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اللجنة التنفيذية للصندوق المتعدد الأطراف
لتنفيذ بروتوكول مونتريال
الاجتماع السادس والسبعون
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حساب مستوى التكاليف الإضافية لتحويل خطوط تصنيع مبادلات الحرارة في المنشئات التي تتحول إلى تكنولوجيا الهيدروكربونات-290 (المقرر 43/75(و))

خلفية

1. نظرت اللجنة التنفيذية خلال اجتماعها الخامس والسبعين المرحلة الثانية من خطة إدارة إزالة المواد الهيدروكلوروفلوروكربونية للبرازيل[1]. ولدى تقديم مقترح المشروع، أوضحت الأمانة أن إحدى المسائل التي حددت خلال استعراض المقترح كانت تتعلق بتعديل خطي إنتاج لمبادلات الحرارة للإستعاضة عن الهيدروكلوروفلوروكربون-22 بغازات تبريد عاملة بالهيدروكربونات-290 في وحدات تكييف الهواء مما يتطلب استبدال الأدوات والقوالب وآلة التثبيت، وآلة الثني وآلة القطع وآلة إدراج حلقة اللحام وآلة التنظيف. ونظرا لأن الأمر يحتاج الى بذل المزيد من العمل لتقييم التكاليف الإضافية لتحويل خطى مبادلات الحرارة، اتفقت الأمانة مع اليونيدو على أن تدرج في التكاليف الإجمالية للمشروع تكاليف تحويل هذين الخطين بمبلغ 1.5 مليون دولار أمريكي للخط الواحد، وفي حالة أن يسفر التقييم عن تكاليف إضافية تقل عن 1.5 مليون دولار أمريكي، يعاد الفرق الى الصندوق المتعدد الأطراف وقت تقديم الشريحة الثالثة من المرحلة الثانية من خطة إدارة إزالة المواد الهيدروكلوروفلوروكربونية.

2. وخلال المناقشات، لاحظ أعضاء اللجنة التنفيذية أن التغلب على الصعوبات في تقييم التكاليف الإضافية لتحويل خطي مبادلات الحرارة غير مشروط بل أنه مبتكر وفعال. ووافقت اللجنة كذلك على المرحلة الثانية من خطة إدارة إزالة المواد الهيدروكلوروفلوروكربونية للبرازيل، وطلبت، *ضمن جملة أمور*، من الأمانة القيام بعمل إضافي بشأن مستوى التكاليف الاضافية لتحويل خطي تصنيع مبادلات الحرارة في المنشئات التي تحول الى تكنولوجيا الهيدروكربونات-290 وتقديم تقرير للاجتماع السادس والسبعين، وتعديل تكلفة المرحلة الثانية من خطة إدارة إزالة

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[1] الوثيقة UNEP/OzL.Pro/ExCom/75/40 and Add.1.

المواد الهيدروكلوروفلوروكربونية للبرازيل، حسب مقتضى الحال، لدى تلقي طلب الشريحة الثانية (المقرر 43/75(و))

<u>صلاحيات لإعداد الوثيقة</u>

3. استجابة للمقرر 43/75(و) أعدت الأمانة صلاحيات دراسة يعدها خبير فني مستقل توفر معلومات تقنية ووقائعية عن التعديلات المطلوبة على مبادلات الحرارة وخطي تصنيع مبادلات الحرارة لتحويل أجهزة تكييف الهواء المعتمدة على الهيدروكلوروفلوروكربون-22، الى غازات التبريد المعتمدة على الهيدروكربونات-290 أو الهيدروفلوروكربون-32 أو R-452B[2]، ووضع تقدير للتكاليف الإضافية المرتبطة بهذا التمويل. وسوف تعتمد الدراسة على تحويل مرافق إنتاج وحدات تكييف هواء الغرف (أي النظم الفردية المقسمة، بطاقة تبريد تتراوح بين 2 الى 5 كيلووات، مع قدرات تصنيع مبادلات الحرارة بمقدار 300,000 الى 350,000 وحدة سنويا) وأجهزة تكييف هواء أكبر حجما (أي وحدات السطح/ المفردة التي يجري تصنيعها عادة بكميات صغيرة تصل الى بضعة آلاف وحدة سنويا). وسوف تتناول الدراسة المسائل النوعية التالية:

(أ) وصف لعملية تصنيع مبادلات الحرارة وما يرتبط بها من معدات وأدوات؛

(ب) تحليل التعديلات المطلوبة في تصميم مبادلات الحرارة للاستخدام في وحدات تكييف الهواء المعتمدة على الهيدروكربونات-290 وR-452B أو الهيدروفلوروكربون-32، وتعديل خط أساس المعدات والأدوات (مثل الكبس اللولبى المرتفع السرعة، والقوالب المتضمنة أداة التراص وآلة ثني الأنابيب الملتوية ،وآلة القطع، وآلة ثني الأنابيب وآلة ثني منحني الربط، وآلة تثبيت آلة القطع، وآلة ثني أنابيب CNC، وآلة تجهيز أطراف الأنابيب، وجهاز كبس التوسيع، وآلة إدراج حلقة اللحام، وآلة التنظيف) ومايتصل بها من تكاليف؛

(ج) تحليل مدى إمكانية تطبيق الاستنتاجات التي تتوصل إليها الدراسة التي أجريت بشأن التعديلات للتحويل الى غازات R-410A على التحويل الى غازات تبريد الهيدروفلوروكربون-32[3]؛

(د) تحليل مدى خفض شحن غازات التبريد عندما تستخدم غازات التبريد المعتدلة القدرة على الاشتعال، (الهيدروفلوروكربون-32) والقابلة للاشتعال (الهيدروكربونات-290)، ومعدلات شحن غازات التبريد التي تعتبر مقبولة لوحدات تكييف الهواء والبدائل الأخرى لخفض شحن غازات التبريد؛

(هـ) تحليل اعتبار السلامة والتكاليف الإضافية المرتبطة بتصنيع مبادلات الحرارة لوحدات تكييف الهواء المعتمدة على الغازات القابلة للاشتعال أو مقاومة كبس الأنابيب والنظام؛

(و) تحليل التغييرات فى التصميم والتكاليف المرتبطة بها لوحدات تكييف الهواء العاملة في البلدان التي ترتفع فيها درجة حرارة البيئة (أعلى من 46 درجة مئوية)؛

(ز) تحليل خيارات تحسين كفاءة مبادلات الحرارة والتكاليف المرتبطة بها.

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[2] أضيف R-452B للدراسة بوصفها خليط يتوقع أن يستخدم في قطاع تصنيع أجهزة تكييف الهواء المنزلية.

[3] خلصت الدراسة المتعلقة بمبادلات الحرارة للمادة R-410A (UNEP/OzL.Pro/ExCom/66/51) الى أن المعدات المستخدمة حاليا أي آلات الكبس الزعنفية وأدوات الثني لتصنيع الأنابيب الملتفة في معدات خط الأساس يمكن استخدامها في وحدات تكييف الهواء المعتمدة على R-410A مع تغييرات طفيفة في الأدوات مثل القوالب الزعنفية أو آلة الثني الخطافية.

