Promoting Low-GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA)

2016

Project Report

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UNITED NATIONS ENVIRONMENT PROGRAMME

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We also acknowledge the independent International Technical Review Team that assist the project team in reviewing the process, results and the report of the project. The team convened several times over a period of two years to review and approve the testing process and results as well as the findings of other PRAHA elements.

Prof. R. S. Agarwal (India- Team Chair)
Dr. Karim Amrane (Vice President, AHRI)
Prof. Abdullatif Ben Nakhi (Kuwait)
Mr. Didier Coulomb (Director General, IIR)
Dr. Alaa Olama (Egypt)
Prof. Roberto Peixoto (Brazil)

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Project Team

The Project was managed by:
Mr. Ayman Eltalouny, Programme Officer – UNEP
Mr. Ole Nielsen, Chief of Montreal Protocol Division– UNIDO

Under the supervisor of:
Dr. Shamila Nair-Bedouelle, Head of Branch, UNEP OzonAction, DTIE
Mr. Stephen Sicars, Director of Environment Department, UNIDO

Project Consultants:
Prof. Walid Chakroun – University of Kuwait
Mr. Bassam Elassaad, P.Eng. – HVAC Expert

With the assistance of:
Mehrunissa De La Cruz – Ex-UNIDO coordinator

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Acronyms

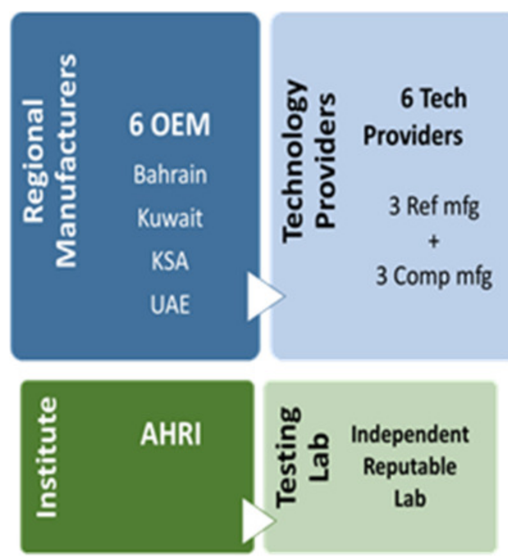
AHRI	Air Conditioning , Heating, and Refrigeration Institute
ANSI	American National Standards Institute
AREP	Alternative Refrigerant Evaluation Program
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BTU/HR	British Thermal Unit per Hour
BV	Burning Velocity
CAP	Compliance Assistance Programme
CC	Cooling Capacity
CFC	Chloro Fluoro Carbon
COP	Coefficient of Performance
DB	Dry Bulb
DC	District Cooling
DX	Direct Expansion
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EGYPRA	Egyptian Program for Promoting Low-GWP Refrigerant Alternatives
EN	European Norms (Standards)
EPA	Environmental Protection Agency (US)
GCC	Gulf Coordination Council
GWP	Global Warming Potential
HAT	High Ambient Temperature
HC	Hydro Carbons
HCFC	Hydro Chloro Fluoro Carbon
HFC	Hydro Fluoro Carbon
HFO	Hydro Fluoro Olefins
HoC	Heat of Combustion
HPMP	HCFC Phase-out Management Plan
HVACR	Heating, Ventilation, Air Conditioning and Refrigeration
ID	Indoor Unit
IEC	International Elector-mechanical Commission
IPR	Intellectual Property Rights
ISO	International Standards Organization
Kg	Kilograms
KSA	Kingdom of Saudi Arabia
kW	Kilowatts
LCCP	Life Cycle Climate Performance
LFL	lower Flammability Limit
MEPS	Minimum Energy Performance Standards
MOP	Meeting of Parties
MP	Montreal Protocol
NOU	National Ozone Unit
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substance

OEM	Original Equipment Manufacturer
PRAHA	Promoting Low-GWP Refrigerants for the Air Conditioning Sector in HAT Countries
PSI	Pounds per Square Inch
ROWA	UNEP Regional Office for West Asia
RTOC	Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee
SASO	Saudi Arabian Standards Organization
SCFM	Standard Cubic Foot per Minute
SNAP	Significant New Alternative Policy
Tdb	Dry Bulb Temperature
Twb	Wet Bulb Temperature
TEAP	Technology and Economic Assessment Panel
TEWI	Total equivalent warming impact
TF	Task Force
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USD	US Dollars
VC	Vienna Convention
VRF	Variable Refrigerant Flow
WB	Wet Bulb
WG	Working Group

Executive Summary

The 69th meeting of the Executive Committee (ExCom) of the multilateral Fund of the Montreal Protocol approved the project titled *"Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries"* which is currently has the short name of **PRAHA** with the aim to support assessing the feasibility of low-GWP refrigerants suitable for high-ambient countries and in particularly for air-conditioning applications. UNEP and UNIDO launched PRAHA in 2013 with a target of completion by end of 2014/early 2015. The project was implemented at the regional level in consultation with National Ozone Units of the Gulf Coordination Council (GCC) countries, namely Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, and the UAE plus Iraq, to ensure incorporating the project outputs within the HPMPs particularly for the preparation of post 2015 policies and action-plans. The project outcome will not only benefit the participating countries, but all regions of the world where high ambient temperatures are prevalent.

Both agencies worked with local industries, international technology providers and national ozone units in mentioned countries to do such assessment through an agreeable independent process that included in its core component building and testing of different prototypes and compare them with respective baseline units currently being produced by the local industry and mainly using HCFC or high-GWP HFC. The process of building and testing the prototypes was completed by end of 2015 and final report is due for releasing by end March 2016. PRAHA included also additional components for assessing the technology transfer barriers, energy efficiency implications and economics of alternatives in addition to an assessment of district cooling opportunities to reduce dependency on high-GWP alternatives and technologies.



Six local Original Equipment Manufacturers (OEMs) built 14 prototypes running with five refrigerant alternatives and shipped 9 other "base units' operating with HCFC or HFC for direct comparison purposes. Testing was done at 35, 46, and 50 °C ambient temperatures with an "endurance" test at 55 °C ambient to ensure no tripping for two hours when units are run at that temperature. The indoor conditions will be kept the same for all tests; dry bulb temperature of 27 ^{o}C and a relative humidity of 50 % as per AHRI test procedures for T1 conditions (35 ^{o}C), and 29 ^{o}C and 50% for T3 (46 ^{o}C and 50 ^{o}C) conditions. A memorandum of understanding (MOU) is signed with AHRI (Air-Conditioning, Heating and Refrigerating Institute) for exchanging experience on the testing methodology benefiting of AHRI relevant research project known as AREP.

The project compares the following refrigerants: R-290, HFC-32, R-444B (herein referred to as L-20), R-447A (L-41), and DR-3 to HCFC-22 or R-410A. Prototypes operating with R-290, R-444B, and DR-3 are compared with HCFC-22 as they portray similar characteristics to HCFC-22, while HFC-32, and R-447A are compared with R-410A. Testing will be done at one location for result consistency. The characteristics of the various alternatives and the reason why they were chosen for this project are included in the project report.

Below table shows the tested categories vs. the candidate low-GWP refrigerants as well as the base units for each category. The selected categories represents the majority of A/C market needs in the respective countries.

	60 Hz		50 Hz	
Refrigerant	**Window A/C** 18000 BTU/HR (5.27 kW)	**Decorative Split** 24000 BTU/HR (7 kW)	**Ducted Split** 36,000 BTU/HR (10.5 kW)	**Package A/C** 90,000 BTU/HR (26.4 kW)
HFC-32	Not Tested	Tested	Tested	Not Tested
R-444B (L-20)	Tested	Tested	Tested	Tested
R-447A (L-41)	Not Tested	Tested	Not Tested	Not Tested
DR-3	Tested	Tested	Tested	Tested
HC-290	Not Tested	Tested	Not Tested	Not Tested
Base Units				
HCFC-22	Tested	Tested	Tested	Tested
R-410A	Not Tested	Tested	Tested	Not Tested

All the prototypes in every category were built to have the same cooling capacity and fit in the same box dimensions as their respective base units, and they all should meet the minimum energy efficiency, EER, of 7 at 46 °C. Tests were performed at an independent reputable lab, Intertek; selected through competitive bidding. Verification for repeatability was performed to ensure that results are within the acceptable accuracy levels. Categories that were not tested under PRAHA were due to non-availability of components, mainly compressors, optimized for high ambient temperature conditions at the time the project started. In addition to that, other low-GWP candidate refrigerants are have been introduced to the market since start of the project; however, it was not possible to consider then due the logistical setups and non-disclosure agreements already signed for the project with each local OEM and technology provider during the initial stage of the project.

The number of tests has been decreased from 90 tests as originally envisioned to a total of 69 tests. The number of prototypes has been decreased from 30 to 23. Due to time constrains, some OEM's could not finish manufacturing their prototypes meeting above mentioned requirements on EER on time. Below table shows the total number of prototypes and tests carried out under for each category and different alternatives.

	Window	Decorative split	Ducted split	Packaged unit	Number of prototypes	Tests per prototype	Total tests
HC-290	NA	1	NA	NA	1	3	3
R-32	NA	2	1	NA	3	3	9
HFO 1	2	2	1	1	6	3	18
HFO 2	1	1	1	1	4	3	12
R-22	2	2	1	1	6	3	18
HFC base	NA	2	1	NA	3	3	9
Total					**23**		**69**

An independent International Technical Review Team was formed to assist the project team in reviewing the process, results and the report of the project. The team members are; Prof. R. S. Agarwal (India- Team Chair), Prof. Roberto Peixoto (Brazil), Prof. Abdullatif Ben Nakhi (Kuwait), Dr. Alaa Olama (Egypt), Dr. Karim Amrane (Vice President, AHRI) and Mr. Didier Coulomb (Director General, IIR). The team convened several times over a period of 2 years to review and approve the testing process and results as well as the findings of other PRAHA elements.

The key elements and findings of PRAHA can be categorized as in the flowing figure:

Technical Feasibility of low-GWP Alternatives

- *Comparison to commercially existing options i.e. HCFCs & high-GWP HFCs*
- *Relation to Energy Efficiency programs Directives*

Safety consideration and and Availbility of Materials

- *Risk assessment of A2L and A3 alternatives in industry and service*
- *Availability and cost of alternatives and components*
- *Technology transfer and IPR considerations*

Research and Development Capacities

- *Knowledge and capacity of industry to design with low-GWP alternatives*
- *Related research programs at global, regional and national levels*

Contribution of District Cooling

- Size and potentiality of district cooling applications
- Use of low-GWP or not-in-kind technologies in district cooling applications

The testing results of the four (4) tested categories under PRAHA includes detailed comparisons to different parameters with focus on comparing the performance and cooling capacity of the built prototypes compared to the respective baseline unit for each category. Building more than one prototype by different OEM, except for the package unit case, allowed the project to better understand the difference in design capabilities and capacities at OEM and extract important key findings from this exercise which beyond the original objectives of the project but turned out to be extremely crucial for the process of promoting alternatives understanding that it represents the real situation on ground.

The results from testing of each category can be summarized as follows, noting that this is not ranking of the alternatives but purely presentation of test results:

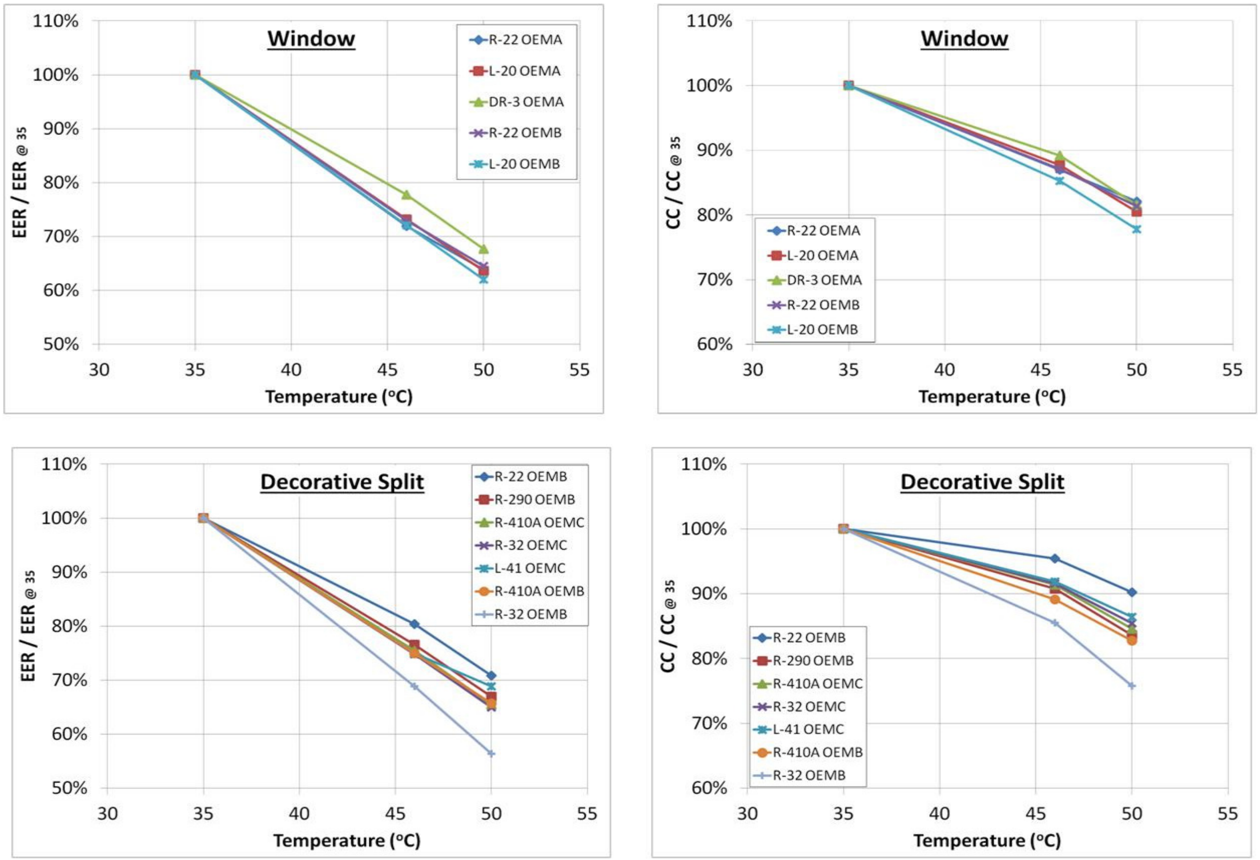
Results for the window category:

- Results from testing L-20 and DR-3 vs. a base of HCFC-22 shows that both alternatives have lower EER values than the base, but varying capacity performance with two prototypes (one L-20 and one DR-3) giving higher capacity and the other prototype using L-20 giving lower capacity;
- The decrease in EER is between 4 and 10%; and
- The degradation in efficiency and in cooling capacity at higher ambient temperature conditions for the alternative refrigerants is consistent with that of HCFC-22 averaging around 35% when the ambient temperature increased from 35 to 50 °C.

Results for the decorative split category:

- The result from testing all five refigerants (HC-290, HFC-32, L-20, L-41, and DR-3) in prototypes of this catogory showed inconsistent results for the L-20 and the DR-3 prototypes for reasons that could not be ratified at the tetsing lab. No conclusions could be drawn for the prototypes using these two refrigerants without further investigation;
- The prototype using HC-290 has a higher cooling capacity than the base HCFC-22, but similar EER; and
- The cooling capacities of the L-41 and HFC-32 prototypes were higher than the base R-410A; however, the EER was lower.

Figure below shows the EER and cooling capacity (CC) degradation for refrigerants at high ambient temperatures (percentage compared to 35 C) for the Window and Decorative Split categories.



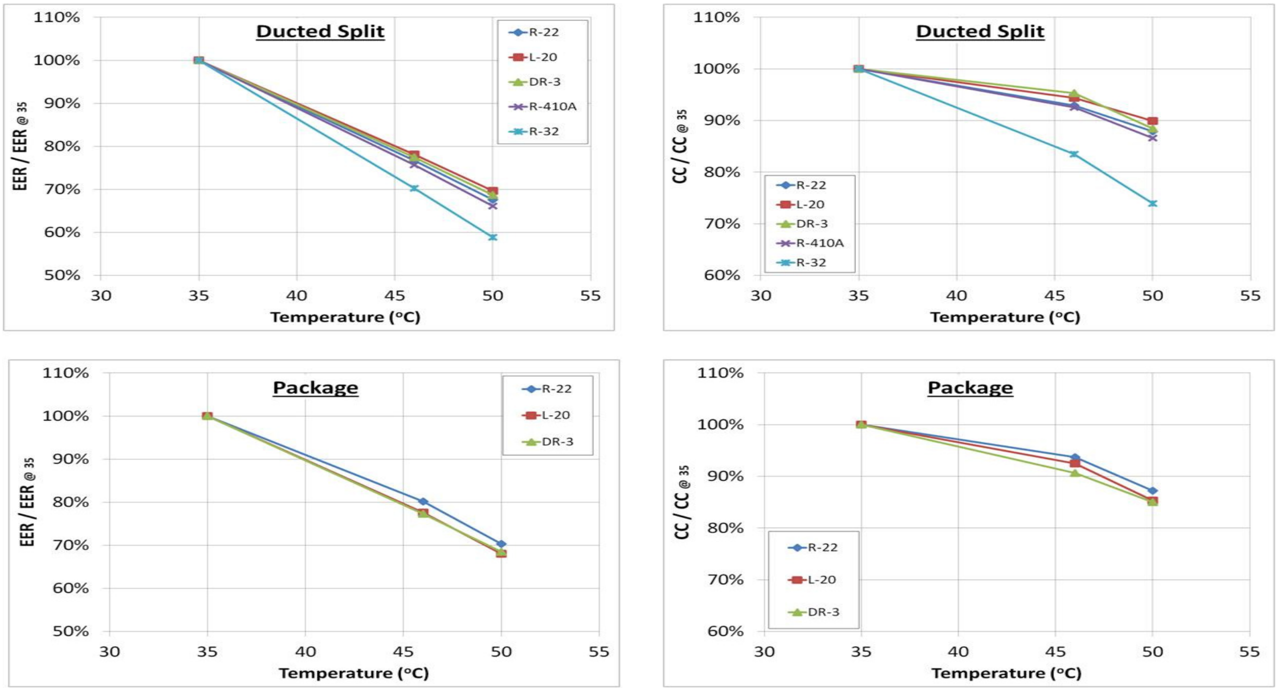
Results for the ducted split category:

- The results of testing L-20, and DR-3 shows both alternatives to have lower cooling capacity and EER than the base HCFC-22;
- HFC-32 shows similar cooling capacity and EER to those of the R-410A base; and
- L-20 and DR-3 degraded less for the cooling capacity and EER at higher ambient temperature conditions than HFC-32

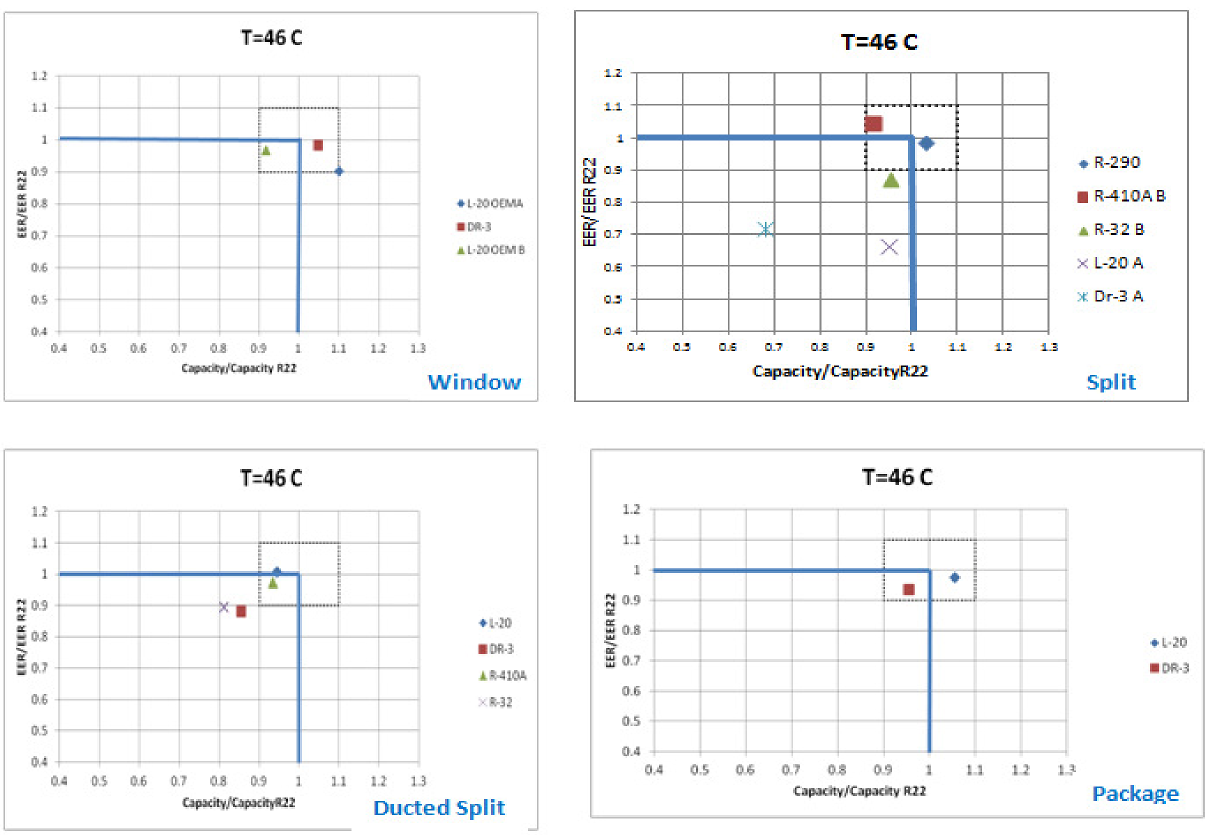
Results from the packaged unit category:

- The results from testing L-20 and DR-3 in this category vs. a base of HCFC-22 show that L-20 has a higher cooling capacity than the base, while DR-3 has a lower cooling capacity;
- The EER of L-20 is similar to the base at 35 °C but lower by 2.5% at higher ambient temperatures;
- DR-3 shows a decrease in both cooling capacity and EER vs. the base; and
- The degradation of both cooling capacity and EER at higher ambient temperatures for both alternative refrigerants is consistent to those of HCFC-22.

Figure below shows the EER and cooling capacity degradation for refrigerants at high ambient temperatures (percentage compared to 35 C) for the Ducted Split and Packaged unit categories.



The figure below plots the cooling capacity vs. energy efficiency, represented by EER, compared as a percentage to the baseline unit of each category. A +/- 10% box is drawn; indicating that alternatives that fall within the box are potential suitable candidates.



Summary results show the following key findings:

I. There are potential alternatives that have close cooling capacity and energy efficiency performance to the baseline refrigerants, or even better in some cases, and that these are worth further investigation. With further engineering, these alternatives can be strong candidates for replacement of HCFC-22 as the main focus for phase-out activities in Article 5 countries.

II. There is a significant need to improve the R&D capacity at the local air-conditioning industry in high ambient temperature countries in terms of re-designing and optimizing products using low-GWP alternatives with their specifics; e.g. flammability; excess pressures; temperature glide; excess discharge temperature etc.

III. Economical and technology transfer barriers (IPRs) will continue to be issues for some time before the international and regional markets stabilize on a limited group of candidates that can continue in business compared to the current long list of options offered and being examined.

IV. Due to the nature of future alternatives, a comprehensive risk assessment tailored to the need of A5 countries and the high ambient temperature conditions in particular. Such an assessment needs to address the dimensions of manufacturing, placing into market, servicing and the end of life of the equipment.

V. There is a lack of institutional programs that are addressing alternative technologies and reducing dependence on high-GWP alternatives in high ambient temperature countries. The market direction in going to the commercially available options is a reflection of such limited research.

VI. The process of improving energy efficiency (EE) standards for air-conditioning application in high ambient temperature countries is progressing in much quicker pace compared to assessing alternative refrigerants. Smart approach needs to be considered in addressing EE in conjunction with low-GWP alternatives in order to avoid promoting higher-GWP alternatives that are commercially available at this stage of time.

Other PRAHA Component: District Cooling Assessment Study

PRAHA included another regional dimension addressing the potentiality of District Cooling (DC) systems, using low-GWP and/or non-vapor compression options, as long term energy efficient solutions. The resources offered for this component was limited and allowed only a desk analysis compiling information, market analysis and experts views from several reliable sources as well as organizing a dedicated District Cooling Symposium for industry and relevant governmental authorities in the region.

The study found that as at 2012, 14% of the estimated total installed air conditioning systems in the Gulf Cooperation Council countries are DC systems 45% of which are serving the residential sector and 31% the commercial sector. Air conditioning system installations are estimated to double by the year 2030 and if all systems are built the conventional way, the power requirement will be increased by 60% equivalent to 1.5 million barrels of oil per day. DC systems consume less energy than conventional air conditioning systems and reduce power demand by 50 to 87%.

DC projects in high ambient countries are mostly using conventional technologies due to the lack of willingness by technology providers or suppliers to promote the use of low-GWP refrigerants or non-vapor compression technologies. The global pressure on phasing-down F-gases there might provide an opportunity to start promoting such concepts.

Summary

In conclusion, the results from the packaged unit tests were better than those for smaller units indicating that the capacity of the air conditioner matters: the larger, the better the result due to ability to utilize more advanced components such as electronic expansion valve (instead of capillary tube) or having less restrictions on the size of the condenser and; hence optimize the product for the alternatives. However, the challenging part is that there are still commercial limitations to advance the use of flammable refrigerants, either A2L or A3, in larger size units due to safety and standards considerations.

The other major conclusion is that units using R-410A are more advanced that those using HCFC-22 or its equivalents, this is understandable given that the development of HCFC-22 units has stopped since 2010, while that of R-410A is still ongoing.

The project contributed to the understanding of the needs of HAT countries in the field of technology transfer. The main findings from the project is the need for a full product redesign taking into consideration the requirements for HAT conditions, but that the components for these products meeting the special requirements also needs to be developed and made commercially available. The technology for these components is presently concentrated in few countries and there are issue with intellectual property rights and patents. The economic impact of the alternative refrigerants is still not fully understood; moreover, there are still areas that require further work in order to ensure putting the process of alternatives on the right track

The main outcome of PRAHA is that it went beyond the level of being an individual project with specific planned objectives and outputs, PRAHA turned to be a **PROCESS** being ongoing now at different levels i.e. governmental, local industry, institutional as well as international technology providers. The activities and projects that are, currently, being implemented to address alternatives for high ambient conditions are many and they were all triggered by the PRAHA process which started in 2012, and are following, more or less, similar approach. Summary of relevant international and individual initiatives and research projects is included in the project report.

Chapter 1

1. Introduction

Hydrochlorofluorocarbons (HCFCs) are ozone-depleting substances and, under the terms of the Montreal Protocol, the production and consumption of HCFCs will be completely phased out worldwide in 2040. In September of 2007, the Parties to the Montreal Protocol agreed to accelerate the phase-out schedule for HCFCs in developing countries. The Parties agreed to reduce HCFC consumption in developing countries to include freeze consumption levels, based on average of 2009-2010, in the year 2013 followed by cuts in that level by 10%, 35%, 67.5% & 97.5% for the years 2015, 2020, 2025 & 2030 respectively allowing 2.5% to continue during the period 2030 - 2040 as service tail which will be further assessed and modified in 2025 by Parties to the Montreal Protocol.

At the 19th meeting of parties to the Montreal Protocol, Parties took Decision XIX/8 "to request the Technology and Economic Assessment Panel to conduct a scoping study addressing the prospects for the promotion and acceptance of alternatives to HCFCs in the refrigeration and air-conditioning sectors in Article 5 Parties with specific reference to specific climatic conditions and unique operating conditions in some Article 5 Parties". The request was in response to concerns raised by several parties about the availability of viable HCFC alternative in air-conditioning applications particularly in high-ambient temperature regions.

Parties to the Montreal Protocol, in their 21st meeting, adopted another decision concerning HCFCs and environmentally sound alternatives. The decision calls for further assessment and support work to enable parties to find the best ways of moving forward particularly those with forthcoming compliance targets related to consumption of HCFC in the air-conditioning sector.

HCFCs are used extensively in the refrigeration and air conditioning industry, in particular in the air-conditioning industry. During the preparation of the HCFC Phase-out Management Plans (HPMPs) in West Asia, industry representatives introduced their concerns and worries of meeting the freeze and reduction targets where alternatives to HCFC-22 in small/medium size air-conditioning applications not yet introduced and verified by local markets. Additionally, governments started to apply new minimum energy performance requirements for placing air-conditioning units into markets which will disqualify most of the commercially available alternatives at current level of development.

On the other hand, the continuation of higher GWP HFCs, which have been promoted as alternatives to CFC & HCFC over the last two decades, is currently being debated due to their contribution to the global warming, both directly and indirectly through higher power consumption due to their inefficiency at certain conditions. These alternatives may not be the best efficient alternatives for many air-conditioning applications particularly in high-ambient operating conditions.

1.1. Montreal Protocol related to High Ambient Temperature conditions

The main challenges to the promotion of low-GWP alternatives in high ambient temperature countries can be summarized as follows:

- Unclear global trend about the suitability of refrigerant alternatives for each category of application specifically since the performance and efficiency of HVAC systems running with alternative refrigerants is still not clearly determined when operating at high ambient temperatures. This challenge has become accentuated by the new and higher minimum energy efficiency performance standards (MEPS) that are coming into effect with immediate applicability;
- Unavailability of components, mainly compressors, that work with low-GWP alternative refrigerants and designed for high-ambient conditions coupled with the expectation for a significant cost implication when adopting low-GWP alternatives to residential and small commercial products;
- Absence of national/regional codes & standards that can facilitate the introduction of low-GWP alternatives and deal with their flammability characteristics.

This situation is leading the future of air-conditioning industry in those countries to uncertainty and vagueness and putting a burden on an important sector in the region. The challenge for the HVAC&R industry is to prepare for the orderly transition from HCFC refrigerants into the many alternatives offered in the refrigeration marketplace. The future refrigerants should not only provide cooling at difficult conditions, but have a substantial benefit for the environment.

UNEP and UNIDO are implementing together all HPMPs in West Asia countries with high-ambient temperature characteristics. Both agencies wish to ensure the correct selection and adoption of long-terms options that ease the implementation of the first stage and facilitate the preparation of subsequent stages and tranches with a clear picture on the way forward.

1.2. Project Objective

UNEP, in collaboration with UNIDO, launched a project to study and compare refrigerants working in air conditioners specifically built for those refrigerants and operating at high ambient. The project, *"Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries"* with the acronym **PRAHA** was launched in 2013 with a target completion in 2015. The project was implemented at the regional level in consultation with National Ozone Units of the Gulf Coordination Council (GCC) countries, namely Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, and the UAE plus Iraq, to ensure incorporating the project outputs within the HPMPs particularly for the preparation of post 2015 policies and action-plans. The project outcome will not only benefit the participating countries, but all regions of the world where high ambient temperatures are prevalent.

The main objective of the project is to shed light into what can be considered as sustainable technologies for high ambient temperature countries. The proposed work was planned to facilitate the technology transfer and experience exchange of low-GWP alternatives for air-conditioning

applications operating in high-ambient temperature countries. The other indirect objectives that will be facilitated through the implementation of the project are:

- Support technical and policy decisions about long-term alternatives to HCFC in air-conditioning industry as part of the HPMP overarching strategies being implemented by most concerned countries.
- Encourage the development of local/regional standards that ease the introduction of alternatives that need special safety or handling considerations
- Sharing of information about demonstration projects, implemented by other bilateral and implementing agencies, amongst the concerned parties.
- Ensure that national and regional energy efficiency programs are linked to the adaption of long term alterative particularly the selection of low-GWP options as feasible.

Six local Original Equipment Manufacturers (OEMs) built 14 prototypes running with five refrigerant alternatives and shipped 9 other "base units' operating with HCFC and HFC for comparison purposes. Testing was done at 35, 46, and 50°C ambient temperatures with an "endurance" test at 55°C ambient to ensure no tripping for two hours when units are run at that temperature.

The project compares the following refrigerants: R-290, HFC-32, R-444B (herein referred to as L-20), R-447A (L-41), and DR-3 to HCFC-22 and R-410A. Prototypes operating with R-290, R-444B, and DR-3 are compared with HCFC-22 as they portray similar characteristics to HCFC-22, while HFC-32, and R-447A are compared with R-410A. Testing will be done at one location for result consistency. The characteristics of the various alternatives and the reason why they were chosen for this project are mentioned in this report.

1.3. Project Components

The project is designed to achieve the above-mentioned objectives allowing countries with high ambient temperature conditions to comply with the Montreal Protocol targets and smooth the transfer to long-term Low-GWP options at industry level through a careful and comprehensive approach to ensure the sustainability of adopted solutions and technologies. A comprehensive approach needs to take into consideration key elements that are important to the success of the project. These components and their description are found in the annex.

1.4. PRAHA Prototype Testing Project Definitions & Components

1.4.1. Temperature considerations

The Technology and Economic Assessment Panel (TEAP) added a definition of HAT to the Sept 2015 update of the XXVI/9 Task Force report (TEAP 2015)

"A high ambient temperature can be defined as the incidence over a number of hours per year of a certain temperature. If this temperature is set above the standard ambient of 35°C, the question becomes at what incidence this occurrence will be considered to constitute a high ambient condition. HAT countries could then be defined as the countries where a certain percentage of the population lives in areas where the HAT conditions are prevalent.

The industry defines values of ambient dry bulb, dew point, wet bulb temperature, and wind speed corresponding to the various annual percentiles of 0.4%, 1%, 2%, and 5% that are exceeded on average by the indicated percentage of the total number of hours in a year (8,760 hours). These values correspond to 35, 88, 175, and 438 hours per year respectively, for the period of record. The design values occur more frequently than the corresponding nominal percentile in some years and less frequently in others.

