EGYPRA – Promotion of Low-GWP Refrigerants for the Air Conditioning Industry in Egypt

2019

Report

Project supported by the Multilateral Fund of the Montreal Protocol

UNITED NATIONS ENVIRONMENT

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Acknowledgement

We would like to acknowledge the assistance given by the government and the National Ozone Unit Officers of Egypt for their support in the implementation of the project phases and their assistance in facilitating communication with the different stakeholders.

We also acknowledge the independent International Technical Review Team that assist the project team in reviewing the process, results and the report of the project.

Prof. Roberto Peixoto (Brazil)
Prof. Walid Chakroun (Kuwait)
Dr. Omar Abdel Aziz (USA/UAE)

Acknowledgement also goes to the “Technology Providers” (Refrigerant and Compressor manufacturers) for providing components free of charge.

Refrigerant Providers: Arkema, Chemours, Daikin, and Honeywell.
Compressor providers: Emerson, Highly, and GMCC.

Also the OEM manufacturers who built the prototypes and tested them at their own facilities. The OEMs are listed under item 1.6

Delta Construction Manufacturing (DCM)
Elaraby
Egyptian German Air Treatment Company (EGAT)
Fresh
Miraco
Power
Unionaire
Volta

Project Team

The National Ozone Unit – Ministry of Environment, Egypt: EGYPRA is funded by the HCFC Phase-out Management Plan (HPMP) of Egypt. The ministry team provided guidance and direction and participated at project meetings and discussions.

The Project Management: UN Environment and UNIDO provided overall management and coordination of the project, established the link with the technology providers, and oversaw the development of the report of the project. The Project was managed by Dr. Lamia Benabbas, Programme Officer – UNIDO and Mr. Ayman Eltalouny, International Partnership Coordinator, OzoneAction Programme – UN Environment

The Egyptian Organization for Standards: provided guidance on the Egyptian standards for testing as well as the minimum energy performance standards (MEPS).

The Technical Consultant, Dr. Alaa Olama advised OEMs during prototype design and construction. Devised testing methodology and testing TOR, consulted with OEMs to provide technical solutions for problems as they arose. The Technical Consultant witnessed-testing of all prototypes and baseline units, compiled testing data, and provided analysis of data.

The Coordination Consultant, Mr. Bassam Elassaad provided logistical support and coordination for the project and helped with writing of the final report.

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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
Btuh	Also denoted as BTU/h or B.t.u/hr = British Thermal Unit per Hour
BV	Burning Velocity
CAP	Capacity
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)
GWP	Global Warming Potential
HAT	High Ambient Temperature
HC	Hydro Carbons
HCFC	Hydro Chloro Fluoro Carbon
HFC	Hydro Fluoro Carbon
HFO	Hydro Fluoro Olefins
HPMP	HCFC Phase-out Management Plan
HVACR	Heating, Ventilation, Air Conditioning and Refrigeration
HX	Heat Exchanger
IU	Indoor Unit
IEC	International Electrotechnical Commission
IPR	Intellectual Property Rights
ISO	International Standards Organization
Kg	Kilograms
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 Substances
OEM	Original Equipment Manufacturer
PRAHA	Promoting Low-GWP Refrigerants for the Air Conditioning in HAT Countries
PSI	Pounds per Square Inch
RAC	Refrigeration and Air Conditioning
ROWA	UNEP Regional Office for West Africa
RTOC	Refrigeration, Air Conditioning, and Heat pump & Technical Options Committee

SCFM	Standard Cubic Foot per Minute
SHR	Sensible Heat ratio
SNAP	Significant New Alternative Policy
Tdb	Dry Bulb Temperature
Twb	Wet Bulb Temperature
TEAP	Technical & Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TF	Task Force
TWB	Wet Bulb Temperature
UNEP	United Nations Environment
UNIDO	United Nations Industrial Development Organization
USD	US Dollars
VC	Vienna Convention
VRF	Variable Refrigerant Flow
WB	Wet Bulb
WG	Working Group

Executive Summary

HCFCs are used extensively in the refrigeration and air conditioning industry, in particular in the air-conditioning industry. Parties to the Montreal Protocol, in their 21st meeting, adopted a 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 for those with forthcoming compliance targets related to consumption of HCFC in the air-conditioning sector.

The aim of this program was to individually test custom-built AC split unit prototypes and central unit prototypes, to operate with alternative refrigerants and compare their performance against baseline units. Those baseline units are either HCFC-22 or R-410A. The list of refrigerants used and the split unit categories tested is as per the table below. The project involved building and testing 19 custom built split unit prototypes with dedicated compressors provided by Emerson, GMCC, and Hitachi Highly, and 16 base units by five OEMs. The refrigerants were provided by Arkema, Chemours, Daikin, and Honeywell. All the prototypes and the base units were tested at locally available accredited labs at the time the tests were conducted and witnessed by the project's Technical Consultant who also advised the OEMs during the manufacturing stage. Tests were repeated for optimization by tweaking some of the components. A total of 140 witnessed tests were performed. The central units were built but could not be tested due to lack of locally accredited available labs.

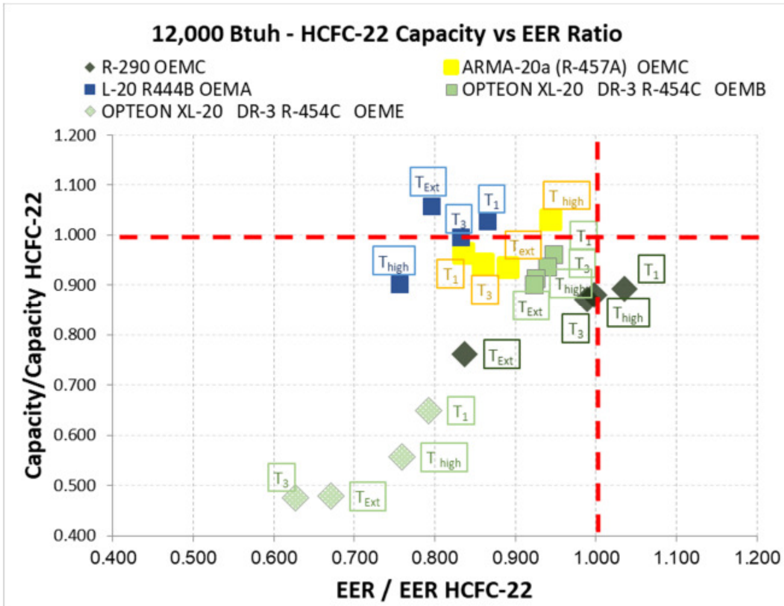
		Split system (mini-split)			**Central 120,000 Btuh**	
	Replacement for	**12,000 Btuh**	**18,000 Btuh**	**24,000 Btuh**	**Std. coil**	**micro channel**
HC-290	HCFC-22					
HFC-32	R-410A					
R-457C (Arkema ARM-20a)	HCFC-22					
R-459A (Arkema ARM -71a)	R-410A					
R-454C (Chemours DR-3)	HCFC-22					
R-454B (Chemours DR-5A)	R-410A					
R-444B (Honeywell L-20)	HCFC-22					
R-447A (Honeywell L-41)	R-410A					
HCFC-22 baseline						
R-410A baseline						

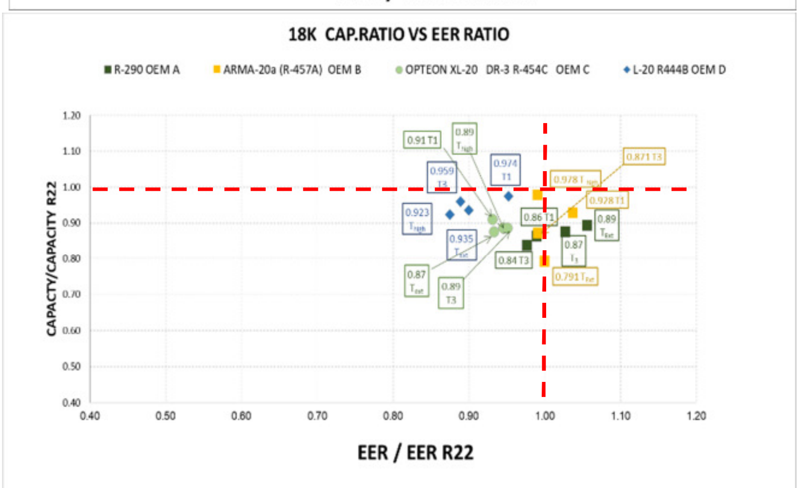
The units were tested at four ambient temperatures: T_1 (35 °C) and T_3 (46 °C) with indoor dry bulb/wet bulb temperatures of 27/19 °C and 29/19 °C respectively, plus two other ambient temperatures of 50 °C termed as T_{High} and 55 °C termed as $T_{Extreme}$ at ISO 5151 specified indoor dry bulb/wet bulb temperature of 32/23 °C (maximum testing condition in ISO 5151). These indoor temperatures are different from the ones used by other testing programs such as AREP and ORNL. The test results gave higher capacities at T_{High} than at T_3.

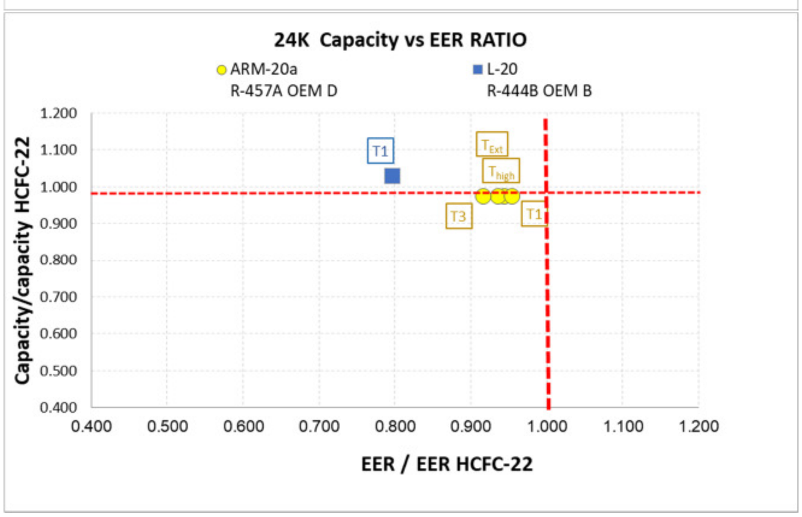
The casual reading of the results may establish confusion, even among specialists, in relation to the increase in capacity and EER at T_{High} compared to T_3. This result is not witnessed in other similar research projects; however, by understanding the impact of changing the dry bulb and wet bulb indoor testing conditions i.e. T_{high} (outdoor 50/24 ^{0}C, indoor 32/24 ^{0}C) compared to T_3 (outdoor 46/24 ^{0}C, indoor 29/19 ^{0}C), the results can be explained. These results were randomly double checked through a simulation exercise. The additional exercise to review the results delayed publishing results.

The test results are presented in comparison to the baseline units and color coded to denote the performance over or below the performance of the comparative baseline units. Scattered charts are plotted for the capacity ratio vs EER ratio for the prototypes vs the baseline units for each of the three unit categories and for the HCFC-22 alternatives and the R-410A alternatives. The red lines denote performance comparable to the base unit

