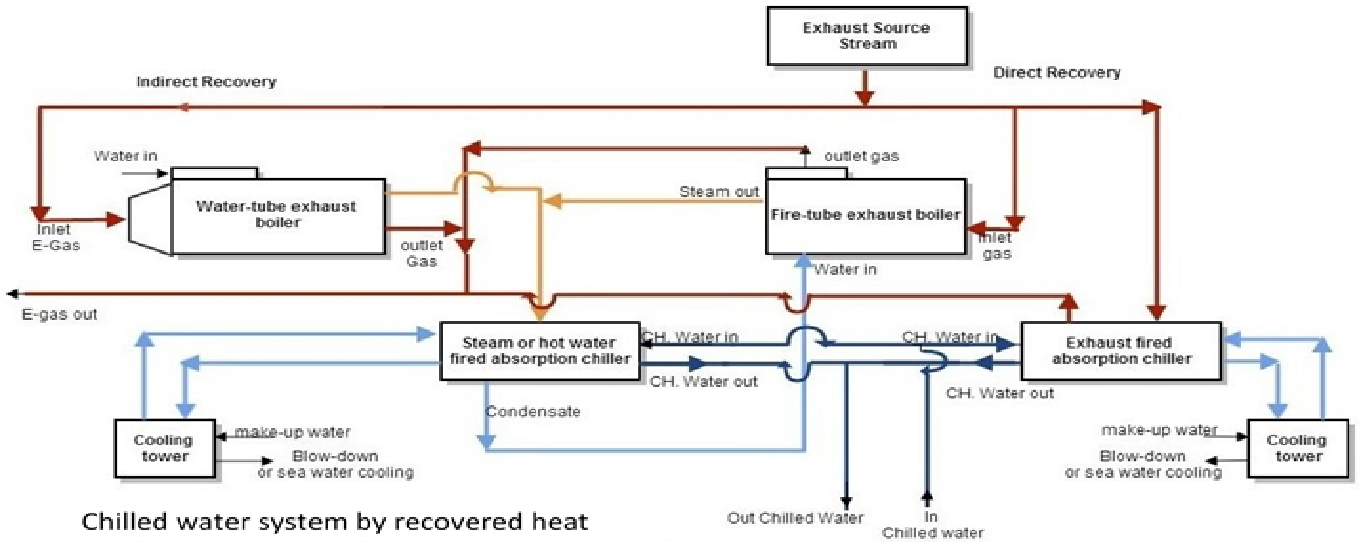

Figure 2.3: Schematic diagram of Exhaust and steam fired absorption chiller.

Figure 2.3 shows a schematic diagram of exhaust and steam fired absorption chiller. When the exhaust stream is relatively clean, with small amount of Sulphur oxides (SOx) and Nitrogen oxides (NOx) in the stream, it is possible to use the stream to fire directly an exhaust fired absorption chiller. Sulphur oxides and Nitrogen oxides when combined with condensate create acids that attack the generator of the absorption chiller and reduces its lifetime considerably. Therefore direct-fired exhaust absorption chillers have to be used with great caution and only when the exhaust stream composition is relatively free of these oxides. When the stream is not clean, a heat recovery boiler is recommended, either a water tube exhaust type or fire tube exhaust type depending on ease of cleaning the tubes from the inside or the outside. The system economics are excellent because of the negligible cost of the exhaust.

B. Solar assisted chilled water absorption cooling systems.

Solar assisted chilled water absorption cooling systems utilises vacuum tube solar collectors or concentrated collectors to heat up water in a closed loop. This heated water fires hot water fired absorption chillers producing chilled water. The capital cost of vacuum or concentrated collectors constitute a large part of the system capital investment. This is why, despite the low operating cost of the system it is not economically feasible to construct the entirety of a chilled water system using solar-fired absorption system. Systems are constructed using 10 to 20 % of the total capacity produced by solar-fired absorption chiller. Systems of total capacities around 500 TR with 50 to 100 TR operating with solar collectors have been constructed and operate successfully. Larger capacities are not be economical. Figure 2.4 shows the schematic diagram of such a system.