"While normally systems are designed for 35°C (T1 in ISO 5151:2010) with appropriate performance (cf. standards requirements) up to 43°C; in some countries, the high ambient temperature condition requires a design at 46°C (T3 in ISO 5151:2010) with appropriate operation up to 52°C."

An example of temperatures in Kuwait is given below (Chakroun 2014):

- Maximum sun radiation temperature (black bulb temperature) in summer: 84°C;
- Maximum ambient temperature in summer: 52°C;
- Maximum relative humidity: 100% at 30°C;
- Annual daily maximum (mean) dry bulb: 49.4°C.

1.4.2. Challenges of HAT operation

Higher ambient temperatures lead to higher compression ratio & discharge temperatures resulting in poor performance & shorter life of air conditioning equipment; moreover, the governing thermodynamic properties and principles result in a declining capacity and efficiency for all refrigerants as the heat-rejection (refrigerant condensing) temperature increases, including HCFC-22. However, some of the HCFC-22 replacements exhibit greater degradation in capacity and efficiency than HCFC-22 under high ambient conditions (UNEP 2015).

A major concern in some regions is the efficiency of the various alternatives to HCFC-22 in high ambient conditions, particularly R-410A which is the most common alternative.

1.4.3. Safety considerations of flammable refrigerants at HAT

Current low-GWP alternatives suitable for air conditioning applications are either classified as A2L (mildly flammable) or A3 (highly flammable). Hence, high ambient operation requires added consideration when it comes to safety. Some of the issues related to safety:

- A major issue is the possible impact on required refrigerant charge, where hotter regions can imply greater heat loads, larger system capacity, for the same floor area, and thus larger refrigerant charge; limits on refrigerant charge may be approached at smaller capacities, where additional (safety) measures would then have to be applied to the equipment. Systems using low-GWP refrigerants are not currently available for large capacity systems in high ambient temperature regions.

- Technical knowledge: The current low-GWP options require a significant technical background to implement, particularly in high ambient temperature countries;

- Regulation and standards: Since most of the alternatives available or that are being developed are flammable, to various degrees, standards have to be put in place before the refrigerants are placed on the market in large quantities;

- Flammability definition: ISO 817 and 5149 as well as ASHRAE standards 15 and 24 define the flammability categories and the application limits of refrigerants. Achaichia (2014) demonstrated how different regions however define the flammability of the various refrigerants differently for transportation purposes. This can affect the import regulation of refrigerants and impose unneeded delays of putting the new ones into the market:

- High pressure: dealing with higher pressure refrigerants take an extra importance in high ambient temperatures.

- Certification of personnel: As in the case of the European F-gas regulation, persons carrying out the installation, servicing, maintaining, repairing or decommissioning of equipment need be certified by an accredited body. This regulation is intended for refrigerant leak management which contributes to the safety of equipment operation. The regulation also applies to persons delivering or receiving refrigerants.

1.4.4. Air conditioning applications in HAT countries

A large part of air conditioning is in small and medium capacity units ranging in application from window units to decorative split systems and packaged rooftop units. Equally, central systems using large chilled water systems are also gaining grounds with several new developments in the GCC using district cooling systems that save energy through focusing the cooling capacity of large chillers where cooling loads are needed.   The Gulf States have an estimated bank of about 30 million small and medium capacity air conditioning units installed, with a couple of million added or replaced every year (Elassaad 2014). Older units leak more and require periodical re-charging, which adds to the refrigerant consumption of these countries.

It is for small and medium capacity air conditioners that solutions are mostly needed. These units now mostly use HCFC-22, but are slowly shifting towards R-410A because of lack of solutions.

1.4.5. Selection of refrigerants for PRAHA project

The Technology and Economic Assessment Panel (TEAP 2015) updates information on alternatives to ozone-depleting substances in various sectors and sub-sectors based on the certain criteria and describes the potential limitations of their use and their implications for the different sectors, in terms of, but not limited to, servicing and maintenance requirements, and international design and safety standards.

PRAHA assessed the refrigerants to be tested based on the same criteria adapting the limitations to the constraints of HAT conditions and market drivers in the six GCC countries with high ambient temperatures. Since the selection was made in 2013, other refrigerant have been introduced, and other manufacturers came forward willing to participate. Some of these refrigerants were included in the EGYPRA project, while others might needed to be further examined in a potential future phase of this project.

The selection of the refrigerants was based on the following aspects which are derived from decision XXIII/9 of the Meeting of Parties (MOP)   More discussion on this subject is found in chapters 3 and .

i. Commercially available;
ii. Technically proven;
iii. Environmentally sound;
iv. Economically viable and cost effective;
v. Safety consideration;
vi. Easy to service and maintain.

1.4.6. Selection of categories for the PRAHA project

The factors affecting the choice of which category or application to test have to do with both current and future market trends as well as the availability of the units from the local manufacturers. As can be seen from section 2.3.6 the high ambient countries have a large base of installed small and medium size residential and commercial units. These units are direct expansion (DX) units with only a primary fluid used in the system and range in capacity between 1.5 to 15 tons (5 to 50 kW). The region still uses IP units and hence reference to these units, with an equivalent SI unit system, will be made throughout the report. The following is a review of the factors that affected the choice of categories:

- **Number of installed units:** PRAHA relied on the market surveys that were conducted in the region as part of the HPMPs. As an example, a study of the installed units in the Kingdom of Saudi Arabia (KSA), showed an estimated installed base in 2010 of around 15 million units in the residential and light commercial categories up to 30 tons (105.5 kW), 99% of which were below 15 tons (50 kW).

  The balance of the Gulf Coordination Council (GCC) countries, GCC constitute the majority of the world's usage of air conditioning units operating at high ambient, make up about 40% of the GCC number of units installed with KSA having the balance 60%. KSA electrical current is 60Hz frequency, while the other GCC countries are 50 Hz. A balance between units operating at 50 Hz and 60 Hz was therefore required.

- **Market growth trends:** The GCC has one of the fastest-growing populations in the world. By 2020 this population is forecast to increase by one-third, to 53m people. The robust population growth, together with the region's affluence and its abundant natural resources, point to continued strong market demand (Economist 2009). The GDP growth is expected to be around the 3.3 - 3.4% for 2015 & 2016, a percentage point above the advanced economies forecast (IMF 2015). To cater for the population and activity growth, 115 million m^2 of built space was planned in 2013 in Saudi alone (MOMRA 2013), 75% of which is residential and light commercial all requiring air conditioning, mostly below 50 kW.

- **Standards and Regulation:** The development of new MEPS is the GCC starts with appliances and develops into units under 5 tons (17.5 kW) before progressing into larger units. Case in point, Saudi regulation SASO 2663/2012 for units below 5 tons was drafted and discussed in 2012 and now is in force, while the regulation for larger units is being

drafted in 2015. This is due to the proliferation of the smaller capacity air conditioners and the need to regulate their energy consumed by them as a first step.

- **HPMP:** In most of the high ambient countries of the GCC, 2015 marks the start of the second tranche of the first phase of the HPMP. Typically, the first phase-out target was met by concentrating on the foam sector for which solutions are readily available. The second tranche, as well as the second phase, tackle HCFC-22 staring with the manufacturing sub-sector. In Bahrain, manufacturing constitute 80% of the consumption of the country and most of it is for the production of small and medium size air conditioners. This requires finding alternative technologies to be available for this category of air conditioners as soon as possible.

- **Trends in manufacturing and import:** All local manufacturers produce DX units with some manufacturing chilled water units. The region is the largest producer of window units due to the local demand**.** To date, local manufacturers have relied on HCFCs which is the majority of their production. Due to the HCFC phase-out as well as the imposition of new MEPS, some manufacturers are now slowly changing into HFCs (407C & 410A). Importers follow their source market: U.S uses R-410A, Japan is starting to use HFC-32 specifically for Variable Refrigerant Flow units (VRF); while China is moving towards HC-290. There is no clear leader in the residential business in the region to set the trend, hence all options remain open for the choice of the alternatives.

Given the above factors, and after consultation with the stakeholders and the National Ozone Units (NOU) of the participating countries, PRAHA adopted four categories in two electrical characteristics:

- Window unit 18,000 BTU/HR = 1.5 tons (5.2 kW) 208-230/60/1
- Decorative, (or mini-split) 24,000 BTU/HR = 2 tons (7 kW) 208-230/60/1
- Ducted split 36,000 BTU/HR = 3 tons (10.5 kW) 220-240/50/1
- Packaged rooftop unit 90,000 BTU/HR = 7.5 tons (26.4 kW) 380-415/50/3

1.4.7. Stakeholders of the PRAHA project

The project methodology showing how the present stakeholders came to participate in the project is detailed in section 2.5. There was no selection process for the stakeholders, all were invited and welcomed to participate. Those who chose not to participate did that for their own reasons and not because they were excluded. Effort was made to give several notices, both in writing and through verbal communication, to those who initially showed interest and then changed their mind about active participation, before removing them from the list of project stakeholders.

The project was open to all OEMs in the countries that were targeted by the project, the only limitation being their ability to design and build a prototype which automatically excluded unit assemblers, if any. The project also called on all refrigerant and compressor manufacturers, both physically present as marketing entities in the countries targeted by the project and those supplying to it from their home bases.

Chapter 2

2. Testing Methodology and Verification

During the preparation of HCFC Phase-out Management Plans (HPMPs) in West Asia, air-conditioning industries expressed their concerns of meeting the freeze and reduction targets, as set by the Montreal Protocol, where alternatives to HCFC-22 in small/medium size air-conditioning applications suitable for high ambient temperatures are not yet introduced and verified by local markets in the region. The current commercially available technologies, used as replacement for HCFC, not only perform less efficiently at high ambient conditions but also possess high-GWP characteristics which do not provide the HCFC phase-out programs in this sector a sustainable dimension. This exceptional project is designed to answer some of the challenges related to the availability of long-term low-GWP alternative refrigerants and their associated technologies including final products, components and accessories in high-ambient temperature countries.

The Executive Committee of the Multilateral Fund of the Montreal Protocol approved PRAHA, assessment project proposed by UNEP/UNIDO to shed light into sustainable technologies for high ambient temperature countries. The proposed work includes building prototypes of air conditioning units in four product categories, and testing them at different ambient conditions to examine their performance (cooling capacity and energy efficiency). The prototypes will be built after a cooperation as required between the OEM's and the technology provider to ensure that design and the manufacturing of the prototype is of high quality. All the prototypes and the baseline units should have a minimum EER of 7 at 46°C and dimensions that are commercially viable and similar to baseline units as per the agreement between the PRAHA project and each manufacturer.

The four categories include window air-conditioner, decorative split, ducted split and package air-conditioning. In the previous section, justification on the choice of these categories was provided.

The objective of this section is to summarize the theoretical performance of the various HCFC-22 options for high ambient air conditioning applications (above 40 °C). The governing thermodynamic properties and principles result in a declining capacity and efficiency for all refrigerants as the heat-rejection (refrigerant condensing) temperature increases, including HCFC-22. However, some of the HCFC-22 replacements exhibit greater degradation in capacity and efficiency than HCFC-22 under high ambient conditions. Currently, the most widely applied replacements for HCFC-22 in unitary air conditioning applications are HFC blends, primarily R-410A and R-407C. Hydrocarbons are also being used in some low refrigerant-charge applications in some countries. This material summarizes the information in Decision XIX/8:

Alternatives to HCFCs at High Ambient Temperatures:

R-410A and R-407C both have lower critical temperatures than HCFC-22. This occurs because HFC-125 (a component of both R-407C and R-410A) has a comparatively low critical point temperature of 66.0°C (150 °F) and would therefore be extremely inefficient if used in systems, unless the condensing temperature was very low. The critical point temperature is important because refrigerants having a low critical point temperature will exhibit a steeper decline in capacity with increased ambient (outdoor) temperatures than refrigerants having higher critical point temperatures. This steeper decline in capacity is of particular importance in geographic regions, which have cooling design temperatures approaching the critical point temperature of the refrigerant.

The evaporator coil design should be reselected/re-designed to adopt the new pressure and pressure drop characteristics at high ambient conditions for the replacement refrigerants. Also the tube diameter can be reduced to enhance the heat transfer for the evaporator coils; typically using ¼ inch OD tube diameters

will enhance the performance and can bear higher pressures for high pressure refrigerants like R-410A and HFC-32.

The condenser coil design should also be reselected/re-designed to accommodate the new pressure drop characteristics for the replacement refrigerants. Micro channel aluminum coils can be used in order to enhance the heat transfer and to reduce the condensing temperature at high ambient conditions, whilst larger condenser coils and special condenser fans also can be used to reduce the condensing temperature at high ambient conditions. Controlling the sub-cooling by using condensers with dedicated sub-cooling circuits is vital in high ambient conditions to enhance the efficiency (Qureshi et al., 2012). In case of R-290, the condenser coil could utilize smaller tube diameter; since this has a significant effect on charge reduction; which is critical for highly flammable refrigerants.

The effect of ambient temperature on system capacity and efficiency with performance dropping and power consumption increasing resulting in reduced efficiency as shown Figure 2.1. The efficiency decrease is different for different types of refrigerants depending on the critical temperature of the fluid. The critical temperature of a substance is the temperature at and above which vapor of the substance cannot be liquefied, no matter how much pressure is applied.

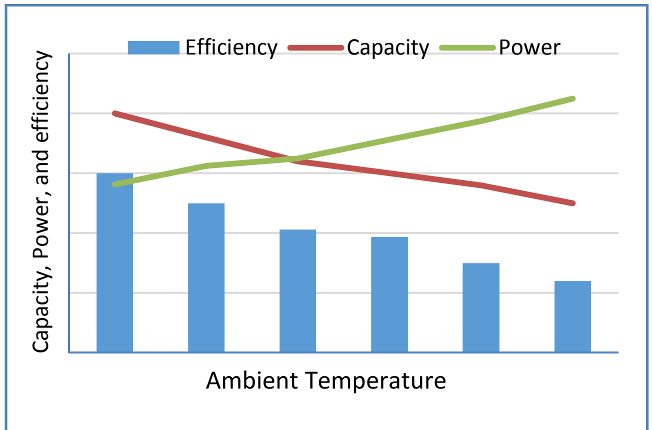


Figure 2.1: Capacity, power & efficiency vs. Temp

The higher the critical temperature, the higher the net cooling capacity with lower power input resulting in higher efficiency at high ambient temperatures (see Figure 2.2 showing the critical point). The critical temperature of HCFC-22 is 96.2 °C while that of R-410A is 72.8 °C. This is one of the reasons why HCFC-22 is more efficient at higher ambient than R-410A.

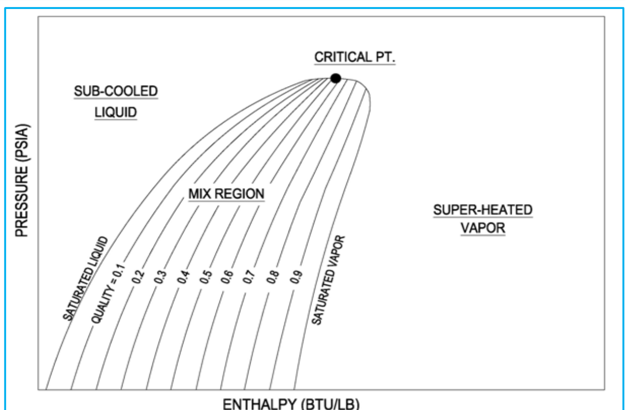


Figure 2.2: PH diagram and critical point

2.1. Relevant Research

The scope of PRAHA is to assess the available alternative refrigerants at high ambient temperatures. In the previous sections, it was discussed how the term "high ambient temperature" is misunderstood by many researchers and its definition is not clear and may vary from place to place.

In order to assess available technologies, a literature survey has been established here and included in Annex D to better understand the availability of current and long-term commercially available refrigerants and air-conditioning equipment, in terms of their suitability to operate in high-ambient conditions. Lots of studies have been performed to assess refrigerants and system performance at temperatures below 35 °C. Very limited work however dealt with high ambient conditions and the assessments presented in those research were not done in a systematic and coherent way.

Coinciding with the PRAHA research on testing alternative refrigerants, two other international research programs have been launched and completed: Low-GWP Alternative Refrigerant Evaluation Program (AREP) by the Air Conditioning, Hearting, and Refrigeration Institute (AHRI), and the Oakridge National Laboratory (ORNL) program. The Egyptian Program for Promoting Low-GWP Refrigerant alternatives (EGYPRA) is an on-going research which is scheduled to be finalized by the end of 2016.

Table 2.1 Comparison of the four research projects (AREP, ORNL, EGYPRA, and PRAHA)

	Low-GWP AREP (AHRI) AREP-I & AREP-II	**ORNL - DOE Evaluation Program**	**EGYPRA (UNEP, UNIDO, Egypt)**	**PRAHA-I (UNEP, UNIDO, High Ambient Countries)**
Type of test	Soft-optimization and drop-in tests of **several A/C, Heat Pumps, and Ref applications**	Soft-optimized tests, of **Two (2) base Split A/C units**	Build and test **36** prototypes **in 3 A/C split and one A/C package categories**	Build and test **23** prototypes **in one Window, 2 A/C split and one A/C package categories**
Status	**started 2014 and completed**	**Started 2015 and completed**	**Started in 2015 and planned to be completed by 2016**	**Started 2013 and completed**
Testing	Units soft optimized and tested at each party's facilities	The 2 units were optimized and tested at ORNL	Prototypes built at eight OEMs, test at NREA (local test laboratory in Egypt)	Prototypes built at seven OEMs, test at Independent Lab
Refrigerants tested	R-1234yf, R-32, D2Y60, L-41a, D-52Y, ARM-71a, DR-5A, HPR-2A, L-41-1 and L-41-2	HFC-32, HC-290, HFC/HFO Blends. 4 types vs. HCFC-22 HFC/HFO blends (4 types) vs. R-410A	HFC-32, HC-290, HFC/HFO Blends. 3 types vs. HCFC-22 HFC/HFO blends (3 types) vs. R-410A	HFC-32, HC-290, HFC/HFO blends 2 types) vs. HCFC-22 HFC/HFO blend vs. R- 410A
Other components	**N/A**	**N/A**	**N/A**	**Several other assessment elements**

2.2. Assessment of Technical Options

The Refrigeration Technical Option Committee (RTOC) in their 2014 Assessment report of the Refrigeration, Air Conditioning and Heat Pumps provided the results of theoretical refrigerant performance calculations for various alternative refrigerants at elevated condensing temperatures, when compared against HCFC-22 at a reference condition of 40°C.

R-410A in High Ambient Applications

R-410A systems have been demonstrated to operate acceptably at ambient temperatures up to 52 °C. However, the performance (capacity and efficiency) of R-410A air-conditioners degrades more rapidly than HCFC-22 systems at high ambient temperatures (above 40 °C).

The optimum selection of compressor, airflow, and condenser design and expansion device can reduce the performance losses at high ambient temperatures. Even with optimized designs, when applying R-410A systems that will operate a significant number of hours at high ambient temperatures, the system designer should take into consideration the reduced high ambient capacity when sizing the equipment.

HC-290 in High Ambient Applications

HC-290 has performance characteristics similar to HCFC-22. The characteristics are close enough that the current products that employ HCFC-22 could be re-engineered to employ HC-290. HC-290 has successfully been demonstrated as an HCFC-22 replacement in low charge, room and portable air-conditioners applications. IEC standard 60335-2-40 has established the criteria for determining the maximum charge limit for flammable refrigerant applications. This standard also establishes mechanical and electrical design requirements and maximum charge limitations for flammable refrigerants. Safely and cost effectively applying hydrocarbons to larger unitary systems will be a significant technical challenge.

R-407C in High Ambient Applications

R-407C systems will typically perform in nearly the same way as HCFC-22 systems at typical ambient temperatures. At ambient temperatures above 40 °C, R-407C systems show less degradation of capacity and efficiency than R-410A systems. Since R-407C refrigerant requires only modest modifications to existing HCFC-22 systems, it has also been used as a transitional refrigerant in equipment originally designed for HCFC-22. There are currently R-407C air conditioning products widely available in Europe, Japan and other parts of Asia.

HFC-32 in High Ambient Applications

HFC-32 is being considered as an alternative to R-410A. HFC-32 will have higher efficiency and capacity at high ambient temperatures. It has a GWP approximately 32% that of R-410A and exhibits better high ambient performance than R-410A. However, it has an A2L flammability, which will need to be addressed in the design and application of the product using appropriate safety standards. Also, HFC-32 is characterized by its high discharge temperature; which in particular high ambient temperatures would require attention and potentially also require a special lubricant.

HFC Replacements for High Ambient Applications

Alternatives to high-GWP HFC refrigerants for air-conditioning applications are in the early stages of development. A number of new refrigerants are being investigated to replace R-407C and R-410A, including HFC-1234yf/HFC-1234ze and blends of other HFC refrigerants with HFC-1234yf/HFC-1234ze. While refrigerant manufacturers are believed to be working to qualify other chemicals or blends that might be new, their development has not progressed to the point where they are available to unitary equipment manufacturers for evaluation and equipment development. Therefore, it is premature to recommend alternatives to R-410A or R-407C at this early stage of the development other than HC-290, which may be applicable in low charge applications when appropriate safety and application requirements are considered.

2.3. Refrigerant Selection

From the summary of Decision XIX/8 and after looking at all available research on alternative refrigerant, HC-290, HFC-32, L-20 (now known as R-444B), L-41 (now known as R-447A), and DR-3 were selected. The selection procedure was based on refrigerant availability at the time we started the project, low GWP, and

expected high performance. The L-20 has now acquired an ASHARE R number; R-444B and the L-41 is now known as R-447A, however they both will be continued to be referred to herein the report by their research name.

The tested refrigerants and their compositions are listed in Table 2.1 Table 2.2 shows the prototype categories and the proposed refrigerants for testing. The shaded parts indicates that no prototype will be developed under this category.

Table 2.2: List of selected low GWP refrigerant

Base line	Refrigerant	Composition (% by mass)	Classification[1]	GWP[2]
HCFC-22	L-20 (R-444B)	HFC-32/R-152a/R-1234ze(E) (41.5%/ 10%/ 48.5%)	A2L	331
	HC-290	HC-290	A3	11
	DR-3	///	A2L	148
R-410A	HFC-32	HFC-32	A2L	675
	L-41 (R-447A)	R-32/R-125/R-1234ze(E) (68% /3.5%/28.5%)	A2L	583

1. Refrigerants' classifications as per ASHRAE Standard 34 (ASHRAE, 2013).
2. Estimated GWP values from chemical producers

Table 2.3: Low GWP refrigerants for the selected categories

	60 Hz		50 Hz	
Prototypes				
Refrigerant	Window A/C	Decorative Split	Ducted Split	Package A/C
HFC-32	Not Tested	Tested	Tested	Not Tested
L-20	Tested	Tested	Tested	Tested
L-41	Not Tested	Tested	Not Tested	Not Tested
DR-3	Tested	Tested	Tested	Tested
HC-290	Not Tested	Tested	Not Tested	Not Tested
Base Units				
HCFC-22	Tested	Tested	Tested	Tested
R-410A	Not Tested	Tested	Tested	Not Tested

2.4. Building Prototypes

An open invitation for all regional manufacturing companies was launched back in October 2012. Assessing all the feedback received, 7 different companies agreed to participate as a collaborator on this project. The conditions in the selection were:

1. Work closely with the technology providers on an agreeable design;

2. Work with UNIDO responsible staff to ensure that the design and manufacturing of the prototype(s) is of high quality;
3. The prototypes and the baseline units should have a minimum EER of 7 at 46 °C;
4. The prototypes should have dimensions that are commercially viable and similar to the baseline units;
5. The prototypes will be tested at an independent testing facility. Within the scope of this agreement, representative from the company, or the technology providers, will not be allowed to witness the testing and no rerun or adjustment on the design can take place after the test has been concluded;
6. The OEM will bear the fees of shipping the prototypes to and from the independent testing lab. The cost of the independent testing will be covered by the project as per testing procedures and conditions;
7. Since the aim of the project is assessing different technologies for high ambient conditions and not a specific design, the name of the company, or any other company involved, will not be disclosed or mentioned in the results that are made public. The name of the manufacturer will only be mentioned among others as contributors on the first page of the final report;
8. The Full testing result of the prototype will be shared only with the company that manufacture the prototype and the corresponding technology providers after the final project report is concluded.

These regional manufacturers worked with the technology providers and the compressor manufacturers as required to make sure that the prototypes are properly designed. Table 2.3 includes the proposed prototypes that will be developed by regional manufacturers using different refrigerants as well as the base units for HCFC-22 respectively HFC-410.

Table 2.4: Proposed prototypes

	Window	Decorative split	Ducted split	Packaged unit	Number of prototypes	Tests per prototype	Total tests
HC-290	NA	1	NA	NA	1	3	3
HFC-32	NA	2	1	NA	3	3	9
HFO 1	2	2	1	1	6	3	18
HFO 2	1	1	1	1	4	3	12
HCFC-22	2	2	1	1	6	3	18
HFC base	NA	2	1	NA	3	3	9
Total					**23**		**69**

The number of tests has been decreased from 90 tests as originally envisioned to a total of 69 tests. The number of prototypes has been decreased from 30 to 23. Due to time constrains and availability of components, some OEM's could not finish manufacturing their prototypes on time. More tests and prototypes will be conducted in future work.

2.5. Testing Facility

The scope of the testing facility includes the performance test for the above-described A/C units that meet the testing requirements defined in the below sections. So testing facility will be delivering the following

mandates; receiving the units, installation the units in the lab, perform testing as per below requirements, package the unit for shipment once completing the test.

As mentioned in Table 2, four different A/C categories will be tested; Window (Rated Capacity=18000 BTU/HR (5.27 kW), electrical frequency= 60 Hz)), decorative split (Rated Capacity=24000 BTU/HR (7 kW), electrical frequency= 60 Hz), Ducted Split (Rated Capacity=36,000 BTU/HR (10.5 kW) , electrical frequency= 50 Hz), and Packaged A/C (Rated Capacity=90,000 BTU/HR (26.4 kW), electrical frequency= 50 Hz). The lab/testing facility should be able to test these A/C categories for the mentioned electrical frequencies.

All prototypes units below 36,000 BTU/HR will operate at 208-230 volts, single phase and at 380-420 Volts for three phases for higher categories.

The refrigerants that are under consideration: HFC-32, HC-290, and four unsaturated HFC's (HFO's). The lab/testing facility should be able to perform thermal test for flammable refrigerants. In addition, some baseline products will be tested using HCFC-22 or R-410 as base refrigerant.

All units do possess typical dimension and weight as per their rated cooling capacity.

2.5.1. Technical Requirement of the Testing Facility

The testing facility must meet the following key criteria:

A. It should be independent testing facility and not belong to any air-conditioning or manufacturing company.
B. All instruments used in determining the performance of the units to be tested should be calibrated to a high degree of accuracy and the calibration certificates for the instrument should be available for inspection by the UNIDO technical consultant.
C. The lab/or testing facility should hold global recognition and accreditations and have agreements with internationally recognized professional institutions/organizations.
D. The lab should hold a Regulatory or Certification Requirements by internationally recognized body such as: DOE, AHRI, AHAM, SASO, EUROVENT, etc.
E. The lab/or testing facility should be able to handle prototype with flammable refrigerants.
F. The performance test should be completed as per one of the standards; for non-ducted Air-conditioning(ISO 5151, JIS 8615-1, and AHRI 210/240), and for ducted air-conditioning (ISO 13253, JIS 8615-2, AHRI 340/360)

2.5.2. Required Specifications for the Tests

A. The testing facility will be used to evaluate the thermal performance of the prototype.
B. Each prototype will be tested at three outside ambient conditions; 35 ^{o}C ((95 ^{o}F), 46 ^{o}C (115 ^{o}F) and 50 ^{o}C (122 ^{o}F) to understand the performance of these refrigerants at high ambient conditions
C. The indoor conditions will be kept the same for all tests; dry bulb temperature of 27 ^{o}C and a relative humidity of 50 % as per AHRI test procedures for T1 conditions (35 ^{o}C) , and 29 ^{o}C and 50% for T3 (46 ^{o}C and 50 ^{o}C) conditions.
D. An endurance test will be performed at 52 ^{o}C to check that the compressor will not trip when run continuously for two hours.
E. All units are usually multispeed but the test should be performed at maximum speed setting (full load).

A TOR with all the required information was initiated by UNIDO to submit bids to perform the required testing. An open call for all available independent testing facility was launched. Assessing all the feedback received, Intertek was chosen to be a potential collaborator on such an important project.

The results of the performance test should include in a report format the following parameters: Indoor Air Flow Rate, Evaporator Outlet Air Temperature, Condenser Outlet Air Temperature, Suction Temperature, Discharge Temperature, Liquid Temperature, Discharge Pressure, Suction Pressure, Measured Gross Cooling Capacity, Measured Sensible Cooling Capacity, Total Sensible Heat Ratio, Total Power, Evaporator Motor Fan Power, Condenser Motor Fan Power, Compressor Power, Power Factor, Efficiency kW/Ton or EER.

2.5.3. Testing Conditions

All the prototypes were tested at Intertek at three outdoor ambient conditions; 35 ^{o}C, 46 ^{o}C and 50 ^{o}C. The indoor conditions were set at 27 ^{o}C dry bulb temperature and 19^{o}C wet bulb temperature for T1 (35 ^{o}C) conditions; and at 29^{o}C and 19 ^{o}C for T3 (46 ^{o}C) and T3+ (50^{o}C) conditions. The wet bulb for the outdoor ambient conditions was set at 24 ^{o}C for the window types otherwise it was left uncontrolled for the case of split and package units. In addition, an endurance test was performed at 52 ^{o}C to check that the compressor would not trip when run continuously for two hours. Table 2.4 includes all the test parameters for window and for split and package units. These setting conditions and the testing procedures follow ISO standards- testing and rating for performance of air-conditioning units.

Table 2.5 Testing Conditions for the PRAHA Project

	Window Type		
	Indoor Temp DB/WB °C	**Outdoor Temp DB/WB °C**	
T1	Tdb = 27 °C, Twb=19 °C	Tdb = 35 °C, Twb = 24 °C	
T3	Tdb = 29 °C, Twb = 19 °C	Tdb = 46 °C, Twb = 24 °C	
$T3^+$	Tdb = 29 °C, Twb = 19 °C	Tdb = 50 °C, Twb = 24 °C	
Endurance	Tdb = 32 °C, Twb = 23 °C	Tdb = 52 °C, Twb = 24 °C	Running continuously for two hours
	All Other Types		
	Indoor Temp DB/WB °C	**Outdoor Temp DB/WB °C**	
T1	Tdb = 27 °C, Twb=19 °C	Tdb = 35 °C, wet bulb temperature not controlled	
T3	Tdb = 29 °C, Twb = 19 °C	Tdb = 46 °C, wet bulb temperature not controlled	
T3+	Tdb = 29 °C, Twb = 19 °C	Tdb = 50 °C, wet bulb temperature not controlled	
Endurance	Tdb = 32 °C, Twb = 23 °C	Tdb = 52 °C, wet bulb temperature not controlled	Running continuously for two hours

2.5.4. Testing Procedure and Verification

The psychrometric testing facility at Intertek is used to evaluate the thermal performance of unitary air conditioning units at different outdoor and indoor ambient temperatures. The testing facility consists of two rooms to simulate indoor and outdoor conditions. Dry bulb temperature and wet bulb/or relative humidity are independently controlled in each room. Airflow measurements are made using ASHRAE specified Air Enthalpy Tunnels (airflow measurement tunnel). One Air Enthalpy Tunnel is located in the indoor room for indoor tunnel airflow measurement, and one Air Enthalpy Tunnel is located in outdoor room for outdoor airflow measurement. The Air Enthalpy Tunnel will enable precise measurement of capacity and efficiency of air conditioners in accordance with the air enthalpy method described by ASHRAE 37-2009. Both the Indoor and Outdoor Room, have air-conditioning compartments (plenums). Each compartment is provided with complete air conditioning capability to compensate for the thermal loads presented by the system under test. The EER value or kW/ton of the machine along with their flow rate will be calculated for each set of outside and inside room conditions.

Schematic diagram of the testing rooms can be seen in Figure 2.3. The two rooms are prefabricated insulated rooms consisting of 4", R-34 urethane foam and a stucco white aluminum cover inside and out. Room is divided by an integral barrier wall creating two adjacent test rooms, one being the indoor side compartment and the other outdoor side compartment. Test room is completely sealed with gaskets.

Air sampling systems are fully automated and includes feedback and controls to maintain approximately 1000 FPM in the psychrometric box at all times. Platinum 4-wire Dry bulb and Wet bulb RTD thermometers are used for the dry bulb and wet bulb readings and interfaced with the data acquisition equipment.

A precision airflow measuring apparatus is installed in the each test room. All necessary transducers are supplied to measure before nozzle pressure, across the nozzle pressure, and test unit static. An air sampling system similar to that used in the test rooms is included for measuring discharge air properties of the test unit. An air flow measuring apparatus is installed in each indoor and outdoor test room for the purpose of determining capacity and airflow. Each flowmeter assembly is complete with an air temperature sampling system, mixer, inlet plenum/diffusion baffle, nozzle plate assembly/pressure taps, discharge plenum / diffusion baffle, and exhaust blower. This system is fully integrated with data acquisition and control system for full automatic control. Computerized Data Acquisition/Control System is designed specifically for use with the test facility. Figure 2.4a and Figure 2.4b show a window and a package units being tested respectively.