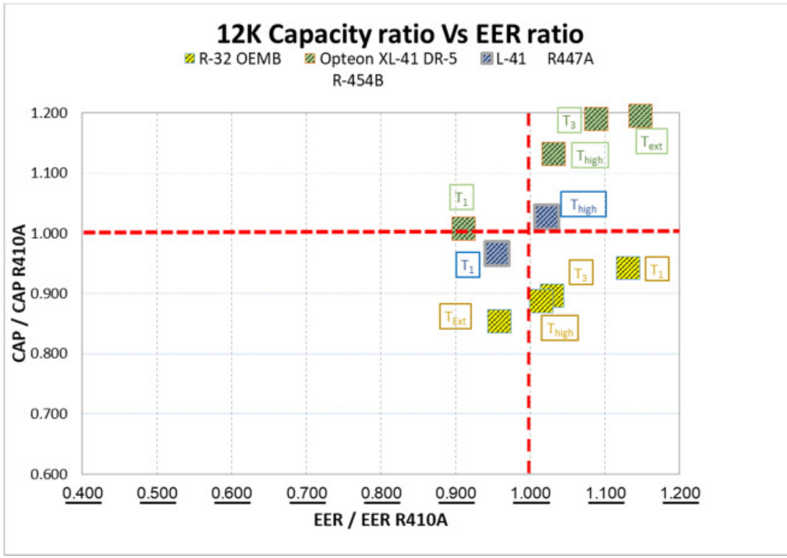
HCFC-22 alternatives

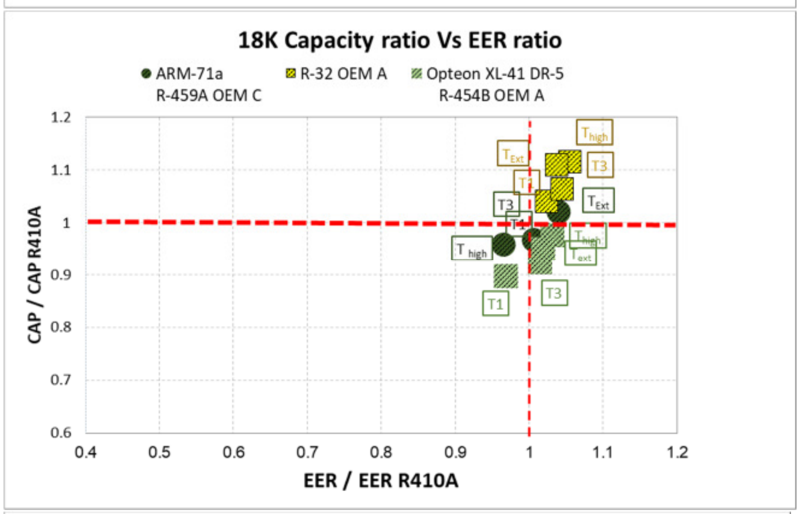


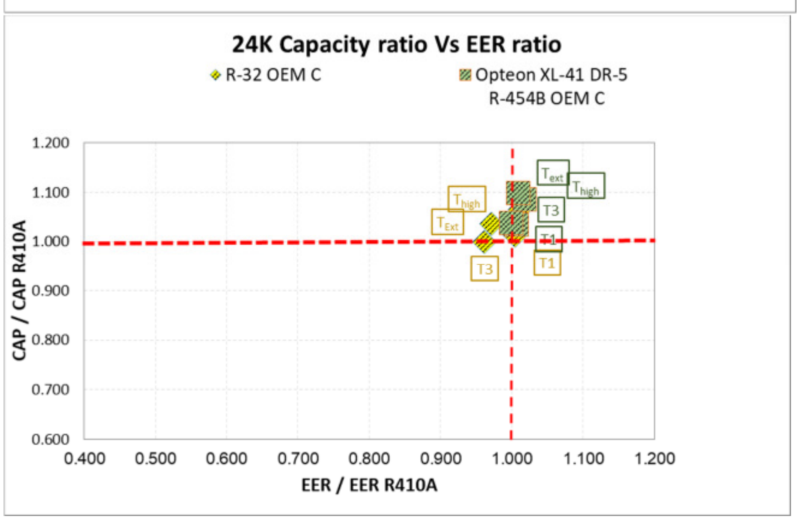




R-410A alternatives







Test results for HCFC-22 alternatives refrigerants demonstrate that:

- Several refrigerant alternatives show 60%, or above, chance for capacity matching or improvement across all categories and at different testing temperatures.
- Most refrigerant alternatives show 50%, or above, chance for EER improvement across all categories and at different testing temperatures.

Test results for R-410A alternatives refrigerants demonstrate that:

- All refrigerants showed improvement in capacity by 25 % to 67 %
- All refrigerants showed improvement in EER by 67 % to 75 %

The results show that there is a potential to improve the capacity and energy efficiency of the prototypes working with alternatives to HCFC-22; however, the potential for improvements for the prototypes working with alternatives to R-410A is better. This conclusion is in line with the outcome of other testing projects shown in Annex 4 and is based on the percentage of test results that were within plus or minus 10% of the results from testing the baseline refrigerants in the same category of equipment. This improvements are dependent on the availability and selection of the right components for units that can deliver the required performance while still be commercially viable.

An outcome of the project is a need for capacity building to enable the participating OEMs to design, optimize, and t test units with flammable refrigerants in order to improve the performance and meet the energy efficiency standards. There is a need to upgrade their testing facilities both in terms of instrumentation as well as to handle flammable refrigerants (refer to Annex 3 for a description of the OEM labs).

Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view; however, when compared to MEPS (Minimum Efficiency Performance Standards) for Egypt - see chapter 4 - results show there are challenges for the industry to provide high efficiency AC units meeting stringent requirements in the coming years. Moreover, the viability in terms of the other criteria like compatibility, commercial availability, safety, and cost among others needs to be further researched.

Chapter 1

1. Introduction

HCFCs are used extensively in the refrigeration and air conditioning industry, in particular in the air-conditioning industry. Parties to the Montreal Protocol, in their 21st meeting, adopted a 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 for those with forthcoming compliance targets related to consumption of HCFC in the air-conditioning sector.

The PRAHA project (*Promoting Low-GWP Refrigerant Alternatives for the Air Conditioning Industry in High Ambient Temperature Countries*) was a pioneer project in testing specially built prototypes by local industries in the Middle East and West Asia region using alternatives refrigerants.

Manufacturers of residential and commercial air conditioning equipment in Egypt met with the Montreal Protocol implementing agencies in July 2014 and agreed on participating in a project to build and test prototypes using various HCFC alternatives at preset conditions in order to compare the performance and efficiency of those refrigerant alternatives.

The project's key elements are to:

a) Asses available low-GWP refrigerant alternatives by building, optimizing, testing and comparing prototypes with those alternatives;
b) Asses local Energy Efficiency (EE) standards and codes and the effect of using low-GWP refrigerant alternatives on those standards;
c) Promoting technology transfer by examining and facilitating technology transfer through the HPMP.

The last two elements are part of the Egyptian HPMP and are not included in this report.

1.1. Egypt HPMP

Egypt's starting point for aggregate reductions in its HCFC consumption is the same as its HCFC baseline consumption of 386 ODP tonnes (ODPt). The analysis of the data by substance and by sector showed that HCFC-22 is used almost entirely in the RAC sector and is the most predominant ODS in metric terms. However, in terms of ODS the use of HCFC-141b is significant, being 35% of the total baseline consumption. Egypt has committed to reduce its consumption by 25% by 2018. The 35% reduction on January 1, 2020 will take the consumption down to 251 ODPt.

The air conditioning manufacturing sub-sector accounts for about 35% of the HCFC-22 consumption. About 56% is used for servicing with RAC manufacturers accounting for the majority of this service consumption, while independent service companies account for just 3% of the HCFC-22 consumption.

The important consumption of HCFC-22 by local AC manufacturers, especially in the RAC sector, is the reason for adopting a project for testing locally built prototypes using low-GWP alternatives in Egypt. The program has been given the name EGYPRA (*Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt)*

1.2. Project Objectives

The aim of the program is to individually test especially made prototype split units and central units, to operate with alternative refrigerants and compare their performance against baseline units. Those baseline units are with either HCFC-22 or R-410A refrigerants.

The project objectives were decided upon in agreement with the local stakeholders and can be summarized as follows:

- Orient the Egyptian air conditioning manufacturers to the new medium and low-GWP refrigerants including those with low and high flammability;
- Support technical and policy decisions regarding long-term HCFC alternatives for the air-conditioning industry as part of the of Egypt's HPMP;
- Streamline the HCFC phase-out program with the Energy Efficiency work in Egypt;
- Promote the introduction of relevant standards/codes that ease the adoption of alternatives needing special safety or handling considerations;
- Exchange the experience with other relevant initiatives and programs which aim at addressing long term alternatives;
- Assess the capacity building and training needs for deploying low-GWP alternatives for different groups dealing or handling refrigerants in Egypt.

The outcomes from the above objectives are not presented in this report which only presents the results of the tests that were carried out for the various prototypes

1.3. Selection of Alternative Refrigerants

The selection of the alternative refrigerants was based on the following aspects which are derived from decision XXIII/9 of the Meeting of Parties (MOP):

I. Commercially available;
II. Technically proven;
III. Environmentally sound;
IV. Economically viable and cost effective;
V. Safety consideration;
VI. Easy to service and maintain.

EGYPRA took into consideration the refrigerants that were tested by PRAHA and added new alternatives that were still at an early stage of development when PRAHA was launched in 2012 even though they were still not commercially available at the time the prototype building and testing was done. The refrigerants were selected to replace either HCFC-22 or R-410A as shown in the two tables below, in line with the other testing projects on alternative refrigerants. It is worth noting that EGYPRA is a larger testing program than PRAHA, since it tested 19 specially made split unit prototypes and 16 baseline units, a total 35 units. It also witness-tested all units at the manufacturers' labs. In all 140 tests were made including baseline refrigerants and eight low GWP refrigerants.

Table 1 List of HCFC-22 alternative refrigerants

Refrigerant	ASHRAE classification	GWP (100 years) – RTOC
HC-290	A3	5
R-444B Honeywell L-20A	A2L	310
R-454C Chemours Opteon XL-20	A2L	295
R-457A Arkema ARM-20a	A2L	251

Table 2 List of R-410A alternative refrigerants

Refrigerant	ASHRAE classification	GWP (100 years) – RTOC
HFC-32	A2L	704
R-447A Honeywell L-41-2	A2L	600
R-454B Chemours Opteon XL-41	A2L	510
R-459A Arkema ARM-71a	A2L	466

While not all the selected refrigerants are not commercially available or cost effective at present, they have all received "R" numbers as per ASHRAE standard 34.

1.4. Selection of Capacity Categories

The selection of prototypes to build took into consideration that the majority of the units produced in Egypt are of the mini-split type with capacities of 12,000 Btuh, 18,000 Btuh, and 24,000 Btuh ((equivalent to 1, 1.5, and 2 refrigeration tons). Some of the units are still manufactured with HCFC-22 and some with HFC refrigerants which prompted building prototypes for alternatives to HCFC-22 as well as R-410A. .

Manufacturers also build what is termed as Central or Packaged units. Several manufacturers produce these units in the 10 Tons (120,000 Btuh or 35 kW) capacity but also in larger capacities of 20 and 25 tons. A 10 Ton Central unit was added to the categories to be tested. Only HCFC-22 alternatives were used for this category. The Central category does not include a prototype with HC-290 because of the relatively high amount of charge needed. The stakeholders preferred to wait for the result of further risk assessment work being done in the region.

One of the technology stakeholders (Danfoss) suggested building at least one prototype with condenser micro-channel heat exchangers (HX). Micro-channel HX technology is proven for conventional refrigerants and uses less refrigerant charge. One of the OEMs took up the challenge to build an extra Central unit with micro-channel HX.

Table 3 below shows the matrix of the prototypes that were agreed upon. Green highlighted areas are for units built, while red denotes the unused portion of the central units as mentioned above.

Table 3 Matrix of prototypes showing refrigerants selected for each equipment category

		Split system (mini-split)			Central 120,000 Btuh	
	Replacement for	12,000 Btuh	18,000 Btuh	24,000 Btuh	Std. coil	micro channel
HC-290	HCFC-22					
HFC-32	R-410A					
R-457C (Arkema ARM-20a)	HCFC-22					
R-459A (Arkema ARM -71a)	R-410A					
R-454C (Chemours DR-3)	HCFC-22					
R-454B (Chemours DR-5A)	R-410A					
R-444B (Honeywell L-20)	HCFC-22					
R-447A (Honeywell L-41)	R-410A					
HCFC-22 base						
R-410A						

OEMs were asked to supply from their standard manufacturing line units with baseline refrigerants equivalent in capacity to each prototypes in order to compare units built by the same OEM.

The test results of the central units are not covered in this report.

1.5. Stakeholders:

The project stakeholders:

The Ministry of Environmental Affairs. The following entities at the ministry provided overall supervision and monitoring of the project**:**

- **The Egyptian Environmental Affairs Agency (EEAA):** The Chief Executive Director of EEAA has direct responsibility for the supervision of the activities of the National Ozone Unit.
- **The National Ozone Unit (NOU):** The NOU as an integral part of the Ministry for Environmental Affairs may draw on the legal and technical expertise and resources of the Ministry to undertake its responsibilities. It cooperates with other relevant divisions and field offices of the Ministry and EEAA for carrying out its activities**.**

The Manufacturers (OEMs): Local manufacturers cooperated with Technology Providers to build and test agreed upon prototypes. Eight OEMs participated in the project, listed in alphabetical order:

- **DCM: (Delta Construction Manufacturing):** a manufacturer of central air conditioning equipment;
- **EGAT (Egyptian German Air Treatment Company):** a manufacturer of ducted split and central air conditioners along with airside equipment for commercial and industrial air conditioning;
- **Elaraby Company for Air Conditioning:** a manufacturer of air conditioners and home appliances, Elaraby partners with Sharp on technology for air conditioning equipment;
- **FRESH Electric for Home Appliances:** a manufacturer of air conditioners and home appliances;
- **Miraco Carrier:** a manufacturer of residential and commercial air conditioning equipment. Miraco also partners with Midea;
- **Power Egypt:** a manufacturer of small and central commercial & residential air conditioning equipment;
- **Unionaire:** a manufacturer of air conditioners and home appliances;
- **Volta Egypt:** a manufacturer of central air conditioning equipment.

Note on Confidentiality: To ensure the confidentiality of results, OEMs were given random designations from A to H and the results were reported under this designation.

The Technology Providers: Provide sample raw materials (refrigerants, compressors, and micro-channel coils) in addition to technical support when needed;

- **Chemours (ex-DuPont):** Provided refrigerants R-454C and R-454B;
- **Daikin:** Provided refrigerant HFC-32;
- **Danfoss:** provided micro-channel HX condenser coils for one central unit;
- **Emerson:** provided compressors for some split systems and all central units;
- **GMCC:** Provided compressors for some of the split systems;
- **Hitachi Highly:** provided compressors for some of the split systems;
- **Honeywell:** provided refrigerants R-444B and R-447A.

1.6. Methodology

The local manufacturers volunteered to build a certain number of prototypes each and provided standard units from their production line running on the baseline refrigerants against which the particular prototypes were compared. Baseline units are with either HCFC-22 or R-410A refrigerants.