الاستعراض النظير

4. وخضعت الدراسة التي أعدها الخبير الذي استأجرته الأمانة لاستعراض نظير[4] بواسطة خبيرى غازات تبريد مستقلين خلصا الى أن الوثيقة تقدم عرضا واضحا لتكنولوجيا تصنيع مبادلات الحرارة، والعمليات المشتركة في تحويل مبادلات الحرارة وأبرز الخبيران اللذان قاما بالاستعراض النظير أيضا أن الدراسة لم تتضمن التكاليف المرتبطة بخفض محيط الأنابيب لخفض شحن غازات التبريد للتحويل الى الهيدروكربونات-290 ويعتبر هذا السيناريو مفيدا حيث أنه يتيح استخدام الهيدروكربونات-290 في وحدات تكييف الهواء الكبيرة بأكثر مما يمكن بمقتضى المعايير الحالية. وقام الخبير بمعالجة التعليقات التي أبداها الخبيران اللذان قاما بالاستعراض النظير بأن أدرج في التقرير تقديرا للتكاليف الرأسمالية لتغيير محيط الأنابيب الملتفة لخفض الشحن بغازات التبريد (بنحو 50 في المائة). وترد النسخة النهائية للدراسة في المرفق الأول بهذه الوثيقة.

مناقشة في اجتماع التنسيق المشترك بين الوكالات[5]

5. قامت الأمانة خلال اجتماع التنسيق المشترك بين الوكالات بتحديث معلومات الوكالات الثنائية والمنفذة عن حالة إعداد الوثيقة مشيرة الى أن من المتوقع صدور المسودة الأولى في أواخر مارس/ آذار 2016. ويظل من الضروري أن تستعرض الأمانة هذه المسودة وإرسالها الى الاستعراض النظير. ورحبت الأمانة بوجهات نظر الوكالات المنفذة وستطلب تعميم الوثيقة على الوكالات بمجرد توافرها، في حين لاحظت أن الإطار الزمني الحالي قد لا يسمح بتوافر الوقت الكافي للأمانة لمعالجة تعليقات الوكالات، وحتى وقت إصدار هذه الوثيقة لم يكن التقرير النهائي قد وزع بعد على الوكالات.

عليقات الأمانة

6. لاحظت الأمانة أن الوثيقة المنقحة التي أعدها الخبير تلتزم بالصلاحيات التي وضعتها الأمانة. وجرت معالجة جميع التعليقات والملاحظات التي أبداها الخبيران اللذين أجريا الاستعراض النظير بصورة مرضية في النسخة الأخيرة من الوثيقة.

7. وجرت مقارنة ظروف تشغيل نظام تكييف الهواء باستخدام غازات التبريد البديلة الثلاثة (الهيدروكربونات-290، وR-452B والهيدروفلوروكربون-32) بوحدات تكييف الهواء المعتمدة على الهيدروفلوروكربون-22. واستخدمت التغييرات في ضغط التصميم، ودرجة حرارة إطلاق المكابس وأحجام تدفق غازات التبريد لتحديد التغييرات اللازمة في تصميم مبادلات الحرارة لاستيعاب غازات التبريد الجديدة. وتم بالنسبة للتغييرات التي حددت في التصميم ، تحديد التغييرات في تصنيع الأجهزة والعمليات وجرى تقدير التكاليف الرأسمالية المرتبطة بها. وجرى حسب مقتضى الحال، استخدام استنتاجات دراسة مماثلة مستكملة بشأن التحويل من الهيدروكلوروفلوروكربون-22 الى R-410A كأساس لتقييم تكاليف التحويل من الهيدروكلوروفلوروكربون-22 الى غازات التبريد البديلة الثلاث.

استنتاجات الوثيقة

8. فيما يلي موجز للاستنتاجات الرئيسية المستمدة من الوثيقة:

(أ) تتمثل الخصائص الرئيسية لغازات التبريد التي تؤثر في التصميم الفيزيائي لمبادلات الحرارة في تصميم الكباسات القصوى. فلدى اثنين من غازات التبريد البديلة في الدراسة (R-452B والهيدروفلوروكربون-32) ضغط تصميم مرتفع بدرجة كبيرة بالمقارنة بالهيدروكلوروفلوروكربون-22 إلاّ أنها في حدود 10 في المائة من ضغط التصميم للغاز R-410A:

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[4] قدم الاستعراض النظير تقييما للتقرير بما في ذلك ما إذا كان القائم بالاستعراض موافقا على النتائج التي توصل الخبير إليها، ويتناول الاستعراض أيضا مدى معالجة التقرير للصلاحيات الواردة في الفقرات 3(أ) إلى(د).

[5] مونتريال من 1 إلى 2 مارس/ أذار 2016.

(1) إن ضغط التصميم لغاز R-452B يقل بنسبة 10 في المائة عن R-410A، ولذا فإن استنتاجات الدراسة بالنسبة للتحويل من الهيدروكلوروفلوروكربون-22 الى R-410A، لا يتطلب سوى تغيير في اختبار الارهاق والانفجار للضغط المستخدم في تأهيل تصميم الملفات وعملية التصنيع؛

(2) أن ضغط التصميم للهيدروفلوروكربون-32 يزيد بنسبة 10 في المائة عن R-410A، ولذا قد يكون من الضروري إجراء تغييرات في بعض الأنابيب الملتفة وكثافة الجدار العلوي بالإضافة الى التغييرات المحددة في الدراسة عن التصميم وعملية التصنيع للتحويل من الهيدروكلوروفلوروكربون-22 الى R-410A (أي سيتعين مواءمة اختبار الضغط مع المستويات المرتفعة اللازمة للهيدروفلوروكربون-32)؛

(ب) يقل ضغط التصميم للهيدروكربونات-290 عن ذلك الخاص بالهيدروكلوروفلوروكربون-22، ولذا لا يتعين إجراء تغييرات في التصميم أو عملية التصنيع؛

(ج) تعتبر غازات التبريد البديلة الثلاثة الواردة في الدراسة قابلة للاشتعال: الهيدروكربونات-290 شديد القابلية للاشتعال (A3) في حين أن الهيدروفلوروكربون-32 وR-452B قابلان للاشتعال بصورة معتدلة. وتتباين مدونات السلامة التي تحكم استخدام غازات التبريد القابلة للاشتعال في الأماكن المأهولة تباينا شاسعا بواسطة المحليات، ويجري استعراضها حاليا ومراجعتها لتجسد انخفاض مخاطر القابلية للاشتعال المرتبطة باستخدام الفئة 21 في حين من المستبعد حدوث تغيير في القيود المفروضة على استخدام غازات التبريد من الفئة 3 في الأماكن المأهولة، ويتوقع أن يتزايد تطبيقها. كذلك فإن هذه الحدود القصوى لحجم الشحن سوف يقيد تطبيق الهيدروكربونات-290 على النظم التي تقل عن طاقة 2 كيلووات دون تخفيف المخاطر، وحتى حد أقصى يبلغ نحو 20 كيلووات مع نظام نشط لتخفيف المخاطر. وجرى تقدير تكاليف نظم التخفيف الأوتوماتيكية للمخاطر بمقدار يصل الى 30 في المائة من تكلفة وحدة تكييف الهواء.وسيؤثر ذلك في الحد من حجم الأجهزة التي تستخدم الهيدروكربونات-290 في الثلاجات والمبردات الصغيرة وربما وحدات تكييف الهواء الصغيرة المقسمة؛