Figure 2.3 Schematic Diagram for the Testing Facility

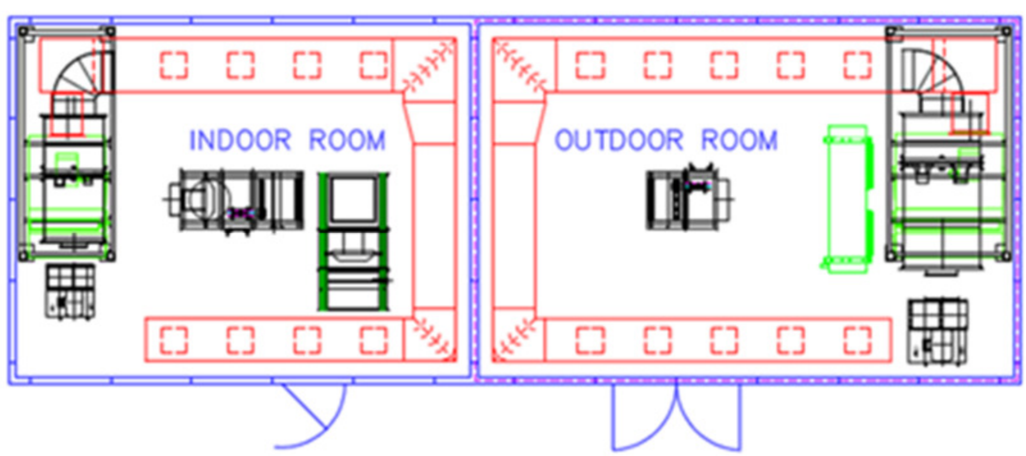


Figure 2.4 Testing Set up for a) Window unit, b) Package unit

(a) (b)

2.5.5. Major Components Accuracy at the Independent Lab (Intertek)

- Volts, Amps, Watts, Watt-hours Under +/- 1.0 %
- Indoor room dry bulb temperature +/- 0.1 °C
- Indoor room wet bulb temperature +/- 0.1 °C
- Outdoor room wet bulb temperature +/- 0.1 °C
- Outdoor room dry bulb temperature +/- 0.1 °C
- Indoor Air flow measuring apparatus dry bulb temperature +/- 0.1 °C
- Indoor Air flow measuring apparatus wet bulb temperature +/- 0.1 °C
- Indoor Air flow measuring apparatus Nozzle dry bulb temperature +/- 0.75 °C
- Outdoor Air flow measuring apparatus dry bulb temperature +/- 0.1 °C
- Outdoor Air flow measuring apparatus wet bulb temperature +/- 0.1 °C
- Outdoor Air flow measuring apparatus Nozzle dry bulb temperature +/- 0.75 °C
- Cooling Capacity +/- 2.5 %
- EER (Kw/ton) +/- 3 %

2.6. Verification of the results

A repeatability test was performed on R-410A unit where the same unit was run twice under similar conditions. The objective here is to give confidence in the results obtained and to verify that the results can be reproduced under the same conditions. The repeatability test was performed at 35 °C, 46 °C, and 50 °C for all the parameters of interest. The tests reveal excellent results where all the measured variables are within the accuracy specifies earlier as stated in Table 2.5.

Table 2.6: Repeatability results performed on R-410A unit at 35 °C, 46 °C, and 50 °C.

Repeatability Test at 35 °C			
Parameters	**1st Test**	**2nd Test**	**% Difference**
Capacity(BTU/HR)	17856	17798	0.32
EER	10.53	10.48	0.48
ID Airflow(SCFM)	575	573	0.35
Repeatability Test at 46 °C			
Parameters	**1st Test**	**2nd Test**	**% Difference**
Capacity(BTU/HR)	15916	15848	0.43
EER	7.89	7.85	0.51
ID Airflow(SCFM)	554	554	0
Repeatability Test at 50 °C			
Parameters	**1st Test**	**2nd Test**	**% Difference**
Capacity(BTU/HR)	14772	14862	-0.61
EER	6.92	6.97	-0.72
ID Airflow(SCFM)	554	556	-0.36

Chapter 3

3. Assessment of Results

As mentioned earlier four different categories for Air-conditioning types were tested namely; Window, Decorative split, Ducted split, and package. The result section is divided accordingly where the window has a cooling capacity 18,000 BTU/HR (5.2 kW) and tested with DR-3 and L-20 refrigerants. The results of these refrigerants will be compared to that of HCFC-22. The Decorative, (or mini-split) has a cooling capacity of 24,000 BTU/HR (7 kW) and tested for HFC-32, HC-290, DR-3, and L-20. The Ducted split has a cooling capacity of 36,000 BTU/HR (10.5 kW) and was tested for HFC-32, DR-3, and L-20. The packaged rooftop has a cooling capacity of 90,000 BTU/HR (26.4 kW) and will be tested for DR-3, and L-20. The results for HFC-32 and the L-41 are compared to R-410A as base however the L-20, DR-3 and HC-290 three other refrigerants are compared to HCFC-22. As mentioned earlier some of the refrigerants were tested with two different prototypes manufactured by two different OEMs to ensure that the differences are due to the refrigerants performance and not influenced by the design of the unit.

All the prototypes in every category should have the cooling capacity and size, and they all should me the minimum efficiency set earlier. In addition, all the prototypes should adhere to the same requirements set in section 5 in chapter 2. For reasons of confidentiality as stipulated in the term of reference mentioned earlier, the detailed specifications of the prototypes will not be included in this report.

The OEM's are referred to here as OEM A, OEM B, OEM C, etc. in every category to ease the discussion. However they do not refer to a specific OEM throughout the report.

Overall it should be noted that the results do not fully correspond to expectations based on theoretical cycle calculations; however, the complete set of test results should be considered as a snapshot on real situation in developing countries; including capability to absorb and adopt new technologies within a short timeframe. Detailed discussions on results for the different categories tested follows through paragraphs 3.1 to 3.4.

3.1. Results for the Window Type Air-conditioning System

The window unit prototypes were manufactured by two different OEMs referred here as OEM A and OEM B. The first company, OEM A, has manufactured two different prototypes to test L-20, DR-3 as alternative to HCFC-22. Both Refrigerants were compared to HCFC-22 unit as base manufactured from the same OEM. The second one, OEM B, manufactured one prototype for the L-20 refrigerant and provided a HCFC-22 unit to serve as base unit. So each alternative is compared to a base unit manufactured by the same company to make sure that the difference in the results is not OEM dependent but rather due to the behavior of that specific alternative inside the unit. Table 1 shows the results of all the 5 prototypes by the two OEMs. The table shows all the measured variables for the alternatives along with their base units. The cooling capacity is provided in (BTU/HR) where 12000 BTU/HR = 1 ton of refrigeration = 3.517 KW. The EER is given here in (BTU/HRW) where the coefficient of performance (COP) =EER/3.412 and the kW/ton=12/EER.

Table 3.1: Results of Window Unit prototypes at 35 °C, 46 °C, and 50 °C.

Test at 35 °C					
	OEM A			OEM B	
Parameters	**HCFC-22**	**L-20**	**DR-3**	**HCFC-22**	**L-20**
Capacity(BTU/HR)	17685	19280	18063	17997	16858
EER	10.73	9.51	9.75	9.44	9.25
Power (W)	1648	2028	1852	1906	1822
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	1.0	7.9	20.6	-	28.5
Compressor Discharge Temperature, °F	136.8	136.4	163.6	-	177.1
Liquid Line Temperature, °F	101.3	92.4	91.6	-	104.7
Compressor Suction Temperature, °F	47.0	54.3	69.7	-	65.9
Compressor Discharge Pressure, PSI	272.2	324.4	296.5	290.7	284.2
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	77.1	80.4	73.4	74.5	68.5
Refrigerant Charge, Kg	1.275	1.0	0.92	0.78	0.68
Test at 46 °C					
Parameters	**HCFC-22**	**L-20**	**DR-3**	**HCFC-22**	**L-20**
Capacity(BTU/HR)	15382	16906	16106	15686	14190
EER	7.72	6.96	7.58	6.90	6.58
Power (W)	1991	2429	2124	2274	2152
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	1.6	6.6	12.7	-	29.2
Compressor Discharge Temperature, °F	163.7	159.9	179.0	-	204.7
Liquid Line Temperature, °F	128.5	116.8	115.6	-	133.0
Compressor Suction Temperature, °F	50.4	56.6	66.3	-	70.2
Compressor Discharge Pressure, PSI	357.7	414.8	376.1	378.9	372.2
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	82.3	86.6	80.0	80.5	73.1
Refrigerant Charge, Kg	1.275	1.0	0.92	0.78	0.68
Test at 50 °C					
Parameters	**HCFC-22**	**L-20**	**DR-3**	**HCFC-22**	**L-20**
Capacity(BTU/HR)	14517	15518	14721	14642	13173
EER	6.85	6.05	6.60	6.09	5.78
Power (W)	2118	2565	2228	2405	2279
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	1.4	5.3	11.5	-	32.3
Compressor Discharge Temperature, °F	173.7	168.3	186.7	-	215.3
Liquid Line Temperature, °F	137.7	126.0	125.9	-	141.6
Compressor Suction Temperature, °F	51.5	57.1	66.9	-	74.2
Compressor Discharge Pressure, PSI	391.0	450.0	408.0	411.2	403.7
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	84.4	88.8	82.0	82.4	73.9
Refrigerant Charge, Kg	1.275	1.0	0.92	0.78	0.68

Since both OEM's were supposed to optimize their HCFC-22 units with similar cooling capacities, the results still reveals that some variations are observed between both HCFC-22 units manufactured by the two OEMs, , indicating that the difference in the design may affect the EER even for the same refrigerant. That is why in this project, each refrigerants is compared to a base unit manufactured from the same OEM. For example at 35 °C the EER were 10.73 and 9.44 for OEM A and B respectively for HCFC-22 refrigerant. The results of cooling capacity and the energy efficiency ratio (EER) for the two alternative refrigerants namely L-20 and DR-3 were plotted in Figures 3.1a, and 3.1b as ratio to their respective base of HCFC-22 units to ease the comparison.

Figure 3.1a Window Unit CC compared to base at different ambient conditions

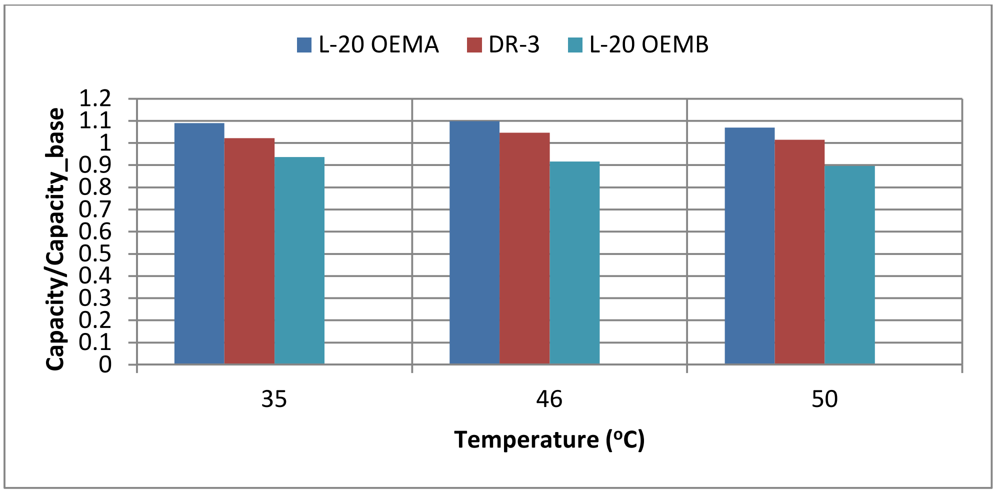


Figure 3.1b Window Unit EER compared to base at different ambient conditions

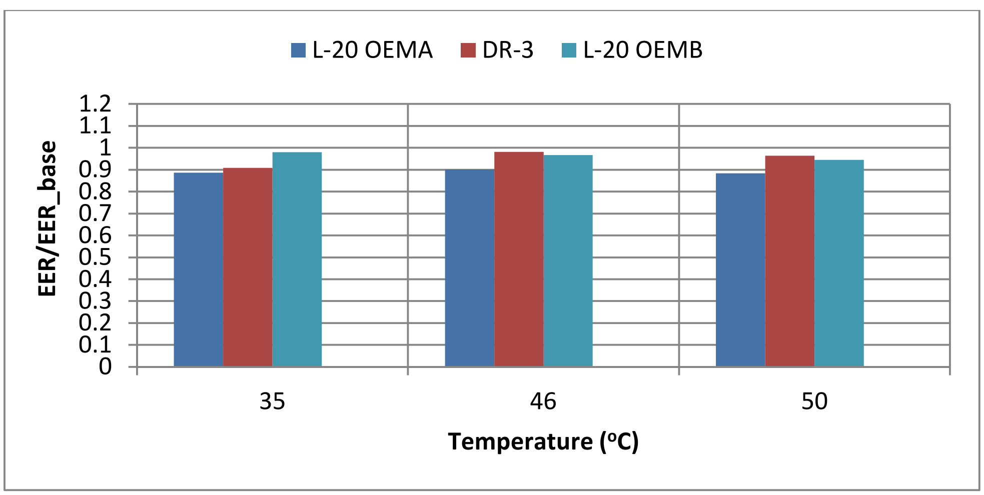
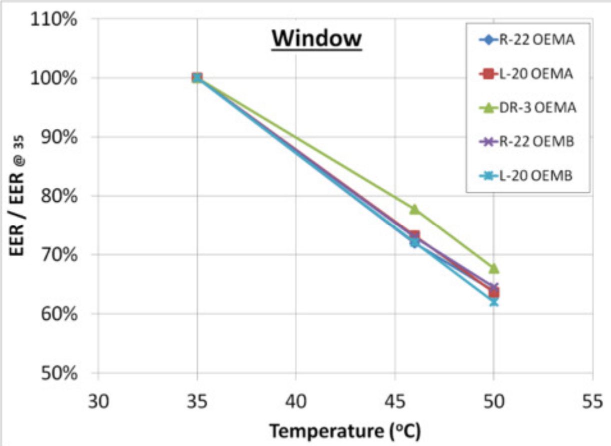


Figure 3.2a and Figure 3.2b indicates the percentage of efficiency degradation and the cooling capacity (CC) degradation respectively for all the refrigerants in this category associated with increasing ambient temperature when going from 35 °C to 50 °C.

Figure 3.2a EER degradation **Figure 3.2b CC degradation**
at high ambient temperatures (percentage compared to 35 °C)



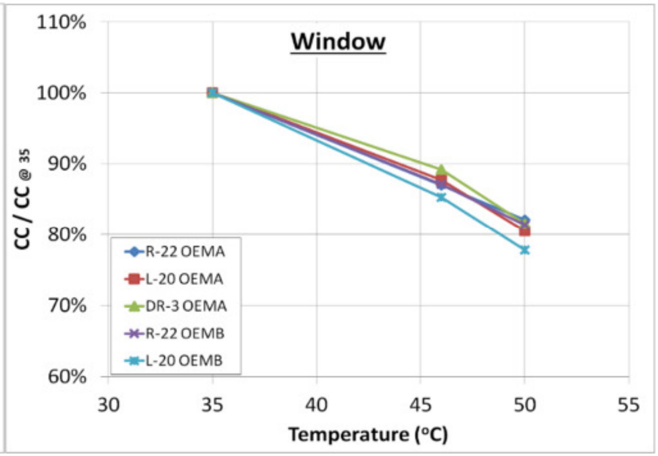
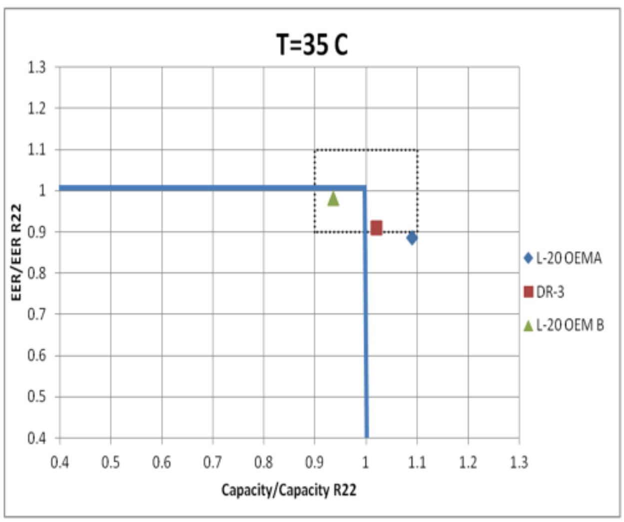


Figure 3.3a, b, and c shows the performance of the alternative compared to that of HCFC-22. The figure compares the EER ratio versus cooling capacity ratio for all the alternative refrigerants where with HCFC-22 being the base at the three temperatures. The figure shows the 10 % boundaries to ease visualizing how each refrigerant is performing compared to HCFC-22.

Figure 3.3a EER vs. CC at 35 C for Window Units **Figure 3.3b EER vs. CC at 46 C for Window Units**



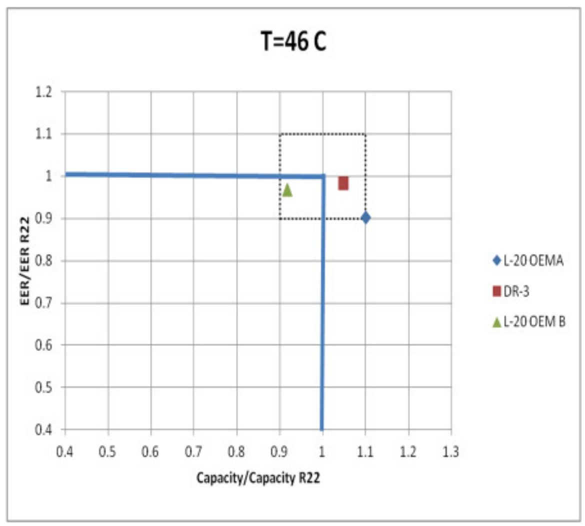
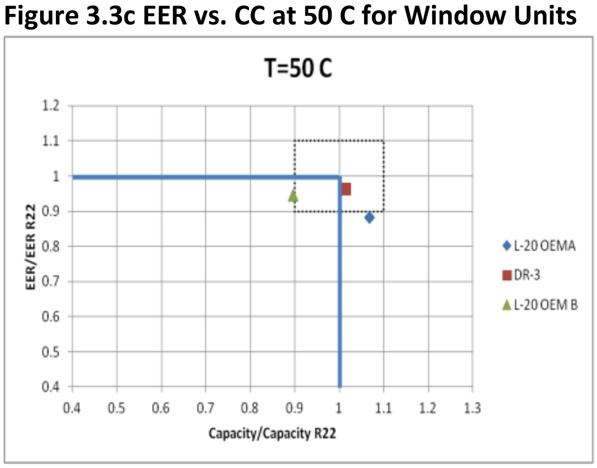


Figure 3.3c EER vs. CC at 50 C for Window Units



The results for the window category can be summarized as follows:

- Results from testing L-20 and DR-3 vs. a base of HCFC-22 shows that both alternatives have lower EER values than the base, but varying capacity performance with two prototypes (one L-20 and one DR-3) giving higher capacity and the other prototype using L-20 giving lower capacity;
- The decrease in EER is between 4 and 10%; and
- The degradation in efficiency and in cooling capacity at higher ambient temperature conditions for the alternative refrigerants is consistent with that of HCFC-22 averaging around 35% when the ambient temperature increased from 35 to 50 °C.

3.2 Results for the Decorative Split Type Air-conditioning System

Three different OEM's have manufactured all the prototypes in this categories. These OEM's are referred to here as OEM A, B, and C. OEM A has manufactured two different prototypes to test L-20, DR-3 as alternative to HCFC-22. OEM B has manufactured two different prototypes. An HC-290 unit is designed and optimized and was compared with HCFC-22 unit. In addition this OEM has manufactured HFC-32 unit and it was compared to R-410A manufacture also by the same OEM. OEM C manufactured another two different prototypes to test HFC-32 and L-41 as alternative to R-410A. Each alternative is compared to a base unit manufactured by the same company to make sure that the difference in the results is not OEM dependent but rather due to the behavior of that specify alternative inside the unit. Table 3.2 shows the results of all alternative refrigerants to HCFC-22 manufactured by two OEMs; A and B. Table 3.3 however, shows the results to the R-410A alternatives manufactured by OEM B and C. The tables shows all the measured variables for the alternatives along with their base units.

Table 3.2: Results of Decorative Split prototypes at 35 °C, 46 °C, and 50 °C. (HCFC-22 Base)

Test at 35 °C					
	OEM A			OEM B	
Parameters	**HCFC-22**	**L-20**	**DR-3**	**HCFC-22**	**HC-290**
Capacity(BTU/HR)	21812	23235	14638	18192	19734
EER	8.61	6.95	6.32	9.39	9.73
Power (W)	2532	3343	2314	1937	2029
Condenser Sub-cooling, °F	1.4	11	7.7	0	0
Evaporator Superheat, °F	17.5	19.4	36.3	6.5	7.4
Compressor Discharge Temperature,	210.9	42.7	201.7	186.4	150
Liquid Line Temperature, °F	79.0	79.8	73.0	56.5	64.1
Compressor Suction Temperature, °F	72.9	203.3	71.3	61.2	54.2
Compressor Discharge Pressure, PSI	145.2	191.9	132.9	95.2	95.9
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	66.2	97.5	54.0	74.7	73.1
Refrigerant Charge, Kg	1.8	1.8	1.8	1.4	1
Test at 46 °C					
Parameters	HCFC-22	L-20	DR-3	HCFC-22	HC-290
Capacity(BTU/HR)	20982	20199	14493	17357	17914
EER	6.84	4.58	4.96	7.55	7.45
Power (W)	3069	4410	2923	2299	2404
Condenser Sub-cooling, °F	1.1	3.5	5.7	0	0
Evaporator Superheat, °F	1.2	20.4	34	6.9	11.82
Compressor Discharge Temperature,	225.3	232.4	224.4	215.2	176.4
Liquid Line Temperature, °F	93.6	94.5	89.8	63.5	71.7
Compressor Suction Temperature, °F	63.4	64.1	78.2	69.2	64.6
Compressor Discharge Pressure, PSI	181.6	234.0	169.7	108.2	108.3
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	75.4	111.2	66.6	83.3	80
Refrigerant Charge, Kg	1.8	1.8	1.8	1.4	1
Test at 50 °C					
Parameters	HCFC-22	L-20	DR-3	HCFC-22	HC-290
Capacity(BTU/HR)	20361	4938	14145	16409	16496
EER	6.17	1.49	4.46	6.65	6.51
Power (W)	3297	3305	3169	2468	2534
Condenser Sub-cooling, °F	1.2	15.4	4.9	0	0
Evaporator Superheat, °F	0.2	5.9	32.9	5.6	11
Compressor Discharge Temperature,	229.7	270.6	233.7	229.3	183
Liquid Line Temperature, °F	99.1	94.2	95.3	65.7	73.8
Compressor Suction Temperature, °F	54.0	78.1	79.8	72.9	64.3
Compressor Discharge Pressure, PSI	197.1	222.9	182.5	112.4	111.6
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	78.9	179.0	70.5	86.4	81.2
Refrigerant Charge, Kg	1.8	1.8	1.8	1.4	1

Table 3.3: Results of Decorative Split prototypes at 35 °C, 46 °C, and 50 °C. (R-410A Base)

Test at 35 °C					
	OEM C			OEM B	
Parameters	**R-410A**	**HFC-32**	**L-41**	**R-410A**	**HFC-32**
Capacity(BTU/HR)	22511	25964	26903	17856	19328
EER	12.02	11.88	10.78	10.53	9.56
Power (W)	1873	2185	2495	1696	2023
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	9.7	0.5	7.9	2.8	0.3
Compressor Discharge Temperature,	161.3	177.2	160.2	159.5	156.2
Liquid Line Temperature, °F	53.5	51.7	52.6	54.9	57.8
Compressor Suction Temperature, °F	57.1	46.8	45.7	55.9	49.6
Compressor Discharge Pressure, PSI	152	149.6	142.7	156.7	163.6
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	135.4	134.4	118.4	136.3	140.4
Refrigerant Charge, Kg	1.95	1.28	1.63	1.74	1.2
Test at 46 °C					
Parameters	**R-410A**	**HFC-32**	**L-41**	**R-410A**	**HFC-32**
Capacity(BTU/HR)	20575	23750	24713	15916	16526
EER	9.07	8.89	8.2	7.89	6.58
Power (W)	2268	2671	3020	2017	2512
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	1.81	0.6	8.8	6.3	0.2
Compressor Discharge Temperature,	179.9	209.4	191	186.8	182.5
Liquid Line Temperature, °F	61	58.1	60.4	61.1	66.4
Compressor Suction Temperature, °F	56.1	52.7	51.1	67.1	56.4
Compressor Discharge Pressure, PSI	173.5	167.5	162.4	174.4	187.5
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	150.1	146.9	130.2	150.3	157.7
Refrigerant Charge, Kg	1.95	1.28	1.63	1.74	1.2
Test at 50 °C					
Parameters	**R-410A**	**HFC-32**	**L-41**	**R-410A**	**HFC-32**
Capacity(BTU/HR)	19041	22153	23246	14772	14649
EER	7.87	7.72	7.25	6.92	5.39
Power (W)	2419	2870	3208	2135	2716
Condenser Sub-cooling, °F	-	-	-	-	-
Evaporator Superheat, °F	0.8	0.7	8.5	7.1	0.2
Compressor Discharge Temperature,	187.4	220.9	200.6	193.1	190.5
Liquid Line Temperature, °F	62.8	60.0	62.5	62.4	69.1
Compressor Suction Temperature, °F	55	53	52.3	69.8	58.2
Compressor Discharge Pressure, PSI	178.6	172.6	167.1	178.4	195
Liquid Line Pressure, PSI	-	-	-	-	-
Compressor Suction Pressure, PSI	152.5	149.5	132.7	153.5	162.7
Refrigerant Charge, Kg	1.95	1.28	1.63	1.74	1.2

The results of cooling capacity for the HC-290, L-20, and DR-3 are plotted on Figure 3.4a as ratio to their respective base HCFC-22. Figure 3.4b shows also the cooling capacity of HFC-32, L-41 compared to their base cases R-410A. Similarly their EER ratios are plotted on Figure 3.5a and Figure 3.5b.

Figure 3.4a CC of Decorative Split prototypes compared to HCFC-22 base

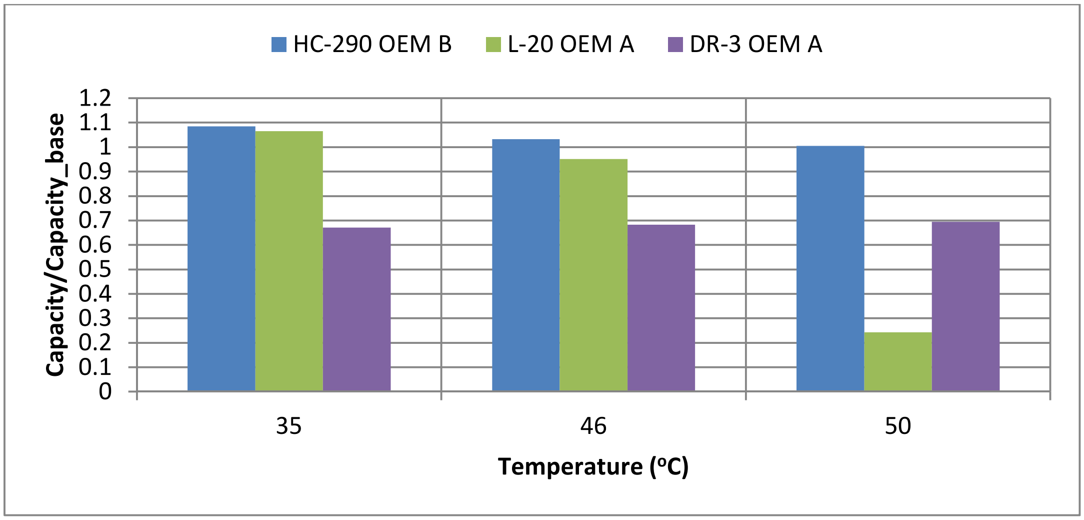


Figure 3.4b CC of Decorative Split prototypes compared to R-410A base

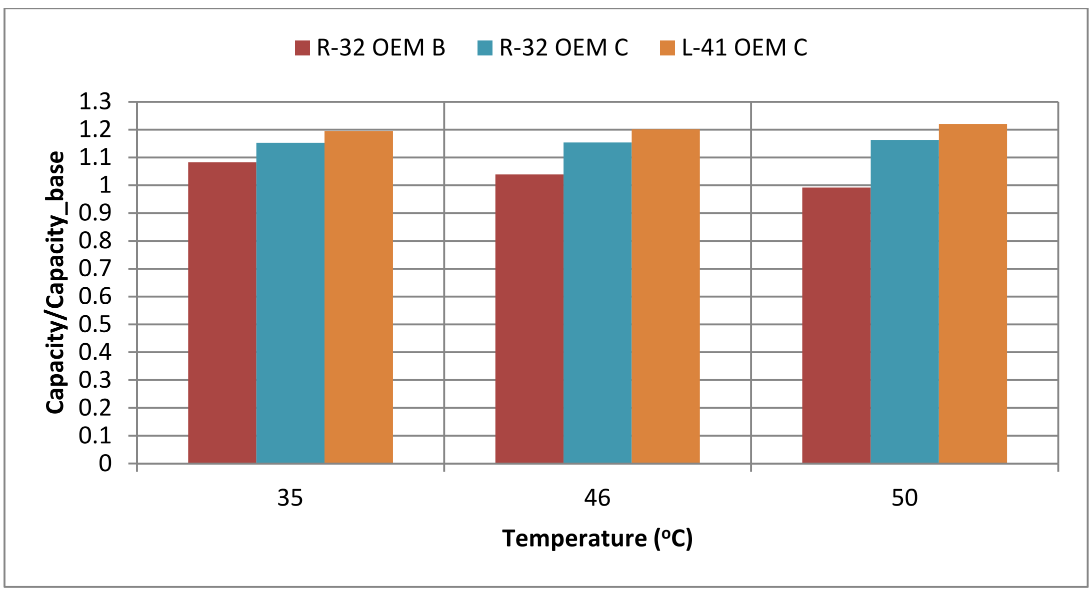


Figure 3.5a EER of Decorative Split prototypes compared to HCFC-22 base

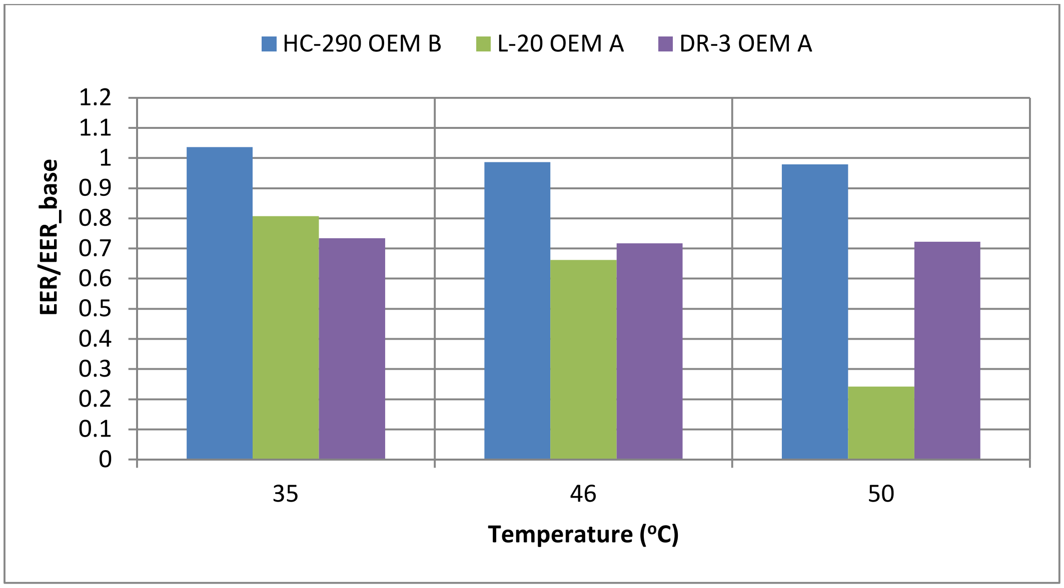


Figure 3.5b EER of Decorative Split prototypes compared to R-410A base

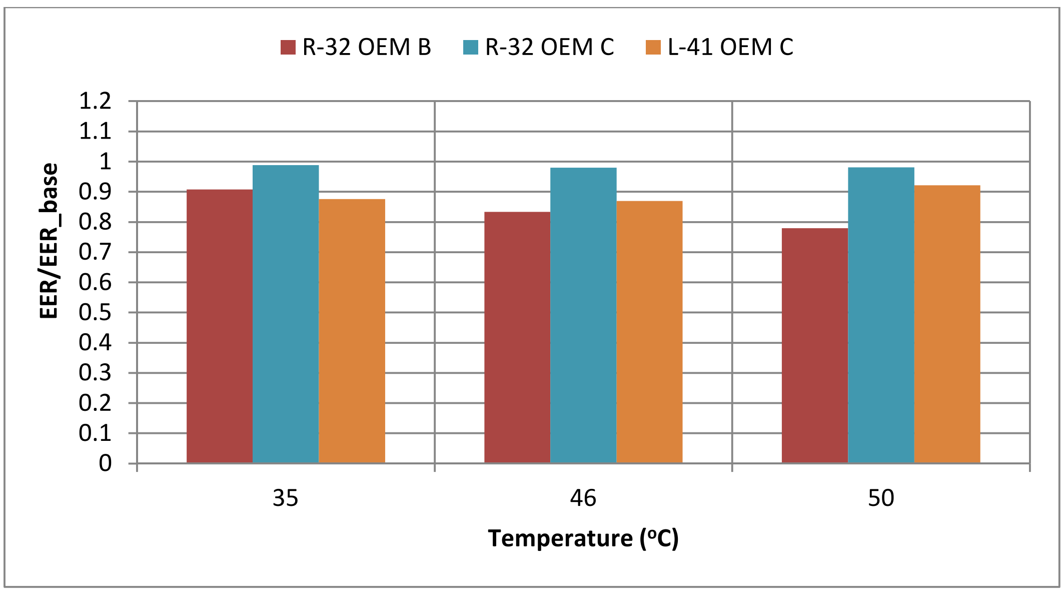
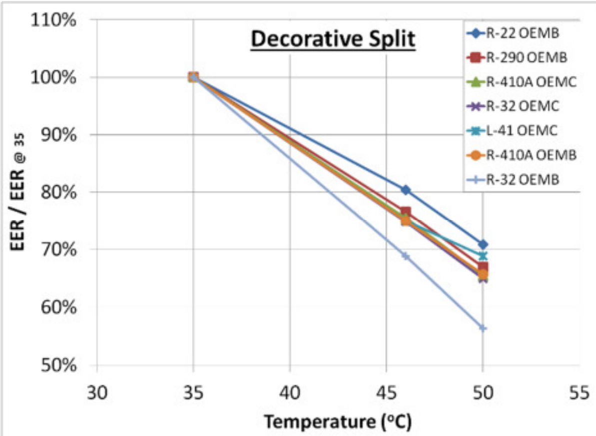
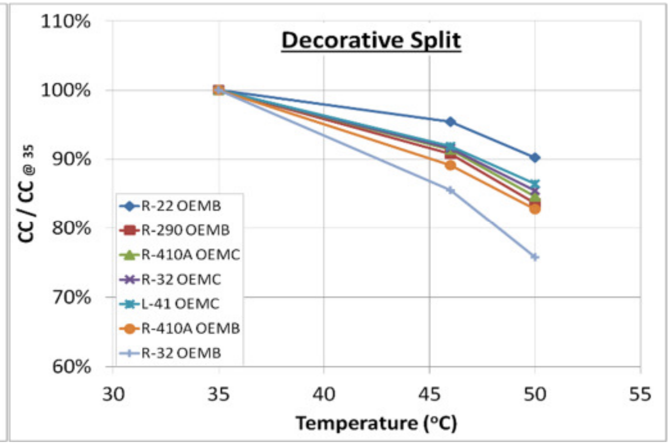


Figure 3.6a and Figure 3.6b indicate the percentage for the efficiency and cooling capacity. The degradation associated with increasing the ambient temperature when going from 35 C to 50 C for the HCFC-22 and its alternatives as well for R-410A and its alternatives.