The assignment of categories and refrigerants to each of the OEMs was based on a questionnaire in which they listed their preferences and their capabilities to take on the work. The questionnaire can be found in Annex 2. Coordination meetings were held with the OEMs in which some of the technology providers were also present. These meetings and the subsequent contacts with the OEMs facilitated the logistics of shipping both the compressors and the refrigerants to the different OEMs

The prototypes were built with the following constraints:

- Using dedicated compressors provided by the project for each type of alternative refrigerant;
- Using the same unit overall dimensions as the base unit, i.e. the heat exchangers could not be oversized in order to compare with the baseline unit. The overall dimensions of the unit were hence kept the same;
- Prototypes needed to meet the MEPS as set out by the Egyptian Organization for Standards EOS 3795:2013 equivalent to ISO 5151 at T_1 conditions as a minimum.
- OEMs provided throttling devices (capillary, flow controls…) according to guidance from refrigerant manufacturers for optimization.

EOS 3795:2013 stipulates for split units less than 65,000 Btuh capacity an EER of 9.5 equivalent to a COP of 2.78 W/W at T_1 conditions.

The OEMs optimized the prototypes by changing the refrigerant charge and the expansion devices. No special coil designs were made for this project except for the micro-channel HX coils used on the central unit. The constraint of keeping the same coils has an effect on the optimization of the prototype; however, since the purpose of the tests is to compare to a baseline unit using HCFC-22 or R-410A refrigerants, this constraint was accepted by the stakeholders.

The Table below shows the number and type of prototype built by each of the OEMs

Table 4 Prototypes and type of refrigerant built by the different OEMs

Category	**12 000 Btuh**		**18 000 Btuh**		**24 000 Btuh**	
OEM	**HCFC-22 Alternatives**	**R-410 A Alternatives**	**HCFC-22 Alternatives**	**R-410 A Alternatives**	**HCFC-22 Alternatives**	**R-410 A Alternatives**
A	R-444B	R-447A	R-290	HFC-32 and R-454B	-	-
B	R-454C	HFC-32	R-457A	-	R-444B	-
C	R-290 and R-457C	-	R-457A	R-459A	-	HFC-32 and R-454B
D	-	-	R-444B	-	R-457C	-
E	R-454C	R-454B	-	-	-	-

1.7. Testing Parameters and Facilities

EGYPRA testing protocol followed the following testing conditions:

Table 5 Testing conditions for outdoor and indoor dry and wet bulb temperatures

	T_1	T_3	T_{High}	$T_{Extreme}$
Outdoor °C db/wb	35/24	46/24	50/24	55/24
Indoor °C db/wb	27/19	29/19	32/23	32/23

The indoor conditions at T_{High} and $T_{Extreme}$ are not the same as those at T_3 conditions, they were chosen in agreement with the OEMs and are in conformity with ISO 5151 which is followed in Egypt. These indoor conditions are also not the same as in the other testing projects shown in Annex 4. Since the objective of EGYPRA is to compare the performance of AC units with medium and low-GWP alternative refrigerants against units with baseline refrigerants, this comparison remains true as long as the conditions of testing are consistent.

EGYPRA testing facilities: The project managers wanted to use one independent testing lab for testing all units in order to provide a continuity and similitude of testing. The government's accredited lab was contacted for that purpose; however, the lab did not have the capability of testing flammable refrigerants. Efforts at upgrading the lab capabilities could not be finished in time for the project timeline and the project adapted the strategy of witness testing at the manufacturers' testing facilities. The Technical Consultant witnessed all the tests and verified the results. A brief description of the OEM testing facilities can be found in Annex 3.

Testing Methodology:

Testing of the units followed the Egyptian standard EOS 4814, non-ducted AC & HP testing and rating performance. The standard is derived from ISO-5151 and is followed by all manufacturers. The standard stipulates that,

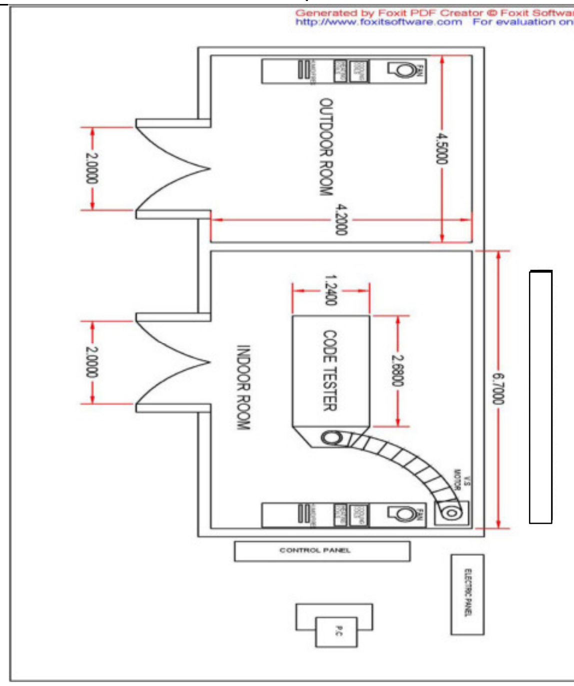
> *"4.1.1.2.5 Machines manufactured for use in more than one of the climatic conditions as T_3, T_2 and T_1 shall be rated and recorded at each of the conditions for which the unit was designed."*

The Egyptian standards do not stipulate testing at temperatures higher than T_3. The T_{High} and $T_{Extreme}$ conditions were derived from ISO 5151 with the agreement of the OEMs.

The tests were witnessed by the Technical Consultant. Re-testing the units was permitted when the results were inconsistent or did not meet the minimum EER stipulated in EOS 3795. The Technical Consultant advised the OEMs on possible remedies and helped them in the determination of the charge and the expansion device setting to achieve better results.

Testing procedure

Table below describes the testing procedure applied by all OEMs

No.	Item	Description
1	Testing lab infrastructure: • Testing chamber description Note: (Typical testing laboratory's testing chambers schematic diagram shown. Dimensions and arrangement of equipment are for indicative purposes only.)	 I. Laboratory is used for measuring capacities less than 1, 1, 1.5, 2 TR. Laboratory of the psychometric type where the air conditioner cooling capacity, heating capacity and unit efficiency (EER, COP) can be measured accurately. II. Other parameters such as unit working pressure, superheat, subcooling and state point's temperature of the refrigeration cycle could also be measured. III. Laboratory consists of two thermally insulated chambers (indoor and outdoor chambers). Both chamber's temperature and humidity can be controlled precisely to achieve the required state point (as per standards) using AC units, humidifiers and electric heater. IV. The accuracy of temperature control for dry and wet bulb temperatures to be 0.01 ^{o}C or better. V. The indoor room to have a thermal insulated code tester to collect all outlet air from the air conditioner, measuring its dry bulb and wet bulb temperatures and air volume
	• Parameters measured & instrumentation used	• All temperature sensors for inlet and leaving air in indoor room as well as outdoor room air temperatures are to be measured. • Surface temperatures to be measured by sensors - accuracy 0.1 ^{o}C or better-for both indoor and outdoor chambers. A minimum of 15 measuring points to be used for each room at various locations on the air conditioner. • All data gathered during an experiment to be read by a computer through a specialized program with multi channels data acquisition to get the required data in a live format fashion. • Factory supplied control panel located outside the chambers space to have all necessary control switches to

		operate the laboratory and set the required conditions with power meters for single phase and 3 phase and all electrical data for tested units. Data to be measured and transferred to computer system.
2	Standards to be used:	All tests for cooling and heating performance to be performed according to the following standards: • EOS 4814 non-ducted AC & HP testing and rating performance • ASHRAE testing standards • ISO 5151 for non-ducted air conditioners • ISO 13253 for ducted type split • EOS 3795-1/2016 • EOS 3795-2/2017
3	Description of the testing procedures: • Description of testing method • Method of selection of capillary tube and choosing refrigerant charge • Achieving steady state for outdoor and indoor conditions (description, time needed…)	 • Psychometric testing method is used as per ISO 5151-2017 annex C, G. Air flow rates are to be measured through nozzles for both entering and leaving dry and wet bulb temperatures. • Optimum selection of capillary size, length, number and refrigerant charge to achieve good matching and improved performance for the unit according to the following: i) Select from preliminary capillary chart size, number and length of the required capillary to match the specified load. ii) Accumulated experience plays an important role in determining the preliminary refrigerant charge. iii) Testing the unit based on pervious selections give an indication for system optimization including increasing or decreasing the charge and/or the size of the capillary. iv) System pressure, superheat, subcooling, power consumption, cooling capacity and refrigerant temperature at various points of the cycle give a strong indication on how the matching is proceeding. • 2 hours' time are needed as a minimum to achieve the steady state condition for testing cooling capacity of the unit as well as EER or COP.
4	Calculating EER and capacity: • How the EER is calculated measurements used and formula • How the capacity was calculated measurements used and formula	 EER= cooling capacity/ total power consumed by the system in Btuh/W or equivalent. As per ISO 5151 see equations in annex C
5	The air psychometric process: • The cycle on psychometric chart • Explanation of state points at T_1, T_3, T_h and T_{ext}	 • Test result to provide all required information to draw the cycle on Psychometric chart: ○ E_{DB},L_{DB},E_{WB},L_{DB} (E=Enthalpy) • Test result to provide all required data to draw and change, when needed, the cycle on the PH diagram: ○ High pressure. ○ Compressor discharge temp. ○ Subcooling amount in condenser. ○ Low pressure. ○ Compressor suction temperature. ○ Superheat amount in evaporator for all required tests T_1, T_3, T_h and T_{ext} .

Chapter 2

2. Results

The results of the various tests were combined under two major headings: results of alternatives to HCFC-22 and results of alternatives to R-410A. The presentation or comparison of results across the two major headings does not lead to tangible conclusions while the separation of the discussion under the two baseline refrigerants leads to a better understanding of the information.

The casual reading of the results may establish confusion, even among specialists, in relation to the increase in capacity at T_{High} compared to T_3. This result is not witnessed in other similar research projects; however, by understanding the impact of changing the dry bulb and wet bulb indoor testing conditions i.e. T_{high} (outdoor 50/24 °C, indoor 32/24 °C) compared to T_3 (outdoor 46/24 °C, indoor 29/19 °C), the results can be justified using the modeling approach explained below. The additional exercise to review and validate all results is the reason for the unplanned delay in concluding the project report.

Modeling Using ORNL Heat Pump Design Model

Since the measurements provided by the labs were somehow limited, it was difficult to explain the hypothesis for the increase in performance under T_{High} conditions. As such, a full-scale modeling using the ORNL Flexible Heat Pump Model was performed on a sample packaged air conditioning system and the indoor and outdoor conditions were changed according to the EGYPRA conditions: T_1, T_3, T_{Hot}, and T_{High}. Table 5 above provides a summary of the indoor and ambient conditions for the four simulations along with the capacity ratio (capacity/capacity at T_1), compressor mass flow rate, compressor power, sensible heat ratio (SHR), and evaporator overall area integral heat transfer for the vapor (UA_vap) and the 2 phase (UA_2-ph) portions respectively.

The T_{Hot} condition was selected to simulate the same ambient conditions as that tested by the OEMs but with the same indoor conditions as T_1 and T_3. The results for this simulation follows the simple intuition that as the ambient temperature increases, the performance degrades at a rough order of magnitude of 1% point per 1°C of outdoor temperature increase. However, when examining the performance of the T_{High} condition; we notice a sudden increase in capacity – coupled with an increase in refrigerant mass flow rate, and reduction in SHR. The simulation results show that for T_1, T_3 and T_{Hot} conditions, the suction saturation temperature change was less than 1°C, while when the indoor conditions were changed to the T_{High} condition, the suction saturation temperature changed by more than 4°C. This has an impact on the compression ratio, compressor suction density, and compressor performance (volumetric and isentropic efficiencies). Furthermore, the higher humidity associated with the T_{High} condition induces the evaporator coil to become wetter and as such results in higher airside performance and higher SHR.

Table 6: Conditions and relevant results for the rooftop unit simulated using the ORNL Flexible HPDM simulation tool

Condition	**EDB**	**EWB**	**Ambient**	**Capacity/Capacity at T1**	**Compressor mass flow rate**	**Compressor Power**	**SHR**	**Evaporator vapor UA**	**Evaporator 2-ph UA**
	°C	°C	°C	%	g/s	W	%	W/K	W/K
T1	29	19	35	100%	379.8	14,074.9	88%	5.6	265.7
T3	29	19	46	89%	383.7	16,952.9	93%	6.7	265.1
T_{Hot}	29	19	50	86%	384.6	18,077.2	95%	6.7	265.2
T_{High}	32	23	50	94%	433.9	18,693.8	78%	9.4	261.3

Hypothesis summary

When the indoor dry bulb and wet bulb temperatures are increased from the T_3 conditions to the T_{High} conditions; the sensible heat ratio of the AC system is reduced, and a large portion of the evaporator is wetted by the condensate. This results in heat transfer enhancement due to reduced free flow area and increased surface velocity and the concurrence of heat and mass transfer at the tubes and fin surfaces. From further analysis provided by the detailed study from OEM C; the evaporator log mean temperature difference is also increased due to the increased air inlet temperature. Hence on the air side, both the increase in overall heat transfer coefficient along with the increased evaporator LMTD and increased latent capacity contribute directly to the increased heat capacity between T_3 and T_3 with elevated indoor conditions (subsequently also the increased capacity at the T_{High} conditions).