(د) وتحدد الخصائص الفيزيائية والحرارية الأخرى لغازات التبريد، ظروف التشغيل وأداء نظم تكييف الهواء التي تستخدم فيها، وتسفر هذه البارمترات الخاصة بغازات التبريد الثلاثة التي تناولتها الدراسة عن تباين كبير فيما بين غازات التبريد في كفاءة النظم وطاقة النظم، ودرجات حرارة التشغيل ومعدلات تدفق الغاز. وتكتسي هذه أهمية في اختيار غاز التبريد لنمط معين من المنتجات، ولترشيد تصميم عناصر مبادلات الحرارة. غير أنها لا تسفر في حد ذاتها عن أي تغييرات مطلوبة في التصميم الفيزيائي لمبادلات الحرارة أو عمليات تصنيعها التي تتطلب مصروفات رأسمالية؛

(هـ) وبالنسبة لتقديرات التكاليف الرأسمالية للتغيير في محيط الأنابيب الملتفة، تشير الدراسة الى أن الملفات التي صممت للهيدروكلوروفلوروكربون-22 تستخدم أنابيب بمحيط أكبر مما هو نموذجي لغازات التبريد البديلة. وفي حالة الهيدروكربونات-290 يمكن استخدام محيط خارجي بمقدار 5 مم دون انخفاض مفرط في الضغط ويمكن من خفض شحن غازات التبريد بدرجة كبيرة (نحو 50 في المائة) وخفض في تكاليف المواد(بنحو 40 في المائة) بالمقارنة بالملفات المعيارية لتصميم الهيدروكلروفلوروكربون-22 المعادلة. ويؤدي الخفض في الشحن الى إحداث زيادة قصوى في طاقة استخدام الغاز في التوسيع المباشر لنظام تكييف الهواء الذي يمكن استخدامه في الأماكن المأهولة دون تجاوز معايير السلامة المعينة التي تفرضها الحدود القصوى للشحن. ومن غير المحتمل أن تؤدي هذه الزيادة بالنسبة لأمريكا الشمالية الى التوسع في تطبيق الهيدروكربونات-290 بدرجة كبيرة إلاّ أن خفض الشحن في الأقاليم الأخرى قد يمكن من تطبيق الهيدروكربونات-290 في النظم المقسمة المنزلية الصغيرة فضلا عن نظم تكييف الهواء المنفردة. ويرد أدناه تقدير للتكاليف الرأسمالية المرتبطة بالتغيير في محيط الأنابيب الملتفة، ويؤثر التغيير في محيط الأنابيب بالنسبة

للملفات الأنبوبية والزعنفية على كل جزء تقريبا من أحد الملفات ومن ثم جميع الأدوات اللازمة لتصنيع هذه الأجزاء.ولايتعين تغيير الأجهزة الرأسمالية الرئيسية مثل المكابس الزعنفية وآلة ثني الأنابيب ومعدات مناولة المواد وترتيبات المصنع. ويتضمن الجدول 1 قائمة بالبنود الرئيسية والتكاليف المرتبطة بها اللازمة لتغيير محيط الأنابيب وعدد بنود المعالجة اللازمة.

الجدول 1: التكاليف الرأسمالية الإضافية لتغيير محيط الأنابيب الملتفة*

البند	التكلفة (بآلاف الدولارات الأمريكية)	التعليق
شرائط المكابس الزعنفية	50 إلى 75	مطلوب واحد لكل مكبس زعنفي
القوالب اللولبية	100 إلى 300	مطلوب واحد لكل أنبوب وطبقة أنابيب
أدوات ثني الأنابيب الرفيعة	5 إلى 10	واحد لكل أنبوب وجدار
أدوات تجهيز أطراف الأنبوب	5 إلى 10	واحد لكل موسع أنابيب
قوالب التوسيع	5	واحد لكل موسع أنابيب
أدوات إدراج حلقة اللحام	10	واحد لكل محطة إدراج لحلقات اللحام
أداة تثقيب للجزء العلوي	6	واحد لكل محطة تثقيب للجزء العلوي
أداة تغضين أنابيب التوزيع	12	واحد لكل محطة لحام
المجموع (تقريبا)	**430-200**	

* تكاليف التطوير المرتبطة بهذه التغييرات على حساب جهات التصنيع ولم تدرج.

توصية الأمانة

9- قد ترغب اللجنة التنفيذية فيما يلي:

(أ) أن تحاط علما بالوثيقة UNEP/OzL.Pro/ExCom/76/59 بشأن حساب مستوى التكاليف الإضافية لتحويل خطوط تصنيع مبادلات الحرارة في المنشئات التي تتحول الى تكنولوجيا الهيدركربونات-290 (المقرر 43/75(و))؛

(ب) أن تطلب من الأمانة تعديل تكاليف المرحلة الثانية من خطة إدارة إزالة المواد الهيدروكلوروفلوروكربونية للبرازيل حسب مقتضى الحال لدى تلقي تقديم طلب الشريحة الثانية وفقا للمقرر 43/75(و) استنادا إلى المعلومات التقنية الواردة في الوثيقة UNEP/OzL.Pro/ExCom/76/59؛

(ج) أن تطلب من الأمانة أن تستخدم المعلومات التقنية الواردة في الوثيقة UNEP/OzL.Pro/ExCom/76/59 لدى تقييم التكاليف الإضافية لتحويل خطوط تصنيع مبادلات الحرارة من تحويل أجهزة تكييف الهواء المعتمدة على الهيدروكلوروفلوروكربون-22 الى غازات تبريد الهيدركربونات-290 والهيدروفلوروكربون-32 وR-452B.

Revision C
Contract No: 2500059491
April 12, 2016

Annex I

A STUDY OF AIR TO REFRIGERANT CONDENSOR AND EVAPORATOR HEAT EXCHANGER MANUFACTURING CHANGES FOR CONVERSION FROM R-22 TO R-290, R-32, AND R-452B

Summary

This study was performed at the request of the Multilateral Fund Secretariat to serve as a basis to evaluate the incremental cost of the heat exchanger conversion proposed in the Brazilian HCFC Phase-out Management Plan (HPMP) as well as future heat exchanger conversions submitted for funding to the Executive Committee (ExCom) for consideration. The study provides technical information on required modifications to heat exchangers and heat exchanger manufacturing lines when converting from-HCFC-22 based AC to: (1) HC-290, (2) HFC-32, and (3) R-452B (DR-55) refrigerants, and provides an estimation of the incremental capital and operating cost associated with the conversion heat exchanger manufacturing lines from R-22 to the three alternative refrigerants. Where appropriate, a similar study completed in October 2011 for conversion from R-22 to R-410A was used as basis for assessment of costs for conversion from R-22 to these three alternative refrigerants. Two types of direct expansion AC systems were considered, 2kw to 5kw mini-spilt systems and 30kw to 1000kw rooftop systems.

The study concludes that no major coil design changes will be required for conversion of this equipment from R-22 to R-32, R-452B, or R-290. However, the significantly higher design pressure for R-32 and R-452B will require a fatigue based pressure cycle and burst test in place of the current burst test for coil design qualification. Coil design modifications that are required will therefore focus on fatigue strength improvement. Minimal new capital equipment will be required to make these changes to the coil manufacturing process. Automated pressure cycling equipment will be required to qualify the coil designs.