Figure 3.6a EER degradation Deco Split **Figure 3.6b CC degradation Decorative Split at high ambient temperatures for HCFC-22 and R-410A alternatives (percentage compared to 35 C)**





Figures 3.7a, b, and c shows the performance of the alternatives compared to that of HCFC-22. The figure compares the EER ratio versus cooling capacity ratio for all the alternative refrigerants where with HCFC-22 being the base at the three temperatures. The figure shows the 10 % boundaries to ease visualizing how each refrigerant is performing compared to HCFC-22.

Figure 3.7a CC and EER at 35 C compared to HCFC-22 for Decorative Splits

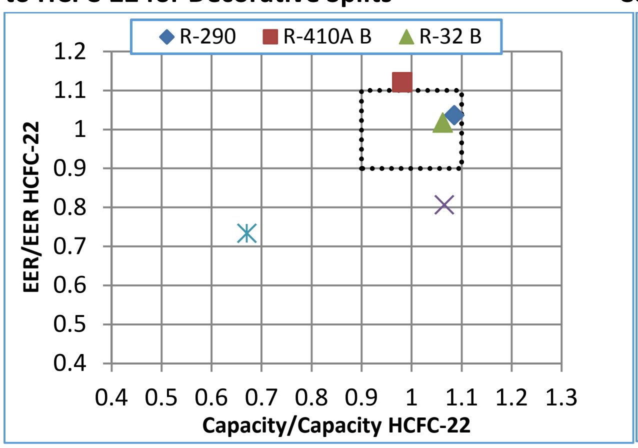


Figure 3.7b CC and EER at 46 C Compared to HCFC-22 for Decorative splits

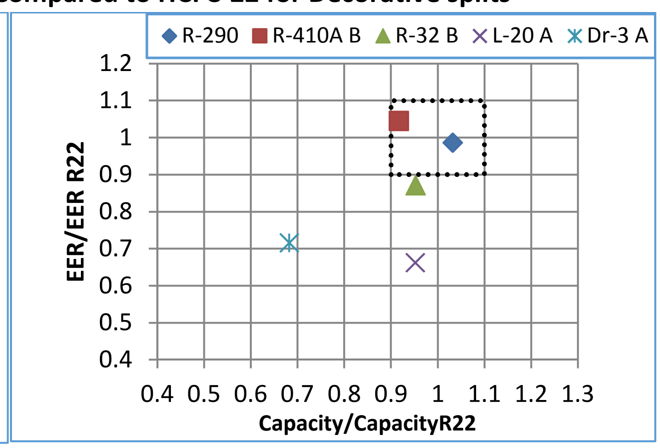
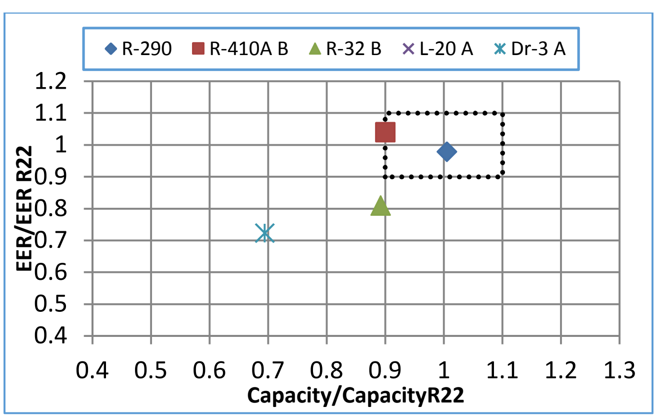


Figure 3.7C CC and EER compared to HFCF-22 at 50 C for Decorative Splits



The results for the decorative split category can be summarized as follows:

- The result from testing all five refrigerants (HC-290, HFC-32, L-20, L-41, and DR-3) in prototypes of this category showed inconsistent results for the L-20 and the DR-3 prototypes for reasons that could not be ratified at the testing lab. No conclusions could be drawn for the prototypes using these two refrigerants without further investigation;
- The prototype using HC-290 has a higher cooling capacity than the base HCFC-22, but similar EER; and
- The cooling capacities of the L-41 and HFC-32 prototypes were higher than the base R-410A; however, the EER was lower.

3.3 Results for the Ducted Split Type Air-conditioning System

For the ducted category, three different alternatives were tested; L-20, DR-3, and HFC-32. In addition, the same OEM has provided two additional units; one with HCFC-22 to serve as a base for the L-20 and the DR-3 and the other one with R-410A to serve as base for the HFC-32. All the three prototypes were manufactured by the same OEM so the effect of variation in the design from one company to another company is eliminated. Table 3.4 shows the actual data for all the measured parameters for HCFC-22 and its alternative at 35 °C, 46 °C, and 50 °C. Table 3.5 shows the actual data the measured parameters for the R-410A and HFC-32 at 35 °C, 46 °C, and 50 °C.

Table 3.4 Results for Ducted Split Prototypes at 35 °C, 46 °C, and 50 °C (HCFC-22 base)

Test at 35 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	39326	36553	29363
EER	9.67	9.56	7.92
Power (W)		3823	3918
Condenser Sub-cooling, °F	-	-	-
Condenser Superheat, °F	9.6	23	33
Compressor Discharge Temperature, °F	184.2	182.8	188.0
Liquid Line Temperature, °F	110.1	107.9	105.5
Compressor Suction Temperature, °F	57.1	68.4	78.6
Compressor Discharge Pressure, PSI	255.2	243.4	238.5
Liquid Line Pressure, PSI	-	-	-
Compressor Suction Pressure, PSI	80.0	70.2	58.2
Refrigerant Charge, Kg	3.175	2.5	2.4
Test at 46 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	36539	34507	28314
EER	7.42	7.47	6.31
Power (W)		4620	4687
Condenser Sub-cooling, °F	-	-	-
Condenser Superheat, °F	4.7	19	-
Compressor Discharge Temperature, °F	206.3	205.7	209.3
Liquid Line Temperature, °F	134.7	129.9	127.6
Compressor Suction Temperature, °F	55.9	69.6	82.6
Compressor Discharge Pressure, PSI	334.8	321.0	314.5
Liquid Line Pressure, PSI	-	-	-
Compressor Suction Pressure, PSI	88.6	78.9	70.5
Refrigerant Charge, Kg	3.175	2.5	2.4
Test at 50 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	34558	32873	27346
EER	6.54	6.66	5.66
Power (W)		4939	5000
Condenser Sub-cooling, °F	-	-	-
Condenser Superheat, °F	2.6	14	-
Compressor Discharge Temperature, °F	213.0	210.9	216.3
Liquid Line Temperature, °F	142.4	137.7	135.4
Compressor Suction Temperature, °F	54.8	65.4	82.3
Compressor Discharge Pressure, PSI	365.3	352.1	344.7
Liquid Line Pressure, PSI	-	-	-
Compressor Suction Pressure, PSI	90.2	81.4	72.8
Refrigerant Charge, Kg	3.175	2.5	2.4

Table 3.5 Results for Ducted Split Prototypes at 35 °C, 46 °C, and 50 °C (R-410A base)

	Test at 35 °C	
Parameters	**R-410A**	**HFC-32**
Capacity(BTU/HR)	36885	35543
EER	9.54	9.45
Power (W)		3761
Condenser Sub-cooling, °F	-	-
Condenser Superheat, °F	12.0	5.0
Compressor Discharge Temperature, °F	182.1	182.7
Liquid Line Temperature, °F	104.5	114.4
Compressor Suction Temperature, °F	60.4	56.6
Compressor Discharge Pressure, PSI	431.1	400.5
Liquid Line Pressure, PSI	-	-
Compressor Suction Pressure, PSI	136.1	153.2
Refrigerant Charge, Kg	2.72	1.8
	Test at 46 °C	
Parameters	**R-410A**	**HFC-32**
Capacity(BTU/HR)	34129	29633
EER	7.22	6.64
Power (W)		4466
Condenser Sub-cooling, °F	-	-
Condenser Superheat, °F	11.17	0.6
Compressor Discharge Temperature, °F	210.0	195.0
Liquid Line Temperature, °F	127.2	132.2
Compressor Suction Temperature, °F	66.3	59.1
Compressor Discharge Pressure, PSI	553.7	507.0
Liquid Line Pressure, PSI	-	-
Compressor Suction Pressure, PSI	152.6	171.7
Refrigerant Charge, Kg	2.72	1.8
	Test at 50 °C	
Parameters	**R-410A**	**HFC-32**
Capacity(BTU/HR)	31948	26242
EER	6.31	5.56
		4723
Condenser Sub-cooling, °F	-	-
Condenser Superheat, °F	11.45	0.5
Compressor Discharge Temperature, °F	221.1	198.0
Liquid Line Temperature, °F	133.7	137.8
Compressor Suction Temperature, °F	67.5	60.9
Compressor Discharge Pressure, PSI	595.6	544.5
Liquid Line Pressure, PSI	-	-
Compressor Suction Pressure, PSI	154.9	177.5

Refrigerant Charge, Kg	2.72	1.8

Figures 3.8a and Figure 3.8b compare the cooling capacity and the EER respectively to their base cases.

Figure 3.8a CC of Ducted Split Prototypes compared to relevant base

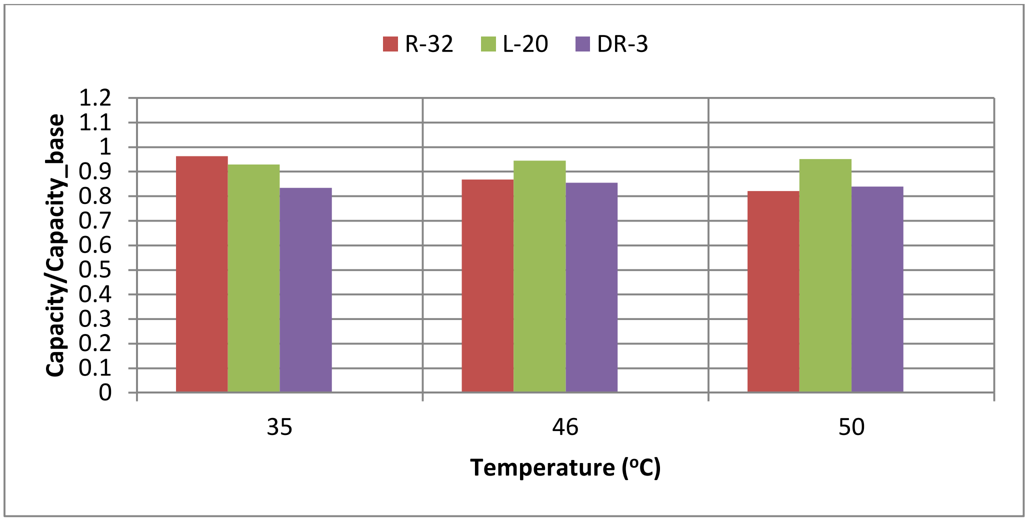
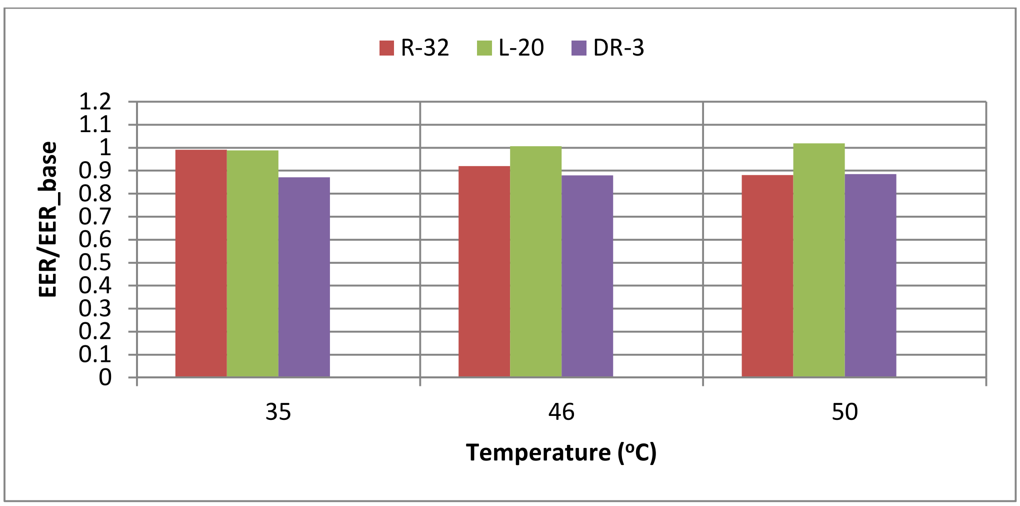
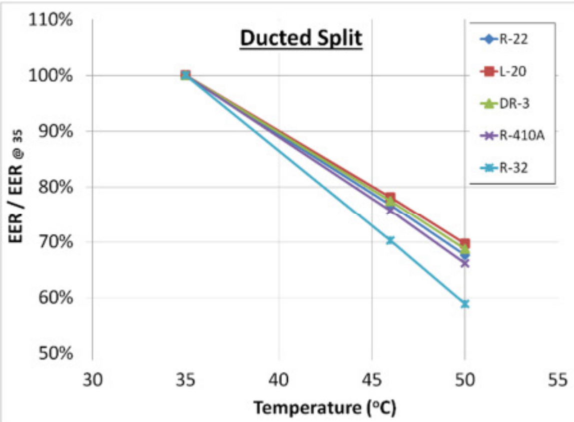


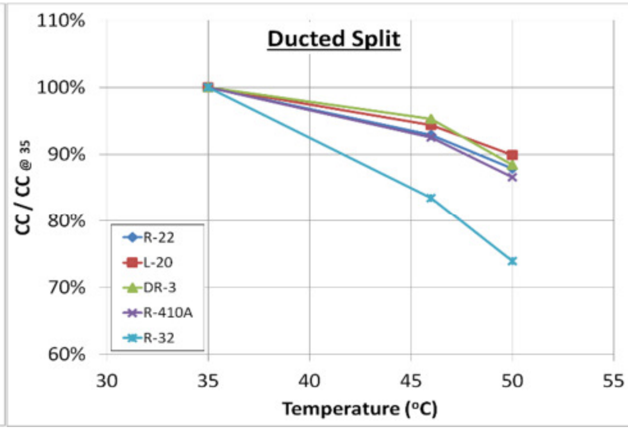
Figure 3.8b EER of Ducted Split Prototypes compared to relevant base



Figures 3.9a and Figure 3.9b indicate the percentage of efficiency degradation and cooling capacity respectively associated with increasing ambient temperature when going from 35 C to 50 C for the HCFC-22 and its alternatives as well as for the R-410A and HFC-32.

Figure 3.9a EER degradation **Figure 3.9b Cooling capacity degradation**
for all refrigerants at high ambient temperatures (percentage compared to 35 °C)





Figures 3.10 a, b, and c show the performance of all alternatives namely, L-20, DR-3, R-410A and HFC-32 and compare the EER and cooling capacity of the refrigerants to HCFC-22 at the three temperatures. The figure shows the 10 % boundaries

Figure 3.10a EER vs. CC at 35 C -Ducted splits

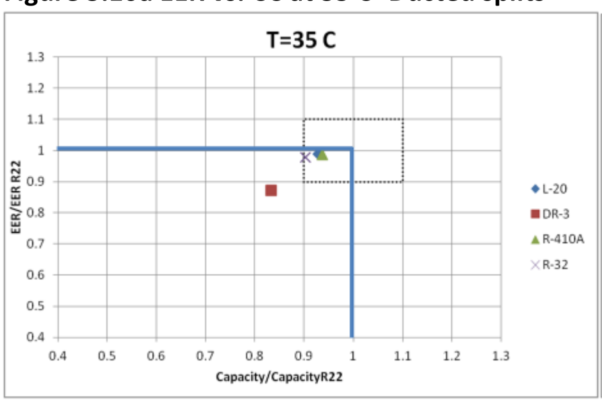


Figure 3.10a EER vs. CC at 50 C for Ducted Splits

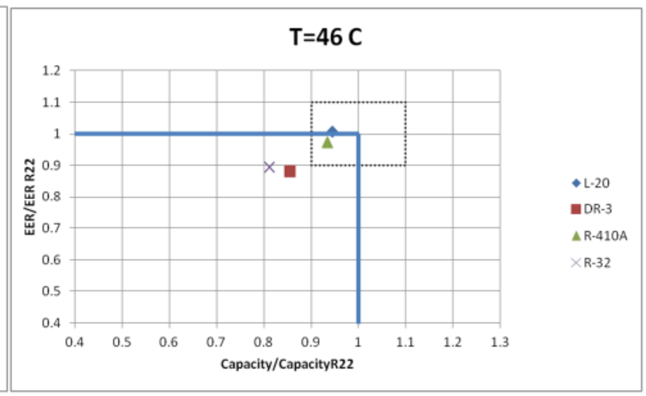
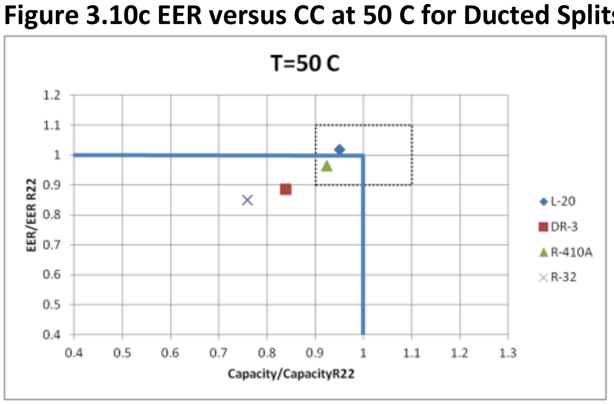


Figure 3.10c EER versus CC at 50 C for Ducted Splits



The results for the decorative split category can be summarized as follows:

- The results of testing L-20, and DR-3 shows both alternatives to have lower cooling capacity and EER than the base HCFC-22;
- HFC-32 shows similar cooling capacity and EER to those of the R-410A base; and

- L-20 and DR-3 degraded less for the cooling capacity and EER at higher ambient temperature conditions than HFC-32.

3.4 Results for the Package Type Air-conditioning System

For the package category, two alternative refrigerants; L-20 and DR-3 were tested at 3 different temperatures; 35 °C, 46 °C, and 50 °C to investigate their performance at high ambient conditions. The results were compared to the results of HCFC-22 base unit. Table 3.6 tabulates all the results showing all the measured parameters.

Table 3.6 Results for Package Unit Prototypes at 35 °C, 46 °C, and 50 °C (HCFC-22 base)

Test at 35 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	86109	92069	85010
EER	10.08	10.16	9.77
Power (W)	8543	9066	8699
Condenser Sub-cooling, °F	1.0	0.5	0
Evaporator Superheat, °F	12.0	12.9	10.7
Compressor Discharge Temperature °F	178.6	171.5	152.8
Liquid Line Temperature, °F	111.0	104.2	102.6
Compressor Suction Temperature, °F	55.9	58.4	60.7
Compressor Discharge Pressure, PSI	253.3	273.5	-
Liquid Line Pressure, PSI	232.3	250.8	231.0
Compressor Suction Pressure, PSI	74.0	79.0	74.8
Refrigerant Charge, Kg	7.0	7.05	8.19
Test at 46 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	80700	85162	77064
EER	8.08	7.88	7.55
Power (W)	9983	10812	10207
Condenser Sub-cooling, °F	1.0	0.1	0
Evaporator Superheat, °F	13.6	11.9	11.6
Compressor Discharge Temperature, °F	205.3	193.0	175.4
Liquid Line Temperature, °F	131.0	125.4	122.9
Compressor Suction Temperature, °F	61.6	61.9	65.2
Compressor Discharge Pressure, PSI	322.8	366.7	-
Liquid Line Pressure, PSI	303.4	333.6	303.5
Compressor Suction Pressure, PSI	80.5	86.3	81.2
Refrigerant Charge, Kg	7.0	7.05	8.19
Test at 50 °C			
Parameters	**HCFC-22**	**L-20**	**DR-3**
Capacity(BTU/HR)	75100	78582	72295
EER	7.09	6.91	6.69
Power (W)	10589	11370	10802
Condenser Sub-cooling, °F	1.0	0.5	0
Evaporator Superheat, °F	15.0	13.2	10.4
Compressor Discharge Temperature, °F	216.7	204.6	183.2
Liquid Line Temperature, °F	138.6	131.9	129.8

Compressor Suction Temperature, °F	63.6	62.3	64.9
Compressor Discharge Pressure, PSI	350.5	382.2	-
Liquid Line Pressure, PSI	332.0	362.5	331.7
Compressor Suction Pressure, PSI	81.6	85.3	82.0
Refrigerant Charge, Kg	7.0	7.05	8.19

The results of cooling capacity and the energy efficiency ratio (EER) for the two alternative refrigerants are plotted in Figures 3.11a and 3.11b as ratio to those of HCFC-22 to ease the comparison.

Figure 3.11a CC of Packaged unit Prototypes compared to HCFC-22 base

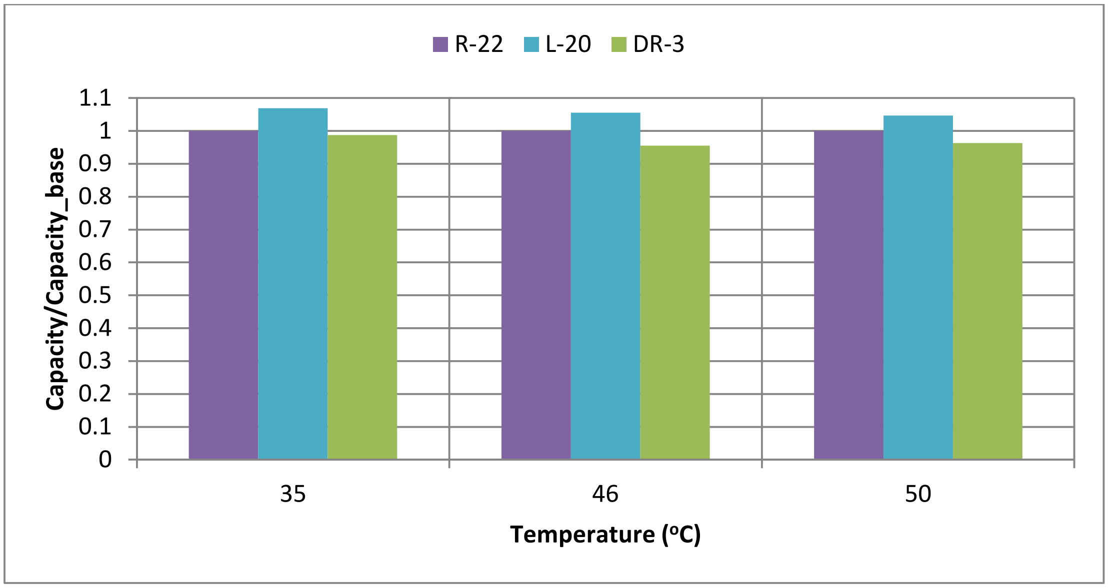
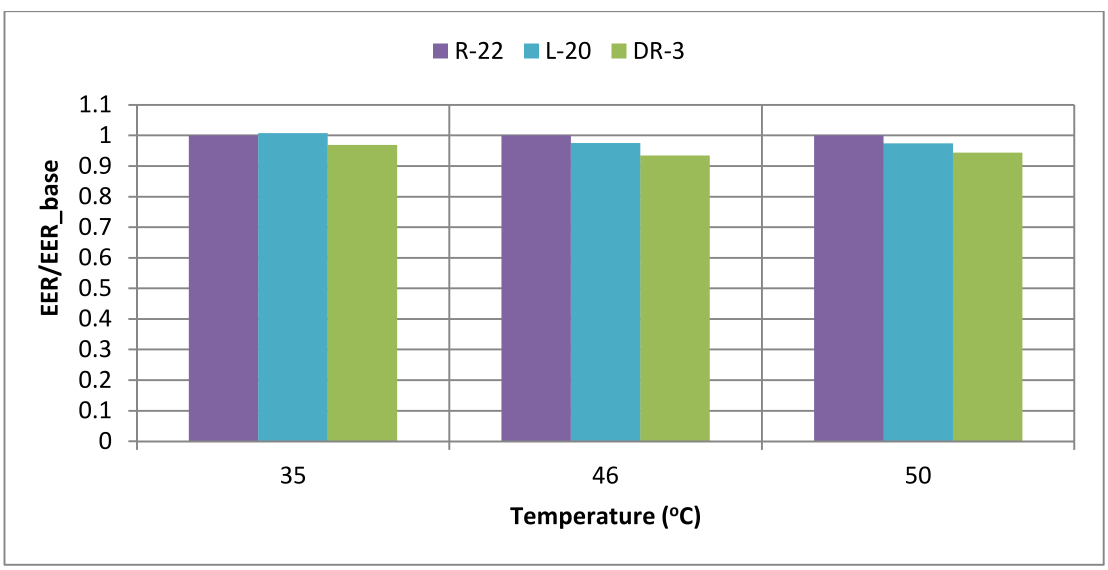
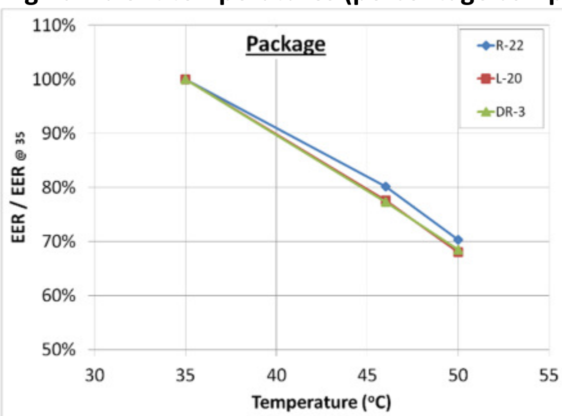


Figure 3.11b EER of Packaged unit Prototypes compared to HCFC-22 base



The results for all refrigerants including HCFC-22 indicated a degradation in Energy Efficiency Ratio (EER) and in cooling capacity when the ambient temperature increases. Figure 3.12a and Figure 3.12b indicates the percentage of efficiency degradation and cooling capacity respectively associated with increasing ambient temperature when going from 35 C to 50 C.

Figure 3.12a EER degradation Figure 3.12b CC degradation at high ambient temperatures (percentage compared to 35 C) for Packaged Units



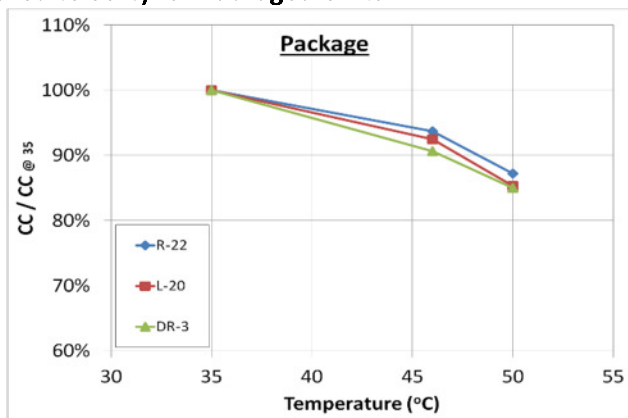


Figure 3.13a, b, and c shows the performance of the two alternatives namely, L-20 and the DR-3 compared to that of HCFC-22. So the figure shows EER versus cooling capacity of the refrigerants compared to HCFC-22 being the base at the three temperatures. The figure shows 10 % boundaries to ease visualizing on how each of the refrigerants is performing compared to HCFC-22.

Figure 3.13a EER vs. CC at 35 C –Packaged unit

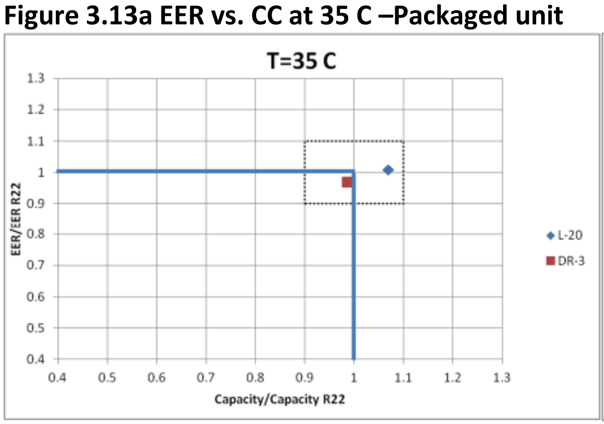


Figure 3.13b EER vs. CC at 46 C –Packaged unit

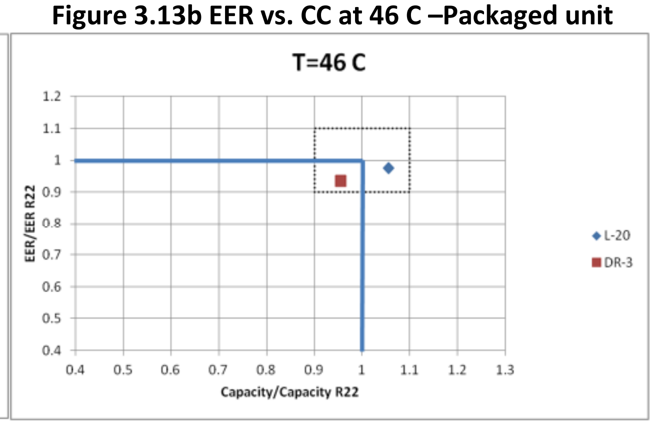
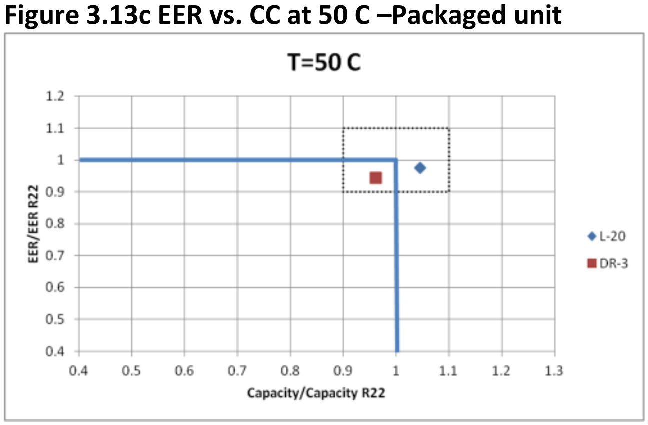


Figure 3.13c EER vs. CC at 50 C –Packaged unit



- The results from testing L-20 and DR-3 in this category vs. a base of HCFC-22 show that L-20 has a higher cooling capacity than the base, while DR-3 has a lower cooling capacity;
- The EER of L-20 is similar to the base at 35 °C but lower by 2.5% at higher ambient temperatures;
- DR-3 shows a decrease in both cooling capacity and EER vs. the base; and
- The degradation of both cooling capacity and EER at higher ambient temperatures for both alternative refrigerants is consistent to those of HCFC-22.

Chapter 4

4. PRAHA Project Components

The main components of the PRAHA project are:

i. **Building and testing prototypes**
This component includes building prototypes for four categories of products, testing them in accordance to agreed testing criteria as shown in Chapter 2 and the results in Chapter 3. The consultation process with technology providers concluded on the following cost-sharing arrangement:

- The technology[1] providers cover the cost of sample row materials i.e. refrigerants and compressors along with the necessary technical support to assist local manufacturers in the redesign/optimization of products
- The local manufacturers cover the cost of developing an adequate number of prototypes per range per refrigerant including internal local manufacturing associated costs

Most of the prototypes for the four categories are built by two different manufacturers to make sure that the result is compared with good accuracy and to make sure that difference in the results is due to the change in the technology and not due only to the design. Each prototype test is compared to base units from the same manufacturer with either HCFC-22 or R-410A. Each combination is tested at three different ambient temperature conditions to better understand the behavior of each model at high ambient temperature.

ii. **Assessment Study on Long-Term Feasible Technologies for Air-Conditioning Sector** (Pilot study in Qatar)
This component is to facilitate the comprehensive assessment of market readiness to accommodate alternate technologies and alternative refrigerants in the air-conditioning sector in the gulf region. It was supposed to be part of the HPMP of Qatar to be conducted in 2013-2014 and to reflect the conditions in other GCC countries. The Study was also extended to a regional dimension addressing the assessment of potentiality of ***District Cooling systems***, using low-GWP and/or non-vapor compression options, as long term energy efficient solutions. This component, except for the district cooling study, was not completed in time and hence not included as part of this project report.