At the refrigerant side, when the indoor conditions are changed from the T_3 to the T_{High} conditions – the compressor pressure ratio is reduced while the compressor inlet density is increased. The refrigerant flow rate also increases which further justifies the increased cooling capacity from the refrigerant side analysis.

2.1 Presentation and Analysis of Results

The analysis of the results is presented in table form. The complete results and comparative bar charts are found in Annex 1.

The Results for capacity in Btuh and energy efficiency in EER (energy efficiency ratio in MBH output/ kW input) are given for the four testing temperatures. The tables show the test results and the percentage increase or decrease in capacity and EER compared to the baseline unit. As a reminder, each OEM was asked to test a baseline unit from their own standard production for each prototype built in order to compare with the results.

The analysis uses shades of color to denote the comparison level to the baseline unit as follows:

No shading	Performance is same as base unit – for capacity and EER
Green	**Increase** in EER or cooling capacity over baseline unit
Yellow	**Decrease** in EER or cooling capacity by **- 0.01 % to - 5 %**
Orange	**Decrease** in EER or cooling capacity from **-5 % to - 10 %**
Red	**Decrease** in EER or cooling capacity over **-10 %**

The results are then plotted on a scattered chart for the ratio of capacity of the prototype to that of the baseline unit vs. the EER ratio at the four testing temperatures. The baseline unit performance is denoted by the two red dotted lines at a ratio of one for both capacity and EER.

The analysis is presented for the alternatives of HCFC-22 and R-410A separately. Some results for inconclusive tests mentioned in the Annex were not used in the analysis.

2.1.1. Analysis of Capacity and EER Performance for HCFC-22 Alternatives

The tables in this section are for alternatives to HCFC-22 for the three categories of mini-split units: 12,000 Btuh, 18,000 Btuh, and 24,000 Btuh.

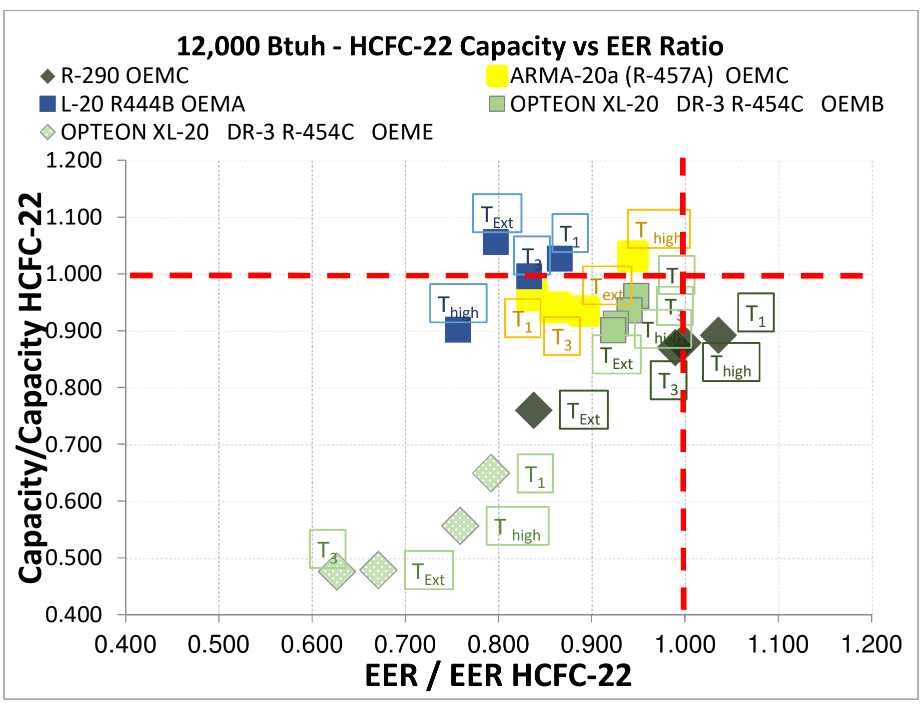
Results for the 12,000 Btuh category

Table 7 Comparison of HCFC-22 alternatives for 12,000 Btuh split units

HFCF-22 12,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
	Capacity in Btuh				EER			
Base Units								
R-22(OEM C)	11,452	9,960	10,560	10,181	10.0	7.25	6.98	6.23
R-22(OEM B)	11,410	9,988	10,900	10,035	8.41	6.38	6.33	5.47
R-22(OEM A)	11,479	9,699	11,353	8,407	9.74	6.88	7.31	5.61
Prototypes								
HC-290 (OEMC)	10,219 (-10.77%)	8,677 (-12.88%)	9,289 (-12.04%)	7,747 (-23.91%)	10.36 (+3.53%)	7.17 (-1.1%)	6.96 (-0.23%)	5.22 (-16.2%)
R-457A (OEM C)	11,023 (-3.75%)	9,376 (-5.86%)	10,892 (+3.14%)	9,517 (-6.52%)	8.36 (-16.44%)	6.24 (-13.93%)	6.58 (-5.63%)	5.56 (-10.83%)
R-454 C (OEM B)	10,968 (-3.87%)	9,349 (-6.40%)	9,946 (-8.75%)	9,042 (-9.90%)	7.97 (-5.23%)	6.00 (-5.96%)	5.86 (-7.42%)	5.05 (-7.68%)
R-444 B (OEM A)	11,790 (+2.71%)	9,661 (-0.39%)	10,241 (-9.79%)	8,881 (+5.64%)	8.43 (-13.45%)	5.73 (-16.72%)	5.53 (-24.35%)	4.47 (-20.32%)

The table shows that for HC-290, the capacity of the prototype at all four temperatures is less than that of HCFC-22 baseline, while the EER is higher at T_1 and within 1% at T_3 and $T_{High.}$ The results for R-457A and R-454C show results for capacity up to 10% less than the baseline with R-457A showing a better capacity at Thigh which is not the case for R-454C. For R-444B, capacity is better than the baseline at both T_1 and $T_{Extreme}$ but 10% worse at T_{High} which cannot be explained. EER for R-444B is more than 10% worse than the baseline. Plotted on a scattered chart as follows

Figure 1 Capacity vs. EER ratio for HCFC-22 alternatives in 12,000 Btuh split units



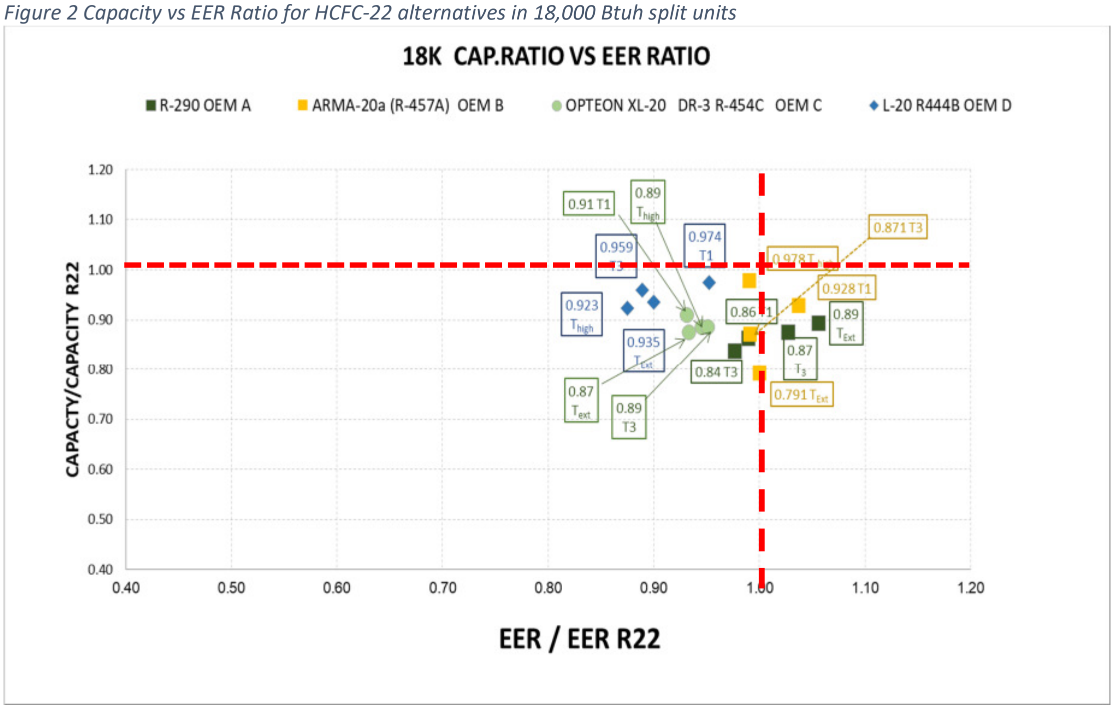
Results for 18,000 Btuh Splits

Table 8 Comparison of HCFC-22 alternatives for 18,000 Btuh split units

18,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline Units								
HCFC-22								
OEM A	18,659	16,799	17,543	15,046	9.41	7.20	6.98	5.55
OEM B	16,433	14,545	13,718	15,350	8.93	6.65	6.37	5.33
OEM C	18,160	16,182	17,632	16,292	10.00	7.37	7.37	6.45
OEM D	17,548	16,422	14,624	13,948	10.50	8.75	7.22	6.00
Prototypes								
R-290 (OEM A)	*16,111 (-13.66%)*	*14,067 (-16.26%)*	*15,343 (-12.54%)*	*13,442 (-10.66%)*	9.31 (-1.06%)	7.090 (-2.34%)	7.170 (+2.72%)	5.860 (+5.59%)
R-444 B (OEM D)	*17,098 (-2.56%)*	*15,746 (-4.12%)*	*13,498 (-7.70%)*	*13,047 (-6.46%)*	10.00 (-4.76%)	7.78 (-11.01%)	6.32 (-12.47%)	5.40 (-10.00%)
R-454 C (OEM C)	*16,510 (-9.09%)*	*14,327 (-11.46%)*	*15,619 (-11.42%)*	*14,250 (-12.53%)*	9.31 (-6.88%)	6.97 (-5.43%)	7.01 (-4.88%)	6.02 (-6.67%)
R-457 A (OEM B)	*15,257 (-7.16%)*	*12,672 (-12.88%)*	*13,418 (-2.19%)*	*12,149 (-20.85%)*	9.26 (+3.70%)	6.59 (-0.90%)	6.31 (-0.94%)	5.33 (0.00%)

The results for HC-290 for capacity are consistent with the results of the 12,000 Btuh category, while the EER shows better results than the baseline at T_{High} and $T_{Extreme}$. The results for R-457C capacity compared to the 12,000 Btuh category show a further degradation compared to the baseline for the 18,000 Btuh category, while the EER results at the four temperatures are better than the 12,00 Btuh category. The same can be said about R-454C, while R-444B has comparable results with the 12,000 Btuh category with a variation with temperature. The results of this category show higher values for both capacity and EER for T High results compared to T3 in line with the discussion at the beginning of this chapter.

Figure 2 Capacity vs EER Ratio for HCFC-22 alternatives in 18,000 Btuh split units