R-290 has a design pressure that is 10% lower than R-22. Therefore use of R-22 coil design qualification processes will be acceptable for the coils when used with R-290.

All three of the alternative refrigerants in this study are considered flammable. At present the safety codes that govern use of flammable refrigerants in occupied spaces vary wildly by locale. The standard used in North America is currently being reviewed and revised to reflect the low flammability risks associated with use of the A2L refrigerants R-32 and R-452B. These revisions are expected to allow use of A2L refrigerants in occupied spaces with only minimal restriction and, in some cases, ignition mitigation systems. These restrictions are not expected to cause application issues with either mini-splits or rooftops.

R-290 is designated as class A3 - highly flammable. Current code restrictions prohibit its use in North America to equipment rooms and restrict the charge to 3kg. Codes in other areas are not as restrictive but still limit charge. The charge limits for class 3 refrigerants generally will restrict the capacity of R-290 systems to about 1kw with current coil designs. Somewhat larger charges will be allowed if additional, and costly, active ignition mitigation is used. Thus practical application of direct expansion AC equipment using R-290 will be limited to refrigerators, small coolers and perhaps small mini-split type AC units.

1.0 Introduction

The Multilateral Fund Secretariat assists the Executive Committee (ExCom) in managing the operation of the Multilateral Fund. At its 75th meeting in December 2015 the ExCom considered the HCFC phase-out management plan (HPMP) of Brazil which included modification of heat exchanger manufacturing lines to produce R-290 based AC units. Due to the complexity of calculating the costs associated with this change the Secretariat was directed to obtain additional information on the incremental cost for conversion of heat exchanger manufacturing lines to alternative refrigerant technologies and report back to the ExCom at the May 2016 meeting.

R-22 (HFC) had been the refrigerant of choice for use in residential and small unitary AC systems up until its phase out beginning in 2010. At that time R-410A (HCFC) became the accepted replacement refrigerant for small residential split systems and medium size unitary (rooftop) products. However, with current focus of using lower GWP for refrigerants, a new set of alternative refrigerants are being considered. This study considered three potential replacements for R-22: R-290, R-32, and R-452B. These refrigerants all have zero ozone depletion, low (<750) GWP and physical/thermodynamic properties suitable for use in small to medium size direct expansion AC systems.

The objective of this study is to provide technical information on required modifications to heat exchangers and heat exchanger manufacturing lines for conversion of HCFC-22 based AC to (i) HC-290, (ii) HFC-32, and (iii) DR-55 refrigerants, and to provide as estimation of the incremental capital and operating cost associated with conversion heat exchanger manufacturing lines from R-22 to the three alternative refrigerants. This study is focused on smaller air conditioning products, specifically 2 to 5 kW residential room air conditioners (mini-splits) and 30 to 1000 kW unitary products.

The operating conditions of an air conditioning system using the three alternative refrigerants were compared to the R-22 base. Changes to design pressure, compressor discharge temperature, and refrigerant flow volumes were used to determine if any changes were required to the heat exchanger designs to accommodate the new refrigerants. For the design changes identified the required manufacturing equipment and process changes were determined and the capital cost to make these changes was estimated. Where appropriate the conclusions of a similar study completed in October 2011 for conversion from R-22 to R-410A were be used as basis for assessment of costs for conversion from R-22 to the three alternative refrigerants.

2.0 Baseline Coil Information

The typical base line or "design standard" coils and the associated manufacturing processes assumed for this report are described in the following paragraphs. Coil designs in developing countries may or may not be similar those described. Older designs may very well be prevalent and upgrade to the design standard is not addressed by this report. The information in this section is based on information in the October 2011 study on heat exchanger conversion from R-22 to R-410A, updated to reflect current coil design standards.

2.1a Residential (2-5 kW): Equipment of this size and type generally has a single refrigeration circuit driven by one non-unloading rotary compressor. The evaporator coil is contained in cassette or cabinet located in the conditioned space and includes a fan. The condenser coil is located outdoors in an enclosure which also contains a fan and the compressor.

Both the evaporator and condenser use 7 mm. O.D. internally finned copper round tube coils with configured aluminum plate fins mechanically bonded to tubes. The tube wall thickness is 0,25 mm. Many manufacturers have switched to aluminum tube for the evaporator coil. Small product uses single row coils, whereas larger product uses two row coils. Both evaporator and condenser coils use hairpin bends and brazed U bends. In the case of evaporators, a short orifice is used to feed the circuits. Headers are made from small diameter copper or aluminum tube. All connections are brazed.

2.1b Unitary (30 – 1000 kW): The evaporator and condenser coils are contained within a complete packaged product, generally located on a roof. Equipment of this size and type generally has two or more separate refrigeration circuits each driven by one or more scroll compressors. The coils generally contain both refrigerant circuits in a single coil slab with the circuits intertwined to improve part-load performance. Multiple coil slabs are typically used for the higher capacity equipment.

Evaporator: 3/8 inch O.D. internally finned copper round tube coils with configured aluminum plate fins mechanically bonded to tubes. Some manufacturers have taken advantage of the lower refrigerant flow volumes with R-410A and have converted to 5/16 inch O.D. tube and may also have changed from copper to aluminum tubes for cost reduction and reliability improvement. The coils have 2 to 4 rows of tubes typically on a 1.0 inch triangular pitch. Coil height, length, rows, and number of refrigerant paths (coil tube circuits) varies by the refrigeration circuit capacity. A combination of hairpin bends and U-bends are used to connect tubes in each coil tube circuit. The U-bend to tube joints are flared and brazed. Tube wall thickness is generally .0118" to .014". The first tube in each coil tube circuit is fed by a dedicated distributor tube connected to the coil tubes using either a crimped or flared brazed joint design. Each distributor tube is fed from a multiport distributor device. To maximize performance of the heat exchanger and minimize tube wall thickness required, the un-fined length of each tube is kept to a minimum, usually around .5". Overall refrigerant flow is controlled by a TXV.

Outlet headers use pierced or pierced and flared braze joints with mitered or saddle type joints for the gas outlet line.

<u>Condenser:</u> 3/8 inch O.D. internally finned copper round tube coils with configured aluminum plate fins mechanically bonded to tubes. The coils have 1 to 3 rows of tubes on a 1.2 inch triangular pitch. Coil height, length, rows, and number of refrigerant paths (coil tube circuits) varies by the refrigeration circuit capacity. A combination of hairpin bends and U-bends were used to connect tubes in each coil tube circuit. The U-bend to tube joints are flared and brazed. Tube wall thickness is .0118" to .014". The first tube in each coil tube circuit is fed from a cylindrical header, and the last tube in each coil circuit is connected to a cylindrical outlet header all made from copper. The diameter of these headers varies by overall refrigeration circuit capacity with the largest outside diameter about 1.625" . To maximize performance of the heat exchanger and minimize tube wall thickness required, the un-fined length of each tube is kept to a minimum, usually around .5". Both inlet and outlet headers use pierced or pierced and flared braze joints with mitered or saddle type joints for the gas inlet and liquid outlet lines. For non-heat pump applications use of aluminum micro-channel slabs is either an option or standard for many manufacturers. Use of this technology significantly reduces refrigerant charge and heat exchanger cost.