The District Cooling study report is included in Annex B of this report.

iii. **Coordinating phase-out requirements with EE Labeling programs targets (National and regional work)**
This component is an ongoing activity under both the regional work led by CAP/ROWA to address the concern of HAT conditions amongst decision makers and relevant authorities and within the framework of implementing HPMP strategies in gulf countries. It is aimed to be a platform to integrate those efforts within a regional approach i.e. ease the introduction and presentation of the final results to different decision makers. This phase could not be completed in time for this report.

[1] Technology providers are alternative refrigerant suppliers and compressor manufacturers

4.1. Assessment of Components

Alternative refrigerants and/or blends with flammability characteristics and/or higher operating pressure require special attention in areas that were not comprehensively addressed in the past. The supply-chain process of refrigerants requires addressing such considerations at the different stages of manufacturing, installation, servicing, and end-of-life disposal. Skills and norms should be carefully followed in order to ensure the sound and safe deployment of any alternative. The issue becomes more complex when selecting alternatives that operate at high-ambient conditions without compromising the energy efficiency requirements; particularly when it comes to a region with 60% or more of its energy production cater for the demand of the residential and commercial air-conditioning sectors.

A symposium discussing the challenges of promoting alternative refrigerants at high ambient was held each year since 2011 in a PRAHA participating country. The theme of each symposium addressed a different aspect of the search for an alternative refrigerant that can be an acceptable replacement for HAT applications. While each symposium provided insight and answers to some of the question, it also raised issues that still need to be properly addressed.

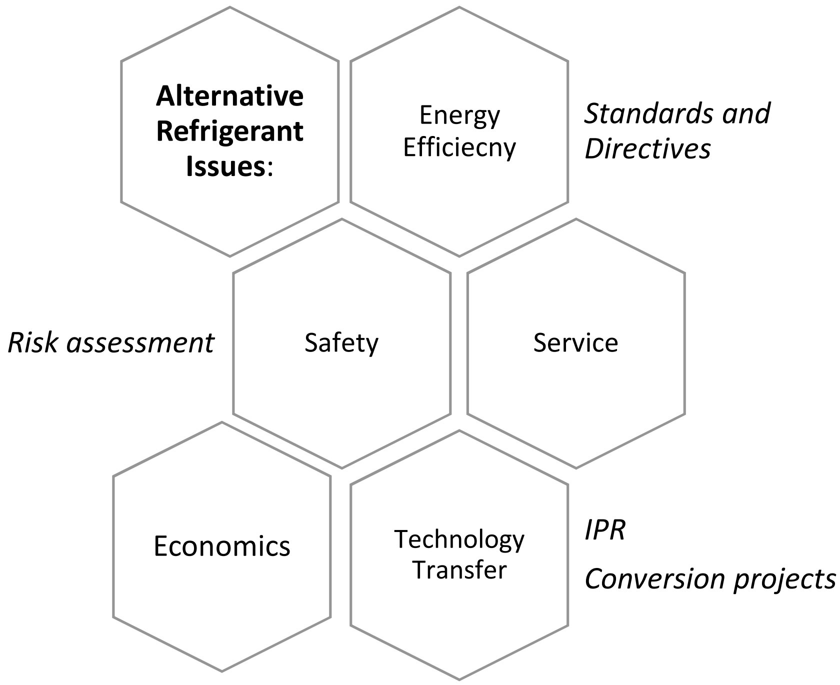
i. **Assessing available technologies:**
The availability of current and long-term commercially available refrigerants and air-conditioning equipment in terms of suitability to operate at HAT conditions including conventional and non-conventional options.

ii. **Assessing relevant Energy Efficiency (EE) standards and codes**:
The impact of EE standards (including buildings' codes and equipment EE rating programs) on selecting low-GWP options in HAT operating conditions.

iii. **Economic comparison of alternative technologies:**
Comparing initial and operating costs of low-GWP air-conditioning technologies with current ODS and high GWP based options taking into consideration perspectives of the manufacturing, consulting sectors and operating/client sectors.

iv. **Promoting Technology transfer:**
Identifying commercial opportunities and associated fiscal implications for facilitating the transfer of low-GWP refrigerant technologies including commercial and trade barriers, patents and relevant intellectual property rights.

This chapter is about the issues relative to alternative refrigerants were identified, what we already know and learned about them and what is still a challenge. The issue come under five headings: Energy efficiency which encompasses standards and regulation; safety including risk analysis; economics addressing the cost of refrigerants, components as well as other costing; technology transfer with emphasis on Intellectual Property Rights (IPR); and lastly service. The illustration below is an overview of the issues for a quick reminder



4.2. Energy Efficiency

Energy efficiency, along with environmental concerns about high-GWP, is the main concern of HAT countries in their search for a suitable refrigerant. The HFC alternatives that were proposed by the industry in the wake of HCFC-22 phase-out in non-article 5 countries were, apart from their still high GWP, mostly not efficient at temperatures above 35C. Some countries participating in the PRAHA project have either MEPS in force at present or planned for the near future. Others are following suit.

TEAP XXVI/9 report lists the MEPS and safety standards that re known in Saudi Arabia, Kuwait and the UAE covering residential and commercial air conditioners that is reproduced in table 4.1 below.

Table 4.1 Energy efficiency and safety standards in selective HAT countries

Country	Number of the standard	Status	Type of requirements	Products in scope	Climate conditions	Test standard to be used
Saudi	SASO 2007/2006	In force	Safety	All	NA	IEC 60335-2-40:1995
	SASO 2663/2014	In force	minimum energy performance values	non-ducted splits and package units < 70000 Btu/h	35°C (T1) and 46°C (T3)	SASO 2681/2007 SASO 2682/2007
	SASO XXXX/2015	Being drafted	minimum energy performance values	all other units	35°C (T1)	ANSI/AHRI 110-2012, ANSI/AHRI 210/240-2008, ANSI/AHRI 340/360-2007, ANSI/AHRI 1230-2010, ANSI/ASHRAE Standard 127-2007, ANSI/ASHRAE/IES 90.1/2010,

Country	Number of the standard	Status	Type of requirements	Products in scope	Climate conditions	Test standard to be used
						ANSI/ASHRAE/IES90.1/2013, ISO 15042/2011
United Arab Emirates	UAE.S.5010-1:2011	In force	minimum energy performance values and energy label	residential and commercial single package and non-ducted split type air conditioners	46°C (T3)	ISO 5151:2011
	UAE.S.5010-1:2014	Published (will replace 2011 version)	minimum energy performance values and energy label	residential single package and non-ducted split type air conditioners	46°C (T3)	ISO 5151:2011
	UAE.S.5010-5: 2014	Published	minimum energy performance values	residential, commercial and industrial ducted split and multiple split-system air-conditioners and heat pumps	46°C (T3)	ISO 13253:2011 ISO 15042:2011
Kuwait		In force	Safety	All	NA	IEC 60335-2-40
		In force	Minimum energy performance values and energy label	Packaged, ducted and non-ducted air conditioners	48°C	AHRI standards

What the table shows is a lack of harmonization among the three countries on the definition of temperature and test standards. What the table does not show is that even the value for MEPS are different. This is a major challenge for the industry in the Gulf region that has to comply with different standards and values for the individual markets.

One of the challenges around the energy efficiency issue is that MEPS introduction has in the most part not been coordinated with the HCFC-22 phase-out dates. The industry looking to replace the inefficient HCFC-22 systems to meet MEPS requirements that are presently being introduced, had only the high-GWP HFCs that exist in non-article 5 countries as a choice since the low-GWP alternatives have not been researched for HAT conditions.

PRAHA arranged meetings between the energy efficiency and the ozone authorities to address this challenge. The meetings helped both sides realize the challenges facing the industry and work out the timelines for the introduction of regulation covering both aspects.

Energy efficiency standards are being prepared for launching in the other GCC countries. Some will try to emulate one of the three countries listed in the table, but this will not bring complete harmonization among all the countries.

The introduction of MEPS is a matter of high priority in the GCC countries. Without MEPS, the consumption of electric power will increase to such an extent that will drive Saudi Arabia, the World's largest oil exporter, to be an importer in the next 15 to 20 years.

HCFC phase-out is also critical as the first tranches of stage I for most HPMPs is coming to an end. Reducing consumption in the next tranches and phases requires immediate action to cut down on manufacturing consumption and reduce or eliminate new HCFC units that require future service consumption in the future.

The two priorities can only be met when proper low-GWP alternatives have been identified that operate efficiently at HAT.

4.3. Safety

Dealing with flammability is an issue for all countries. It is not directly related to HAT as flammability characteristics are not significantly affected by ambient temperatures. The issue is being addressed as a general concern for the HAT countries that have not dealt with flammable refrigerants before.

GWP and flammability are related: lowering the GWP intrinsically means that the substance is less stable with increasing reactivity, such as flammability for example. This is unavoidable due to the physical characteristics of chemicals. The push for environmental sustainability and regulation conformity brings the question about the safe handling of flammable refrigerants to the forefront.

4.3.1. What we know: Safety Standards

The safety standards in most countries with HAT conditions are in the early stages of development. In this section, the relevant international standards are presented as a reference. UNEP and ASHRAE Factsheet dated Oct 2015 lists the new refrigerant designations and safety designation (UNEP-ASHRAE 2015)

ISO Standards:

An International Standards Organization (ISO) Working Group (WG) proposed to extend the relaxed anti-explosion requirements for ammonia, which is known as difficult to ignite substance, to all similar refrigerants with lower flammability. The WG concluded by using the burning velocity with the upper boundary of 10cm/s as an additional category. This category was named 2L to distinguish it from conventional flammable class 2. ASHRAE 34 adopted this concept in 2010, while ISO 817 finally adopted it in 2014. In order to ensure the safe use of refrigerants with this flammability class, experts on the issue have been conducting research for more than 10 years. Many risk assessments factors were considered. They

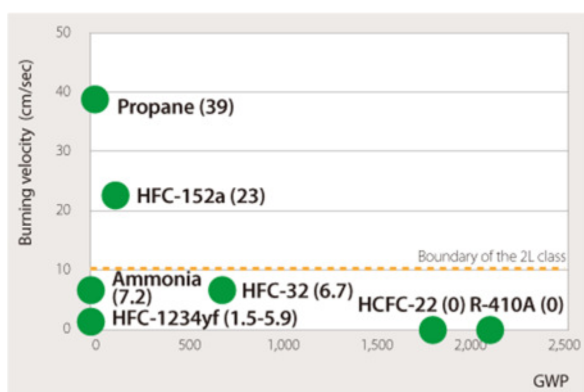


Chart 4.1: GWP vs. burning velocity for typical refrigerants (JSRAE 2014)

indicated that 2L refrigerants' flammability is acceptable when systems comply with standards for equipment safety such as ISO 5149 which sets the standard for safety requirements for refrigeration and air conditioning equipment. Chart 4.1 is a plot of some refrigerants showing both GWP and burning velocity (JSRAE 2014).

ASHRAE Standards

ASHRAE Standard 15 is directed toward the safety of persons and property on or near the premises where refrigeration facilities are located. The hazards of refrigerants are related to their physical and chemical characteristics as well as to the pressures and temperatures that occur in refrigerating and air-conditioning systems. Personal injury and property damage from inadequate precautions may occur. The first Safety Code for Mechanical Refrigeration, recognized as American Standard B9 in October 1930, appeared in the first edition, 1932–1933, of the ASRE Refrigerating Handbook and Catalog (Chakroun 2015).

Standard 15 is based on three classifications: refrigerant used; type of building involved based on the occupancy type; and type of refrigerating or air-conditioning system used. Based on this information, the standard establishes appropriate restrictions and requirements to ensure safeguards for humans and property for the duration of the life of the building.

Requirements must be defined in some shape or form such as how refrigerants are used, where can refrigerant be located, what quantity of refrigerant is allowed, how is the equipment designed and built, whether in a factory or on the job site, and to what standards for electrical safety and pressure safety, as well as how the equipment is operated and tested. These requirements must be defined for all the possible combinations of the three classifications.

IEC standards

Regarding electrical equipment safety, standard IEC60335-2-40 was revised for flammable refrigerants in 2013 as defined by ANSI/ASHRAE 34 [ISO 817] classification. The standard covers the design and construction of equipment, requirements for utilization, and operating procedures. For example, Standard IEC60335-2-89 sets the limit for the maximum charge of hydrocarbons in small commercial refrigerated systems at 150 g.

EN Standards

European Standards (ENs) have been ratified by one of three European Standardization Organizations recognized as competent in the area of voluntary technical standardization as European Union regulations and automatically becomes a national standard in each of the 33 member countries. EN standards applicable to safety are:

- EN 378: 2008 (under revision) entitled *Refrigerating Systems and Heat Pumps – Safety and Environmental Requirements.* The stated aim of the standard is to reduce the number of hazards to persons, property and the environment caused by refrigerating systems and refrigerants. The standard is in four parts:
  - Part 1 basic requirements, definitions, classification and selection criteria;
  - Part 2 design, construction, testing, marking and documentation;
  - Part 3 installation site and personal protection;
  - Part 4 operation, maintenance, repair and recovery.
- EN 1127-1: Explosive atmospheres — explosion prevention and protection;
- EN 60079: Requirements for electrical systems used in potentially explosive atmospheres
- EN 13463: Non-electrical equipment for use in potentially explosive atmospheres.

All the European countries must follow European standards as a minimum. In addition, national rules can be stricter, particularly regarding flammability. For instance, in Italy, there are a number of Ministerial Decrees affecting various public access buildings including hotels, shopping malls, hospitals, schools, offices and airports. These ban the use of any flammable refrigerant in split air-conditioning applications. This includes both higher flammability (A3) and lower flammability (A2L) refrigerants. Ammonia is permitted for water chillers but other flammable refrigerants are banned for chillers. In France there is a decree that addresses the risks of fire and panic in public buildings. This applies to buildings such as hotels, restaurants and bars, shops and shopping malls, hospitals, schools, offices and museums. It applies to all HVAC applications and bans the use of flammable, including mildly flammable, refrigerants.

4.3.2. What we know: Safety regulation regarding leakage

There are laws and regulations in some countries already in place to maintain safety or prevent risks by reducing leaks. These laws regulate the manufacture, operation, and maintenance of air conditioners. Based on these laws, technical standards, application procedures, and inspection procedures are specified in details, as well as exemptions to laws and values that require notification reports. Some examples from around the world:

In the European Union: ATEX (***AT****mosphères* ***Ex****plosives*) is the Directive that covers the legal requirement for controlling explosive atmospheres and the suitability of equipment and protective systems used in them:

- ATEX 95 (Equipment Directive 94/9/EC) covers the design of equipment and protective systems intended for use in potentially explosive atmospheres;
- ATEX 137 (Workplace Directive 99/92/EC) covers the minimum requirement for improving the safety and health of workers potentially at risk from explosive atmospheres. It applies to service engineers working on HC systems

Europe: The regulation regarding the use of stationary air conditioners is known as F-gas Regulation (EC) No. 842/2006. The regulation focuses on reducing refrigerant leakage from air conditioners and requires proper management, instructional courses for operators, labeling of equipment containing F-gas, and reports by producers, importers, and exporters of F-gas. In Jan 2015, the EU Commission enhanced the existing regulations by reducing the leakage of F-gas by 79% of the present level and prohibiting the placing on the market of equipment using F-gas in sectors where an environmentally friendly refrigerant has been developed. To achieve this, a phase-down schedule has been decided. (IIR 2015)

United States: The Significant New Alternatives Policy (SNAP) program of the US Environmental Protection Agency (EPA) listed five flammable refrigerants as acceptable substitutes in several end-user refrigeration and air conditioning units. The list includes HFC-32 and HC-290 which are used in the prototypes being tested under PRAHA (EPA 2015). The Climate Action Plan announced in June 2013, calls on EPA to use its authority through the SNAP Program to encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals.

The rule approves five flammable, climate-friendly alternatives for various kinds of refrigeration and AC equipment, subject to use conditions. EPA believes that those refrigerants present overall lower risk to human health and the environment compared to other available or potentially available alternatives in the same end-uses. The refrigerants include:

- Ethane in very low temperature refrigeration and in non-mechanical heat transfer;
- Isobutane and propane in retail food refrigeration (e.g., stand-alone commercial refrigerators and freezers) and in vending machines;
- Isobutane in household refrigerators, freezers, combination refrigerators and freezers, vending machines, and room air conditioning units;
- R-441A in retail food refrigeration (e.g., stand-alone commercial refrigerators and freezers), vending machines and room air conditioning units; and
- R-32 in room air conditioning units, which according to EPA's definition include packaged terminal air conditioners and heat pumps, window air conditioners and portable air conditioners designed for use in a single rooms (but not central air conditioners, mini-splits and multi-split air conditioners).

The use conditions set requirements to ensure that these substitutes do not present significantly greater risk in the end-use than other substitutes that are currently or potentially available for that same end-use. Currently, there are no air conditioning equipment using R-32 or hydrocarbons in the U.S.

Japan: the Global Environment Sub-Committee of the Central Environment Council and the Chemical and Biotechnology Sub-Committee of the Industrial Structure Council jointly created a task force and compiled an outline for the regulation of HFCs. Based on these discussions, the "*Law on regulation of management and rational use of fluorocarbons*" was established at the National Parliament on June 5, 2013. The name of the law was changed from the "Law for ensuring the implementation of the recovery and destruction of fluorocarbons concerning specific products." The new law requires the replacement of high-GWP HFCs, refrigerant management, and refrigerant recovery to reduce leakage of HFCs (JSRAE 2014

4.3.3. Safety Challenges: Risk assessment

Risk assessment is based on the worst case scenario, which is an accidental leakage where the full refrigerant charge is discharged inside the occupied space. The mass of refrigerant inside the machine is hence a major consideration in risk assessment; moreover, the LFL depends on the mass. An estimate of refrigerant charge for a typical 3.5 kW machines is as follows:

- HCFC-22 = 1,150 grams   HFC-32 = 900g
- R-410A = 1,100g   HC-290 = 330g

Assessment of risk from a leakage of an air conditioning unit installed indoors covers:

- Location of unit;
- Location and intensity of the leak;
- Presence of source of ignition.

Characteristics of the refrigerant are studied for:

- Lower flammability limit in Kg/m^3;
- Heat of combustion in Joules or Mega Joules per KG;
- Burning velocity in meters or centimeters per second.

Risk assessment on flammable refrigerants has been done by several institutions in China, Japan, and the US among others. Some examples are found in the annex. Also in the annex are other considerations like the effect of refrigerant charge limitation and the characteristics of flammable refrigerants.

It should be noted, that there is ongoing research on identifying technical solutions that can prevent the worst case scenario. The challenges facing the HAT countries of the PRAHA project is in the adaptation of the risk assessment to the conditions in these countries. For this, the countries need to carry on their own risk assessment work to verify at the actual working conditions.

4.4. Economics

In theory, high energy efficiency and safety can be achieved in almost any application with any refrigerant. The challenge is to choose a refrigerant that allows high enough energy efficiency and sufficient safety to be achieved at a cost which is low enough for the system builder to compete with other system builders. The total system cost and total system energy has to be considered, not only the refrigerating circuit cost and energy consumption. Besides cost, installation space and sound levels are other challenges for the system designer that may limit the choice of systems and refrigerant. The economical dimension was not considered when assessing the prototypes in this project. Some of the components used in this study were not globally commercialized yet and their cost were not available. Additionally, those components should be further optimized for high ambient conditions and introduced at commercial level. Accordingly the economical dimension should be considered in future work due to its importance.

What constitutes an optimal design is highly dependent on the ambient temperatures. In high ambient conditions there will be a tendency towards larger systems due to the higher heat load, larger heat exchangers compared to the rest of the systems, and refrigerants with low critical point have much lower performance than in colder climates. . The higher the energy level the higher the cost and size impact of refrigerants and systems that are not optimal in view of energy efficiency. High energy efficient, compact units with low weight and high recyclability will become the future tendency. This will be even more important for larger equipment as needed for high ambient zones (TF XXVI/9 2015)

The discussion about the economic implications of alterative refrigerants covers the lifetime of the systems using these refrigerants. In this section the effect of the price of the refrigerant and the components used in building the new systems will be discussed as well as the impact of the new alternatives on operating costs including energy, service & maintenance and end-of-life.

The HFO/HFC blends have not been put on the market yet, and hence their price is not yet defined. Moreover HFC-32 and HC-290 are not yet available in commercial quantities in HAT markets, but can be available through different channels. In conclusion, at the time of preparing the PRAHA report, there is insufficient information available about the cost of low-GWP alternatives in the HAT region.

The alternative refrigerants selected have either HCFC-22 equivalent pressure or R-410A equivalent pressure; consequently, the price of components, including oil, will be either equivalent to those of HCFC-22 or R-410A. The industry might develop special compressors for the HFO/HFC blends to meet energy efficiency requirements; this will affect the cost of the air conditioners.

Design for flammability will induce a first-cost increase to meet regulation on reducing the risk of ignition and leak tightness. The industry has experience building both HFC-32 and HC-290 systems and hence the residual first cost increase has been reduced with increased commercialization.

4.5. Technology Transfer

For the purpose of this report, the term Intellectual Property (IP) covers patents and industrial design rights, the other forms of IP such as copyright and trademark are outside the scope of this report.

Patents and design rights have time and geographic limitations and have to be investigated on these basis.

Patents for refrigerants are classified into the following four classifications based on the characteristic of the invention: (1) related to the refrigerant itself; (2) related to the refrigerating machine oil; (3) related to the operating condition or handling of the refrigerant; and (4) related to the apparatus using the refrigerant. Up to Oct 2014, there are 1,826 patents in the four categories that have been filed globally, out of which 1,399 are related to HFOs & HFCs and 679 related to HCs (IPIR 2014). Note that there are some overlap, reason why the total does not add up.

The patent applications that have been filed HFO & HFC refrigerants mostly apply to refrigerant itself, the air conditioning and refrigerating machines as well as the operating conditions; while those for HCs apply for the air conditioners and the oil used in the machines

The discussion about intellectual property related to the building and testing of prototypes for PRAHA covers apart from refrigerants the components used in building of the prototype namely the compressors. The discussion involves all stakeholders from OEMs to technology providers.

The discussion about industrial design rights is related to the overall design and outside look of the machines. This is less of concern as far as this report is concerned.

Patent infringement is the use of the patented material without the permission of the patent holder. Permission may typically be granted in the form of a license. Patents are territorial, and infringement is only possible in a country where a patent is in force. A clearance search, also called **freedom-to-operate** search or infringement search, is a search done on issued patents or on pending patent applications to determine if a product or process infringes any of the issued patents or pending patent applications (Wikipedia).

To date, the following information on patents related to the refrigerants used in PRAHA is known:

- HC-290 no restriction on use in machines;
- HFC-32: Daikin also holds patents related to the apparatus using the refrigerant; however, some of these patents are waived for some of the developing countries;
- HFO/HFC blends: most of these blends are still in the freedom-to-operate search mode. Refrigerant manufacturers do not normally divulge the status of their search or patent claims before a patent is issued.

As far as components are concerned, some of the compressors were developed especially for PRAHA to operate at T3 conditions and 60 Hz for example but no patents are pending as at present.

4.5.1. Technology transfer issues related to economics

PRAHA sent out a survey to the refrigerant suppliers to find out if there are any restrictions on patents that will affect the future marketability of their products. The questionnaire covered the refrigerant itself, its chemical components, as well as its use inside air conditioning units. PRAHA has not received any response and were made to understand that the information asked is proprietary and confidential as long as the refrigerants are not put on the market. Since most of the HFO/HFC blends are still in the research mode, there was no feedback response to report on in this section.

The effect of IPR and patents on price of the HFO/HFC blends could not be determined either as there is no indication of what the price levels will be. Verbal comments made by the manufacturers put the price per Kg of the blends higher than the available HFCs, some of whose patents are expiring, and much higher than the prevalent price of HCFC-22 even with the latest increase due to its dwindling production.

HC-290, which in proper refrigeration quality is approximately double the price of HCFC-22, but with the reduced charge, there is no incremental cost.

Components – and especially compressors – are not yet fully commercially available. With larger demand prices will decrease.

4.6. Service

The discussion on service covers several factors:

- **Handling of flammability and averting the risk of accidents:** The careless promotion of hydrocarbons, or hydrocarbon-based blends, as drop-in refrigerants is a major concern in the industry. Handling of new equipment that are specifically designed to work with flammable refrigerants is less of a concern but needs to be addressed through effective education and training on the safe handling of flammable refrigerants.

  There are a number of industry guides on managing the health and safety risks associated with the safe design, manufacture, supply, installation, conversion, commissioning, operation, maintenance, decommissioning, dismantling and disposal of refrigeration and air conditioning equipment and systems that use a flammable refrigerant. UNEP introduced a guide on the safe use of HCFC alternatives in refrigeration and air conditioning (OzonAction 2015) addressing the risks of flammability and toxicity, but also pressure (figure 4.2).

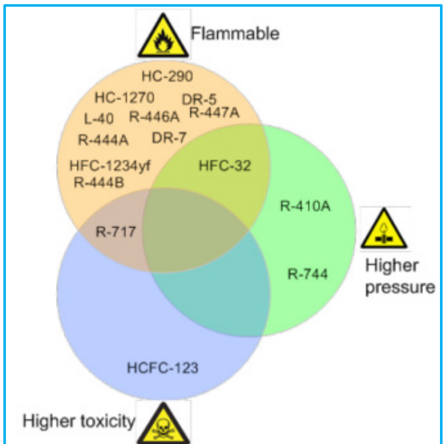


Figure 4.2: Map of safety hazards of alternative refrigerants (OzonAction 2015)

  Mandatory charge restrictions apply to the use of flammable refrigerants in many applications. Designers, manufacturers, importers and suppliers must ensure that the equipment they design, manufacture, import or supply is safe, before it is introduced to the market place. Installing contractors and service technicians must ensure that the equipment they install and service is safe (AIRAH 2013).

- **Service training and certification of technicians:** Several countries, including China and South Africa, have adapted regulation from ISO 5149 and 817 and EN 378 in order to establish regulations on training and certification schemes for refrigerating systems. The EU F-gas Regulation which requires certified personnel to work with fluorinated gases has been adapted into national law in several European Union countries. STEK in the Netherlands for certification of personnel and companies was introduced in 1992 and has contributed to emission reduction from 20% to 3.5% (IIR 2015)

  A survey of European contractors on the needs for handling alternative refrigerants found that the safety, reliability and efficiency of alternative refrigeration systems in Europe could be at risk due to lack of availability of expertise and skills in design, component selection, installation, service & maintenance, and containment of refrigerant. There is a clear need for improving skills, especially

for flammable refrigerants, and the effectiveness of re-training to address safety, reliability, and leakage. The survey found a high level of interest and commitment from small and medium size businesses in both classroom and on-line training (Buoni 2015).

The situation is similarly, if not more, critical in HAT countries where HCFC systems are still prevalent. For some of the technologies, technicians have to meet the double challenge of dealing with higher pressures and flammable alternatives. There is a need to certify technicians in Article 5 countries as the countries' transition to flammable refrigerants with more sophisticated systems.

- **Temperature glide of refrigerants:** The industry is starting to build knowledge about glide. Computer modelling, confirmed by field tests, has shown that adding R-407C to the depleted charge in the system to restore the charge to its correct mass level tends to bring the composition back close to its correct formulation. After a series of leak/recharge cycles in a fully instrumented test system under standard conditions, cooling capacity had dropped by ~5% and with even less impact on system energy efficiency (Campagna 1997). Further assessment needs to be done to validate such conclusion for HFO/HFC blends.

Chapter 5

5. Conclusion and way Forward

The main result of PRAHA is that it went beyond the level of being an individual project with specific planned outcomes and outputs; PRAHA developed into being a **PROCESS** at different levels, i.e., governmental, local industry, institutional as well as international technology providers. A number of activities and projects that are currently being implemented to address alternatives for high ambient conditions were all triggered by the PRAHA process which started in 2012, and they are following, more or less, a similar approach. Some of the activities are listed in Annex F.

The PRAHA project included several components, but the major one is building and testing prototypes designed for high ambient temperature conditions. The non-testing components under PRAHA-I assessed technological, economic and energy efficiency aspects in conjunction with high ambient temperature in addition to addressing the potentiality of District Cooling (DC) systems, using low-GWP and/or non-vapor compression options, as long term energy efficient solutions. The sufficiency of funding and availability of information led to limited progress in the other than testing components.

5.1. Conclusion

In order to discuss the conclusions of PRAHA, there is a need to present the key findings of PRAHA in a categorized way to presenting the key findings and related conclusions. Below figure represent the categories of the PRAHA findings:

Figure 5.1 Key Findings of PRAHA-1

Technical Feasibility of low-GWP Alternatives

- *Comparison to commercially existing options i.e. HCFCs & high-GWP HFCs*
- *Relation to Energy Effeceincy programs Directives*

Safety consideration and Availability of Materials

- *Risk assessment of A2L and A3 alternatives in industry and service*
- *Availability and cost of alternatives and components*
- *Technology transfer and IPR considerations*

Research and Development Capacities

- *Knowledge and capacity of industry to design with low-GWP alternatives*
- *Related research programs at global, regionla and nationla levels*

Contribution of District Cooling

- Size and potentiality of district cooling applications
- Use of low-GWP or not-in-kind technologies in district cooling applications

5.1.1. Technical Feasibility of Low-GWP Alternatives

Through the examination and analysis of the component of building and testing prototypes with low-GWP alternatives under PRAHA, several important findings were captured and led to important conclusions that will set the pathway for future needed work. The key conclusions from testing prototypes are:

I. There are potential alternatives that are close to baseline refrigerants, or better in some cases, and worth further investigation. With further engineering those alternatives can be strong candidates for replacement of HCFC-22.

II. The process of developing an optimized compressors for high ambient temperatures to work with one of the low-GWP refrigerants is still in its early stages. This means that future compressors, well designed for high ambient operating conditions, would likely perform better and hence may achieve the same or near performance characteristics as the baseline units

III. While acknowledging the fact that HCFC-22 performs more efficient compared to R-410A, thermodynamically, market products show different results. Globally, the development of units working with HCFC-22 has not taken place since around 2012 due to the Montreal Protocol accelerated phase-out regime for HCFCs which was adopted in 2007. This is true even for many manufacturers in A5 countries. This led to the fact that many of exiting R-410A units, commercially being marketed now, are more advanced in comparison to HCFC-22 similar size units.

IV. Comparing the performance of prototypes designed for new alternatives with the performance of HCFC-22 or R-410A units is not technically sufficient to establish a decisive argument about the feasibility of a particular alternative. The heat load per square meter of space in HAT countries is an important factor which gives an added importance to the cooling capacities of the units working with alternatives refrigerants at higher ambient temperatures. This is very important market factor that will affect the selection of successful candidates to be placed in HAT markets.

V. The size of the units affect, considerably, the impact of thermodynamic difference between alternatives in comparison to HCFC-22 and R-410A. The bigger the unit, in cooling capacity, the easier to accommodate successfully and efficiently the alternatives. There is however a limitation of the refrigerant charge amount that these units can accommodate due to the flammability characteristic of the tested alternatives, both A2L and A3 candidates.

VI. The process of introducing higher energy efficiency (EE) standards for air-conditioning applications in HAT countries is progressing at a quicker pace compared to the process of assessing the feasibility alternative refrigerants. A smart approach is needed to jointly consider EE and low-GWP alternatives in order to avoid continuing the use of higher-GWP alternatives that are commercially available at present.

5.1.2. Safety consideration and Availability of Materials

I. Due to the flammability nature of future alternatives, a comprehensive risk assessment needs to be tailored to the needs of A5 countries, in particular for high ambient temperature conditions with their specific use pattern. Such assessment needs to address manufacturing, placing into market, servicing and the end-of-life of the equipment.

II. Standards and codes related to the use of flammable refrigerants are going to be cornerstones for the success of deploying any of the low-GWP alternatives. However, the contradiction between the equipment standards which internationally allow, with limitations, the use of flammable refrigerants in A/C applications and the buildings' codes in most of HAT countries which limit, if not prohibit, the use of flammable materials in high rising buildings, will be another major challenge for the process of promoting the low-GWP refrigerants.

III. The availability in local markets of low-GWP refrigerant components optimized for HAT conditions is a factor in the process of promoting the alternatives. Absence of exact, or even estimated, information about when and how much these materials will be commercially available is another challenge that would take some time before being addressed.

IV. The long list of candidates, especially HFC/HFO blends, being offered for testing at the current stage is a confusing factor in the process of selecting the winning candidate(s). High ambient temperature countries are current technology recipients even with large equipment manufacturing capacities.

V. Understanding the implication of Intellectual Property Rights (IPRs) related to the use of refrigerants and components is another important barrier. Compared to the historical technological shifts from CFC to HCFC, and then to HFC, which witnessed limited IPR-related considerations, in particular to most A5 countries, the vagueness associated with this subject at present is clearer with the very limited information and fora being offered to discuss and clarify this subject.

VI. The cost implication on the final products, when using low-GWP alternatives, cannot be calculated or even estimated at the current stage due to the lack of commercial pricing and availability of the relevant components. It's understood, from historical lessons learned, that cost goes down over time with the development and commercialization of refrigerants and components. However, for the case of low-GWP alternatives, the associated cost implication is expected to be notable with the safety considerations not only for the final product but also for the work related to placing them into the market and servicing requirements as well as liabilities, if applicable, for using equipment with hazardous consideration. This is expected to have an impact on the industry as well as public and private budgets but can't be presently assessed and would need more time to allow for the commercialization of such products.

5.1.3. Research and Development Capacities

I. The research and development (R&D) personnel at OEMs in HAT countries have diverse skills and designs capabilities; however, there is still limited knowledge of designing using low-GWP alternative refrigerants despite the assistance offered by the technology providers.

II. A full product redesign is needed for most of products, this means that a comprehensive process of design analysis, optimization and validation is needed. This type of process requires capacities and intervention beyond what currently exist at OEMs in HAT countries.