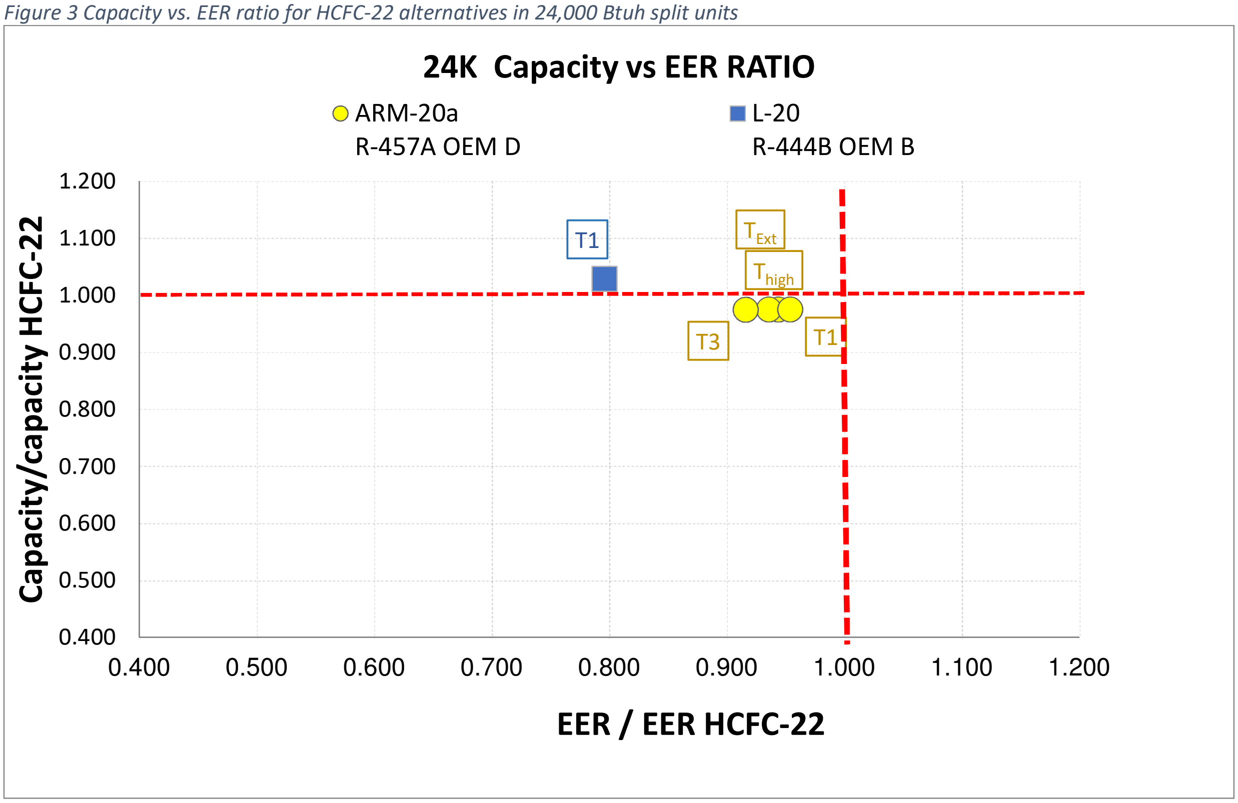
Results for 24,000 splits

Table 9 Comparison of HCFC-22 alternatives for 24,000 Btuh split units

24,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
HCFC-22 OEM B OEM D	 22,782 22,318	 N/A 21,202	 N/A 20,144	 N/A 19,148	 9.27 9.30	 N/A 7.32	 N/A 6.10	 N/A 5.73
Prototypes								
R-444 B (OEM B)	23,436 (+2.87%)	N/A	N/A	N/A	7.38 (-20.39%)	N/A	N/A	N/A
R-457 A (OEM D)	21,758 (-2.51%)	20,670 (-2.51%)	19,636 (-2.52%)	18,657 (-2.56%)	8.78 (-5.59%)	6.85 (-6.42%)	5.82 (-4.59%)	5.25 (-8.38%)

Unfortunately, the data for R-444B at temperatures other than T_1 were not available. Data for R-457A as a percentage of the baseline by the same OEM show a better trend than for the other two categories; however, in absolute terms the EER of the baseline of the 24,000 Btuh category is lower than the other two categories which explains the higher percentage.

Figure 3 Capacity vs. EER ratio for HCFC-22 alternatives in 24,000 Btuh split units



Note that the results for the capacity for R-457A at the four temperatures are similar and hence the yellow circle label points seem almost concentric.

2.1.2. Analysis of Capacity and EER Performance for R-410A Alternatives

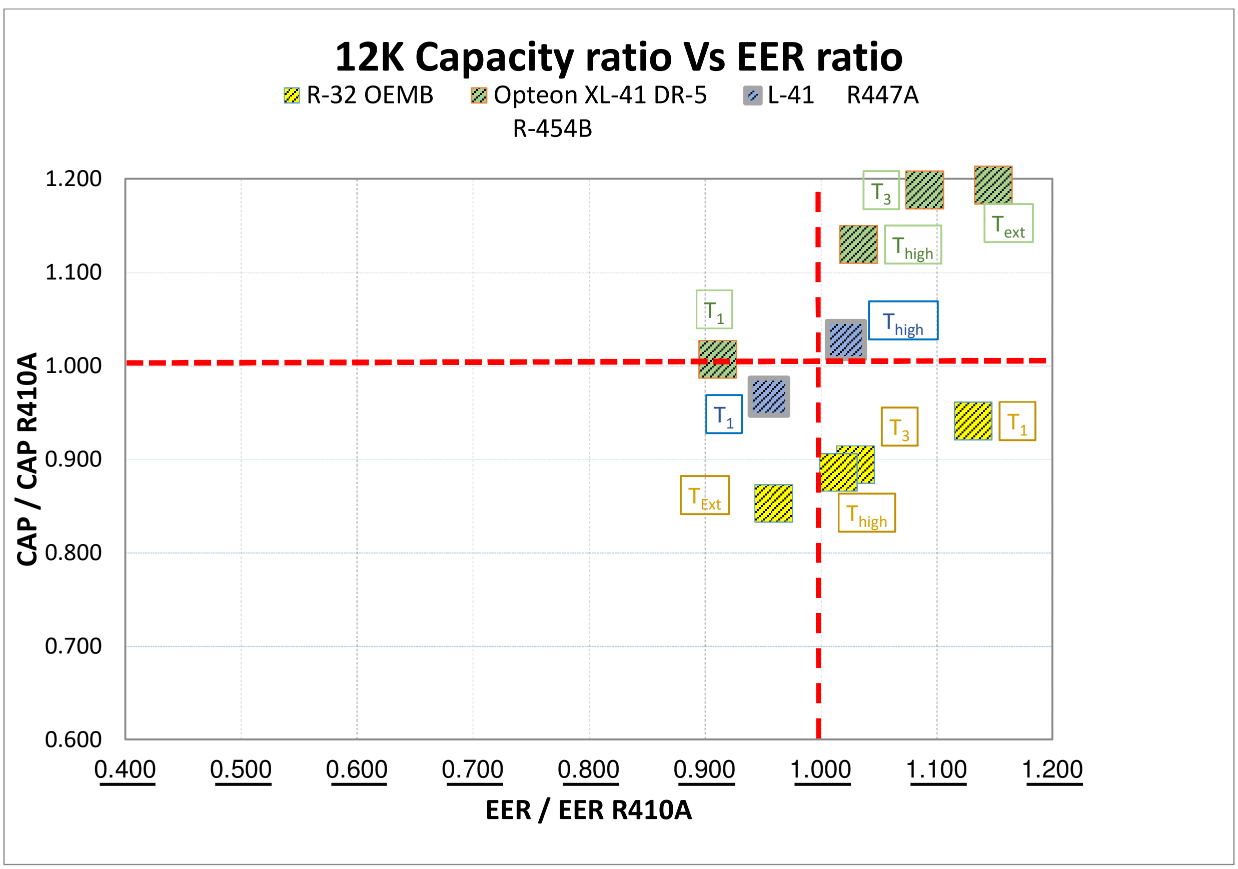
Results for 12,000 Btuh splits

Table 10 Comparison of R-410A alternatives for 12,000 Btuh split units

12,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R-410A								
OEM A	10,307	N\A	8,313	N\A	8.77	N\A	5.43	N\A
OEM B	12,068	10,343	11,089	9,968	10.17	7.31	7.15	5.93
OEM E	11,905	9,369	10,848	9,299	10.88	7.29	7.42	5.89
Prototype								
HFC-32 (OEM B)	11355 (-5.91%)	9,249 (-10.58%)	9,822 (-11.435)	8,499 (-14.74%)	11.51 (+13.18%)	7.53 (+3.01%)	7.26 (+1.54%)	5.69 (-4.05%)
R-454B (OEM E)	11,987 (+0.69%)	11130 (+18.8%)	12,257 (+12.99%)	11,094 (+19.30%)	9.92 (-8.82%)	7.95 (+9.05%)	7.66 (+3.27%)	6.7 (+14.90%)
R-447A (OEM A)	9963 (-3.34%)	N\A N\A	8539 (+2.72%)	N\A N\A	8.38 (-4.45%)	N\A N\A	5.55 (+2.21%)	N\A N\A

The results for R-454B compared to the baseline is better except for the EER at T_1. Results for HFC-32 compared to the baseline show a higher performance for EER but lower for capacity.

Figure 4 Capacity vs EER ratio for R-410a alternatives in 12,000 Btuh split units



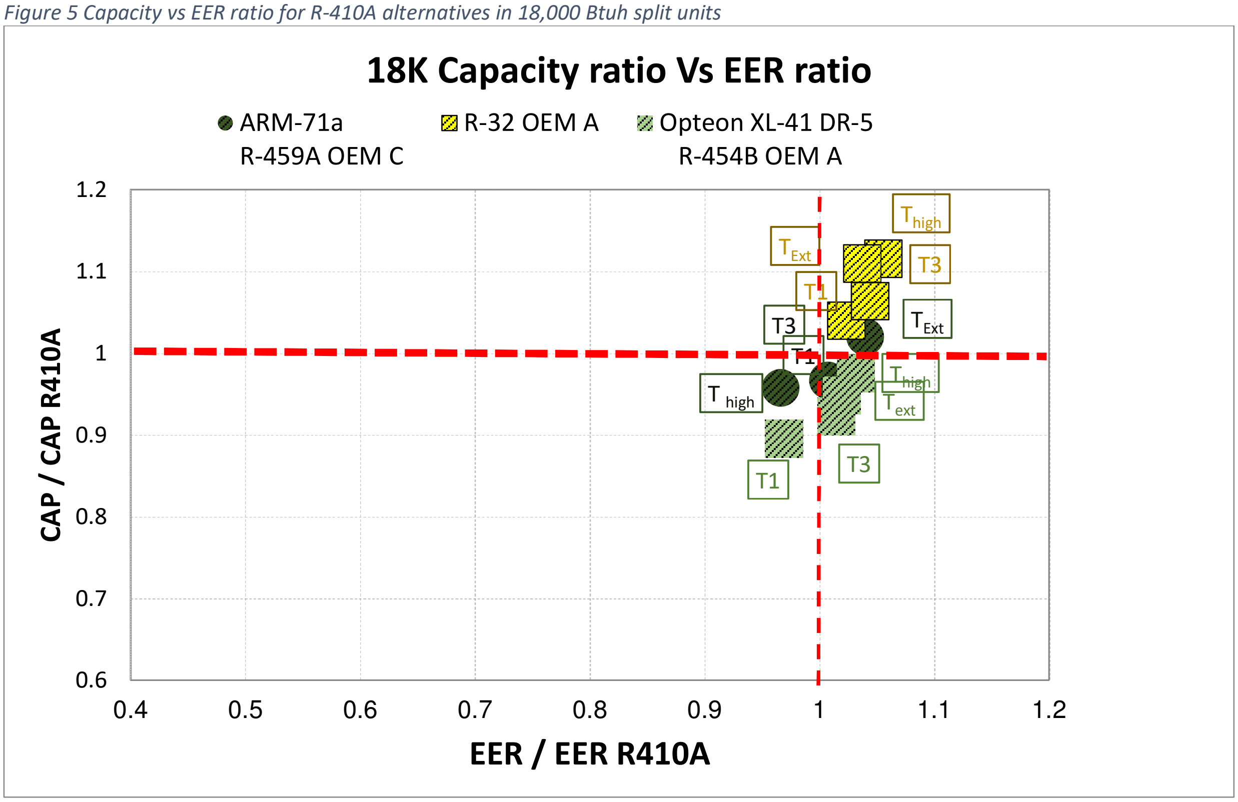
Results for 18,000 Btuh

Table 11 Comparison of R-410A alternatives for 18,000 Btuh split units

18,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R- 410 A OEM A OEM C	 16,938 17,800	 14,337 14,924	 14,123 16,075	 12,441 13,746	 9.8 9.15	 6.8 6.50	 6.3 6.49	 5.1 5.12
Prototype								
R-459A (OEM C)	17,115 (-3.85%)	14,430 (-3.31%)	15,392 (-4.25%)	14,023 (+2.02%)	9.28 (+1.42%)	6.54 (+0.72%)	6.27 (-3.39%)	5.32 (+3.99%)
HFC-32 (OEM A)	17616 (+4.00%)	15,255 (+6.40%)	15,761 (+11.60%)	13,809 (+11.00%)	10.03 (+2.35%)	7.10 (+4.41%)	6.65 (+5.56%)	5.29 (+3.73%)
R-454B (OEM A)	15,167 (-10.46%)	13,229 (-7.73%)	13,782 (-2.41%)	11,800 (-5.15%)	9.5 (-3.06%)	6.90 (+1.47%)	6.50 (+3.17%)	5.20 (+1.96%)

The results for R-454B show a similar trend of higher values against the baseline to the 12,000 Btuh category for EER but lower for capacity. Results for HFC-32 are higher than the baseline for both capacity and EER, which is different from the 12,000 Btuh category.

Figure 5 Capacity vs EER ratio for R-410A alternatives in 18,000 Btuh split units



The plot shows that most of the results are on the positive side when compared to the baseline units for EER with some results for capacity showing lower values.