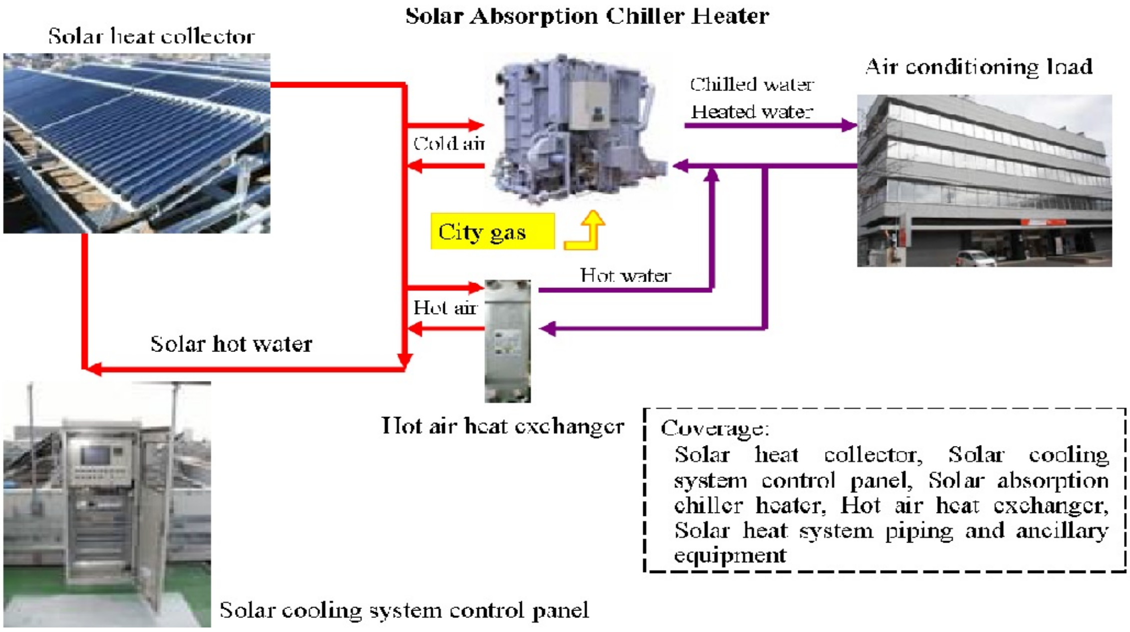

Figure 2.4: Solar assisted chilled water absorption cooling system.

C. Natural gas fired double effect absorption chillers/heaters systems.

This system can be economically advantageous if the price of natural gas in a country is cheaper than that of electric power, which is usually the case. The system is not dependent on electric supply irregularities at on-peak periods; hence, it helps shave and stabilizes electric power demand. Furthermore, when it is responsible for taking care of on-peak surges in a system, it limits use of electric power in those peak periods and reduces power demand surcharges. Figure 2.5 shows an 8,000 TR DC plant with gas fired absorption chillers. There are three generations of absorption chillers. The most common are the Double Effect second-generation units with a heat ratio (efficiency) of 1.2 to 1.45

8 000 TR gas fired absorption chiller plant

Figure 2.5: DC plant with 8000 TR gas fired absorption chiller/heaters.

2.2.5 Steam or hot water indirect fired absorption systems.

Indirect fired absorption systems operate with steam or hot water from industrial processes or from reject heat. Some of the most important examples are Turbine Inlet Cooling System (TIC) used to increase the efficiency of gas turbine power plants. In summer, the turbine efficiency deteriorate due to high ambient temperatures. Cooling combustion air inlet to turbine from ambient conditions to ISO conditions (15 ^{o}C) increases turbine efficiency thus increasing output up to 20%**.**
Figure 2.6 shows a typical schematic diagram for a TIC system utilizing steam or hot water from the Heat Reject Steam Generators (HRSG) of the power station.