III. Maturity in designing and optimizing products using low-GWP alternatives with their specific characteristics, such as flammability, higher operating pressures, temperature glide, etc. needs time and special programs to build such sufficient capacity.

IV. Research programs at local institutes and centers in HAT countries related to assessing future refrigerants and technologies is another deficiency that needs to be addressed. The link between any existing programs and the local industry is a dimension that requires attention and dedicated efforts

5.1.4. Contribution of District Cooling

I. The magnitude of the potential district cooling (DC) business in HAT countries is huge and very promising. However, the absence of local institutional framework, public or private, to fairly govern the relationship amongst DC stakeholders is a key challenge in scaling up the use of DC applications and make them successful models.

II. DC sites and projects in HAT countries still depend on conventional technologies with a lack of technology providers or suppliers willingness to promote the use of low-GWP refrigerants or non-vapor compression technologies. However, with the global pressure on F-gases, there might be a chance to start promoting such concepts.

III. The flammability and safety considerations, associated with low-GWP alternatives, can be a promoting factor to expand the use of DC systems or central plants. The lack of technological and institutional models to promote such trend is another obstacle that need to be addressed in any future work.

5.2. The way forward

Taking into account the key findings and conclusions of PRAHA as well as other ongoing research projects and initiatives at regional and/or international levels, areas of work that need additional work are presented in the table 5.1 below along with the priority of work of each.

Table 5.1 Prioritization of Issues

Issue	Priority (Short- Medium- long)
1. Building the capacities of local OEM to design with low-GWP Alternatives	Short-Medium
2. Developing comprehensive risk assessment on use of A2L and A3 refrigerants	Short-Medium
3. Assess economical implication of use of low-GWP refrigerants	Medium-Long
4. Assess technological barriers and IPRs issues related to low-GWP refrigerants and components	Medium-Long
5. Institutionalizing the assessment of low-GWP alternatives in local research programs	Short-Medium
6. Building technical capacities of the servicing sector	Short-Medium-Long
7. Upgrading local standards and codes to allow deployment of low-GWP alternatives	Short-Medium

The above list is not exclusive but represents the most significant issues identified as priorities for advancing the process of promoting low-GWP alternatives in the air-conditioning industry. Some of the priority areas are partially and adequately covered by other projects including:

- Building technical capacities of the servicing sector: Which is part of training programs in most of HPMPs as well as other regional and international capacity-building programs.
- Upgrading local standards and codes to allow deployment of low-GWP alternatives: Several HPMPs, including those in West Asia, include components for upgrading local standards to allow use of future refrigerants. This is in addition to regional support being offered through UNEP's Compliance Assistance Programme (CAP).

Some priority areas, such as the availability of alternatives in local markets, issues related to intellectual property rights, and the realistic assessment of economic implications for the use of low-GWP alternatives, may be difficult to advance at this stage of time. The issues listed as items 3 and 4 in table 1 above, were preliminary assessed under PRAHA and it was concluded that more time is needed to reach the stage of building a real analysis of the technological and economic barriers due to current market considerations, availability and limitations to access information.

References

References for Chapter 1

1. Achaichia, N. 2014. Flammability Characteristics and Handling of A2L Class Refrigerants. Alternatives Refrigerants for High Ambient Countries, Dubai 2014.
2. Amrane, K. 2013. Overview of AHRI Research on Low-GWP Refrigerants. Webinar Aug 2013
3. Biswas, A., Cremaschi, L. 2012. Performance and Capacity Comparison of Two New LGWP Refrigerants Alternative to R410A in Residential Air Conditioning Applications. Proc. International Refrigeration and Air Conditioning Conference at Purdue, USA.
4. Chen, Z. H. 2012. Research on Rotary Compressors Based on R-290 Technology. Proc. UNEP conference on technologies for high ambient conditions, Dubai, 2012.
5. Chin, L., Spatz, M.W. 1999. Issues Relating to the Adoption of R-410A in Air Conditioning Systems, 20th International Congress of Refrigeration, IIR/IIF, Sidney, Australia.
6. Colbourne, D. Rajadhyaksha, D., Sahu, A., and Wadia B.J 2013. HC-290 as an Alternative Refrigerant for Split Air Conditioning Systems in High Ambient Temperatures. Papiernicka, 2013
7. Chakroun, W. 2014. Challenges for High Ambient Countries. ASHRAE Winter Conference, New York.
8. Devotta et al, 2005a Devotta, S., Padalkar, A.S., Sane, N. K., 2005a. Performance assessment of HCFC-22 window air conditioner retrofitted with R-407C. Applied Thermal Engineering, Vol. 25, Issue 17–18, 2937–2949.
9. Domanski, P.A., Payne, W. V. 2002. Properties and cycle performance of refrigerant blends operating near and above the refrigerant critical point. Task 2: Air conditioner system study, Final report. ARTI-21CR/605-50010-01-Pt. 2.
10. Economist, 2009. Economist Intelligence Unit report: GCC in 2020, The Gulf and its People.
11. Eltalouny, A. 2014. Challenges in Identifying Low-GWP Refrigerants for High Ambient Temperature Climates. International Conference on Efficient Building Design, Oct 2014 Beirut, Lebanon.
12. Elassaad, B. 2014. Low-GWP refrigerants in High Ambient Countries: Challenge or Opportunity. ASHRAE Winter Conference New York, NY Jan 2014.
13. Hamed, S. 2012. Using HC and HFC refrigerants in rooftop package units – Which refrigerant is the future? Proc. UNEP conference on technologies for high ambient conditions, Dubai, 2012.
14. IMF. 2015. International Monetary Fund Regional Economic Outlook Update. Jan 21, 2015.
15. Li, T. 2014 Performance of R-290 RAC and Risk assessment, The 4th Regional Symposium on Alternative Refrigerants for High-Ambient Countries; Installation, Service, and Risk Assessment of Future Refrigerants Dubai Oct 2014.
16. MOMRA 2013. Ministry of Municipal and Rural Affairs, KSA Building permits for 1434 Hijri. www.momra.gov.sa
17. Motta, S. F. Y., Domanski, P. A. 2000. Performance of HCFC-22 and Its Alternatives Working at High Outdoor Temperatures. Proc. International Refrigeration and Air Conditioning Conference at Purdue, USA.
18. TEAP, 2015. Decision XXVI/9 Update Task Force Report Additional Information on Alternatives to Ozone-Depleting Substances. Ozone Secretariat website, September 2015.
19. Sethi, A., 2013. Low GWP Replacements for R-410A in Air Conditioning Applications. Proc. 2013 ASHRAE Summer Meeting, Denver, CO, USA.
20. Tu, X., Liang, X., and Zhuang, R, (2011) Study of HFC-32 Refrigerant for Residential Air-Conditioning Applications. International Conference on Refrigeration, Prague 2011.

21. UNEP, 2014 UNEP Nairobi, Ozone Secretariat, 2015. 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Option Committee, 2014 Assessment. ISBN: 978-9966-076-09-0.
22. UNEP, 2015. Air Conditioning and Refrigeration Technical Options Committee Assessment Report. 2014 Edition to be published in 2015.

References for Chapter 4

1. ADoE. Australian Government Department of Commerce website www.environment.gov.au
2. AIRAH 2013. Australian Institute of Refrigeration, Air Conditioning and Heating. Safety Guide, Flammable Refrigerants. ISBN: 978-0-949436-05-4. 2013.
3. BRA 2012. British Refrigeration Association. Guide to Flammable Refrigerants, issue 1, October 2012.
4. Buoni 2015. Buoni, Marco. Refrigerant Emissions and Leakage, Blended Learning for Alternative Refrigerants in New Equipment. Chicago, Jan 2015
5. Campagna 1997. Campagna, Ennio and Morely, John. The Use of R-407C Applications and Guidelines. Reproduced at Centro Galileo website
6. Chakroun 2015. Chakroun, Walid. Refrigerants and ASHRAE Flammability Standards. Energy and Environment in Ships Conference, Athens, Greece. May 2015.
7. Chen 2012. Chen, Jainping. The impact of flammable Refrigerants on the Servicing Sector. Shanghai Jiao Tong University, Oct 2012.
8. EPA 2015. US Environmental Protection Agency, Protection of Stratospheric Ozone: Listing of Substitutes for Refrigeration and Air Conditioning and Revision of the Venting Prohibition for Certain Refrigerant Substitutes. EPA–HQ–OAR–2013–0748; FRL-9922-26-OAR. February 2015.
9. IIR 2015. 28th Informatory Note on Refrigeration Technologies, Qualification and Certification of Refrigeration technicians. Sept 2015.
10. IPIR 2014. Intellectual Property Research Institute – Japan, website.
11. JSRAE 2014. Risk Assessment of Mildly Flammable Refrigerants 2013 Progress Report, April 2014. The Japan Society of Refrigerating and Air Conditioning Engineers.
12. Kataoka 2014. Kataoka, Osami. Safety Considerations when Working with 2L Flammability Class Refrigerants. Presentation at the Institute of Refrigeration, Oct 3, 2013 London.
13. Li 2014. Li Tingxun. Performance of R-290 RAC and Risk Assessment. 4th Symposium on Alternative Refrigerants for High Ambient Countries, Dubai Oct 2014
14. ORNL 1997. Sands, James; Fischer, Steven; and Baxter, Van. Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies. Oak Ridge National Laboratory report, 1997.
15. OzonAction 1995. Safe Use of HCFC Alternatives in Refrigeration and Air Conditioning, An Overview for Developing Countries. 2015
16. TEAP 2015. Technical and Economic Assessment Panel Task Force XXVI/9 report. May 2015. UNEP OzonAction website
17. UNEP-ASHRAE 2015. Update on New Refrigerants Designations and Safety Classifications. October 2015.
18. Wikipedia www.wikipedia.org
19. Zhang 2013. Zhang, W., Yang, Z., Li, J., Ren, C.-x., Lv, D., Wang, J., Zhang, X., Wu, W., Research on the flammability hazards of an air conditioner using refrigerant R-290, International Journal of Refrigeration (2013), doi: 10.1016/j.ijrefrig.2013.03.015.

Annex A – Technical Review Team Biographies

Prof. R. S. Agarwal (India)

Radhey Agarwal is a mechanical engineer. He received his PhD from the Indian Institute of Technology in Delhi (India) in 1975. He specializes in refrigeration, air-conditioning, and alternative refrigerants to CFCs and HCFCs. He is a former Deputy Director (faculty), Dean of Industrial Research and Development and Chairman, Department of Mechanical Engineering, at IIT Delhi. He was the Co-Chair of the UNEP Technical Options Committee on Refrigeration, Air-conditioning and Heat Pumps (RTOC) and a member of the Technology and Economics Assessment Panel (1996–2008) of the Montreal Protocol. He has been actively contributing toward efforts to protect the ozone layer as part of the Technology and Economics Assessment Panel (UNEP TEAP) since 1989. He is the recipient of the 1998 US Environmental Protection Agency (EPA) Stratospheric Ozone Protection Award for Technical Leadership in CFC-Free Refrigeration and the 2007 US EPA Stratospheric Ozone Protection Award Best of the BEST. Dr. Agarwal was the Vice-President of the International Institute of Refrigeration (IIR), Commission-B2, and a member of the scientific committee of the IIR. He is a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Indian Society of Heating, Refrigerating and Air-Conditioning Engineers (ISHRAE).

Dr. Karim Amrane (USA)

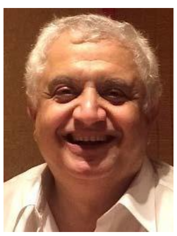
Karim Amrane is Senior Vice President of Regulatory and International Policy at the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). He manages the industry's cooperative research program and is responsible for the development and implementation of AHRI's regulatory and international policy. He holds a PhD in mechanical engineering from the University of Maryland at College Park (Maryland, USA) where he currently is apart-time faculty member. Dr. Amrane has over 25 years of experience in the air-conditioning and refrigeration industry. He is a member of ASHRAE, the International Institute of Refrigeration, and the American Society of Mechanical Engineers.

Prof. Abdullatif E. Ben-Nakhi (Kuwait)

Abdullatif Ben-Nakhi is a professor at the Department of Mechanical Power and Refrigeration at the University of Kuwait in Shuwaikh teaching mechanical engineering courses, such as thermo-fluid courses, HVAC&R courses, Statics, and Strength of Materials. He earned his doctorate degree at the University of Strathclyde, Glasgow, Scotland and his Master at the University of Dayton in Ohio, USA. Dr Ben-Nakhi is a chair of several NGOs and committees and has chaired the Continuous Education Committee of ASHRAE in 2002/2003.

Mr. Didier Coulomb (France)

Didier Coulomb is the Director of the International Institue of Refrigeration (IIR). He is a qualified engineer of the Ecole Polytechnique de Paris (1982) and the Ecole Nationale du Génie Rural, des Eaux et des Forêts (1984), and of the Institut des Stratégies Industrielles (1995). After internships, in particular in the Food industry, he worked for the French Ministry of Agriculture and Forestry in the North of France and Paris (Departmental Directorate for Agriculture and Forestry, Commissariat Général au Plan, General Department for food questions) in which he was more specifically in charge of technology and innovation (1984-1993).He then worked at the French Research Ministry, in particular as Deputy Director for innovation and technological development (1994-2002). He was then General Secretary of the CIRAD (Centre for General Cooperation in Agronomic Research for Development), a French center of research for developing countries, till 2004.



Dr. Alaa Olama (Egypt)

Alaa Olama received his M.Sc. and PhD from King's College, London University (England), in mechanical engineering, specializing in refrigeration and air-conditioning. He is the founder, board of directors' member, and past vice chair of the first district cooling company in Egypt, GasCool. He is a member of the Refrigeration and Air-Conditioning Technical Options Committee of the United Nations Environment Programme. Dr. Olama is the head of the committee writing the first District Cooling code for Egypt and a member of the committee writing the Egyptian Code of Air Conditioners, Refrigeration and Automatic Control and the Arab Refrigeration and Air-Conditioning Code. He is a past president of the Board of Directors of ASHRAE Cairo Chapter 2002–2003 and general Chair, ASHRAE, of the Second Regional Conference of Refrigeration (ARC) Region-At-Large in Cairo, September 2003. He is a member of the international reviewers' panel of the low-GWP refrigerants testing program of PRAHA and a technical advisor of EGYPRA. Dr. Olama is an independent consultant

Prof. Roberto Peixoto (Brazil)

Professor of Mechanical Engineering, teaching courses and doing research in the fields of thermal sciences and refrigeration and air conditioning, at the Instituto Maua de Tecnologia, a Technical University in Sao Caetano do Sul, Sao Paulo, Brazil. He works occasionally as an independent consultant and consultant for various entities. These include organizations dealing with refrigeration and air conditioning issues, and organizations dealing with Montreal Protocol and UNFCCC related climate issues, including the United Nations Development Programme (UNDP).

Annex B – District Cooling Study in HAT Countries

About the District Cooling Study

PRAHA included an assessment Study on Long-Term Feasible Technologies for the Air-Conditioning Sector. This component is to facilitate the comprehensive assessment of market readiness to accommodate alternate technologies and alternative refrigerants in the air-conditioning sector in the gulf region. The Study has been extended to include a regional dimension addressing the potentiality of District Cooling systems, using low-GWP and/or non-vapor compression options, as long term energy efficient solutions. This report will cover the District Cooling component of this study. Note: District Cooling will be referred to as "DC" in this report.

Scope and modalities of the study

PRAHA did not include a financial component to cover the DC study since the Long-Term assessment which is covered by Qatar HPMP. The elements of this study include a research study by a UNEP ROWA intern whose college project was collecting market information about DC projects and trends. The other elements included in this report were researched from different sources by the consultants of PRAHA with input from UNEP project Manager. Care has been taken to reference the different sources of information.

The report will shed light on whether the usage of DC systems will eventually lead to a reduction in CO_2 emissions through the use of alternative refrigerants, alternative cooling technologies, or by making the process more efficient.

This report is part of the on-going research on DC systems. UNEP/UNIDO continue to get involved in DC fora across the GCC region, while simultaneously promoting the PRAHA project original principals.

Executive Summary

The main conclusions from this report are:

- Installed DC systems in 2013 are still a fraction of the total installed air conditioning systems in high ambient countries but growing at a faster rate compared to the conventional systems;
- DC system applications are mostly in the residential and commercial market sectors where most of the HCFC-22 conventional systems are presently installed;
- DC systems contribute to power savings in the air conditioning sector due to several factors;
- While present DC systems mostly rely on conventional technology of vapor compression cycle and conventional refrigerants, new trends in using low-GWP refrigerants and not-in-kind systems are seeing the light;
- The direct and indirect emissions of DC systems are lower than conventional systems;
- DC systems proliferation will contribute to reducing the number of conventional system with higher direct or indirect emissions;
- DC systems have their limitation and some of the presently installed systems are not fully used.

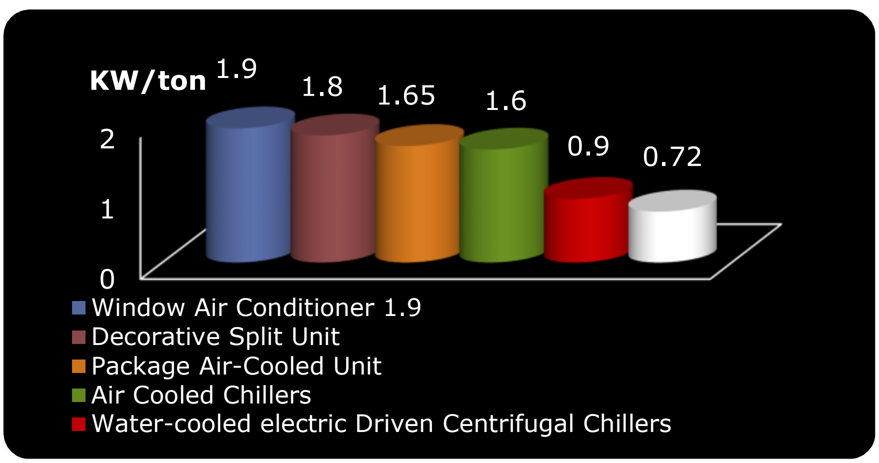
DC SECTOR IN NUMBERS

A study by Frost and Sullivan[2] estimates the installed capacity of DC systems in the Gulf Cooperation Council (GCC) countries in 2012 at 6 million tons of refrigeration or 14% of the total installed systems of 43 million tons. 45% of the installed capacity is serving the residential sector and another 31% the commercial sector. Data collected by the UNEP intern[3] put the total installed at 5.3 million tons.

The planned DC systems in the Gulf until 2030 were estimated by Frost and Sullivan to cover a construction market of USD 1.5 trillion. Middle East Economic Digest (MEED), a regional publication, estimates the construction projects over USD 2 trillion[4]. With air conditioning estimated at 25% of the cost, this translates into approximately 38 million tons of air conditioning which could have gone into conventional systems.

Dr. Alaa Olama, a Refrigeration Technical Options Committee (TROC) member, estimates the present installed DC capacity at around 4 million tons, but has similar projections for the growth until 2030 of 30 million tons of refrigeration. If these systems are built the conventional way, Dr. Olama expects the additional power requirement to increase by 60% consuming the equivalent of 1.5 million barrels of oil per day[5]. A study by DAR Al-Handasah[6], a mechanical consultancy, estimates that DC systems reduce power demand by 50 to 87% in comparison to conventional air conditioning systems, and consume 40 to 50% less energy for every refrigeration ton-hour than conventional in-building technologies. Chart 1 below shows the power consumption in kW for DC systems compared to conventional systems. The measure of kW/ton of refrigeration is used in the region to denote efficiency, the lower the number, the more efficient the system. Water cooled centrifugal chiller, and chillers with thermal storage (TES) are used in DC systems

Chart 1: comparison of DC system efficiency to conventional systems[7]



When coupled with the reduction in direct emissions, DAR estimates that each refrigeration ton of DC air conditioning system could reduce annual emissions by 1 MT $CO_{2\,eq.}$ For the GCC countries, the installed DC

[2] Frost & Sullivan, "*An overview of opportunities in District Cooling in the GCC*" delivered by Pranav Sarpotdar, Senior Research Analyst at the 4th Annual District Cooling Summit in Riyadh Sept 2013.

[3] Annam Hameed, "*District Cooling in the GCC*" 2013 report to UNEP ROWA

[4] MEED on-line

[5] Dr. Alaa Olama contribution to the 2014 RTOC assessment report

[6] DAR Al-Handasah, "*establishing Indicators for Assessing the Impact of District Cooling within Green Building Developments & Implementation Challenges"* delivered by Maroun Khoury at the 4th Annual District Cooling Summit in Riyadh Sept 2013

[7] Same source DAR Al-Handasah

systems are contributing already contributing to 6 million MT of $CO_{2\ eq.}$ reduction annually with a potential of further 38 MT $CO_{2\ eq.}$ for the coming years as new DC systems are added to the pipeline.

DC Systems Concept and Implementation Considerations

Since DC systems have a better energy efficiency, consume less power, and contribute less to emissions, can it be assumed that all air conditioning systems will eventually be switched to DC? This section will shed some light on the application of the DC systems and their technological and economic challenges.

Cost Considerations

DAR Al-Handasah lists two cost indicators for assessing the feasibility of DC projects:

- The larger the size of the DC system the more favorable it is due to the economies of scale and the increased efficiency;
- The less dispersed the demand - e.g. higher floor to area ratio (FAR) - the better the delivered cooling price due to the substantial capital cost savings in the district cooling network.

A study conducted by DAR for Dubai World Central showed that the range of DC system sizes that are most favorable compared to decentralized cooling systems for three sample cities with different FARs are:

- Commercial City (FAR 4.5): any size up to 60,000 tons and areas > 45,000 m^2
- Residential City (FAR 2.0): larger than 10,000 ton and areas of 160,000 to 650,000 m^2
- Golf Resort (FAR 1.1): larger than 24,000 ton and areas of 400,000 to 700,000 m^2

DAR concluded that to be feasible a DC operator should be able to save USD 250 -300 per annum for every ton-hour of DC system.

DC Challenges at Project Concept Stage

Climate Control[8], a UAE publication, lists the following challenges for DC projects:

- High capital cost, financing needs, uncertain construction cost, and non-guaranteed cash flows: To overcome this, many developers and service providers are now using the alternative option of Public Private Partnerships (PPP) and Built-Own-Operate- Transfer (BOOT) model.
- Non-transparent billing system, inappropriate and non-standard accounting system: Educating customers about the tariff structure and installing smart meters at customer premises will measure the exact usage and ensure transparency in billing.
- Lack of fresh water: However, with advancement of technology, treated sewage water or seawater is being used in pilot projects for DC applications.

[8] Climate Control On-line, "*District cooling: A market poised for strong growth in the Kingdom of Saudi Arabia"* Published Feb 2013 quoting a Frost & Sullivan report.

DC Challenges at implementation stage

DAR identified the following challenges to the implementation stage:

- Lack of governmental regulation that encourage district cooling in urban development;
- Low electricity tariffs across the GCC obscure the economic advantages of district cooling;
- Charge tariffs by developers are artificially expensive;
- Overestimation of cooling requirements;
- The allocation of connection, capacity, and consumption costs vary resulting in inconsistent cost recovery models.

DC Benefits

District cooling systems offer environmental, societal, and economic benefits[9]. The three benefits are inter-related such that the economic benefits can also environmental and societal in nature. The three benefits are explained below.

The environment:

The benefits include reduction in CO_2 emissions, contribution to refrigerant phase-out, and improving the local environment.

- ***Reduction in CO_2 emissions*** by using district cooling comes from several sources, namely:
  - Reduced electrical power consumption due to improved energy efficiency. Depending on how the electricity is produced, a saving in CO_2 emissions of between 350 and 950 kg/kWh electric power can be achieved;
  - Reduced need for cooling capacity due to centralized production synergies (a power factor between 0.7 and 0.9 is normal for large district cooling systems);
  - Centralized equipment needs less refrigerant. This, together with better possibilities to control leakage from the equipment, results in much lower emissions.
- ***Phase-out of refrigerants***
  - In line with the above, less refrigerant is needed for the same end-user demand for cooling comfort;
  - Centralization into a few production units also enables the operator to choose newer technologies, i.e. ammonia, carbon dioxide or even HFC centrifugal chillers with better efficiencies.
- ***Improving local environment***: Larger plants result in less cooling water for the cooling towers, fewer water treatment chemicals, smaller footprint for the dry coolers, and less noise.

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[9] AREA, The Air Conditioning and Refrigeration European Association,"*Guidelines, How to Approach District Cooling"* January 2014 www.area-eur.be

Societal

The security of electrical supply is enhanced by avoiding demand peaks in hotter months. Demand peaks are one of the drivers behind building new power plants which contribute to higher emissions and more spending on infrastructure.

Economic:

Infrastructure savings for electricity, water, and other services as well as better operational costs with less price risks.

DC technologies

All the existing plants in the GCC area are vapor compression units using HCFC-123 or HFC-134a. HCFC-123 has an ozone depleting potential (ODP) of 0.012 and a global warming potential (GWP) of 76 making it one of the last gases to be phased out under the HCFC Phase-out Management Plan (HPMP). HFC-134a is non-ozone depleting and its GWP is 1300, also making it a late candidate for the proposed HFC phase-down plan.

The indirect emissions from central air conditioning plants like district cooling plants is far great than their direct emissions of refrigerant gases. This is true for both HCFC-123 which is a negative pressure gas with little chance of leakage, as well as HFC-134a which is a moderate pressure gas. DC plants are populated by centrifugal chillers which are state-of-the-art machines with advanced controls and covered by meticulous service schedules due to their initial cost, making them the best maintained machines in the industry. Each machine holds hundreds of kilograms of refrigerant gas making leakage an expensive proposition and hence a major target for quick service.

The alternative for centrifugal chillers with HCFC or HFC chillers fall in two categories:

Alternative refrigerants for vapor compression cycles:

Several alternatives are considered with their limitation:

- **Unsaturated HFCs:** there are chillers on the market in Europe with HFC-1234ze(E) with good efficiencies; however, there might be a limitation on the capacity;
- **Ammonia (R-717)** has been used in industrial chillers for some time. The disadvantage of the toxicity of ammonia can be tolerated in a DC plant which can be located in non-residential areas and water piped in for long distances;
- **Hydrocarbons:** with their flammability, R-290 and R-1270, have a limitation on the chiller size requiring many units for a large DC plant which increases the risk;
- **Carbon dioxide (R-744):** CO_2 is not efficient at high ambient temperatures.

Alternative technologies

This section considers not-in-kind technology and other efficiency enhancing measures:

- **Absorption:** low electric consumption and high heat input from different sources like surplus heat or combined heat and power schemes (CPH). Absorption machines can go to high capacities; however, they have lower coefficient of performance (COP) and require up to 50% more water for the cooling process than electric driven chillers;

- **Thermal storage:** or ice storage in this case would have the plant make ice at night when the ambient temperature and the electric demand are lower and then melt the ice at high load demand during the day hours. DC systems are best suited for this option due to economies of scale.

Effect on HCFC Phase-out Plans

Effect of the elimination of HCFC-123 in existing plants

Even though some district cooling plants are HCFC-based, the overall ODP tons (ODPt) elimination due to their conversion is not the focus of the first stage of HPMPs. At 0.012 ODP, it takes 83.3 tons of HFCF-123 to contribute to 1 ODPt elimination, this is equivalent to 85,000 tons of refrigeration.

Out of the estimated 6 million tons of DC systems, less than one third are HCFC systems or about 2 million tons of refrigeration. The total charge in these systems is about 2,000 MT equivalent to 24 ODPt for the whole GCC. This charge inside the machines that is well controlled and very small amounts are vented into the atmosphere. Even if the service requirement of HFCF-123 machines is estimated at 5% of this charge, this will translate in 1.2 ODPt service consumption. Since the baseline for the GCC countries is more than 2,500 ODPt, the HCFC-123 service requirement constitutes a negligible amount.

Effect of planned DC plants in replacing HCFC-22 plants

District cooling typically needs around 15% less capacity for the same cooling loads than conventional cooling systems due to load diversity[10]. Each refrigeration ton of new DC plant replaces an approximate 1.15 tons of otherwise conventional HCFC-22 which would have consumed 0.17 Kg of HCFC-22 per annum[11]. Assuming that 45% of the planned 38 million tons of DC plants would serve the residential sector, equivalent to the present percentage, and that 86% of this residential sector would have used HCFC-22 units (presently 14% is using DC), district cooling would be preventing the annual service consumption of:

(38,000,000 x 45% x 86% x 0.17 x 0.055)/1000 = 137.5 ODPt or close to 6% of the baseline.

Furthermore, the total 38 million tons planned will reduce emissions by 38 million tons of $CO_{2\ eq.}$ as shown in section 5.

Effect of existing DC plants in replacing existing HCFC-22 plants

Existing plants have spare capacity. DAR estimates that "for most DC systems at least 20-30% of installed capacity is used for a maximum 250 hour/annum. For partially used plants this may exceed 50% of installed capacity." Estimating that 20% of the present installed capacity can be used to replace existing HCFC plants, and using the same calculation method as in 9.2 above but with leakage rates of 25%, the annual savings in service consumption would be 37 ODPt[12].

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[10] Maroun Khoury, DAR Al-Hnadasah

[11] Assuming 15% leakage rate

[12] (6,000,000 x 45% x 86% x 0.29 x 0.055)/1000 = 37 ODPt

KEY FINDINGS FROM THE DC SYMPOSIUM IN KUWAIT

A symposium on the use of District Cooling as a mean of energy conservation in the region was held in Kuwait May 19 & 20, 2014. The Symposium focused on the environmental, efficiency, and economic advantages of district cooling and how all can be maximized by proper planning and execution. Lessons-learned from implementing district cooling in different applications like cities, educational campuses, major medical facilities and other large building complexes were presented. Special attention was devoted in considering district cooling as a mean to energy conservation and leapfrogging high-GWP refrigerants. The key outcomes of the symposium are:

On Policy:

- A recommendation to combine the DC code under preparation in Egypt with the ASHRAE DC Guidelines;
- The business cases presented are a good reference for donor agencies in order to direct subsidy;
- Suggestion to form a Forum for DC and to present policy makers with a summary on the opportunities;

On Design Guidelines:

- Guidelines should be flexible, up-to-date, and based on local experience;
- Suggestion to specify that an air conditioning plant above a certain capacity should be considered a DC plant for code purposes;
- Japan has guidelines for DC plants in as far as capacity and equipment;
- MEW in Kuwait has guidelines for loads starting at 1000 TR;
- A new Hot Climate Design Guide by ASHRAE can have an addendum on DC.

On Advancement of technology and research:

- Need for a GCC think-tank;
- Adapt international policy to local requirements;
- Thermal storage is not fully utilized. Also the use of natural resources;
- Long term sustainability action is needed;
- Bridging industry and government work;
- Include high-ambient, water technology, and refrigerant alternatives in the research work.

On Operation and Training:

- Need for a generic training manual;
- Capacity building is an issue;
- Partnership of local stakeholders with ASHRAE is needed.

On Advocacy and awareness:

- Need for end-user awareness;
- Need to follow-up with governments on the outcome of the symposium.

Annex C - Project Methodology

The project preparation involved exhaustive consultation process and coordination among several stakeholders: refrigerant manufactures who are researching new technologies, component manufacturers who provide the compressors compatible with the alternative refrigerants, and original equipment manufacturers (OEM) who will be building the prototypes. Forming partnerships among members of these three categories of stakeholders requires a rigorous consultation process to ensure the success of the endeavor. The consultation process took place in stages:

a. First Stage

The first stage of consultation took place in October 2012 on the borders of a symposium which took place in Dubai entitled, “Alternative Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries; the Way Forward” organized by UNEP in collaboration with ASHRAE and the Air Conditioning, Heating and Refrigeration Institute (AHRI). UNEP and UNIDO invited the stakeholders who were present at the meeting to explain the project concept and listen to their feedback. Present at the meeting were: nine OEMs representing a full spectrum of manufacturers who are producing units for HAT applications in the GCC countries; three refrigerant suppliers; two component manufacturers; as well as three Ozone officers from the GCC countries, two UNEP/UNIDO international consultants, and staff from UNEP and UNIDO in the region and beyond.

The feedback from those present was positive and supportive of the project. Comments and suggestions revolved around issues of concern like confidentiality or suggestions about other projects, like the Alternative Refrigerant Evaluation Project (AREP) which is conducted by AHRI and in which some of the international manufacturers, who are also manufacturing in the region, have participated through their mother companies. The suggestion was to contact AHRI to learn more about the project and see how the outcome from AREP could contribute some best practices to the project.

Another outcome of the meeting was a recommendation by the OEMs to include other component and refrigerant manufacturers, specifically the ones with whom those OEM deal. After the meeting, UNEP & UNIDO project managers and their consultants provided other input and the list of component manufacturers grew to eight and refrigerant manufacturers to four.

b. Second Stage

In order to gauge the stakeholders’ interest and their capabilities in contributing to the project, two survey questionnaires were prepared: one destined to equipment manufacturers (OEM) and the other towards component and refrigerant suppliers grouped as “Technology Providers”.

OEMs were asked to provide information about their preferences for technology, component supplier, type of equipment, capacity of equipment, and their capability in building and testing prototypes. Technology providers were asked about their preference to work with certain OEMs, type and capacity of equipment and their willingness to provide material and share technology.

c. Third Stage

Having received feedback from five OEMs and five technology providers, UNEP called for a third consultative meeting on Feb 10, 2013 in Riyadh, KSA on the borders of a preparatory meeting aimed at organizing the HVAC industry in the region. The meeting included OEM manufacturers, but not technology providers. The purpose of the meeting was to inform the OEMs about the survey feedback received to date and offer clarifications to those who have not responded which could help them make an informed decision about the project. Participants were given explanations about the proposed testing process and the sharing of results in a way that preserves the confidentiality of the process. Discussions also touched on the type and capacity of equipment that constitute the bulk of the market and which need to be included in the project, the number of prototypes needed per equipment type, and the testing conditions.