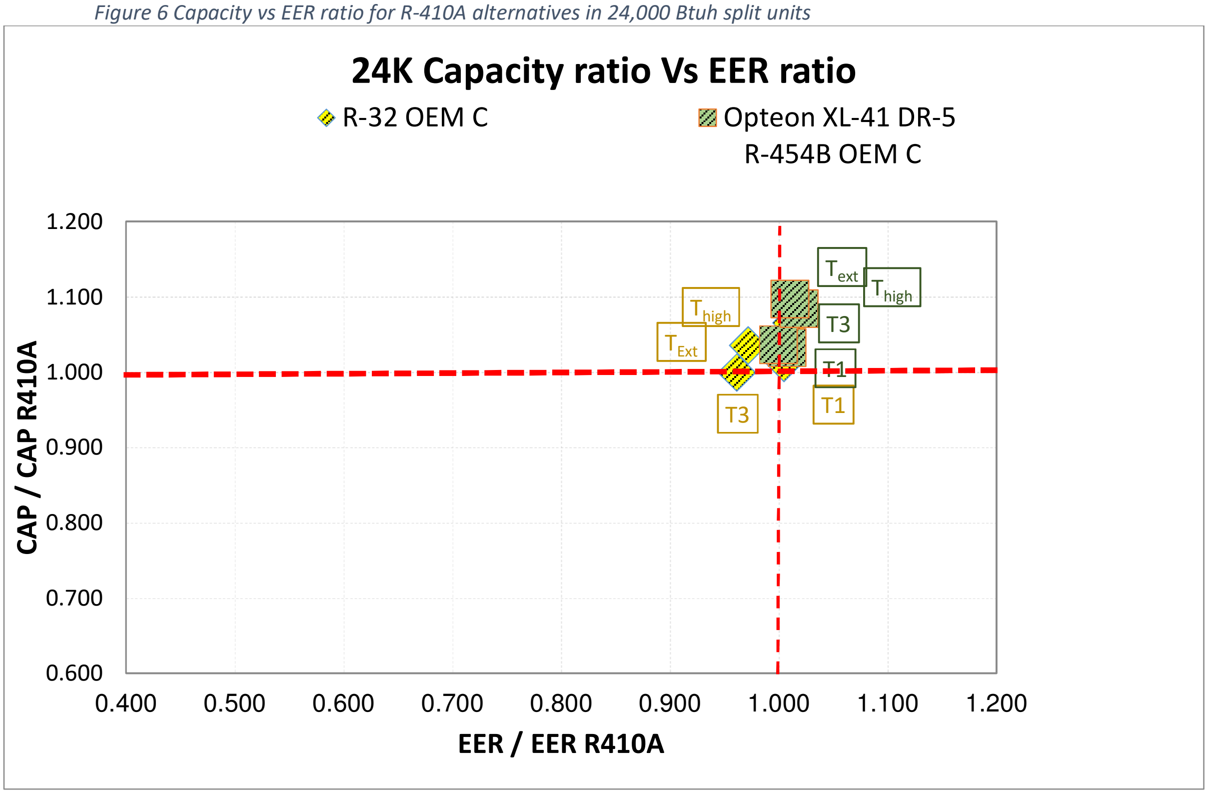
Results for 24,000 Btuh

Table 12 Comparison of R-410A alternatives for 24,000 Btuh split units

24,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R- 410 A OEM C	23022	19531	20534	18379	10.57	7.518	7.376	6.161
Prototype								
HFC-32 (OEM C)	23310 (+1.25%)	19522 (-0.05%)	21876 (+6.54%)	19035 (+3.57%)	10.62 (-0.47%)	7.228 (-3.86%)	7.459 (+1.13%)	5.988 (-2.81%)
R-454B (OEM C)	23766 (+3.23%)	20241 (+3.64%)	22268 (+8.44%)	20160 (+9.69%)	10.653 (+0.79%)	7.516 (-0.03%)	7.515 (+1.88%)	6.224 (+1.02%)

Results are mostly positive for the two refrigerants tested at this category.

Figure 6 Capacity vs EER ratio for R-410A alternatives in 24,000 Btuh split units



Chapter 3

3. Analytical comparison & way forward

The purpose of the comparative analysis in this section is to determine the potential for improvement for the different alternative refrigerants at the different testing temperatures and for the three categories. Since we have three variables: refrigerants, testing temperatures, and category of equipment, the analysis fixed one of the variables and then calculated the percentage of incidence of cases where either the capacity or the EER are compared to the base unit falls in the five color categories defined earlier and repeated here for ease of reference.

No shading	Performance is same as base unit
Green	**Increase** in performance or cooling capacity over base unit
Yellow	**Decrease** in performance or cooling capacity by **- 0.01 % to - 5 %**
Orange	**Decrease** in performance or cooling capacity from **-5 % to - 10 %**
Red	**Decrease** in performance or cooling capacity over **-10 %**

As an example, consider the 12,000 Btuh category for all refrigerants and at all testing temperatures for the capacity comparison. We come up with the following table:

Table 13 Example of calculation of the comparative pie charts

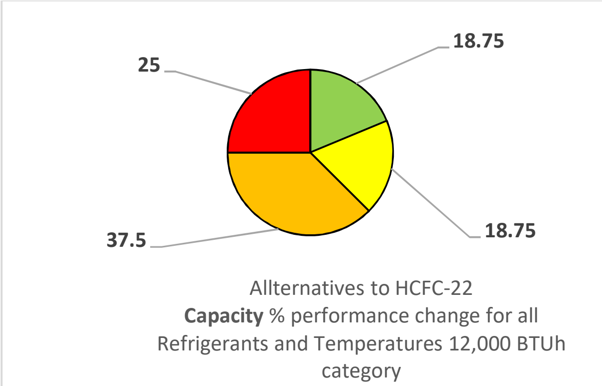
12,000 Btuh category	**Capacity**				
Refrigerant	T_1	T_3	T_{High}	$T_{Extreme}$	
R-290	10219	8677	9289	7747	
(OEM C)	(-10.77%)	(-12.88%)	(-12.04%)	(-23.91%)	
R-457 A	11023	9376	10892	9517	
(OEM C)	(-3.75%)	(-5.86%)	(+3.14%)	(-6.52%)	
R-454 C	10968	9349	9946	9042	
(OEM B)	(-3.87%)	(-6.40%)	(-8.75%)	(-9.90%)	
R-444 B	11790	9661	10241	8881	
(OEM A)	(+2.71%)	(-0.39%)	(-9.79%)	(+5.64%)	
	Calculation of incidence percentage				
	Green	Yellow	Orange	Red	No shading
Incidence: number of entries per color	**3**	**3**	**6**	**4**	**0**
Percentage of the 16 entries	**18.75%**	**18.75%**	**37.5%**	**25%**	**0%**

And the respective pie chart will look as in Figure 7 with the percentage of each incidence marked on the respective color. The pie chart is telling us that when we consider all the HCFC-22 refrigerant alternatives at all testing temperatures for the 12,000 category, there is

- 18.75% certainty that the result is better than the base,
- 18.75% that the result is up to 5% less compared to the base,
- 37.5% that the result between 5 and 10% less, and
- 25% that the results is over 10% less than the base.

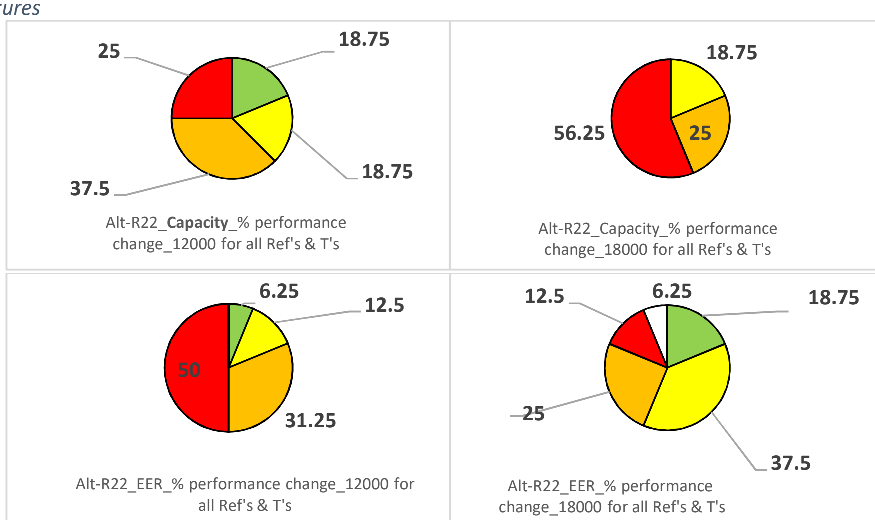
Similar comparative analysis will be made for the different cases for HCFC-22 alternatives and R-410A alternatives. The analysis clarifies the way forward and recommendations can be made for all the cases.

Figure 7 Example of pie chart for HCFC-22 alternatives in the 12,000 Btuh category



3.1. Capacity and EER behaviour of HCFC-22 Alternatives for each category across all refrigerants and testing temperatures

Figure 8 capacity and EER Performance of HCFC-22 alternatives for each category across all refrigerants and all testing temperatures



This analysis shows the following key observations:

For 12,000 Capacity:

- There is, certainly, potential to improve the capacity across 75% of refrigerants and at different testing temperatures
- On the EER side, the potential improvement drops down to 50%

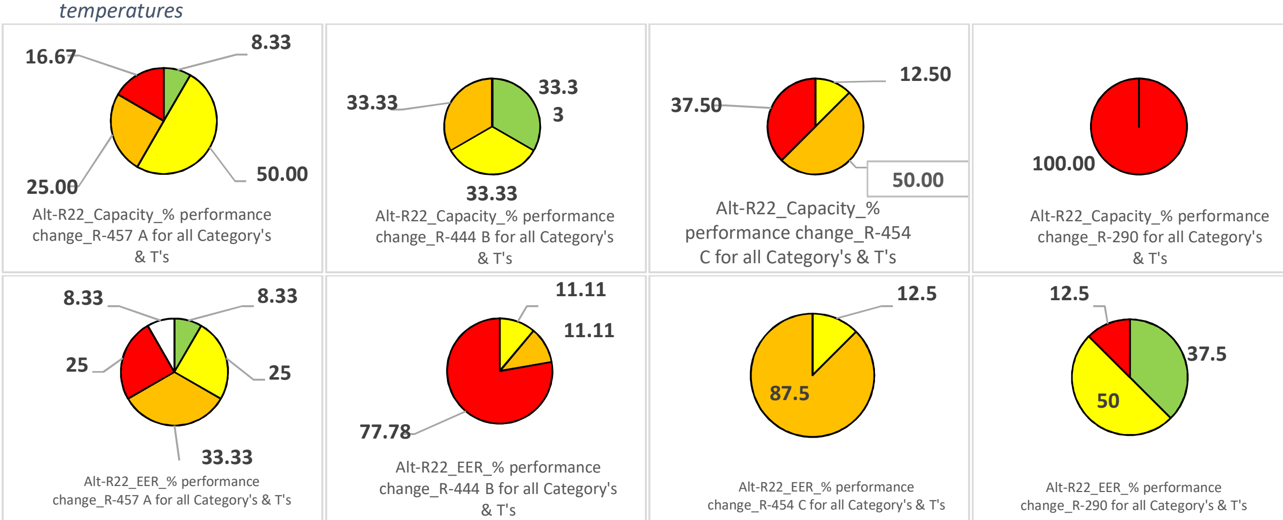
For 18,000 Capacity:

- There is less potentiality to improve capacity across all refrigerants and at different testing temperatures compared to the 12,000 category.
- However, opportunities to improve EER is much higher reaching over 85% across all refrigerants and at different testing temperatures

The 24,000 prototypes results were disregarded, since only one OEM tested one refrigerant across all test temperatures conditions. The other OEM tested another refrigerant at only one testing temperature condition. Therefore, a comparison of the results would be misleading.

3.2. Capacity and EER behaviour of HCFC-22 Alternatives for each refrigerant across all categories and testing temperatures

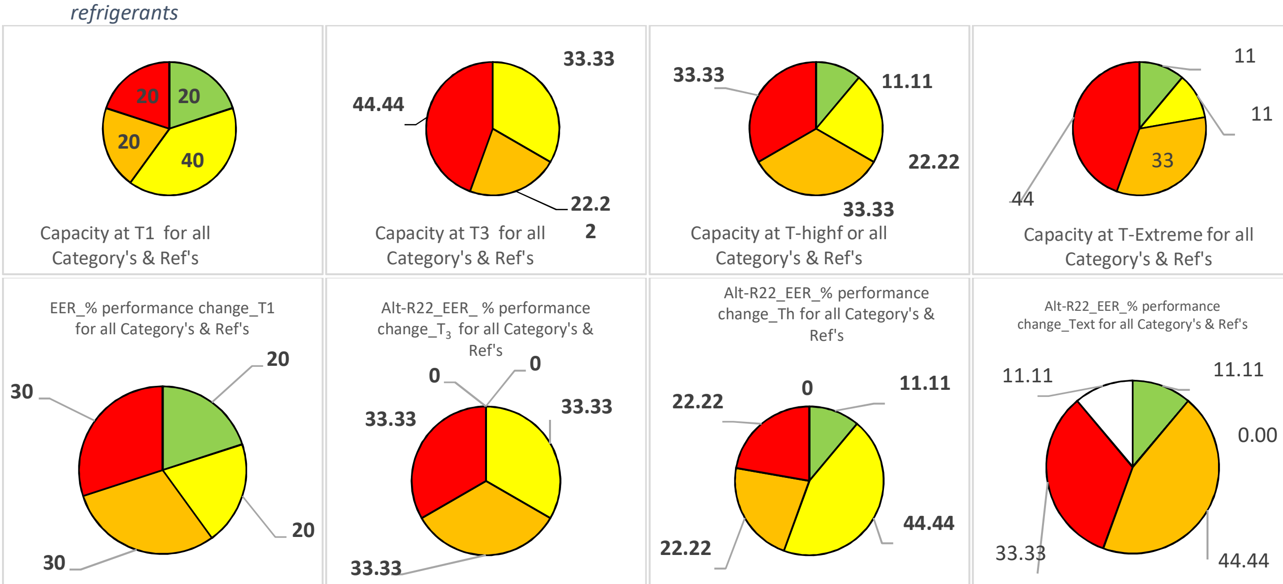
Figure 9 capacity and EER performance for HCFC-22 alternatives for each refrigerant across all categories and all testing temperatures



- Several alternatives to R-22 shows 60%, or above, chance for Capacity matching or improvement across all categories and at different testing temperatures.
- Most alternatives to R-22 shows 50%, or above, chance for EER improvement across all categories and at different testing temperatures.