<u>All Coils:</u> Some manufacturers have taken advantage of the improvement opportunities afforded by conversion from R-22 to R-410A and made changes to the baseline coil designs. These changes improve AC system performance, lower refrigerant charge and lower coil material cost. They were made possible by the conversion to R-410A but were not required as part of the conversion process. Examples of these changes include tube diameter reduction (generally down to 7mm), tube pitch changes to take advantage of smaller diameter tubes, and coil re-circuiting. One current direction for coil design, especially in small window or split systems, is to go to tube diameters as small as 4mm. This is especially beneficial to R-290 systems where charge volume is limited by safety codes.

2.2 Standard Manufacturing Processes: The standard manufacturing processes generally used for both condenser and evaporator coils in residential and unitary systems are as follows. The amount of automation, and use of alternative processes is driven by volume/cost, manufacturing cycle time, manufacturing capacity investment considerations, and manufacturing quality control. Most tooling (fin dies, stackers, tube expanders, support plate stamping dies) used in these processes is specific to tube O.D. and I.D, tube pitch, and fin heat transfer surface design. Therefore they would all need to be replaced if any of these design details are changed. However, the major capital equipment, such as fin presses and tubing benders would not need to change.

Fins: Punched using a high speed progressive die fin press with automated feedstock and fin stacking. Fins are highly configured with features to improve air side heat transfer.

Tube Cut Off: Automated feed and cut machine

Hairpin Bend: Hairpin bender with mandrels and automated feed

Headers: Punched or drilled with automated or semi-automated machines. T-drill or similar may be used for more robust brazed joint, especially in larger diameter headers

U-Bends: Purchased (brazing rings filler metal may be included)

Coil Structural Support: Sheet metal is punched using a progressive pierce and bulge dies and press.

Coil Assembly: Manual or semi-automatic

Tube Expansion: Ball end multi-rod expanders, or ball expanders moved with hydraulics for low volume coils

Headers, U-bend or Distributor Tubes: Brazed with dry nitrogen purge. Single and multi-tip torches. Automated multi-joint brazing for aluminum tube coils.

Pressure and Leak Test: Air under Water immersion in water tank with safety cover

Final Product Pressure and Leak Test: Dry air plus halogen leak detector

Process Fluids: All process fluids used during manufacture and testing of the heat exchangers are selected to be compatible with R-22 (or refrigerant used in the refrigeration system) and the compressor lubricant (currently POE oil for R-410A)

Many low volume equipment manufacturers choose to purchase heat exchanger components rather invest in the manufacturing facility and equipment to build them. This is especially true for aluminum micro-channel air to refrigerant slabs that are often used in cooling only condensers for unitary AC products.

3.0 Heat Exchanger Design and Manufacturing Equipment Modifications Required for Refrigerant Conversions

3.1 R-290 Pressure Related Modifications

The design pressure for R-290 is about 10% less than the design pressure for R-22 therefore pressure related heat exchanger design/or manufacturing changes will not be necessary. Current coil designs and coil qualification tests that are used for R-22 designs will be acceptable for R-290. Typically this consists of a burst test on several representative samples for each coil design. The minimum burst test pressure required is 5 times the design working pressure. For each production coil a pressure proof test is performed at 1.5 times design pressure. The lower design pressure will allow a reduction to these test pressures. This will have no impact on product or manufacturing cost. The lower design pressure may also allow a small reduction to tube wall thickness, on the order of .001”. This change could result in a tube cost reduction of several percent. Heat transfer improvement from a wall thickness reduction would be small and the impact on overall system performance would be negligible.

The only coil design changes that result in manufacturing tooling cost are design changes to minimize the frequency and severity of leaks. Joint count reduction (if possible) and improvement in header to coil tube, and distributor tube to coil tube joint designs will likely be made to mitigate risks due to the high flammability of the refrigerant. These design changes will carry a minimal capital cost for new header T-drill ($6,000 each) and distributor tube crimp tooling ($12,000 each). Production cost to add these processes to the build have not been determined but are expected to be small.

In addition, R-290 with its class A3 rating may in many cases require some system level safety related features. These will be part of the refrigerant system and will not impact the design or manufacture of the heat exchanger coils.

3.2 R-452B

The design pressure for R-452B is 50% higher than the design pressure for R-22 but 10% lower than the R-410A design pressure. Therefore pressure related heat exchanger design changes that were identified for R-410A (See section 3.4 for details) will apply directly to conversion to R-452B. In addition, R-452B has an A2L flammability rating and may require some system level safety related features. These will be part of the refrigerant system and will not impact the design or manufacture of the heat exchanger coils.

3.3 R-32

The design pressure for R-32 70% is higher than the design pressure for R-22 and 10% higher than the R-410A design pressure. Pressure related heat exchanger design and manufacturing process changes that were identified for R-410A (see section 3.4) will apply with changes to account for the higher design pressures required for equipment using R-32. The higher design pressure may require design changes such as heavier wall tubes and headers. This is not expected but if it is the case, new hairpin bender mandrels and tube expander rods would be needed. These are considered consumable items and would not be counted as a capital expenditure. R-32 has an A2L flammability rating and may require some system level safety related features. These will be part of the refrigerant system and will not impact the design or manufacture of the heat exchanger coils.

3.4 Pressure Related Considerations Common to R-452B, R-32, and R-410A

The design pressure for R-32, R-452B and R-410A are 50% to 70% higher compared to R-22. The coil design changes that are necessary to withstand these pressures are driven by governing codes and standards.

ASHRAE 15, **Safety Standard for Refrigeration Systems**, and its companion UL 1995, **Heating and Cooling Equipment**, govern product safety for end use air conditioning products in North America. The typical design pressure for R-22 coils is 450 psig, corresponding to 160 F saturation temperature. Note that the design pressure is not set by the ambient temperature for the application, but rather by consideration of temperatures that may be experienced during shipment and storage. Per UL 1995 (Clause 61) the design is required to pass a burst test with a minimum burst pressure of 2250 psig (5 times design pressure). For R-22 the coils achieved 2250 psig using the standard design and standard manufacturing methods. Employing the same test method and strength requirements to heat exchanger coils using R-410A, R-32, or R-452B would result in a minimum burst test pressure of 3900, 4050, and 3750 psig respectively. Designing coils to meet these pressures would not be practical.

An alternative fatigue test method can be used to quality coil designs for air conditioning products and is found in UL 1995 Clause 61A (Fatigue Test Analysis). For this method, 3 test samples of each design are subjected to a 250,000 cycle pressure test between low and high side design pressures for the actual application, followed by a burst test at 3 times the design pressure. This recognizes the actual system operation where pressure changes occur during cooling cycles from shutdown during the night to the hot afternoon, as well as pressure fluctuations induced by the compressor. The manufacturer has some latitude in determine the high and low pressure for the fatigue test. For R410A, after successful fatigue tests, a burst test pressure is required at 1950 psig. (3 times maximum design pressure of 650 psig -- well below the 2250 psig burst test pressure used for R-22 coils). Burst test pressures for R-32 and R-452B would be approximately 2040 psig and 1860 psig respectively. (Note that these pressures are also below the 2250 psig burst pressure generally used for R-22 coil design qualification. After initial qualification the test must be repeated at least annually, (or every 3 months if coils are considered regular production), on one sample of each coil design produced. Manufacturers of R-410A equipment have found that most existing coil heat exchangers designed for R-22 pass this test with minimal design changes, but with some feature changes. The same is expected to be the case for the design and test pressures used for R-32 and R-452B refrigerants.