Annex D - Risk Assessment

An example from a report by The Tokyo University of Science, Suwa, from a project titled "Evaluation of Combustion and Explosion Hazards and Risk Assessment on A2L Refrigerants for the Air-conditioning Systems". The project performed with the Research Institute for Safety and Sustainability (RISS), AIST for a service and maintenance situation.

- Sub-scenario (a): Evaluated the physical hazard for a commercial portable gas lighter used in the space where the A2L refrigerant leaked and accumulated. When a piezo gas lighter was used, no ignition was confirmed. Although ignition and small flame propagation near the outlet of a turbo lighter was confirmed, the flame quickly went out.
- Sub-scenario (b): Simulated an A2L refrigerant leakage from a fracture or pinhole formed in the pipes or hoses during service and maintenance. When the refrigerant was leaked from a 4 mm diameter pinhole for the simulation of a pipe breaking, the flammable zone was only formed near the outlet of the refrigerant. Even when excess energy than the conceivable ignition source in an actual situation was given to the refrigerant jet, there was no confirmation of an ignition and flame propagation to entire the refrigerant jet.
- Sub-scenario (c): A2L refrigerant leaked inside a device for the service and maintenance such as a collection device. When there was no opening to diffuse the accumulated, leaked refrigerant in the model collection device to the outside, the refrigerant was ignited when an ignition source having with energy much larger than in an actual situation. When there no opening of suitable width in the model collection device, the accumulation of refrigerant could be controlled in a very short period of time and ignition could be prevented (JSRAE 2014).

A3 Refrigerant Risk Assessment:

A risk assessment study made by Midea in China for the above unit concluded the following (Li 2014):

- At floor level, the concentration within the room cannot reach LFL/ The concentration only approaches or exceeds LFL in an extremely localized area directly beneath the leak position;
- If the leaking is slow and the indoor unit fa runs at high speed, the room has similar concentrations whether the leak is from inside the unit or from the connecting piping.

A study made at the Taijin University in China (Zhang 2013) concluded that the flammable range of a release of HC-290 is only located within the close locality of the indoor unit, and can only be ignited when the leak mass flow rate is extremely high, there are some means by which the release can be diffused to a sufficiently large flammable volume, and sources of ignition are present in the immediate vicinity of the indoor unit. The most dangerous situation is if R-290 is ignited during the leak process and continues burning thus igniting the plastic casing of the indoor unit and producing a lot of smoke having an impact on personal safety of room occupants. The study concludes with the following recommendations to help alleviate such risks:

- Ensure that the indoor unit is installed away from any potential sources of ignition;
- Install a cut-off valve in the refrigerant pipeline, which can immediately close off the refrigerant pipelines once a loss of refrigerant is detected; this will help minimize the quantity of refrigerant emitted;
- Minimize the use of combustible materials for the construction of the indoor unit;
- Implement the use of a highly reliable connectors for the interconnecting piping between the indoor and the outdoor units.

(Note: Input received from Karim) In the U.S., Gradient (AHRI 2012) conducted a risk assessment to evaluate the use of three Class 2L refrigerants (HFC-32, R-1234yf, and R-1234ze(E)) in residential split heat pump systems. The work included CFD modeling, experimental measurements, and a fault tree analysis (FTA) to quantify ignition risks. The charge amounts used in the assessments were those that would be typical of a 3-ton (10.5 kW) heat pump. The assessment indicated that large accidental releases of HFC-32, R-1234yf, and R-1234ze(E) (i.e., on the order of 170 g/s for HFC-32, 78 g/s for R-1234yf and ze(E)) could create flammable concentrations in a very narrow area immediately in front of the leak location for heat pump units installed in basements, garages, or attics, but that refrigerant concentrations in the majority of each room would be substantially below the lower flammable limit (LFL). Further, the assessment found that large releases of these refrigerants from a heat pump unit located in a utility closet can produce concentrations above the LFL, although the refrigerant exceeds the LFL only briefly (approximately 70 s for HFC-32 and R-1234yf and 45 s for R-1234ze(E)). Flammable concentrations did not occur with smaller leaks of HFC-32, R-1234ze(E) or R-1234yf (e.g., 1.5 g/s or less) in utility closets.

Incorporating these findings, the FTA estimated that the risks of refrigerant ignition due to an accidental refrigerant leak of HFC-32, R-1234yf, and R-1234ze(E) were 9 x 10-5, 2 x 10-5, and 2 x 10-5 events per unit per year, respectively. For comparison, the overall risk of a significant home fire in the US is 1 x 10-3 per home per year. For all three refrigerants, the risk of ignition was highest in the scenario involving release in the outdoor portion of the unit. When considering indoor leaks only, the ignition risks for HFC-32, R-1234yf, and R-1234ze(E) were 7 x 10-8, 8 x 10-9, and 3 x 10-10 events per unit per year respectively. The FTA in this study considered refrigerant ignition and did not determine whether a fire would ensue due to the ignition of surrounding materials. The analysis also did not include potential mitigation factors that would further reduce the probability of refrigerant ignition. All heat pump systems were assumed to contain the same mass of refrigerant charge.

Charge limitation of flammable refrigerants:

For residential air conditioning applications, the maximum charge is based on the LFL of the refrigerant, the floor area, and the height of the indoor unit:

$M = 2.5 \times LFL^{1.25} \times h \times \sqrt{A}$,   where:

M   =   mass charge in kg,
LFL =   lower flammability limit in kg/m^3
H   =   height of unit in meters (0.6 for floor mounted, 1.0 for window, 1.8 for wall, and 2.2 for ceiling)
A   =   floor are in m^2

Example: a split AC unit with a ceiling mounted indd0or unit in a room 9 x 5.5 meter:

- For HC-290: $M = 2.5 \times 0.038^{1.25} \times 2.2 \times \sqrt{(9 \times 5.5)} = 0.65$ kg
- For HFC-32: $M = 2.5 \times 0.307^{1.25} \times 2.2 \times \sqrt{(9 \times 5.5)} = 8.84$ kg

EN378-1 specifies charge limitations for the different classes of refrigerants according to different scenarios of occupancy and location of the air conditioning and refrigeration machines. Table 4.2 is an of some of the scenarios for overall maximum charge sizes (BRA 2012)

Area being cooled	**System Location**	**Maximum Charge A2 refrigerants**	**Maximum charge A3 refrigerants**
All Areas	Part of all system below ground	as below	1 kg
General occupancy	Whole system at ground level or above	38 x LFL	1.5 kg
General occupancy	Whole system above ground in an unoccupied machine room or open air	132 x LFL	5 kg
Supervised occupancy	Whole system at ground level or above in human occupied areas	10 kg	2.5 kg

Characteristics of two refrigerants used in the PRAHA project is given in table 4.2 below:

Table 4.2: Example of flammability characteristics of two refrigerants (Kataoka 2013)

	ISO 5149	**ASHRAE 34**		**ISO 817**
	LFLv in %	**LFLw in Kg/m3**	**HoC in MJ/Kg**	**BV in m/s**
HC-290	2.1	0.039	46	0.43
HFC-32	12.7	0.275	9	0.07

LFL = Lower Flammability Limit, HoC = Heat of combustion, BV = Burning velocity

Annex E - Relevant Research

In addition to their environmental concerns and their high GWP, all the results for systems with R-410A and R-407 C revealed efficiency degradation when compared to that of HCFC-22 at high ambient temperatures.

Chin and Spatz (Chin & Spatz, 1999) reported a drop by about 7 % in cooling capacity and a similar decrease in COP when using R-410A compared to HCFC-22 at 52 C. Similar results are obtained by Payne and Domanski (Payne & Domanski, 2002) who performed an experiment for a unitary air conditioner using R-410A and reported a drop by 9 % and 15 % for cooling capacity and COP respectively at a high ambient temperature of 54 C.

Devotta et al. [3] performed an experimentation on 1.5 TR window air-conditioner, retrofitted with R-407C as a substitute to HCFC-22. The results showed that R-407C had a lower cooling capacity in the range 2.1–7.9% and the COP was lower by 8-13.5% when operating between 35 C and 48 C respectively.

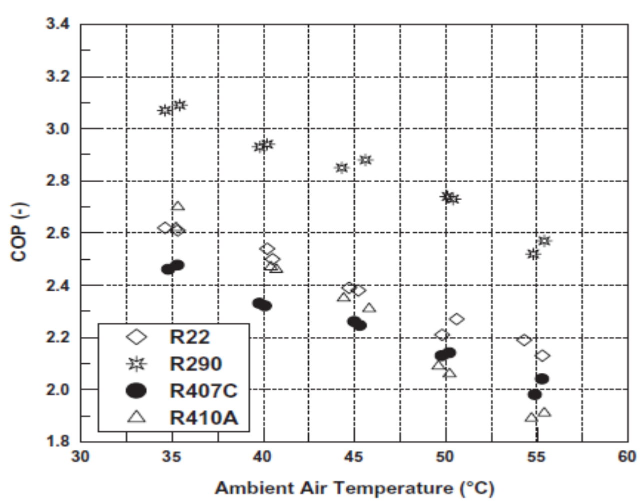
Some more work was reported on alternative refrigerants with lower GWP, where Joudi et al. [4], experimentally investigated the performance of split AC systems using HCFC-22 and other alternatives including HC-290 at high ambient temperatures. The temperature range tested was 35 to 55°C. Two split type air conditioners of 1 and 2 TR capacities were tested.

Table **E.1** below. It was also found that the COP of the system decreased as the ambient air temperature was increased as shown in the Figure below.

Table E.1 - Summary of results for 50°C ambient air temperature case [4]

Refrigerant		Power Consumption (kW)	Cooling Capacity (kW)	COP
HCFC-22	1 TR	1.31	2.93	2.24
	2 TR	2.62	6.61	2.52
HC-290	1 TR	1.06	2.92	2.75
	2 TR	2.42	6.33	2.62

Figure E.1 - Effect of the ambient air temperature on the COP for the 1 TR system [4]



Similar to that study, a laboratory air-conditioning set up tested HC-290 and compared it to HCFC-22 at the evaporation and condensation temperatures of 7 and 45^{o}C [5]. The temperature glide of HC-290 is 0^{o}C. The COP of the HC-290 system was found to be 1.9% greater than the HCFC-22 system whereas the cooling capacity of the HC-290 showed an 11.5% decrease in the cooling capacity as compared to HCFC-22. The compressor discharge temperature for the HC-290 system was 63^{o}C.

In a window AC setup, Devotta et al. [6] presented experimental results with HC-290 as a drop in substitute to HCFC-22. The outdoor room conditions tested were 35 and 46^{o}C (dry bulb). The cooling capacity of the HCFC-22 system at the higher outdoor temperature was around 4kW whereas the HC-290 had a 10% lower capacity. The lower capacity for HC-290 was attributed to its lower volumetric capacity than HCFC-22. The COP of the HCFC-22 system at the high temperature was found to be 1.76 and the HC-290 performed at a 3% increased COP.

In another window AC setup and also testing the HCFC-22 and HC-290 refrigerants, Teng et al. [7] tested and analyzed the performance of the system for ambient temperatures of 26, 29, 32^{o}C for a fixed cooling capacity of 2kW. They found that once again the HC-290 system performed better than HCFC-22 with a higher COP with a charged mass of more than 50% of HCFC-22. This phenomenon was due to the fact that HC-290 has a higher vapor heat and lower viscosity. The EER was also found to exhibit an upward trend as the outside air temperature increased with an almost 20% improvement observed.

Taking a look at the other refrigerants now, Leck [8] modeled the performance of an AC cooling cycle utilizing refrigerants including R-410A, HCFC-22, HFC-32 and HFO-1234yf. The HFC-32 refrigerant had a 9.7% increase in the cooling capacity over the R-410A system, but the HFO system had a 57% decrease over the R-410A system. However the COP's of the HFO and HFC-32 refrigerants were 6% and 0.3% greater than the R-410A system respectively. Finally the discharge temperatures were also significantly different. The HFC-32 refrigerant had a temperature of 102^{o}C and the HFO refrigerant was found to have a discharge temperature of 55^{o}C.

Other ideal cycle performance studies of the HFO1234yf and HFC-32 refrigerants were performed by Endoh et al. [9] and Fujitaka et al. [10]. Endoh et al. [9], tested the HFO refrigerant at the rated cooling capacity of 4kW for a room air conditioner. The discharge temperature of HFO was about 18^{o}C lower than that of R410A and the COP ratio of HFO/R410A was calculated to be 105%. It was found by Fujitaka et al. [10] that adding HFC-32 to the HFO mixture resulted in a diminished performance as the COP decreased by about 3%. The table below summarizes the main results from that paper.

Table E.2 - Results summary from the theoretical refrigeration cycle calculation [10]

Refrigerant		Discharge Temperature (^{o}C)	Volumetric Capacity (kJ/m^{3})	COP
R-410A		64.7	6629	6.42
HFO-1234yf		48.0	2855	6.78
HFC-32/1234yf Mixture (wt %)	20/80	58.1	4227	6.69
	50/50	65.2	5621	6.58
HFC-32		75.8	7228	6.56

Biswas et al. (2013) measured the performance of R1234yf, HFC-32, DR-4, and R-410A. At 46°C, the fluids "DR-5" (72.5% HFC-32/27.5% HFC-1234yf) had a COP about 5% higher than R-410A, but the same as 35°C. The capacity of these mixtures was about 2-3% above R-410A for "DR-5".

Table E.4 summarizes the results for all the research work presented above. It is clear that alternatives for the HCFC-22 refrigerant possess some challenges specifically in high ambient temperature conditions.

International Projects

There are key four international testing projects that are independently assessing the use of low-GWP alternatives in air-conditioning applications (AREP includes also refrigeration applications). The four projects include testing on high ambient temperature conditions with different approaches of optimizing the prototypes, refrigerants selected, and cooling capacities of units being tested. The table below summarizes the key characteristics of the four projects.

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) completed the first phase of its low global warming potential alternative refrigerants evaluation program (Low-GWP AREP). Thirty-eight low-GWP refrigerants were tested by 21 companies during the first phase of the program in a variety of products; including air conditioners, heat pumps, chillers, ice makers and commercial bottle coolers. The GWP's for the tested refrigerants range from 1577 to 4 without prioritizing them. Wang and Amrane [11] reported that the drop-in tests were conducted with the alternative refrigerants placed in systems designed for baseline refrigerants with only minor adjustment, if any, such as charge or superheat setting. Soft-optimized tests were performed using baseline refrigerant systems. These systems were modified for the alternative refrigerants using standard production line components. The results show that there are several alternative candidates that can be used to replace HCFC-22 but since most results were obtained from drop-in and soft-optimized tests performed on equipment designed for the baseline refrigerants and not the alternatives, the results should not be viewed as universally applicable.

AHRI launched a second phase of testing at the beginning of 2014 that includes newly developed refrigerants and performance testing under high ambient conditions that were not covered in the first phase.

The ORNL project aims to develop an understanding of the performance of low-GWP alternative refrigerants to HCFC and HFC refrigerants in mini-split air conditioners under HAT conditions. ORNL designed a test matrix of 84 tests. ORNL selected the refrigerants based on their GWP, commercial availability and physical properties while considering whether information about the characteristics of the refrigerants is readily available. ORNL conducted tests using two "soft-optimized" ductless mini-split air conditioners have a cooling capacity of 5.25 kWh (1.5 TR). One unit is designed to operate with HCFC-22 refrigerant (2.78 coefficient of performance [COP], equivalent to a 9.5 energy efficiency ratio [EER]). The other is designed to use R-410A refrigerant (3.37 COP, equivalent to an 11.5 EER).

Egypt adopted a similar initiative as part of the HPMP to test refrigerant alternatives for air-conditioning units built in Egypt. The initiative, "Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt" or EGYPRA proposes to test eight different refrigerants: HC-290 and HFC-32, plus two HFC/HFO blends from three different refrigerant manufacturers, one replacing HCFC-22 and one replacing R-410A. The initiative was launched back in June 2014 and is expected to have the results by the end 2015. Eight manufacturers are building 27 prototypes in 4 categories and shipping 9 "base units" running on HCFC-22

and R-410A. The testing will be done at T1, T2, and T3 conditions (the latter covering high ambient conditions) and will be carried out at one testing lab in Egypt.

Table E.3 Comparison of four research projects: PRAHA, EGYPRA, ORNL, and AREP-II[13]

<table>
<tr><th colspan="2">Program</th><th colspan="4">PRAHA</th><th colspan="4">EGYPRA</th><th colspan="2">ORNL – Phase I (Mini-split AC)</th><th>AREP-II</th></tr>
<tr><td>1</td><td>Type of test</td><td colspan="4">Custom built test prototypes, comparing with base units: HCFC-22 and R-410A</td><td colspan="4">Custom built test prototypes, comparing with base units: HCFC-22 and R-410A</td><td colspan="2">Soft optimization tests, comparing with base units: HCFC-22 and R-410A</td><td>Soft optimization or drop in of individual units tested against a base R-410A unit</td></tr>
<tr><td>2</td><td>No. of prototypes</td><td colspan="4">13 prototypes, each specific capacity and refrigerant built by one or two OEMs, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 22</td><td colspan="4">28 prototypes, each specific one capacity and one refrigerant built by one OEM, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 37</td><td colspan="2">2 commercially available units, soft modified to compare with base refrigerants: HCFC-22 and R-410a</td><td>22 units from different OEMs ranging from splits to water chillers</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">No. of categories</td><td colspan="2">60 Hz</td><td colspan="2">50 Hz</td><td colspan="4">50 Hz</td><td colspan="2">60 Hz</td><td>60Hz</td></tr>
<tr><td>Window</td><td>Mini Split</td><td>Ducted</td><td>Packaged</td><td>Mini Split</td><td>Mini Split</td><td>Mini Split</td><td>Central</td><td>Split unit</td><td>Split unit</td><td rowspan="2">34 MBH chiller, 2x 36 MBH split, 48 MBH packaged, 60 MBH packaged, 72 MBH packaged</td></tr>
<tr><td>18 MBH</td><td>24 MBH</td><td>36 MBH</td><td>90 MBH</td><td>12 MBH</td><td>18 MBH</td><td>24 MBH</td><td>120 MBH</td><td>18 MBH R22 eq.</td><td>18 MBH R-410a eq.</td></tr>
<tr><td>4</td><td>Testing conditions</td><td colspan="4">ANSI/AHRI Standard 210/240 and ISO 5151 at T1, T3 and T3+ (50°C) and a continuity</td><td colspan="4">EOS 4814 and 3795 (ISO 5151) T1, T2, and T3 conditions</td><td colspan="2">ANSI/AHRI Standard 210/240 and ISO 5153 T3 (2010) condition</td><td>ANSI/AHRI 210/240, at T1, T3, and 125 °F</td></tr>
<tr><td>5</td><td>Prototypes supplied and tests performed</td><td colspan="4">Prototypes built at six OEMs, test at Intertek</td><td colspan="4">Prototypes built at eight OEMs, test at NREA (local test laboratory in Egypt)</td><td colspan="2">ORNL, one supplier – soft optimization in situ</td><td>Individual suppliers, testing at own premises</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Refrigerants tested</td><td colspan="4">Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3</td><td colspan="4">Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3, R-457A (ARM-32d)</td><td colspan="2">Eq. to HCFC-22:N-20B, DR-3, ARM-20B, R-444B (L-20A), HC-290</td><td rowspan="2">Eq. to R-410A: HFC-32, DR-5A, DR-55, L-41-1, L-41-2, ARM-71a, HPR2A</td></tr>
<tr><td colspan="4">Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A)</td><td colspan="4">Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A), ARM-71d</td><td colspan="2">Eq. to R-410A: HFC-32, R-447A (L-41-1), DR-55, ARM-71d, HPR-2A</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Expected delivery dates</td><td colspan="4">Testing completed end of 2015</td><td colspan="4" rowspan="2">End of 2016</td><td colspan="2" rowspan="2">Final Report October 2015</td><td rowspan="2">Final report Oct 2015</td></tr>
<tr><td colspan="4">Final report end March 2016</td></tr>
<tr><td>8</td><td>Constraints</td><td colspan="4">To build new prototypes with dedicated compressors for the selected refrigerants fitting in the same box dimensions as the original design and comparing performance and efficiency to base models with HCFC-22 and R-410A units</td><td colspan="4">To build new prototype with dedicated compressors for the selected refrigerants with the condition to meet same design capacities of the selected models in comparison to the HCFC-22 and R-410A units</td><td colspan="2">To change some components of the two prototypes to accommodate the different refrigerants, within a “soft optimisation” process</td><td>- Drop-in;
- soft optimization by advjusting expansion device, adjusting charge amount, and changing type of oil;
- One case of compressor speed adjustment using variable speed drives</td></tr>
<tr><td>9</td><td>Other components</td><td colspan="4">The project includes other non-testing elements to assess relevant issues of energy efficiency (EE) standards, technology transfer and economics in addition to special reporting on the potential of District Cooling to reduce the use of high-GWP alternatives</td><td colspan="4">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

[13] Source: TEAP report XXVII/4

Table E.4 Summary of Earlier Research Work

Author & Year	Refrigerants Studied	A/C Type	Ambient Air Temp	Major Results
Park et al., 2007	R1270, HC-290, HFC152a			• COP of HC-290 1.9% higher than HCFC-22 • Compressor T_{dis} 17.3°C lower than HCFC-22 • Charge levels 520g vs 1170g for HC-290 vs HCFC-22
Joudi et al., 2014	HCFC-22, HC-290, R407C, R410A	Split (1 & 2 TR)	35-55°C	• HC-290 better candidate to replace HCFC-22 under high ambient air temperatures. • It has lower TEWI values and a better COP than the other refrigerants tested. • COP of HC-290 23% (1 TR) and 4% (2 TR) higher than HCFC-22 (50°C case) • It is suitable as a drop-in refrigerant. • COP values decrease for all refrigerants, as the ambient temperature increases.
Leck, 2010	HFC-32, HFO-1234yf (and others)	AC cooling cycle model		• COP of HFO 6% lower than HCFC-22 • Compressor T_{dis} 28°C lower than HCFC-22
Devotta et al., 2005	HCFC-22, HC-290	Window	35, 46°C (Dry bulb)	• COP for HC-290 7.9% higher for the lower operating conditions and 2.8% higher for the higher operating conditions.
Teng et al., 2012	HCFC-22, HC-290	Window	26, 29, 32°C	• Cooling capacity 2kW • EER of HC-290 exhibits an upward trend as the outside air temperature increases, improving the EER by approximately 20% under ideal conditions. • COP of HC-290 system improves with increasing outside temperature
Endoh et al., 2010	HFO1234yf		35°C (dry bulb), 24°C (wet bulb)	• Cooling rate capacity 4kW • The ratios of HFO1234yf/R410A COP are 97/88% at the rated/medium cooling capacity and 93/98% at the rated/medium heating capacity
Fujitaka et al., 2010	HFO-1234yf, HFC-32/HFO-1234yf mixtures		35°C (dry bulb)	• Drop in test • Cooling rate capacity 4kW • The performance of HFO-1234yf is significantly lower than that of R-410A as a result of the pressure drop increasing. • The performance of HFC-32/HFO-1234yf improves as the HFC-32 concentration becomes richer.

Author & Year	Refrigerants Studied	A/C Type	Ambient Air Temp	Major Results
Biswas and Cremaschi (2012)	HFO-1234yf, HFC-32, DR-5, R-410A	Ducted Split	43°C and 46°C	• R1234yf has slightly lower COP at mild ambient temperature but higher COP at high ambient temperature. • HFC-32 has a higher capacity and similar COP to that of R-410A but its discharge temperature and pressure are higher • DR-5 has 5% higher COP than R-410 at high ambient temperature

Bibliography

[1] L. Chin and M. Spatz, "Issues relating to the adoption of R-410A in air conditioning systems," in *20th International Congress of Refrigeration, IIR/IIF*, Sydney, 1999.

[2] W. V. Payne and P. A. Domanski, "A comparison of an R22 and an R410a air conditioner operating at high ambient temperatures," in *International Refrigeration and Air Conditioning Conference at Purdue*, 2002.

[3] S. Devotta, A. Padalkar and N. Sane, "Performance assessment of HCFC-22 window air conditioner retrofitted with R-407C," *Applied thermal engineering,* vol. 25, no. 17, pp. 2937-2949, 2005.

[4] K. A. Joudi and Q. R. Al-Amir, "Experimental Assessment of residential split type air-conditioning systems using alternative refrigerants to HCFC-22 at high ambient temperatures," *Energy Conversion and Management,* vol. 86, pp. 496-506, 2014.

[5] K.-J. Park and D. Jung, "Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications," *Energy and Buildings,* vol. 39, no. 6, pp. 675-680, 2007.

[6] S. Devotta, A. Padalkar and N. Sane, "Performance assessment of HC-290 as a drop-in substitute to HCFC-22 in a window air conditioner," *International journal of refrigeration,* vol. 28, no. 4, pp. 594-604, 2005.

[7] T.-P. Teng, H.-E. Mo, H. Lin, Y.-H. Tseng, R.-H. Liu and Y.-F. Long, "Retrofit assessment of window air conditioner," *Applied Thermal Engineering,* vol. 32, pp. 100-107, 2012.

[8] T. J. Leck, "New High Performance, Low GWP Refrigerants for Stationary AC and Refrigeration," in *International Refrigeration and Air Conditioning Conference*, West Lafayette, Indiana, USA, 2010.

[9] K. Endoh, H. Matsushima and S. Takaku, "Evaluation of cycle performance of room air conditioner using HFO1234yf as refrigerant," in *International Refrigeration and Air Conditioning Conference*, West Lafayette, 2010.

[10] A. Fujitaka, T. Shimizu, S. Sato and Y. Kawabe, "Application of low global warming potential refrigerants for room air conditioner," in *International Symposium on Next-generation Air Conditioning and Refrigeration Technology*, Tokyo, Japan, 2010.

[11] B. O. Bolaji, "Performance investigation of ozone-friendly R404A and R507 refrigerants as alternatives to R22 in a window air-conditioner," *Energy and Buildings,* vol. 43, no. 11, pp. 3139-3143, 2011.

[12] J. Chen and J. Yu, "Performance of a new refrigeration cycle using refrigerant mixture R32/R134a for residential air-conditioner applications," *Energy and Buildings,* vol. 40, no. 11, pp. 2022-2027, 2008.

[13] K. Kontomaris, T. J. Leck and J. Hughes, "Low GWP refrigerants for air conditioning of large buildings," in *10th REHVA World Congress, Sustainable Energy Use in Buildings*, Antalya, Turkey, 2010.

[14] M. O. McLinden, A. F. Kazakov, J. S. Brown and P. A. Domanski, "A thermodynamic analysis of refrigerants: Possibilities and tradeoffs for Low-GWP refrigerants," *International Journal of Refrigeration,* vol. 38, pp. 80-92, 2014.

[15] M. Mohanraj, S. Jayaraj and C. Muraleedharan, "Environment friendly alternatives to halogenated refrigerants—a review," *International Journal of Greenhouse Gas Control,* vol. 3, no. 1, pp. 108-119, 2009.

[16] K.-J. Park and D. Jung, "Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications," *Energy and Buildings,* vol. 39, no. 6, pp. 675-680, 2007.

[17] A. Biswas, A. Barve and L. Cremaschi, "An experimental study of the performance of new Low Global Warming Potential (LGWP) Refrigerants at extreme high temperature ambient conditions in residential AC ducted split systems," *ASHRAE Transactions,* vol. 119, p. J1, 2013.

[18] X. Wang and K. Amrane, "AHRI Low Global Warming Potential Alternative Refrigerants Evaluation Program (Low-GWP AREP)--Summary of Phase I Testing Results," in *15th International Refrigeration and Air Conditioning Conference at Purdue*, 2014.

Annex F – Summary of Activities

Meetings, Conferences, and Visits, discussion sessions convened and or attended for different stakeholders involved in PRAHA *(In chronological order)*

Date	Location	Purpose	Participants
Project Coordination Meetings			
June 2013	Dubai, UAE	First meeting of PRAHA stakeholders	- PRAHA project team - NOUs from 6 countries (GCC) - Technology providers (compressors - Refrigerants), 7 companies - Local OEM, 8 companies - AHRI - ESMA (as host of the meeting)
Aug 2013	Arlington, VA	Coordination meeting on cooperation with AHRI on the testing methodology	- PRAHA project team - AHRI
Sept 2013	Dubai, UAE	The second coordination meeting was held on the margin of the 3rd symposium on high ambient alternatives	- PRAHA project team - NOUs from 7 countries (GCC + Iraq) - Technology providers, 6 companies - Local OEM, 7 companies - AHRI
Jan 2014	New York, NY	Concluding MOU with AHRI, coordination meeting in margins of ASHRAE Annual Conference	- PRAHA project team - AHRI
May 2014	Kuwait	Follow-up meeting with NOUs	- PRAHA project team - NOUs from 6 countries (GCC) - AHRI
Oct 2014	Dubai, UAE	Follow-up meeting of PRAHA stakeholders on procedures for testing under PRAHA, in margins of 4th high ambient symposium	- PRAHA project team - NOUs from 7 countries (GCC + Iraq) - Technology providers, 6 companies - Local OEM, 7 companies - AHRI & Intertek
Technical Review Team Meetings			
Oct 2014	Dubai, UAE	First meeting of the Technical Review Team, in margins of 4th high ambient symposium	- PRAHA project team - Members of the Technical Review Team
July 2015	Paris, France	Second meeting of the Technical Review Team, back-to-back with OEWG-36	- PRAHA project team - Members of the Technical Review Team
Aug 2015	Yokohama, Japan	Third meeting of the Technical Review Team, in margins of 24th International Congress of Refrigeration	- PRAHA project team - Members of the Technical Review Team
Jan 2016	Paris, France	Fourth and final meeting of the Technical Review Team	- PRAHA project team - Members of the Technical Review Team

Date	Location	Purpose	Participants
Field trip			
Oct/Nov 2013	China/ Japan	Study tour to China and Japan for HC-290 and HFC-32 technologies	Six OEMs, NOU Kuwait, PRAHA team in cooperation with CHEAA and METI
Events organized by PRAHA			
Sept 2013	Dubai, UAE	3rd Symposium on Alternative Refrigerants for High Ambient Countries (Two-Days)	150+ participants from HVAC industry and experts + NOUs from GCC & Iraq + AHRI, ASHRAE, EPEE, IIR, JRAIA and GIZ
May 2014	Kuwait	1st Symposium on District Cooling titled " District Cooling; Saving Energy and Environment"	100+ participants from DC industry and experts + NOUs from GCC + AHRI and ASHRAE
Oct 2014	Dubai, UAE	4th Symposium on Alternative Refrigerants for High Ambient Countries (Two-Days)	250+ participants from HVAC industry and experts + NOUs from West Asia + AREA, AHRI, ASHRAE, CHEAA, EPEE, IIR, JRAIA and GIZ
Oct 2015	Dubai, UAE	Technical Forum on "Research Projects for Alternative Refrigerants in High Ambient Countries" (Fifth round of the high ambient Symposia), one-day back to back with MOP-27	150+ participants from HVAC industry and experts + NOUs from parties to MP+ AREA, AHRI, ASHRAE, CHEAA, EPEE, IIR, JRAIA and GIZ and secretariats, bilateral and IAs
Sessions organized at other international technical events			
Jan 2014	New York, NY	Special session titled "Evaluating Low-GWP Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries - PRAHA Methodology and Expectations" At ASHRAE 2014 Annual Winter Conference	
Aug 2015	Yokohama, Japan	Special session titled "Evaluating Low-GWP Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries - Preliminary Findings of PRAHA" At 24th International Congress of Refrigeration	
Jan 2016	Orlando, FL	Special session titled "Evaluating Low-GWP Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries - Final Results and Findings of PRAHA" At ASHRAE 2016 Annual Winter Conference	

In addition to other side coordination meetings, with PRAHA stakeholders, organized in margins of several Montreal Protocol and HVAC&R events as well as several presentations and outreach sessions on PRAHA organized in margins of relevant HVAC&R conference and exhibitions in the region.

Testing of HVAC Equipment with Alternative Refrigerants

By Byron Horak
Director of Engineering, HVAC Performance
Intertek

Table of Contents

Introduction

As components, assemblies, and products for heating, ventilation, and air conditioning—or HVAC—evolve, so do the refrigerants that are used within them. These new, alternative refrigerants are increasingly becoming available in the marketplace, and this has given rise to questions about how to safely utilize and test such refrigerants. As such, the need for laboratories and programs that can reliably test such products is increasing. However, there are precedential parameters that should be relied on when beginning to ask these questions, and it is important to look at what special considerations come into play when flammable refrigerants are involved.

This white paper was prepared at the request of and in cooperation with UNEP and UNIDO.This white paper will explore some of the safety and quality issues laboratories should examine to become involved in alternative refrigerant testing for HVAC products. When developed correctly, labs with the capability to test alternative refrigerants to be used in HVAC products should be able to answer questions such as: Is the unit electrically safe? Can the pressures encountered be handled safely? Does the unit design allow for the non-containment of the refrigerant charge if leaked? And are all electrical components within the unit certified for use with flammable refrigerants? Additionally, a quality testing program should be able to address performance questions for HVAC products that utilize alternative refrigerants, including: What kind of capacity and EER (energy efficiency ratio) will be observed? How will higher ambient temperatures affect capacities and EERs? What kind of operating pressures will be encountered? Can units operate at extreme conditions? Do acoustical values change as ambient temperatures rise? And, how do these new, alternative refrigerants interact with other materials?

Asking these questions in advance is an essential best practice to ensuring that, to the extent possible, risks are identified before a test begins.

Preparing a Lab for Testing Products with Flammable Refrigerants

To sufficiently prepare a lab space to handle testing of HVAC products that utilize alternative refrigerants that are flammable or semi-flammable, several points must be considered and addressed.