3.3. Capacity and EER behaviour of HCFC-22 Alternatives for each testing temperature across all categories and refrigerants

Figure 10 Capacity and EER performance of HCFC-22 alternatives for each testing temperature across all categories and all refrigerants

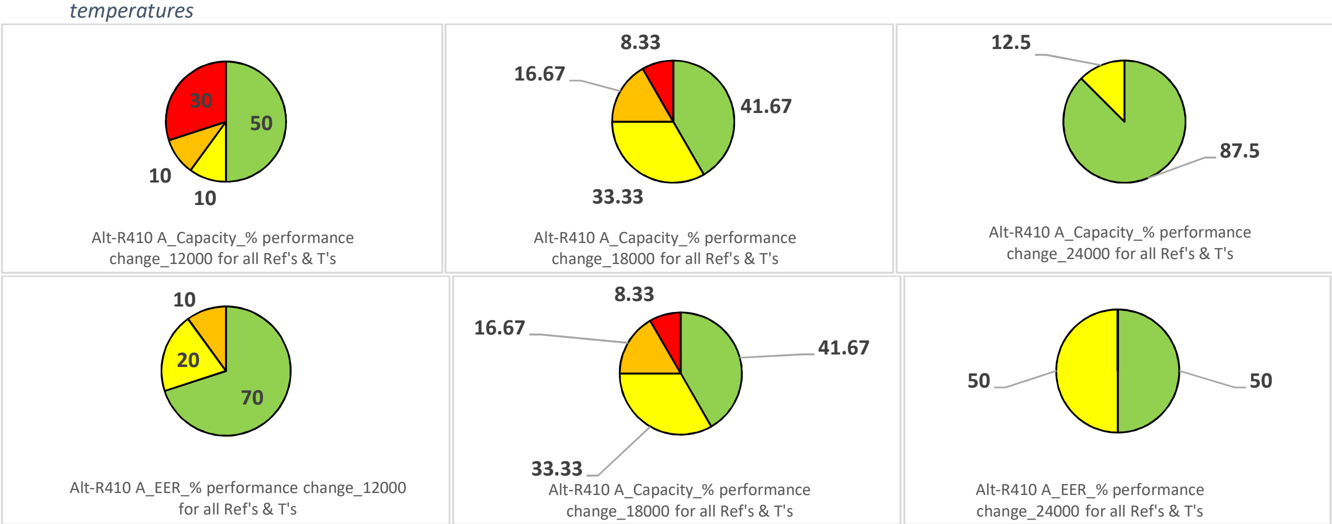


- As expected, moving from T1 to T3 testing temperatures, both capacity and EER deteriorate, at different levels, across all categories and refrigerants
- At T_{High}, the increased indoor wet bulb testing condition, as per EOS & ISO-5151, leads to better results for EER and capacity compared to T3

- Since $T_{Extreme}$ testing condition is similar to T_{High}, with regard to indoor wet bulb testing condition, both EER and capacity re-deteriorate.
- In general, there are candidates with potential improvement, more than 50%, across all categories at all high temperature testing conditions i.e. T_3, T_{high} & $T_{extreme}$.

3.4. Capacity and EER behaviour of R-410A Alternatives for each category across all refrigerants and testing temperatures

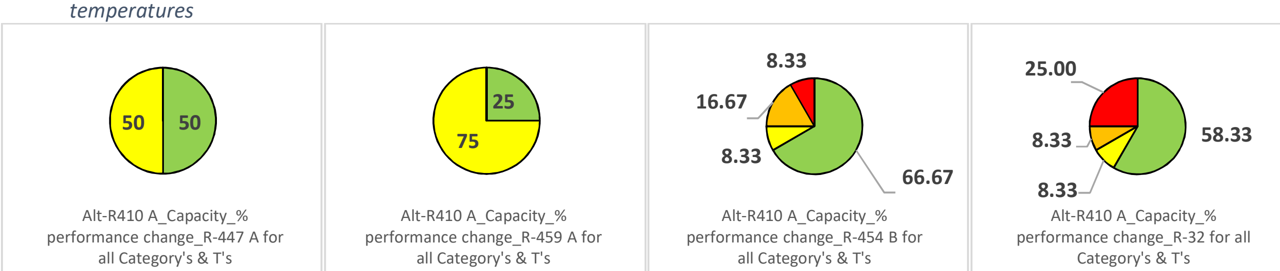
Figure 11 capacity and EER performance of R-410A alternatives for each category across all refrigerants and all testing temperatures

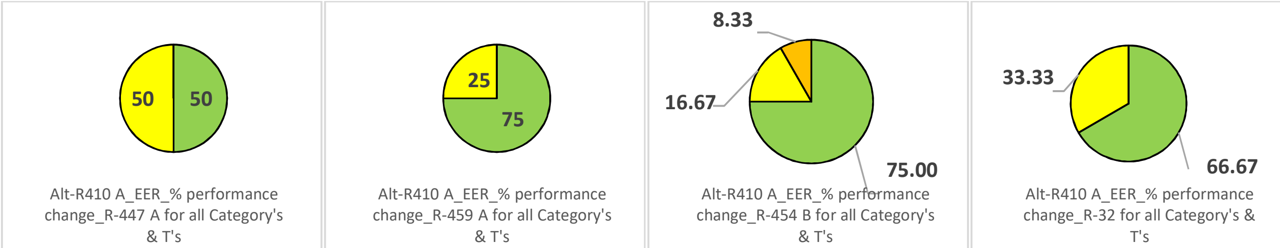


- Increase in capacity as category size increases, across all refrigerants and all testing temperate conditions.
- Capacity increases are from 50 % to 87.5 %.
- However, EER decreased as category size increases.
- EER improvement decreases from 70 % to 50 %.
- 18,000 showed capacity readings for all ranges similar to EER readings.
- 18,000 in the range (-0.1 % to - 5 %) readings for both capacity and EER were the same, 33.33 % instead of 10 % and 20 % in 12,000 size.
- The possibility of improving by optimization capacity and EER compared to R-410A are high

3.5. Capacity and EER behaviour of R-410A Alternatives for each refrigerant across all categories and testing temperatures

Figure 12 Capacity and EER performance of R-410A alternatives for each refrigerant across all categories and all testing temperatures

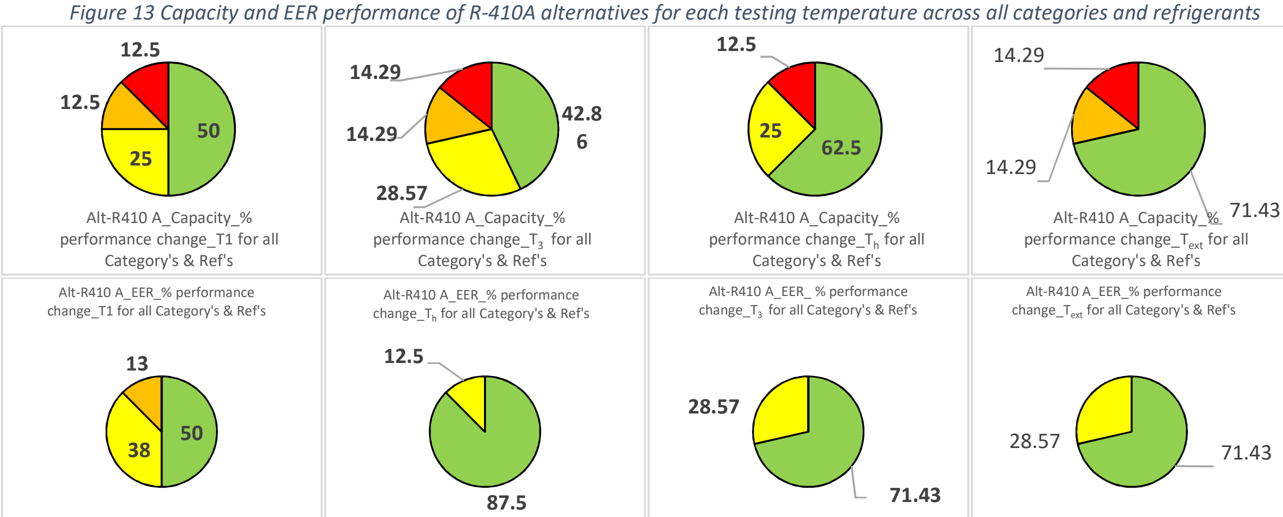




- All refrigerants showed improvement in capacity by 25% to 67 % and 50 % to 75 % in EER.
- One refrigerant was excluded from the comparison because of lack of data.
- All refrigerants have excellent chances of improvement in capacity and EER by optimization.

3.6. Capacity and EER behaviour of R-410A Alternatives for each temperature across all categories and refrigerants

Figure 13 Capacity and EER performance of R-410A alternatives for each testing temperature across all categories and refrigerants



- At $T_{1:}$ 50 % of all test readings show better capacities than R-410 A for all refrigerants and categories and 50% better EER.
- At $T_{3\,:}$ 42.86 % decrease in capacity improvement to 42.86% and then improvement rose to 62.5% and 71.43 % at T_h and T_{ext}.
- At T_3 : 87.5 %improvement in EER. Improvement diminished slightly to 71.43 % for both T_h and T_{ext}.

Excellent prospects for improvement in capacity and EER by optimization compared to R-410 A across all temperature testing conditions for all categories and all refrigerants.

Chapter 4

4. Energy Efficiency and Progressive Changes in MEPS for Egypt

Egypt's MEPS (Minimum Energy Performance Standards) energy efficiency label requirement for mini split air conditioning units and window type, ES: 3795-/2013 and ES: 3795-/2016 Part 1-for constant speed compressors- define EER (BTU/W.hr) at T_1 condition (ISO 5151) across several efficiency classes, A 5+ to E as listed in the tables below according to regulation years, 2014 to 2021.

MEPS progression across the years:

The standards, starting June 2014, lists EER values for energy efficiencies that define a certain class, termed calibration level, starting from E to A^{++}, see table below.

Table 14: Egypt Energy Ratings per 2014 Standard

Calibration	Energy Efficiency ratio of a room air conditioner (Split AC)	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{++}	Higher or equal to 4,1	Higher or equal to 14
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11
D	Higher than or equal to 2, 93 and less than 3, 08	Higher or equal to 10 and less than 10, 5
E	Higher than or equal to 2, 78 and less than 2, 93	Higher or equal to 9, 5 and less than 10

Those EER classes' changes to become progressively stricter, as of June 2017, see table shown below, new class created **A^{+++}** and class **E** removed:

Table 15: Egypt Energy Ratings per 2017 Standard

Calibration	Energy Efficiency ratio of a room air conditioner (Split AC)	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{+++}	Higher or equal to 4,4	Higher or equal to 15
A^{++}	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11
D	Higher than or equal to 2, 93 and less than 3, 08	Higher or equal to 10 and less than 10, 5

And in June 2019 as shown below, new class created **A⁺⁺⁺⁺** and class D removed:

Table 16: Egypt Energy Ratings per 2019 Standards

Calibration	**Energy Efficiency ratio of a room air conditioner (Split AC)**	
	Watt/ Watt	**B.T.U/ Watt/h**
A⁺⁺⁺⁺	Higher or equal to 4,69	Higher or equal to 16
A⁺⁺⁺	Higher or equal to 4,4 and less than 4,69	Higher or equal to 15 and less than 16
A⁺⁺	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11

Finally in June 2021 it becomes as shown below, new class created **A⁺⁺⁺⁺⁺** and class **C** removed:

Table 17: Egypt Energy ratings per 2021 Standard

Calibration	**Energy Efficiency ratio of a room air conditioner (Split AC)**	
	Watt/ Watt	**B.T.U/ Watt/h**
A⁺⁺⁺⁺⁺	Higher or equal to 4,98	Higher or equal to 17
A⁺⁺⁺⁺	Higher or equal to 4,69 and less than 4, 98	Higher or equal to 16 and less than 17
A⁺⁺⁺	Higher or equal to 4,4 and less than 4,69	Higher or equal to 15 and less than 16
A⁺⁺	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12

When the EER values are tabulated according to efficiency class (calibration) versus the year(s) when standards come into operation, the below table is obtained, where the most efficient class for each year(s) is in red followed by green, violet, sky blue, orange, light blue and navy blue as the class of efficiency becomes less and less . For all years there are 7 classes of efficiency.

The highest EER in 2014-2016 was 14 for class A^{2+} while in 2021 the highest EER will be 17 and a new classis created; A^{5+}. This continuous progression to more efficient systems is reflected in the graph below, where EERs are plotted across all years from 2014 to 2021. The top line denotes the highest EER for each regulation year, while the other lines are in descending order. The colors of the rows in the table correspond to the colors of the lines in the graph, 7 classes of efficiency for each year(s).