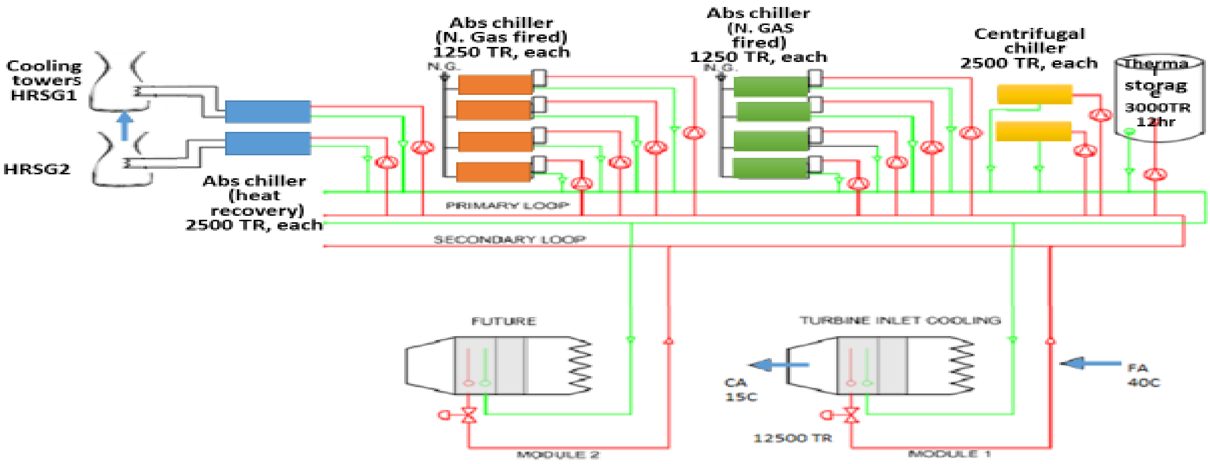

Figure 2.6: Turbine Inlet Cooling -TIC- in a power station using steam or hot water fired absorption chillers.

Figure 2.7 shows the TIC cooling coil installed at air inlet of the gas turbine. Other combination of natural gas fired absorption chillers, electric centrifugal chillers and Thermal Energy Storage (TES) tanks are used to optimize cooling techniques depending on availability of energy at demand.

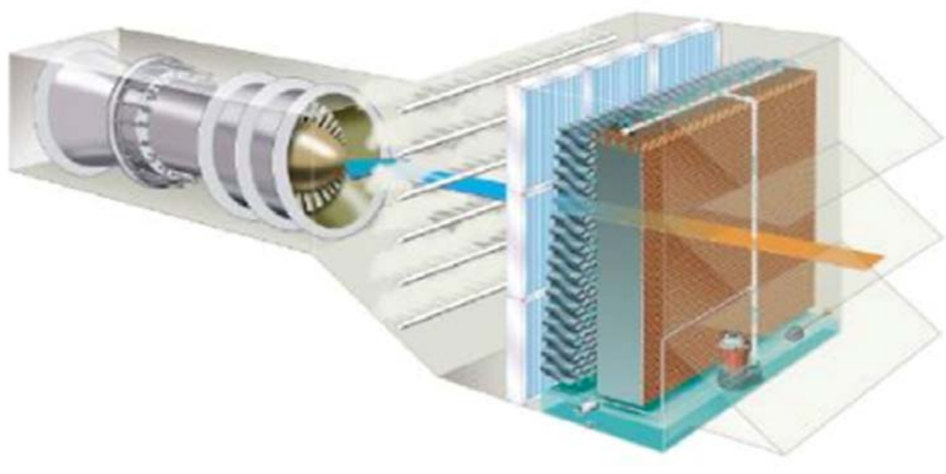

Figure 2.7: TIC cooling coil installed at the air inlet of the gas turbine.

3. Distribution Piping Networks Pumping Arrangements.

There are five chilled water distribution network-pumping arrangements. Those are

A. Constant Flow Arrangement.
B. Variable flow systems
C. Variable Speed Primary Pumping.
D. Primary-Secondary Pumping Arrangement.
E. Primary-Secondary-Tertiary Pumping Arrangement.
F. Primary-Secondary Distributed Pumping Arrangement.

Pumping arrangements differ depending of the cooling application chosen. There could be more than one arrangement suitable for a single application, although this is rare, usually one arrangement will be most economical to build and operate for a certain air conditioning system. The following text is a short description on the suitability of each pumping arrangement:

i. *Constant flow arrangement*

Applied to small capacity district cooling systems where the advantages of variable flow systems are not appreciable. Those advantages are primarily saving in electric energy with frequency inverters.

ii. Variable Flow Arrangements

The primary advantages of those arrangements are their reduced consumption of pumping energy and use of distribution system diversity, saving pumping energy. Those systems are used in relatively larger air conditioning systems.

iii. Variable Speed Primary Pumping

In this system, the primary pumping regulates chilled water flow according to load demand. Pumping energy consumption is reduced compared to constant speed. This system is suitable when the plant pumps can satisfy building's pressure drops, otherwise buildings with larger pressure drops may not be served adequately.

iv. Primary-secondary pumping arrangement.

This system is used when the chilled water distribution system is long, and the variable primary system cannot cope with flows and pressure drops. This arrangement is flexible when an expansion scheme is not clear at inception, and additional buildings may be added at a later stage.

v. Primary-secondary-tertiary pumping arrangement.