The method described above is equally applicable to smooth bore tubes and internally finned coils.

Experience of manufacturers using this coil design qualification method has shown that many fatigue test failures are caused by areas of weakness that can be easily resolved either by manufacturing process improvement, design feature changes, or component quality improvement. Areas of particular importance are:

- Coil heat exchanger tubes must be free of defects such as dents and scratches. Damaged tubes will always produce a fatigue failure.
- The length of coil tubes not covered by fins must be kept to a minimum. This is particularly true for the heat affected zone in tubes outside of the coil casing that are brazed to U-bends or header stubs. The fins provide support for the tube and increase the burst strength of the tube. R-22 designs used 0.5 inches of length. This was reduced for higher pressure designs.
- Header joint designs need to include reinforcement such as saddle type or flared holes that provide sufficient overlap of material for a sound braze joint. This means that a T-drill or similar is necessary. Cost of T-drill tooling is typically less than $6000 per drill head.
- U-bends are generally purchased and it may be necessary to increase the wall thickness of these parts since they will thin during U-bend manufacture.

- The crimp joints that are sometimes used for distributor to coil attachment will not always be sufficiently strong. Designs may need to be changed to a flared end distributor or a purchased flared adapter for this joint. Tooling changes for these features are typically less than $12,000 per station.
- For headers larger than 1.375” diameter “K” wall thicknesses will probably be required. The heavier wall tube should work on up to 1.625” diameter headers. This does not eliminate the need for high quality saddle or flared header to tube joints.
- Brazing quality must be carefully controlled. Especially important are standard brazing procedures and qualification of the manufacturing technician, use of a nitrogen purge during brazing and routine inspection to insure quality. Poor brazing is the largest single source of leaks, which is the largest single warranty expense for manufacturers, and is especially problematic with higher pressure refrigerants.

Purchase or lease of fatigue test equipment that can induce rapid pressure cycles using hydraulic fluids will be direct cost associated with the changeover to any of the higher pressure refrigerants. This cost will vary depending on the size and number of testers required to support a particular facility. A ballpark cost for a multi coil test facility will be $150,000. Alternatively, an agency could purchase and install the necessary facilities for use for a group of manufacturers. In this case the service is provided as an expense, rather than a capital acquisition or lease. A single test at such a facility will be around $5000.

As previously noted in the baseline discussion, process fluids and mineral oils are carefully chosen and qualified to insure compatibility with R-22. Systems using R-452B and R-32 both use synthetic POE oils for compressor lubrication. Systems using R-290 will use mineral oil lubricant similar to the oil used in R-22 systems. Process fluids used in the manufacture of the heat exchanger coils must be chosen carefully to confirm that they are compatible with the compressor lubricant used in the system and do not cause lubricant breakdown. Lubricant breakdown will ultimately lead to premature compressor failures.

4.0 Manufacturing Facility Conversion Cost for Alternative Refrigerants

In Section 3, a summary was given of the primary manufacturing processes and tooling used to produce condenser and evaporator coils for small residential and unitary AC units. Given below is a summary of the manufacturing tooling changes that might be expected for a typical conversion. These items are applicable to all three refrigerants unless an exception is noted.

Fins: No required changes – No tooling cost

Tube Cut Off: No required changes – No tooling cost

Hairpin Bender: No required changes – No tooling cost

Coil Headers: T-drill or similar must be used. T-drill is a trade name and other alternatives exist to raise a more robust brazing collar on the header to strengthen and improve the reliability of the coil tube to header joint. T-drill heads cost approximately $6000 per drill head and can be used with the either manual or automated drilling equipment. The basic drilling equipment itself does not change. The number of drilling machines and type is widely variable depending on production volumes.

U-Bends: Purchased item – No tooling cost

Coil Structural End Plates and Supports: No required changes – No tooling cost

Coil Assembly: No required changes – No tooling cost

Tube Expansion: No required changes – No tooling cost

Headers, U-bend or Distributor Tubes: Crimping of distributor tube to coil tube estimated to cost about $12,000 per station. A station is the production facility where the work is performed, usually one per production line.

Pressure and Leak Test: No required changes – No tooling cost

Final Product Pressure and Leak Test: No required changes – No tooling cost

As mentioned in Section 3.4 heat exchanger coils designed for use with the higher pressure refrigerants (R-32 and R-452) will require a fatigue test to qualify the design and manufacturing processes. The cost for a test facility to perform this test on multiple coils is around $120,000. This facility of this size is capable of testing 3 coils in parallel with test duration for 250,000 cycles of about 1 week (150 hours). Initial qualification requires 3 coils to be tested as above. Maintaining design/manufacturing process qualification requires test of 1 sample of each design performed at least annually depending on production level. Coils in continuous production require retest every 3 months. In addition to the initial cost to purchase and install the test equipment there is a significant cost to certify, operate and maintain the equipment. For these reasons some smaller manufacturers decide to outsource the testing to a lab that provides this type of service. The cost per test at such a facility is about $5000. Doing the math and assuming some retesting is required shows an initial qualification cost per coil design of about $30,000. Annual cost to maintain qualification for a single design is between $5000. and $20,000 depending on production level.

This adds up to a total manufacturing facility change over cost per coil line for either R-32 or R-452B of around $18,000. for production tooling and $150,000. for a fatigue test facility. Alternatively, if the fatigue testing is outsourced there would be an additional changeover cost of $30,000., and an annual coil qualification cost of $5000. to $20,000. These costs are for each discrete coil design produced.

Note that the capital costs required for the manufacturing process changes (primarily the design qualification tests) for the higher pressure refrigerants (R-32 and R452B) are driven by the pressure fatigue tester. It is expected that only one of these units will be required for each coil production facility. Therefore the per unit cost will be vary inversely with product volume. The tooling required for the other manufacturing process changes (T-drill and tube crimper) that are required for all three refrigerants are low cost. The number of these systems required in a facility will be proportional to product volume. Therefore the capital cost per unit will not change significantly with volume.