The first step is to make sure that an explosive atmosphere cannot be developed in case a leak in the test sample occurs. In order to do this, you must compute the maximum allowed charge for each test room. For example, in calculating the maximum volume of charge allowed for propane, you should use the smallest room of the test facility. In this example, let’s say the

smallest room has 62.3 cubic meters (m3) of volume and the practical limit for propane equals 0.008 kg/m3. The calculation would appear:

62.3 x 0.008 = 0.498 kg, which is the maximum charge limit for this facility for propane

Another example with a different alternative refrigerant may proceed thusly. In calculating the maximum volume of charge allowed for R-32, again, use the smallest room of the test facility. And again, say our example facility equals 62.3 m3 of volume, with the practical limit for R-32 equaling 0.061 kg/m3. The calculation would appear:

62.3 x 0.061 = 3.80 kg, which is the maximum charge limit for this facility for R32

The following table gives examples of allowable amounts of refrigerant from each class for a test facility of a given size.

Refrigerant Flammability Classification	**Volume of Testing Facility (VTF)**	**Minimum Charge Practical Limit (kg/m3)**	**Maximum Allowable Amount of System Refrigerant (MRC = VTF x PL)**
1	62.3 m3 (example)	No Limit	No Limit
2L	62.3 m3 (example)	0.061 (R-32)	3.8 kg
2	62.3 m3 (example)	0.056 (R-143a)	3.49kg
3	62.3 m3 (example)	0.008 (R-290)	0.498 kg

If a test room/lab space is not large enough to safely handle total charge loss, then detection and mechanical ventilation equipment must be installed. The detection device must be suitable to detect the refrigerants being used, and the ventilation blower must be a Class 1 blower. Also, the ventilated gas must be ducted to a large and open area at the highest point possible. This will allow the flammable gases to dilute to a point where they are well below the lower flammability limit, and ducting the gas outdoors would be preferable. Additionally, signs should be posted on the test facility entrances, as well as at the ventilation point, in order to let personnel know flammable refrigerants are in use.

For an added measure of safety, the room volume can be calculated using the installed height of the test unit instead of the height of the test room. This will limit the size of units that can be

tested in the room but is mentioned here because this method is called out in the IEC 60335-2-40 standard for installations of AC equipment in the field.

The potential operating pressures of the test sample should be checked, and new gauge lines for checking test unit pressure should be installed throughout the test facility. Have available separate, labeled canisters for each of the refrigerants that are to be tested. Mixing refrigerants can be quite dangerous, so having accurate labels will help deter any risky mix-ups. Also, provide a well-ventilated storage area free from ignition sources and large enough to accommodate the combustible load.

Check your reclaimers and know their capabilities and limitations. Are they correct and prepped to handle all the new refrigerants that are to be tested? And raise all electrical components to one (1) meter off of the floor. A general inspection for potential ignition sources (electrical and non-electrical) also is recommended.

The Role of Training and Needed Procedures

Training is vital for all staff members involved in the testing of these alternative, flammable and semi-flammable refrigerants. Training should cover all potential types of products, assemblies, componentry, materials, and refrigerants the lab may encounter, and it also should be an ongoing endeavor. Continuous updates on new regulations and safety practices should be available, as well as opportunities for staff to review and reacquaint themselves with procedures they may have already covered in previous training.

The following recommendations on HVAC product and refrigerant set-up procedures come from the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) *Flammable Refrigerants Industry Guide 2013*. They help outline particular procedures for safety and performance testing for HVAC products that utilize these new alternative refrigerants, but you should also familiarize yourself with any and all applicable local and national procedures and regulatory requirements of your business and for its products as well.

Brazing Procedures

There are a few particularly important points to be considered when brazing piping on a test sample. Remove the entire refrigerant charge in case of unexpected failures. Once the refrigerant has been removed, the system must be flushed with oxygen-free dry nitrogen (OFDN). OFDN must be purged through the system both before and during the brazing process. This operation is absolutely vital if brazing operations on the tubing are to take place. Due to the possibility of explosion, compressed air or oxygen must never be used for flushing, pressure testing, or filling the system. And, where possible, use cold-connection technologies—such as flare fittings or compression fittings—instead of brazing when performing system repairs where residual flammable refrigerant may be present.

Reclaiming Charge
The machine used for refrigerant recovery must be suitable for use with flammable refrigerants, meaning there must be no potential sources of ignition. Also, hydro-fluorocarbon (HFC) refrigerant recovery machines may not have been approved for use with flammable refrigerants. Approval must be sought from the manufacturer before using a standard HFC recovery machine with any flammable refrigerant. Some machines may be safe to use with flammable HFCs but not hydrocarbon refrigerants. A refrigerant recovery machine suitable for use with hydrocarbon refrigerants is available, and it may be used with other flammable refrigerants.

Additionally, the recovery cylinder must be specifically suitable for the refrigerant used, particularly in terms of the pressure rating, compatibility of valves, and other such elements. Refrigerants of different safety group classifications—such as A1, A2, and A3—must not be mixed in recovery cylinders, and container(s) must be carefully weighed during transfer of the refrigerant.

Adjusting Charge
When adjusting the charge of HVAC product under test, there are certain methods for alternative refrigerants that will provide greater success.

A system with one refrigerant should never be topped off with another type of refrigerant, particularly a flammable one. Also, very accurate scales are necessary when charging small, critically charged systems with some flammable refrigerants. Scale accuracy must be suitable to the system refrigerant type and charge size, and many scales traditionally used for HFC refrigerant service may not be sufficiently accurate for use with hydrocarbon refrigerants.

Refrigerant charge is an important risk factor, and any scales used should provide the appropriate accuracy to ensure installed charges are correct. Additionally, “dial a charge” cylinders, with a sight glass in the cylinder, should not be used to charge systems with flammable refrigerant.

The Role of the Independent Testing Laboratory

By providing testing services for HVAC products that utilize alternative refrigerants, independent testing labs can offer a range of distinct advantages for businesses in developing their products. By undergoing such testing from an independent, third-party body, manufacturers can be assured of the tests’ and results’ credibility. Independent testing labs are typically very informed and timely regarding safety and regulatory standards, meaning these products are being put through the correct and proper paces. They can ensure efficiency parameters are being met and that particular performance ratings and claims are verified.

Independent labs also often have a much broader reach, helping manufacturers potentially gain access to new markets around the world. Additionally, this is a chance for manufacturers to have their own in-house data and testing results double-checked and verified, which is a fact that can be marketed and promoted to help products gain a competitive edge.

Independent lab testing offers other advantages as well. For manufacturers that don't have the capabilities, bandwidth, or potentially the wherewithal to test in-house, independent testing partners are a must. For a new product such as these alternative refrigerants, using a third party for these testing requirements may be much faster than building the capability in-house. These testing-dedicated facilities can offer extra capacity for such businesses, even supplementing manufacturer labs during periods of overflow. The knowledge provided by an independent testing lab also can include assistance with national or regional research projects, the development of product testing standards, and/or managing the complexity of a testing or certification project. They also can also help grant manufacturers and suppliers access to national or regional certification or verification programs (where applicable).

Primarily, manufacturers and customers can be assured, from an independent source, of the safety, performance, and quality attributes of a product, component, or material. Seeing a third-party independent test report often helps build confidence in consumers, retailers, and government agencies, and this kind of partnership can also help with liability. Independent testing labs can act as true partners, sharing their knowledge of testing procedures and regulatory and safety standards that will lead to an optimized product.

Conclusion

The new alternative refrigerants are increasingly popular, and HVAC products must be prepared to handle them adequately. There can be no doubt that there are significant and fundamental changes occurring in this industry that will continue to challenge and provide opportunity to manufacturers. Meeting these new market demands requires robust and verifiable testing to particular standards, as well as industry collaboration and engagement to help make these products and their performance strong. We strongly encourage all manufacturers, countries, organizations, and associations to enter into open discussions on topics, issues, and best practices regarding and related to the testing of products with new flammable refrigerants. We look forward to continuing to share findings on the safe handling and testing of HVAC equipment with these alternative, flammable, and semi-flammable refrigerants.

About Intertek

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Annex H - Programs of key events organized by PRAHA

The 3rd Regional Symposium on

Alternative Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries; Bridging Environment, Standards and Research"

Dubai- UAE (10-11 Sept 2013)

First Regional Symposium on

District Cooling; Saving Energy and Environment

Kuwait, 20-21 May 2014

The 4th Regional Symposium on

Alternative Refrigerants for High-Ambient Countries; Risk Assessment of Future Refrigerants in Production, Installation and Service

Dubai, UAE 28-29 Oct, 2014

Technical Forum on

Research Projects for Alternative Refrigerants in High Ambient Countries

Dubai, UAE 31 Oct, 2015

Organizers

Co-Sponsors

Under the Patronage of

H.E. Dr. Rashid Ahmad Bin Fahad

Minister of Environment & Water- United Arab Emirates

ESMA/MOEW/AHRI/ASHRAE/UNEP

Organize

The 3rd Regional Symposium on

"Alternative Refrigerants for Air-Conditioning Industry in High-Ambient Temperature Countries; Bridging Environment, Standards and Research"

Intercontinental Hotel (Festival City) - Dubai, UAE (10-11 Sept, 2013)

Program

Day One: Tuesday, Sept 10

08:00 REGISTRATION

09:00 OPENING SESSION

Opening Statements by:

- Statement of the Symposium's Patron
- Statements of AHRI, ASHRAE & UNEP

09:30 WELCOME BREAK

10:15 SESSION I:

Where We Stand;

Environmental & Standards Policies Affecting Future of Refrigerants; Global Perspective

Moderator: Dr. Radhey S. Agarwal - Senior Advisor and Coordinator For HCFC Phase-out, SPPU- India

Sustainable Alternatives, the future we want

Mr. Ayman Eltalouny- Programme Officer
United Nations Environment Programme (UNEP)
Regional Office for West Asia (ROWA)

&

Mr. Ole Nielsen, Unit Chief
Refrigeration and Aerosols Unit - Montreal Protocol Branch
Programme Development and Technical Cooperation Division
United Nations Industrial Development Organization (UNIDO)

How to reduce the refrigerants impact on the climate : the IIR point of view

Mr. Didier Coulomb- Director
International Institute of Refrigeration (IIR)

Refrigerant Choice – Steps and Missteps

Mr. Stephen R. Yurek - CEO
Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

Reducing F-Gas emissions in the EU; The F-Gas Regulation and its revision

Ms. Andrea Voigt -, Director General
EPEE – The European Partnership for Energy and the Environment

New Policy Measures for Reducing F-Gas Emissions in Japan - Outline of the Amendment of Japan's Fluorocarbons Recovery and Destruction Law

Mr. Shuji Tamura - Director for Chemical Management Policy (International Affairs)
Chemical Management Policy Division- Manufacturing Industries Bureau
Ministry of Economy, Trade and Industry (METI)

12:30 Break

Organizers

Co-Sponsors

13:00 SESSION II:
Where We Stand;
Environmental & Standards Policies Affecting Future of Refrigerants; Regional Perspective
Moderator: Mr. James K. Walters, AHRI

MEPS Development and Effectiveness – All Climates
Mr. James K. Walters - Vice President for International Affairs
Air-Conditioning, Heating, and Refrigeration Institute

Energy Labeling Programs for Air-Conditioning Appliances in UAE
Mr. Abdulla Al Muaini
Director of Conformity Affairs Department
Emirates Authority for Standardization and & Metrology, ESMA

Towards unified GCC MEPS
Eng. Saud Al-Askar (tbc)
Director of Conformity Affairs Department
Gulf Standardization Organization, GSO

Continuing & Future Challenges Facing Ozone Layer Protection
Eng. Aisha Al Abdooli
Acting Undersecretary- Environmental Affairs Sector
Ministry of Environment and Water of UAE

Phasing-out HCFC in GCC Countries; toward unified policies
Eng. Yaqoub Almatouq
Refrigeration Expert - Kuwait National Ozone Committee- Environmental Public Authority
Head of Refrigeration Team - General Service Department - Ministry of Social Affair & Labor

14:00 SESSION III:
Relevant Research Programs and Initiatives for Finding Alternatives
Moderator: Dr. Walid Chakroun - Professor Mechanical Engineering, Kuwait University

Hydrocarbon Refrigeration: Status, Challenges and Opportunities
Dr. TieJun (TJ) Zhang - Assistant professor of Mechanical Engineering
Masdar Institute of Science and Technology

PRAHA - Finding low-GWP solutions for A/C industry in high ambient countries
Mr. Bassam Elassaad
Consultant to UNEP High Ambient Project

AHRI Low-GWP Alternative Refrigerants Evaluation Program (AREP)
Mr. James K. Walters - Vice President for International Affairs
Air-Conditioning, Heating, and Refrigeration Institute

15:00 Lunch

AFTERNOON CLOSED SESSION (by invitations only) Day One: Tuesday, Sept 10		
16:00 - 18:00	**Promoting long-term Alternatives in high-ambient countries; Independent & Verified Testing Project** UNEP & UNIDO Joint Initiative	**Coordinate Governments' actions about MEPs and HCFC Phase-out Plans** GCC Environmental and Standardization Authorities

19:00 **Celebrating Ceremony on the occasion of the symposium and the International Day for the Preservation of the Ozone Layer cordially hosted by the Government of United Arab Emirates**

Organizers

Co-Sponsors

Day Two: Wednesday, Sept 11

09:00 **SESSION IV:**
Hydrocarbons (HC) for Air-Conditioning Applications
Moderator: Mr. Bernhard Siegele, GIZ Proklima Programme, Manager

Global overview and trends on HC Air-Conditioning Equipment
Mr. Bernhard Siegele - Manager
GIZ Proklima

Hydrocarbons in air-conditioning: Performance in high-ambient temperatures
Dr. Sukumar Devotta - Chemical & Environmental Engineering Consultant
Former NEERI Director, India

HC: Environmentally sound option for China RAC sector
Mr. Dou Yanwei- Deputy director Department of Comprehensive Affairs
Chinese Household Electrical Appliances Association, CHEAA

R290 as Alternative Refrigerant for Split Air-Conditioning Systems in High Ambient Temperature
Authors: Dilip Rajadhyaksha, Anil Sahu, B. J. Wadia, Godrej & Boyce Mfg. Co. Ltd, Mumbai, India
(given by Mr. **Bernhard Siegele**)

HC chillers in warm climates
Mr. Alexander Cohr Pachai- Technology Manager Building Efficiency
Johnson Controls, Denmark

10:30 **Break**

11:00 **SESSION V:**
HFC-32 for Air-Conditioning Applications
Moderator: Mr. Osami Kataoka- JRAIA

JRAIA Refrigerant policy for Climate Change
Mr. Osami Kataoka, Senior Manager
International Affairs Department - The Japan Refrigeration and Air Conditioning Industry (JRAIA)

HFC-32 for A/C Applications; progress and actual use
Mr. Tadafumi Mikoshi - Senior Manager
CSR & Global Environment Center - Daikin Industries, LTD

JRAIA risk assessment on mini-split with A2L refrigerants
Mr. Kenji Takaichi, Conditioner Risk Assessment WG
The Japan Refrigeration and Air Conditioning Industry (JRAIA)

12:00 **SESSION VI:**
Components Development; Refrigerants and Compressors for the Future
Moderator: Mr. Didier Coulomb, Director - IIR

New Zero ODP, Low GWP and high Efficiency Fluids for High Ambient Temperature
Mr. Joachim Gerstel - Business Development Manager
DuPont Opteon® Refrigerants EMEA

Evaluation of LGWP refrigerants for use in a/c systems operating in hot climates
Dr. Nacer Achaichia - Technical Manager
Refrigerants, EMEAI - Honeywell

Refrigerants – Getting Ready For The Future
Mr. K. Jayakumar
Vice President - Marketing & Business Development
Emerson Climate Technologies

13:00	Break

13:30 SESSION VII:
Others Potential Solutions for the Future
Moderator: Mr. Ole Nielsen, UNIDO

CO2 as refrigerant; an option for high ambient
Dr. Predrag Pega Hrnjak
Co-Director, Air Conditioning and Refrigeration Center, Professor of Mechanical Science and Engineering Department of Mechanical Science and Engineering - University of Illinois

CO2 as refrigerant in high ambient temperature applications
Torben Funder-Kristensen - Head of Public and Industry Affairs
Danfoss A/S - Refrigeration and Air Conditioning Controls (RC

Absorption solutions, can it work for A/C unitary applications
Dr. Alaa Olama
Air Conditioning & Refrigeration Consultant

14:30 SESSION VIII:
Concluding Session: Bridging Environment, Standards, and Research for High-Ambient Needs
Moderators: Dr. Alaa Olama & Mr. Bassam Elassaad

Overview of Alternatives to HCFCs for RAC Applications in High Ambient Conditions
Dr. Radhey S. Agarwal
Senior Advisor and Coordinator For HCFC Phase-out, SPPU- India

- **Feedback on environmental issues**: NOUs, NGOs, and government representatives
- **Feedback on standards**: standards organizations, regional and international OEMs
- **Feedback on Technology**: regional and international OEMs & technology providers
- **Feedback on research**: associations and research institutes
- **Next steps**: what should the next event include

15:00	Lunch

AFTERNOON CLOSED SESSION (by invitations only) Day Two: Wednesday, Sept 11		
16:00 - 19:00	Incorporating alternatives and future A/C technologies for high-ambient climates in the regional research programs Regional Research Institutes/centers Plenary session open to all interested participants	Organizing the Industry in the region AHRI and UNEP Initiative Regional HVAC manufacturers

Local Organizers

ASHRAE Kuwait Chapter

MINISTRY OF ELECTRICITY & WATER
STATE OF KUWAIT

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Regional Symposium on

District Cooling; Saving Energy and Environment

Kuwait, 20-21 May 2014
Conference Hall-Shuwaikh Campus
Kuwait University

Background Note

Objectives:

It is proposed to hold a symposium on the use of District Cooling as a mean of energy conservation in the region. The Symposium will focus on the environmental, efficiency, and economic advantages of district cooling and how all can be maximized by proper planning and execution. This symposium will present lesson-learned for district cooling systems when implemented in different applications like cities, educational campuses, major medical facilities and other large building complexes. Special attention will be devoted in considering district cooling as a mean to energy conservation and leapfrog high-GWP refrigerants. Energy planners, researchers and users, with the objective of exchange ideas and best practices will discuss DC applications in light of energy savings and friendly environmental technology.

Scope:

The scope of the symposium is related to the latest development in the region when it comes to implementing district cooling. The symposium will comprises of two main themes and several sub-thematic topics as follows:

. Energy Conservation for District Cooling Applications

- Power Security
- Lesson Learned from DC applications
- Cost and Regulations of District Cooling
- How Sustainable District Cooling?

. Use of non-conventional technologies in DC plants

- Alternative Refrigerants in DC Application
- Environmental benefit of DC; GWP and LCCP impacts
- Use of renewable resources in DC plants
- Availability of technical backstopping for new technologies

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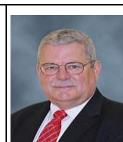
The Program

Tuesday 20th May 2014

8:00– 8:45		Registration
8:45–9:15		Opening Ceremony
9:15–9:30		**Break**
		Session I: Regional Experiences Moderated by: Dr. Ali E. Hajiah & Dr. Abdullatif Ben-Nakhi
9:30– 10:00		**Eng. Roger Baroudi** ***Blue Print for the Implementation of District Cooling in Kuwait***
10:00– 10:30		***Eng. Fadhel alKazemi*** ***Design and build Kuwait Future Cities Township Districts Neighborhood; On the Foundation of Happiness Is the Way of Life in Kuwait***
10:30– 11:00		**Eng. Magdi Rashad** ***Saudi District Cooling; Potentials and Opportunities***
11:00– 11:30		**Session I Discussion**
11:30– 12:00		**Break**
		Session II: District Cooling-Code Design Guide Moderated by: Eng. Suhaila Marafie & Dr. Essam Omar
12:00– 12:30		**Dr. Gary E. Phetteplace** ***Overview of the New ASHRAE District Cooling Guide***
12:30– 1:00		**Eng. Marco Masoero** ***AREA's View on District Cooling***
1:00– 1:30		**Dr. Alaa Olama** ***Developing a National and Regional Code for District Cooling***
13:30– 14:00		**Session II Discussion**
14:00– 14:45		**Lunch Break**
		Special Workshop: Energy Efficiency 90.1 Moderated by Dr. Asad Alebrahim
14:45– 17:30		**Eng. Ron Jarnagin** ***Understanding ASHRAE Standard 90.1-2010 "Energy Standard for Buildings Except Low-Rise Residential Buildings"***

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Wednesday 21st May 2014

		Session III: District Cooling Technology Moderated by Dr. Hassan Sultan & Dr. Ahmed Alaa
9:00– 9:30		**Eng. John Stephen Andrepont** ***Efficient Technologies That Are Also Economically Sustainable: The Big 3 (District Energy, CHP and TES), where 1+1+1 can equal 10***
9:30– 10:00		**Eng. Frank Mills** ***District Cooling Through Tri-Generation***
10:00– 10:30		**Eng. Gautham Belthur** ***Low load & low delta T syndromes in typical DC Plants***
10:30– 11:00		**Ing. Gerhard Bingel** ***Water utilization and TSE use TSE - the only Real Alternative as makeup water***
11:00– 11:30		**Session III Discussion**
11:30– 12:00		**Break**
		Session IV: District Cooling-Environmental Sustainability Co-Moderated by Eng. Ole Nielsen & Eng. Yaqoub Almatouq
12:00– 12:30		**Dr. Husamuddin Ahmadzai** ***District Cooling and Heating — Protecting the Climate and Ozone Layer: Global and Regional Initiatives in the EU and Nordic Countries***
12:30– 13:00	 	**Eng. Bassam Elassaad & Dr. Walid Chakroun** ***Obstacles and Challenges of District Cooling in High-Ambient Temperature Countries***
13:00– 13:30		**Session IV Discussion & Closing Remarks**
13:30– 14:15		**Lunch Break**
		Special Workshop: District Cooling Design Practices Moderated by Dr. Nawaf Almutawa
14:15– 17:15	 	**Eng. Roger Baroudi & Dr. Alaa Olama** ***District Cooling Design and Best Practices***

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Organize

The 4th Regional Symposium on

Alternative Refrigerants for High-Ambient Countries;

Risk Assessment of Future Refrigerants in Production, Installation and Service

Dubai, UAE 28-29 Oct, 2014

Sofitel Downtown- Diamond Ballroom

Under the Patronage of
H.E. Dr. Rashid Ahmad Bin Fahad
Minister of Environment & Water- United Arab Emirates
ESMA/MOEW/AHRI/ASHRAE/UNEP/UNIDO
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The 4th Regional Symposium on

Alternative Refrigerants for High-Ambient Countries;

Risk Assessment of Future Refrigerants in Production, Installation and Service

Dubai, UAE 28-29 Oct, 2014
Sofitel Downtown- Diamond Ballroom

PROGRAM

Day One: Tuesday, 28 Oct

08:00 **REGISTRATION**

09:00 **OPENING SESSION**
Opening Statements by:

- **Statement of the Symposium's Patron**
- **Statements of AHRI, ASHRAE, UNEP & UNIDO**

09:30 **WELCOME BREAK**

10:00 **SESSION-I**
Air-Conditioning Industry with Global Dynamic Refrigerant Policies
Moderators: **Mr. Ayman Eltalouny** & **Mr. Ole Nielsen**

The New F-Gas Rules in Europe: Challenges and Opportunities for Industry
Ms. Andrea Voigt
Director General, EPEE
The European Partnership for Energy and the Environment (EPEE)

EU Efforts to Reduce Direct HFC Emissions
Dr. Arno KASCHL
Policy Officer, Directorate-General for Climate Action Transport & Ozone
European Commission

New Progress of R-290: RACs Promotion in China
Dr. ZHU Liucai
Division Director and Senior Research Fellow
Foreign Economic Cooperation Office (FECO) -Ministry of the Environmental Protection of China

Actions to Control HFC Emission and to Promote Alternatives in Japan
Mr. Kazuhiro Sato
Senior Manager, International affairs Department
The Japan Refrigeration and Air Conditioning Industry Association (JRAIA)

U.S. Policy Measures on HFCs
Dr. Federico San Martini
Foreign Affairs Officer, Office of Environmental Quality and Transboundary Issues
Department of State, USA

The Need for Global Refrigeration Education, Training, and Management
Mr. Steve Yurek
CEO
Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

12:00 **LUNCH** (At Les Cuisines Restaurant)

13:15 **SESSION II**
Impact of MEPS and Labeling Programs on A/C Industry
Moderators: **Mr. James K. Walters** & **Dr. Walid Chakroun**

Towards a Unified GCC MEPS
Eng. Saud Al-Askar
Director of Conformity Affairs Department
Gulf Standardization Organization, GSO

Dubai's DSM strategy
Mr. Faisal Ali Rashid
Director for Demand Side Management
Supreme Council of Energy

ESMA Future Plan and Strategy
Eng. Jasim Mohamed Al Ali
Acting Head of Internal Conformity
Emirates Authority for Standardization and Metrology (ESMA)

Air-Conditioners Energy Efficiency Plan in Egypt
Eng. Esraa Ahmed Abd El-Aziz
Mechanical Standard Specialist.
Egyptian Organization For standardization & Quality (EOS).

Seasonal Efficiency Concept for the Middle-East
Mr. Kazuhiro Sato
Senior Manager, International affairs Department
The Japan Refrigeration and Air Conditioning Industry Association (JRAIA)

14:45 **BREAK**

15:15 **SESSION III: International & Regional Initiatives to Assess/Promote Future Refrigerants**
Moderators: **Mr. Bernhard Siegele** & **Mr. Marco Buoni**

Phasing out HCFCs Without Increasing Greenhouse Gases Emission: Introduction of low-GWP Alternative Solutions
Mr. Didier Coulomb
Director
International Institute of Refrigeration (IIR)

AHRI Low-GWP Alternative Refrigerants Evaluation Program, AREP
Dr. Karim Amrane
Senior Vice President, Regulatory & International Policy
Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

Promoting Alternative Refrigerants for High-Ambient Countries, PRAHA
Mr. Bassam Elassaad
Consultant
UNEP-UNIDO PRAHA Project

HC Refrigerant Performance in UAE Air-Cooled Chillers
Dr. Peter Armstrong
Associate Professor in Mechanical Engineering
Masdar Institute of Science and Technology

<table>
<tr><th colspan="2">SPECIAL SESSIONS (BY INVITATIONS ONLY)
At Aquamarine Ballroom- 1st floor</th><th>OPEN SESSIONS
At Diamond Ballroom</th></tr>
<tr><td>16:30
-
18:00</td><td>Meeting of the Regional RAC Association (ARAMENA)
<u>Members, Affiliates, and Guests</u></td><td>Technology Showcase
<u>By the Industry Sponsors</u></td></tr>
</table>

Day Two: Wednesday, 29 Oct

08:30 SESSION IV:
Risk Assessment in the Production of Systems Using Future Refrigerants
Moderators: **Dr. Ghalib Y. Kahwaji** & **Mr. Bassam Elassaad**

HC-290 Split AC Units – a Safe, Efficient and Reliable Reality in the Market
Mr. Bernhard Siegele
Programme Manager
GIZ- Proklima

DAIKIN's Experience in the Production with R-32
Mr. Tadafumi Mikoshi
Global Project Manager
CSR Global Environment Center, Daikin Industries, Ltd

Risk Assessment Using Low-GWP Refrigerants in a Safety Perspective
Dr. Torben Funder-Kristensen
Head of Public and Industry Affairs
Danfoss A/S (Denmark) - Refrigeration and Air Conditioning Controls (RC)

Flammability Characteristics and Handling of 2L Class Refrigerants
Dr. Nacer Achaichia
Technical Manager
Refrigerants, EMEAI - Honeywell

Performance of R290 RAC and Risk Assessment
Dr. Li Tingxun
Responsible for R&D of low GWP alternative refrigerants RAC in Midea Co.
Associate professor of Sen Yat-sen University China

Development of R290 Compressor Used for Air Conditioner

Mr. Li Zhang
Senior Engineer, R&D Center
Shanghai Hitachi Electrical Appliances Co.

10:30 **BREAK**

11:00 SESSION V:
Installation & Service: Best Practices in Installing and Servicing Systems with New Refrigerants
Moderators: **Ms. Andrea Voigt** & **Dr. Alaa Olama**

Certification in the Safe and Efficient Use of Alternative Refrigerants
Mr. Marco Buoni
Vice-President
Air conditioning Refrigeration European Association (AREA)

Working with HC in A/C Applications in China
Mr. Ole Nielsen *(on behalf of CHEAA)*
Unit Chief Refrigeration and Aerosols Unit
United Nations Industrial Development Organization (UNIDO)

Safety Guidelines For Low GWP Refrigerants From A Compressor Manufacturer's Perspective
Dr. Rajan Rajendran
Vice President - Systems innovation Center And Sustainability
Emerson Climate Technologies

Working HC in RAC Equipment: Handle with Care and Competence
Mr. Bernhard Siegele
Programme Manager
GIZ- Proklima

Safety Concerns for A2L Refrigerants in AC Service Procedures
Mr. Osami Kataoka
Senior Manager
On behalf of The Japan Refrigeration and Air Conditioning Industry (JRAIA)

12:30	**BREAK**

13:00 **SESSION VI:**

Standards and Testing: Relevant Standards and Testing Requirements
Moderators: **Dr. Karim Amrane & Mr. Kazuhiro Sato**

ISO 5149 (2014); Changes in View of Alternative refrigerants for HVACR Applications
Ms. Els Baert
Working group member
ISO -TC86SC1WG1

The Technical Basis for ASHRAE-15 Standard Changes; An Analytical Investigation of Class 2L Refrigerants
Mr. Dennis Dorman
Chairman of ASHRAE Standard-15 Committee

Testing of HVAC Equipment with Future Refrigerants
Mr. Byron Horak
Director of Engineering - HVAC Performance
Intertek

14:00 CONCLUDING SESSION

Policy and Technical Measures for Consideration by Industry and Governments to Promote Future Refrigerants
Moderator: **Dr. Radhey S. Agarwal**

Panelists:

Mr. Abdulla Al Muaini
Acting Director General, Emirates Authority for Standardization and & Metrology, ESMA

Eng. Othaibah Al Qaydi
Head of Chemicals Department, Ministry of Environment and Water of UAE

Dr. Ahmed Alaa Eldin
Regional Vice Chair for government activities, ASHRAE Falcon Chapter

Mr. Stephen Yurek
CEO, Air-Conditioning, Heating and Refrigeration Institute, AHRI

Mr. Stephan Sicars
Director of Montreal Protocol Branch, UNIDO

Dr. Shamila Nair-Bedouelle
Head of OzonAction Branch, UNEP

15:00	**LUNCH** (At Les Cuisines Restaurant)

SPECIAL SESSIONS *(BY INVITATIONS ONLY)* - At **Aquamarine** Ballroom- 1st floor	
16:30 - 18:00	**Meeting of the UNEP-UNIDO High-Ambient Project (PRAHA)** _UNEP & UNIDO and PRAHA participants_

Organized by

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Under the Patronage of
H.E. Dr. Rashid Ahmad Bin Fahad
Minister of Environment & Water- United Arab Emirates
ESMA/MOEW/AHRI/ASHRAE/UNEP/UNIDO
Organize

Technical Forum on
Research Projects for Alternative Refrigerants in High Ambient Countries

31October 2015
Conrad Hotel - Dubai, UAE

PROGRAM

08:15 REGISTRATION

09:00 **Welcome Note by the Government of UAE**

09:05 **SESSION I**: **The future of refrigerants; Challenges and Potentials**

Keynote messages by:

- **Mr. Stephen Yurek** - President & CEO, AHRI
- **Dr. Shamila Nair-Bedouelle** - Head of OzonAction Branch **/ Dr. Iyad Abumoghli** – Director & Regional Representative, United Nations Environment Programme
- **Mr. Stephan Sicars** - Director, Program Development and Technical Cooperation Division, UNIDO
- **Dr. Ebrahim Al Hajri** - President, ASHRAE Falcon Chapter- UAE

09:30 **SESSION II**: **Findings of the High Ambient Research projects**

Classification and Designation of new refrigerants
Dr. Walid Chakroun - Professor, Kuwait University & ASHRAE Fellow & Vice President
Dr. Karim Amrane - Vice President, Regulatory and International Policy, AHRI

High-Ambient-Temperature Environments"
Dr. Suely Carvalho - Member (co-chair) of the International Expert Panel for the High Ambient Testing Program
Dr. Omar Abdelaziz - Group Leader, Building Equipment Research Group, Oak Ridge National Laboratory

Low-GWP Alternative Refrigerants Evaluation Program (AREP-II)
Dr. Karim Amrane - Vice President, Regulatory and International Policy, AHRI

Findings and Conclusions of UNEP-UNIDO High Ambient Project (PRAHA)
Dr. Walid Chakroun - ASHRAE Fellow & Consultant to PRAHA Project
Mr. Bassam Elassaad - Independent Expert & Consultant to PRAHA Project

11:30 BREAK

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12:00 **SESSION III**: **Other efforts towards addressing alternatives for high ambient conditions**

Transition of refrigerants for air-conditioners in high ambient temperature region
Mr. Tetsuji Okada - President, Japan Refrigeration and Air Conditioner Industry Association (JRAIA)

Real Alternatives EU project: Blended learning for Alternative Refrigerants in High Ambient Countries
Mr. Marco Buoni - Vice President, Air-conditioning Refrigeration European Association (AREA)

Research progress on the application of natural refrigerants in HAT conditions
Mr. Juergen Usinger - National Expert, GIZ-Proklima

13:00 **CONCLUDING SESSION: Alternative Refrigerants for High-Ambient; Prospects and Remaining Work**

PANELISTS

- Mr. Didier Coulomb- Director General. International Institute of Refrigeration (IIR)
- Ms. Andrea Voigt - Director General, The European Partnership for Energy and the Environment (EPEE)
- Dr. Roberto Peixoto- RTOC Co-Chair
- Dr. Alaa Olama- RTOC member, PRAHA Technical Review Team and US Project Advisory Team
- Mr. Samir Hamid- RTOC member and Director of Research & Development at Petra Engineering

(5 minutes to each followed by plenary comments)

13:45 VOTE OF THANKS AND CLOSING

THE PROGRAM IS MODERATED BY:

James K. Walters - Vice President, International Affairs, AHRI
Ole Reinholdt Nielsen - Chief, Montreal Protocol Unit, UNIDO
Ayman Eltalouny - Programme Officer, UNEP