It may be necessary, when supply and return chilled water distribution lines become too long with heavy loads in building, to add in-building pumps to provide necessary flow and pressure for each building. These systems are also commonly used in district cooling systems.

*vi.	Primary-secondary distributed pumping arrangement.*

Some systems may have a very large cooling load. It is possible for this system to use a primary-secondary distributed pumping arrangement. This system is probably the most suited system for large applications, because it eliminates secondary pumps in central plants. Reduction in total chilled water pump power of 20%–25% is possible**.** Although this system is highly attractive, it is not suitable when additional buildings may be added at a later stage. The chilled water supply gradient pressure is lower than the return gradient in those systems. Pipes are oversized compared to other systems, which increases the initial capital cost. The operational savings mitigate all those factors in large systems.

4. District Energy for a city using reject heat in power stations.

Figure 2.8 is a Sankey diagram [(4)] that shows two scenarios to provide heating, cooling, and electricity to a city. One scenario uses a traditional coal-fired power station, business as usual (BAU) scenario, whereas the second scenario uses natural gas in a modern combined heat and power (CHP) station.
In the first scenario with a conventional power station, the typical average thermal efficiency of this simple cycle power station is around 35%. More advanced power stations with combined cycles have thermal efficiencies around 45%. Natural gas-fired CHP stations that recover exhaust gases have overall thermal efficiencies of 80%–90%, and sometimes even higher.
This is why the total primary energy utilized in BAU scenarios shown in Figure 2.6 is 601.6 GWh compared to a primary energy utilization of 308.2 GWh with a CHP station. This is a savings of 293.4 GWh or 48.8% compared to BAU, although in both cases the same energy is produced and taken up by end users: 100 GWh of heat, 100 GWh of cooling, and 100 GWh of electricity.
High thermal efficiencies were obtained because recovered heat was used to fire absorption chillers and assisted by wind and geothermal heat. District heating and cooling technology is utilized with this modern CHP station.
This is why district cooling [(5), (6), (7), (8)] and heating is such an important technology. It reduces carbon footprint, increases efficiency of power stations especially when coupled with recovered process heat, and makes use of diversity factors in reducing overall heating and cooling needs. However, district cooling and heating can also be applied at a district level, not only at the power station level.

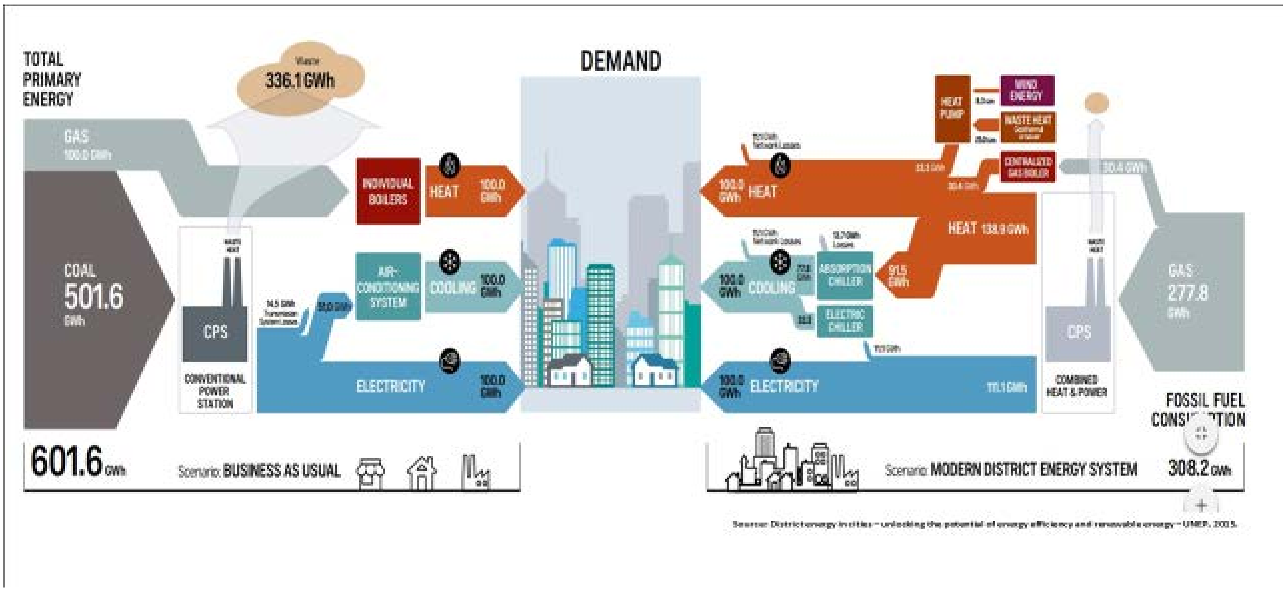

Figure 2.8: The economic and environmental benefits of district cooling in a modern power station for a city.