Capital Cost Summary for Coil Conversions

	R-32 & R-452B	R-290	Comments
Fin press stackers, fixtures & parts	**0**	**0**	**No tube or fin changes req'd**
Fin dies	**0**	**0**	"
Hair pin tube bending tools	**0**	**0**	"
Tube end processing tools	**0**	**0**	"
Expander dies	**0**	**0**	"
Braze ring insertion tooling	**0**	**0**	"
T-drill for headers	**$6000**	**$6000**	**One req'd for each drill station**
Crimp tool for distributor tubes	**$12000**	**$12000**	**One for each distributor braze station**
Automatic pressure cycle test machine	**$150,000**	**0**	**Typically one for each plant**

5.0 Refrigerant Volume Reduction for AC Equipment using A3 and A2L Refrigerants

5.1 Regulatory Background and Direction

All three of the alternative refrigerants in this study are considered flammable. One, R-290, has a (highly flammable) A3 classification. The others, R-32 and R-452B, are classified as A2L, which is defined as having a flame speed less than 10 cm/sec. This means that these refrigerants may be difficult to ignite and sustain a flame. At present the safety codes that govern use of flammable refrigerants in occupied spaces vary wildly by locale. The two most widely recognized standards that govern the safe application or refrigeration systems are ASHRAE 15, **Safety Standard for Refrigeration Systems**, and ISO 5149, **Refrigerating Systems and Heat Pumps – Safety and Environmental Requirements.** Limiting this discussion to the occupied spaces that are served by residential split systems and rooftops, both ASHRAE 15 and ISO 5149 take an engineering approach to limit the charge and employ ignition mitigation

At this writing, ASHRAE 15 has not yet published application rules for the use of A2L refrigerants. Additionally, product standards that are published by Underwriters Laboratory (UL) have not been published. Once ASHRAE 15 is changed and UL product standards become available, it takes 1-3 years to be adopted by the model codes that legally govern the installation of refrigeration systems in North

America. Full adoption of standards that allow use of A2L is several years away. However, the process to change these standards to allow the use of A2L refrigerants is well along. The current view is that ASHRAE 15 will allow A2L refrigerants to be broadly used in all sizes of direct expansion AC systems with minimal restrictions or cost impact. Charge limits will be based on an engineering calculation that will prevent leaked refrigerant from reaching the lower flammability limit (LFL). Ignition mitigation may also be used under some circumstances.

ISO 5149 was published in 2014 and offers a three level LFL based approach for use with class A2L, A2, and A3 refrigerants. In this standard there are three charge levels calculated using LFL for the refrigerant. These charge levels are coupled with the type of ignition mitigation required. The first charge level (m_1) can be used without ignition mitigation in any size room provided the refrigeration system is sealed with no field service ports provided. The second charge level (m_2) is the maximum refrigerant charge allowed for a specified minimum room area without refrigerant detection and mechanical ventilation. If the room area requirement is met, no other ignition mitigation is required; otherwise mechanical ventilation is required in this m_2 range. This range also requires a sealed system without service ports. Above m_2 mandatory detection and mechanical ventilation is required and a maximum charge limit is set at m_3. ISO 5149 treats A2L, A2, and A3 refrigerants the same except that an additional multiplier on LFL is used when calculating the maximum charge levels for A2L refrigerants. Applying ISO 5149 to R-32 and R-452B gives refrigerant charge limits of 2kg, 12kg, and 59kg for m_1, m_2, and m_3 levels respectively. Using these charges R-32 and R- 452B could be applied w/o mitigation to split systems up to about 8kw, with minimum room size limit up to about 43kw, and with ignition mitigation up to about 215kw per refrigeration circuit. These limits will have minimal impact on application or cost of direct expansion AC products within the scope of this study.

5.2 Regulatory Impact for R-290 Applications

Presently ASHRAE 15 restricts the use of A3 refrigerants to equipment rooms only and with a maximum charge of 3kg. There are no proposals to change this.

Appling the formula in ISO 5149 to R-290 provides the following refrigeration charge limits for each level:

- 150gms maximum for no ignition mitigation but with a sealed, non-serviceable refrigeration system.
- 1kg maximum for no ignition mitigation, with minimum room size and sealed, non-serviceable refrigeration system.
- 1kg to 5kg maximum will require leak detection, mechanical ventilation, minimum room size, and a sealed non-serviceable refrigeration circuit.

Of interest is how these refrigerant change limits would impact direct expansion refrigeration system capacity for equipment using R-290. Using the above refrigerant charge limits along with current direct expansion AC system design technology and reducing the charge per unit capacity to account for the thermodynamic properties of R-290 results in the following maximum equipment cooling capacity levels:

.50kw – no mitigation, no room size limits, sealed system

3kw – no mitigation, minimum room area requirement, sealed system

Above 3kw – mitigation, room size restriction, sealed system

16kw - maximum size for R-290 AC equipment operating in an occupied space.

Design changes to the AC equipment such as use of micro-channel heat exchangers, component size reduction, and component elimination can be considered to reduce charge in an exercise to determine the maximum capacity of direct expansion systems that could use R-290 without mandatory mitigation systems. Based on discussions with one manufacturer a best case charge reduction would be 25 to 50%. Therefore the largest R-290 single circuit split system that would comply with safety standards and not require active ignition mitigation systems would be 6kw. Larger split system AC equipment would need to have multiple refrigeration compressors and circuits.

From this assessment it becomes clear that for equipment designed using current technology the practical application of R-290 will be limited to refrigerators, small bottle coolers, and small single zone mini-split AC products.

Options to expand Application of A3 Refrigerants

The obvious way to increase allowable R-290 system capacity is by charge reduction. The refrigerating effect of R-290 is about double that of R-32 and R452B. Therefore less mass flow is required for a given refrigerating effect. This, coupled with liquid and vapor density, allows charge reductions of about 50% vs. R-22 in a “drop-in” situation. Lower refrigerant flow rates allow use of smaller flow passages (smaller tube diameters) in the coils. Tube OD of 5mm for evaporators and 7mm for condensers has been tested and found to reduce system charge by an additional 25%. This works out to a charge of about 100gms per kw of cooling for a non-split (window type) AC system. This is still not low enough allow application of R-290 to the entire range of window units without some form of ignition mitigation. (Assumes the ISO 5149 charge limits for R-290). Changing tube OD also requires changing tube pitch, coil circuiting, and fin surface design. These changes require significant design work and major manufacturing tooling cost. An additional benefit of tube diameter reduction accompanied by fin surface changes is a substantial coil cost reduction. One study performed by Heat transfer Technologies shows a 40% reduction in heat exchanger cost by going from 9.5mm to 5mm tube OD.

Indirect refrigeration systems, commonly referred to as chillers, are used extensively for large capacity applications. They have the advantage of reduced charge and higher operating efficiency at the unit level but at the expense of system complexity and additional system cost. They also are typically sited outside of the occupied space and therefore may avoid some of the ignition mitigation normally required for equipment using A3 refrigerants. Overall AC system performance usually ends up on a par with a direct expansion system when energy to operate a fluid pump and efficiency degradation caused by an air to fluid heat exchanger are included in the analysis. Refrigerant charge reduction potential for indirect cooling systems is significant and would roughly double the maximum refrigeration capacities at each of the m_i limit points. Thus maximum capacities increase to 1kw, 6kw, and 32kw for m_1, m_2, and m_3 mitigation levels respectively.

6.0 High Ambient Considerations

For the purposes of heat exchanger coil physical design high ambient operating conditions do not come into play. This is because the heat exchanger coils are designed to a pressure corresponding to the highest temperature that could be encountered during shipment or while sitting idle in a hot equipment room. The saturation pressure corresponding to 160F was used for this study. This is well above any ambient operating condition likely to be encountered.

7.0 Heat Exchanger Efficiency Improvement Options

The condenser and evaporator heat exchangers that are part of all AC systems are designed using a complex process of system optimization with inputs such as refrigerant thermal and physical properties, heat transfer surface performance, material and component costs, compressor performance, and system operating conditions. The system design optimization process is performed and the output is an AC system with desired power consumption and capacity. Done correctly this process results in the lowest total cost system to achieve a desired set of performance goals.