5. Load Interface Techniques and Energy Calculation Methods.

District cooling systems are connected to distribution networks through load interfaces. These in turn are connected to end users by one of the two methods:

- Direct connections.
- Indirect connections.

Both types of connections are used successfully. The type of connection used depends on the nature and application of the district cooling system.

Direct connections:

The same chilled water produced circulates in the DC plant and the distribution network. Therefore, there is no interface between the chilled water of the plant and in-building distribution network, and hence no separation of chilled water between the production, distribution, and in-building HVAC system. Some insurance companies' demand that direct connection not be used in large DC systems because of the DC provider liabilities in case flooding occurs due to chilled water leaks, which may result in buildings being flooded.

Indirect connections:

In indirect connection, an interface is used, usually a plate heat exchanger. Plate heat exchangers are the preferred heat exchangers in DC systems because traditional shell and tube or shell and coil heat exchangers are bulkier when they are designed to operate at the small approach temperatures in use in DC systems. Those are normally 0.5 to 2°C. In addition, traditional heat exchangers are often more costly. Space is limited in DC buildings' mechanical rooms and
is at a premium, especially in commercial and administrative applications. Rent is often considerable.

Metering and energy meters:

To measure the energy used by end users, energy meters are installed at the building's mechanical rooms. Energy meters utilize equipment for measuring flow, temperature differences between supply and return of chilled water, time duration between two readings and an energy calculator. There are two types of energy meters: dynamic and static.

Collection of DC meter readings:

Collecting energy meter data is done either at the meter or remotely. Local reading of meter uses a handheld terminal that connects to the meter. Remote energy meter reading is made wirelessly by a radio signal from a device in the meter, via the telephone network, or via an Internet connection. In energy meters fitted with radio frequency modules, RF concentrator connected to a central computer uploads the data, and bills can be produced for each end user. In meters connected via the Internet, meters are fitted with a TCP/IP module and can be read by a central computer. Often there is a need for submetering, when a building is rented to more than one end user. In this case, a secondary sub meter is needed or the use of water meters at end users to measure flow rates and allocate sub meter reading proportionally according to water flow meter readings. This method is more economical than using sub meters and is cost effective. Another method used by some DC providers is to calculate individual consumption by floor area of the space instead of submetering. This method does not provide incentives for end user to conserve energy.

6. Daily Cooling Load Profile, Diversity Factors and Thermal Energy Storage (TES).

Daily Cooling Load Profile:

Several important factors must be clearly defined when designing a district cooling system. Some of the most important factors are the daily cooling load demand curve and peak loads. A customer design engineer or consultant usually defines a building's cooling load. Those buildings could be administrative, shopping malls, hotels, schools, and other types of buildings. Cooling load estimates of those buildings will usually vary a great deal from building to building. An administrative building's cooling load estimate will probably include loads attributed to the prevalent weather, loads of occupants, electrical and electronic appliances, lighting and other loads. Those cooling load estimates will differ from those of a shopping mall, where the occupant's load will probably constitute the major part. The same applies to other buildings as well where the loads will vary a great deal. Shopping mall loads peak at a different time of the day compared to administrative loads or residential loads. Deciding how large also when those loads occur is of crucial importance in calculating the total design load of a district cooling plant. In estimating the cooling load of buildings for a certain district, it is possible to use computerized simulation programs and thus obtain an accurate understanding of peak loads' occurrence and their magnitude.

Diversity Factors:

Individual buildings peak at different times. This is why the coincident overall peak demand of a district cooling system depends on the sum of each individual building peak demand at certain time of the day.
Diversity factors are used to calculate the overall peak load of a district cooling system. Those diversity factors may be as low as 0.6 or 0.7 of the sum of individual building peak demands, in applications where there is a great diversity of use. There are different types of diversity factors. Diversity factors inside a building are dependent on the actual use pattern of a building. Diversity factors between one building and the other in a district depend on each building's function, orientation, use, and diversity factors between district cooling plants that may be serving a single
district's distribution network. Chilled water-piping networks are also subject to diversity factors between distribution loops serving different buildings in parallel. All those diversity factors must be taken into account when calculating the overall peak demand of a district cooling system and when designing chilled water distribution networks.

Thermal Energy Storage (TES):

Thermal energy storage (TES) stores cooling enthalpy during off-peak times to use during on-peak times. A specially constructed insulated tank stores the cooling energy at off-peak times and uses it at on-peak times. This technique allows using fewer chillers at on-peak times than those necessary to cope with peaks in the daily cooling load demand curve.
The rating of TES is based on its ability to hold a certain refrigeration capacity for so many hours. For example, a 20,000 TR.h capacity TES will hold 10,000 TR for 2 h or 5,000 TR for 4 h or other combinations totalling 20,000 TR.h. District cooling systems have incorporated successfully TES systems for many years. TES is accepted as an integral part of all air conditioning systems.
Applications range from universities, colleges, airports, museums, sport complexes, and hospitals to leisure centres and administrative buildings; military facilities use TES as do many other applications. The most widely used TES system is the stratified tank type.

Annex VII

TEXT TO BE INCLUDED IN THE UPDATED AGREEMENT BETWEEN THE GOVERNMENT OF THE PHILIPPINES AND THE EXECUTIVE COMMITTEE OF THE MULTILATERAL FUND FOR THE REDUCTION IN CONSUMPTION OF HYDROCHLOROFLUOROCARBONS IN ACCORDANCE WITH STAGE II OF THE HCFC PHASE-OUT MANAGEMENT PLAN

(Relevant changes are in bold font for ease of reference)

9. The Country agrees to assume overall responsibility for the management and implementation of this Agreement and of all activities undertaken by it or on its behalf to fulfil the obligations under this Agreement. **UNIDO** has agreed to be the lead implementing agency (the "Lead IA") in respect of the Country's activities under this Agreement. The Country agrees to evaluations, which might be carried out under the monitoring and evaluation work programmes of the Multilateral Fund or under the evaluation programme of the Lead IA taking part in this Agreement.

17. **At the 83rd meeting the World Bank stopped being the Lead IA in respect of the Country's activities under this Agreement. Therefore, the responsibilities of the World Bank under this Agreement only extend up to the 82nd meeting. This updated Agreement supersedes the Agreement reached between the Government of the Philippines and the Executive Committee at the 80th meeting of the Executive Committee.**

APPENDIX 2-A: THE TARGETS, AND FUNDING

Row	Particulars	2017	2018	2019	2020	2021	Total
1.1	Montreal Protocol reduction schedule of Annex C, Group I substances (ODP tonnes)	187.56	187.56	187.56	135.46	135.46	n/a
1.2	Maximum allowable total consumption of Annex C, Group I substances (ODP tonnes)	129.52	129.52	129.52	105.87	82.56	n/a
2.1	Lead IA (**UNIDO**) agreed funding (US $)	1,010,023	0	1,450,029	0	290,005	2,750,057
2.2	Support costs for Lead IA (US $)	70,702	0	101,502	0	20,300	192,504
3.1	Total agreed funding (US $)	1,010,023	0	1,450,029	0	290,005	2,750,057
3.2	Total support costs (US $)	70,702	0	101,502	0	20,300	192,504
3.3	Total agreed costs (US $)	1,080,725	0	1,551,531	0	310,305	2,942,561
4.1.1	Total phase-out of HCFC-22 agreed to be achieved under this Agreement (ODP tonnes)						23.44
4.1.2	Phase-out of HCFC-22 to be achieved in previously approved projects (ODP tonnes)						2.00
4.1.3	Remaining eligible consumption for HCFC-22 (ODP tonnes)						83.88
4.2.1	Total phase-out of HCFC-123 agreed to be achieved under this Agreement (ODP tonnes)						0.00
4.2.2	Phase-out of HCFC-123 to be achieved in previously approved projects (ODP tonnes)						0.00
4.2.3	Remaining eligible consumption for HCFC-123 (ODP tonnes)						1.70
4.3.1	Total phase-out of HCFC-141b agreed to be achieved under this Agreement (ODP tonnes)						1.15
4.3.2	Phase-out of HCFC-141b to be achieved in previously approved projects (ODP tonnes)						43.00
4.3.3	Remaining eligible consumption for HCFC-141b (ODP tonnes)						7.70