When a new refrigerant with properties different from the original refrigerant is “dropped” into the system many of the key input parameters for the system design will be changed. The degree to which this effects the performance of the heat exchangers and how close they are to being optimized for the new refrigerant depends on how close the new properties are to the original refrigerant properties.

In general, use of a replacement refrigerant as a “drop-in” will not result in an optimized AC system and there will be opportunity for improving system performance by optimizing the design of all components including the heat exchangers.

There are several heat exchanger coil design parameters and operating conditions that can be changed to improve the performance of air to refrigerant heat exchangers for a given refirgerant. These include:

- Improving internal and/or external surface performance
    - Improving the outside surface (fin) performance by changing its geometry. (large tooling cost for new fin dies)

  - Improving the inside surface (tube) performance by enhancing the inside surface of the tube. (usually a purchased component)
  - For evaporator coils, improve the refrigerant metering and distribution system to achieve more uniform refrigerant distribution.
  - Increased air flow across the coil (higher fan power required)
  - More uniform air flow across the coil (geometry of cabinet or component placement)
- Increasing the internal and/or external surface area
  - Increasing the outside surface area by increasing the fin count. (minimal tooling change but adds to fan power)
  - Increasing the inside surface area by decreasing the tube pitch and thus increasing the number of tubes. (large tooling cost for new fin dies)
  - Coil surface increase through additional number of rows or total surface area. (small tooling cost but new design required and higher fan power)

- Improved fluid flow within each coil refrigerant circuit by “interweaving” tubes within the circuit to achieve more ideal temperature profiles on the air and refrigerant sides.
- Use of micro-channel tube/fin surfaces to greatly increase surface area to volume ratio and reduce refrigerant charge. (System redesign, microchannel coil slabs usually purchased)

The heat exchanger coils operate as part of the refrigeration system. Therefor heat exchanger coil design changes should be done as part of the system re-optimization for the new refrigerant. Merely adding surface to a coil is costly and, as approach temperatures become smaller, decreasingly effective.

8. Conclusion

The primary input parameter for structural design of a coil is maximum design pressure. Two of the alternative refrigerants under consideration, namely R-452B, and R-32, have substantially higher design pressures than R-22. The results of this study show that minimal design changes and addition of a pressure cycle test to the coil manufacturing qualification process will allow existing coil designs to be used at the higher design pressures for R-452B and R-32. The third alternative refrigerant being evaluated, (R-290), has a design pressure lower than R-22 and will therefore not require any pressure related design or manufacturing process changes.

Physical and thermodynamic properties of refrigerants determine the operating conditions and performance of the air conditioning system in which they are used. For the three refrigerants considered in this study these parameters result in significant variation between the refrigerants in system efficiency, system capacity, operating temperatures and refrigerant flow rates. These are of great importance in making a refrigerant selection for a particular type of product, and for design optimization of the heat exchanger components. However, they do not by themselves result in any required changes to the heat exchanger physical design or manufacturing processes that would require capital expenditures.

All three refrigerants have properties that allow significant charge and refrigerant flow volume reductions compared to R-22. This allows, but does not require, the opportunity to cost reduce the coil designs by use of smaller diameter tubes. The cost savings available are substantial but come with a significant capital cost for new manufacturing tooling.

All three of the alternative refrigerants in this study are considered flammable. One, R-290, is highly flammable A3 classification. The others, R-32 and R-452B, are classified as A2L, which is defined as having a flame speed less than 10 cm/sec. (This means that these refrigerants may be difficult to ignite and sustain a flame.) At present the safety codes that govern use of flammable refrigerants in occupied spaces vary wildly by locale. These standards are currently being reviewed and revised to reflect the low flammability risks associated with use of the class 2L refrigerants. For class 2L refrigerants the revisions are expected to allow use within concentration limits established for each refrigerant and risk mitigation systems required on equipment. These restrictions are not expected to cause application issues with either mini-splits or rooftop, but could increase the product cost relative to R-410a. Similar changes to ISO and IEC standards are expected to follow. The timing of these changes to the standards will align with the expected market implementation date for AC equipment using the new refrigerants.

Bottom line for R-32 and R-452B refrigerant is that they will be allowed for use in small (2kw to 5kw) split systems located in an occupied space with no mitigation in place. Larger unitary equipment (30kw to 1000kw rooftop) will be able to use the refrigerants with leak detection and mechanical ventilation mitigation required on most AC equipment in this range. There will likely be maximum charge limits per circuit but they are not expected to be an issue for application of products in this size range. Therefore charge reduction below the current charge levels is not required for AC equipment using R-32 or R-452B.

Current code restrictions for use of class 3 refrigerants in occupied spaces are unlikely to change significantly but rather will become more widely applied. These charge volume limits will restrict the application of R-290 to systems <2kw capacity without risk mitigation, up to a maximum of about 20 kw with an active risk mitigation system. The cost of the automatic risk mitigation systems have been estimated at up to 30% of the small AC unit cost. This has the effect of limiting the size of equipment using R-290 to refrigerators, small coolers and perhaps small mini-split type AC units.

ANNEX A - Capital Cost Estimate for Coil Tube Diameter Change

As stated previously in this study substitution of R-32, R-452B, or R-290 for R-22 does not by itself require any significant design changes to coil heat exchangers. However, coils designed for R-22 use larger diameter tubes than are optimal for the alternative refrigerants. In the case of R-290 a tube OD of 5mm can be used without excessive frictional pressure drop and enables significant refrigerant charge reduction (approximately 50%) and substantial material cost reduction (around 40%) compared to the

equivalent R-22 design standard coil. The charge reduction increases the maximum refrigerating capacity of a direct expansion AC system that can be used in an occupied space without exceeding a given safety standard imposed charge limit. For North America this increase is not likely to expand application of R-290 significantly but in other regions charge reduction may enable application of R-290 to small residential split systems as well as unitary AC systems. Therefore an estimate of capital costs associated with a coil tube diameter change was requested and is presented in this annex.
Changing the tube diameter for a fin and tube coil effects nearly every part of a coil and therefore all of the tooling required to manufacture those parts. Major capital equipment such as fin presses, tubing benders, material handling equipment and plant arrangement should not need to be changed. The table below lists the major items required for a tube diameter change and a rough cost for each item. The comments column provides an idea of how many duplicates of a tooling item will be required and thus an means of assessing how the capital cost scales with production volume.

Capital Cost Summary for Coil Tube Diameter Change

ITEM	Capital Cost ($000)	Comments
Fin press stackers, fixtures & parts	**50 to 75**	**One req'd for each fin press**
Fin dies	**100 to 300**	**One req'd for each tube OD and tube pitch**
Hair pin tube bending tools	**5 to 10**	**One for each tube OD and wall**
Tube end processing tools	**5 to 10**	**One for each tube expander**
Expander dies	**5**	**One for each tube expander**
Braze ring insertion tooling	**10**	**One for each braze ring insertion station**
T-drill for headers	**6**	**One for each header drill station**
Crimp tool for distributor tubes	**12**	**One for each braze station**
TOTAL (approximate)	**200 to 430**	

This does not address the development cost associated with these changes. Costs of this nature are proprietary to manufacturers and will vary greatly depending upon how the coil designs are developed or obtained. They are not considered to be within the scope of this study.