Table 18: EER Values at T1 according to the Egyptian Standard ES: 3795/2016

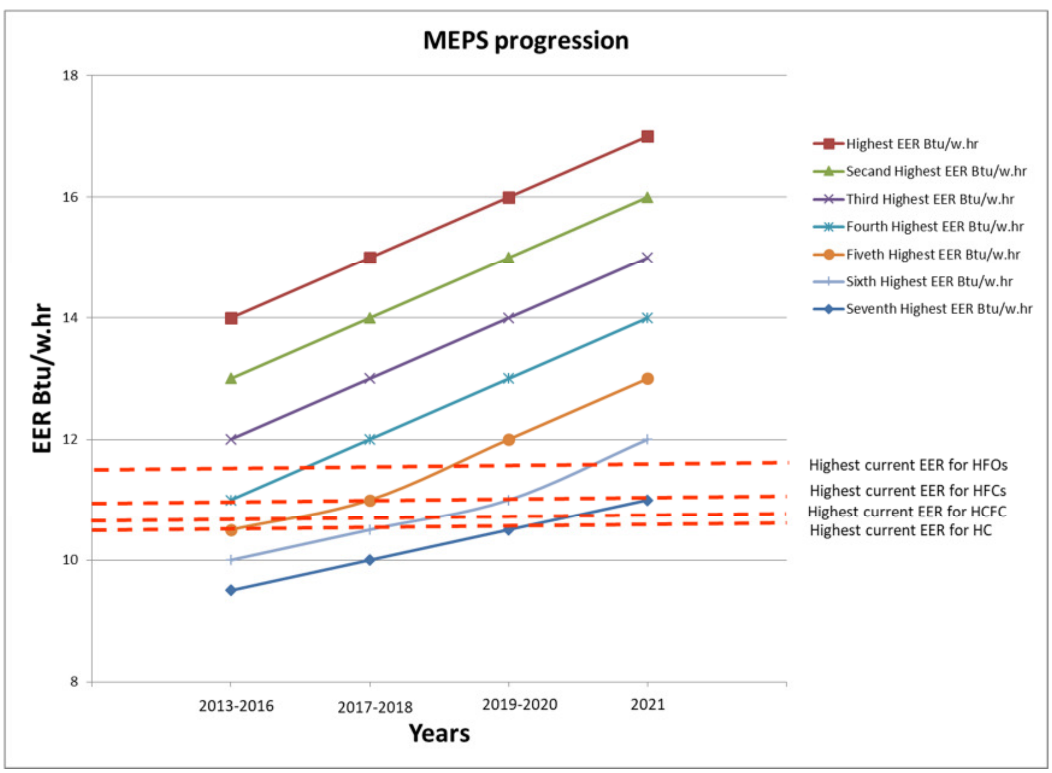
Eff. class /yr.	2014-2016	2017-2018	2019-2020	2021
A^{5+}				17
A^{4+}			16	16
A^{3+}		15	15	15
A^{2+}	14	14	14	14
A^{+}	13	13	13	13
A	12	12	12	12
B	11	11	11	11
C	10.5	10.5	10.5	
D	10	10		
E	9.5			

The table shows how the energy efficiency classes are increasing progressively with the years.

EER versus years:

The graph below shows the highest to lowest EER plotted against the years it came/coming into effect. The graph shows the progression to higher EER with the years. The values are taken from the table above. Seven classes are represented for each year.

Figure 14: EER curves for the highest in each class plotted vs. the standard regulation year



When the results of the Egyptian program for testing alternative low-GWP refrigerants for the Egyptian air conditioning industry, EGYPRA, are plotted on the graph as straight lines showing the best EER achieved for HCFCs, HFCs, HC and HFO, the following is shown:

- The highest EER of prototypes using HC-290 refrigerant is 10.35
- The highest EER of tested units using HCFC refrigerant is 10.5
- The highest EER of tested units using HFC refrigerant is 10.88
- The highest EER of prototypes using HFO refrigerant is 11.5

EGYPRA prototypes, especially made for the program, were optimized by choosing an optimum refrigerant charge and suitable selection of capillary tube (expansion device). No changes were made to either evaporator or condenser.

The best EER of alterative refrigerants cannot achieve at current optimization more than class B (light blue) for MEPS 2019-2020 and class B (navy blue) for 2021.

However, there is potential for improvement. The potential for improvement is based on the fact that the prototypes were built with many constraints (size and type of heat exchangers, size if the units, etc…). In future further optimization through the selection of compressors better suited to alternative refrigerants and the selection of heat exchangers that can improve the efficiency of the units will increase EER of the systems.

Can EER improvement be made from the current 11.5 to 16 in 2019 and 17 in 2 years? This remains to be seen, although it is unlikely. How far can EERs improve is related to the optimization process itself which requires research and development capabilities and capital cost and time. This might be beyond the capability of the majority of the manufacturers.

Further results of this correlation is as follows:

- Shifting to variable speed split units is inevitable if the higher efficiency EER standards are to be achieved by 2019 and beyond, with the resultant additional incremental costs associated with this shift, in manufacturing equipment and end product cost (USD 50 to 100).
- The introduction of Not-In-Kind cooling technology must be accelerated, if energy efficiency rates are to be improved for the air conditioning sector.

Chapter 5

5. Conclusion

EGYPRA is funded from Egypt's HCFC Phase-out Management Plan (HPMP) as an enabling activity for the benefit of the Egyptian air conditioning industry to help local manufacturers experiment working with new alternative lower-GWP refrigerants.

EGYPRA tested refrigerants with medium pressure characteristics similar to HCFC-22 and others with high pressure similar to R-410A in split system units. Testing of central units with higher capacity was not finalized in time for this report due to lack of testing facilities for flammable refrigerants at those capacities. Results will be reported in the future once testing and evaluation is done.

This conclusion is in two parts: technical and institutional regarding capacity building requirements.

5.1. Technical Conclusion

EGYPRA results lead to the following conclusions:

- As expected, and for all refrigerants, moving from T_1 to T_3 testing temperatures, both capacity and EER deteriorate, at different levels, across all categories and refrigerants;
- At T_{High}, the increased indoor wet bulb testing condition, as per EOS & ISO-5151, leads to better results for EER and capacity compared to T_3;
- Since $T_{Extreme}$ testing condition is similar to T_{High}, with regard to indoor wet bulb testing condition, both EER and capacity re-deteriorate;
- In general, there are candidates with potential for improvement; however, since high pressure refrigerants show better results vs. R-410A, the potential for improvement is higher.

Almost all of the OEMs who have participated in EGYPRA have already introduced R-410A units into the market. One uncorroborated study shows that more than 10% of the units sold in 2017 were with R-410A. This might make it easier for OEMs to leap-frog solutions for HCFC-22 and pass directly to high pressure alternatives to R-410A as the possibility for performance and EER improvement is higher for those alternatives.

Results also show that the potential for improvement applies also at higher ambient temperatures, an important factor for some of the regions in the south of Egypt that experience higher ambient temperatures than 35 °C. This is also important for the export market as some manufacturers export to neighboring HAT countries in the region.

5.2. Capacity Building Requirements

The conclusion from chapter 4 is clear: at the current optimization level, none of the prototypes tested will be able to meet more than class B of the 2021 MEPS values; however, the fact is that prototypes were built with many constraints

- The prototypes could be further optimized through the selection of compressors better suited to the tested refrigerants and the selection of heat exchangers that can improve the efficiency of the units;
- Variable speed technology would improve the Seasonal EER of the units where applicable;
- The optimization process requires research and development capabilities that might go beyond those available at some of the manufacturers;

- A further conclusion concerns the testing facilities of the EGYPRA OEMs. Witness testing has enabled the Technical Consultant to carefully assess the capabilities of each lab, especially for testing flammable refrigerants. For confidentiality purposes, the general description of the lab facilities given in Annex 2 does not aim to critique the individual labs or divulge where the individual labs need to be upgraded; however, the fact remains that some of the labs could benefit from an upgrade program;
- The lack of an accredited independent lab to test larger than 65,000 Btuh units using flammable refrigerants was the reason for the delay in testing central units which are part of the EGYPRA project. These units were built by the respective manufacturers; however, the arrangement for testing them independently and with good certainty could not be made on time for this report.
- Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view. The viability in terms of the other criteria like commercial availability, cost, and safety – among others - needs to be further researched.

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Annex 1: Test Results

The annex includes tables and charts from the test results. All OEMs results were compiled by category, for HCFC-22 equivalent refrigerants and for R-410A equivalent refrigerants.

The tables show the results for capacity in Btuh and EER at the four testing temperatures. The tables are per category of 12,000 Btuh split units, 18,000 split units and 24,000 Btuh split units. They include all alternatives refrigerant tested by each OEM.

The equivalent bar charts reflect the results in the tables: one bar chart for capacity and one bar chart for EER.

The sequence in which they are presented is:

- Table and bar chart equivalents for HCFC-22 alternatives in the 12,000 Btuh category;
- Table and bar chart equivalents for HCFC-22 alternatives in the 18,000 Btuh category;
- Table and bar chart equivalents for HCFC-22 alternatives in the 24,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 12,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 18,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 24,000 Btuh category.

Table 19 A1: Capacity and EER Results for HCFC-22 alternatives in 12,000 Btuh category

HCFC-22 eq. 12,000 Btuh		OEM A				OEM B				OEM C				OEM E			
Ambient		T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}
R-22	CAP	11479	9699	11353	8407	11410	9988	10900	10035	11452	9960	10560	10181	10753	10415	10352	9381
	EER	9.74	6.88	7.31	5.61	8.410	6.380	6.330	5.470	10.002	7.249	6.975	6.231	10.290	8.300	7.380	6.230
R-290	CAP									10219	8677	9289	7747				
	EER									10.355	7.171	6.959	5.217				
ARM-20a R-457A	CAP									11023	9376	10892	9517				
	EER									8.358	6.239	6.582	5.556				
Opteon XL-20 R-454C	CAP					10968	9349	9946	9042					6980.6	4958.27	5762.15	4489.25
	EER					7.970	6.000	5.860	5.050					8.150	5.200	5.600	4.180
L-20 R-444B	CAP	11790	9661	10241	8881												
	EER	8.43	5.73	5.53	4.47												

Figure 15 A1 - Equivalent capacity charts for HCFC-22 alternatives in 12,000 Btuh category plotted vs HCFC-22 results

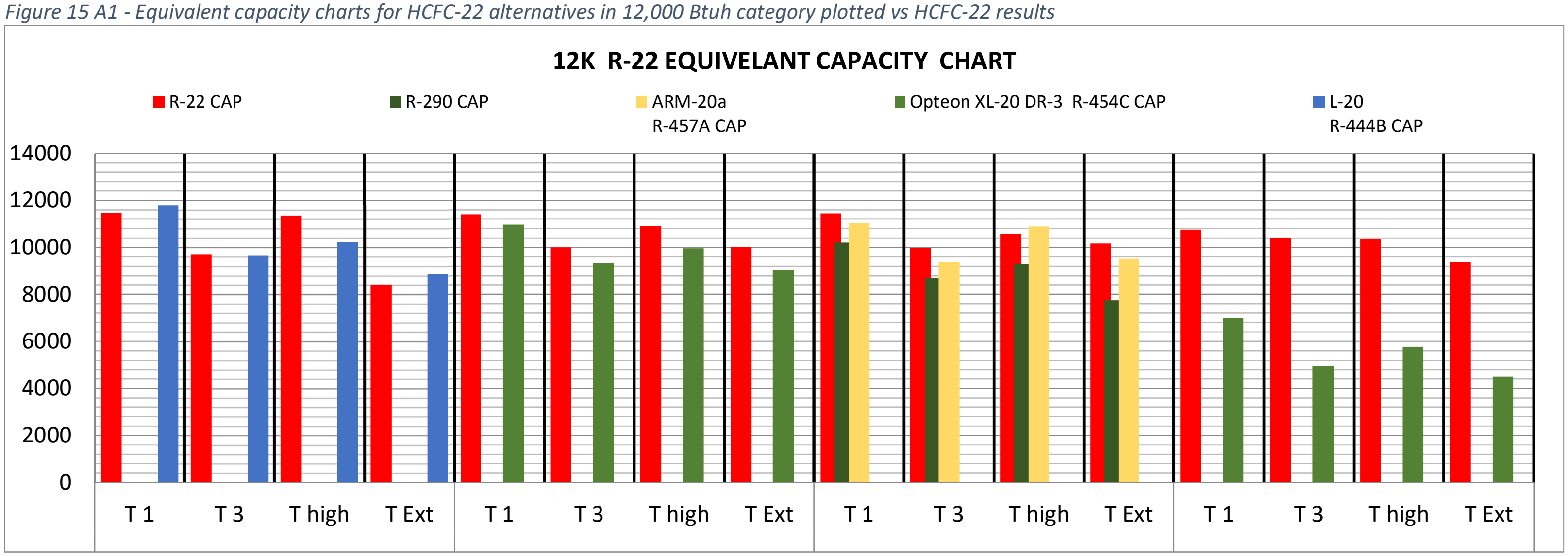


Figure 16 A1 - Equivalent EER chart for HCFC-22 alternatives in 12,000 Btuh category plotted vs HCFC-22 results

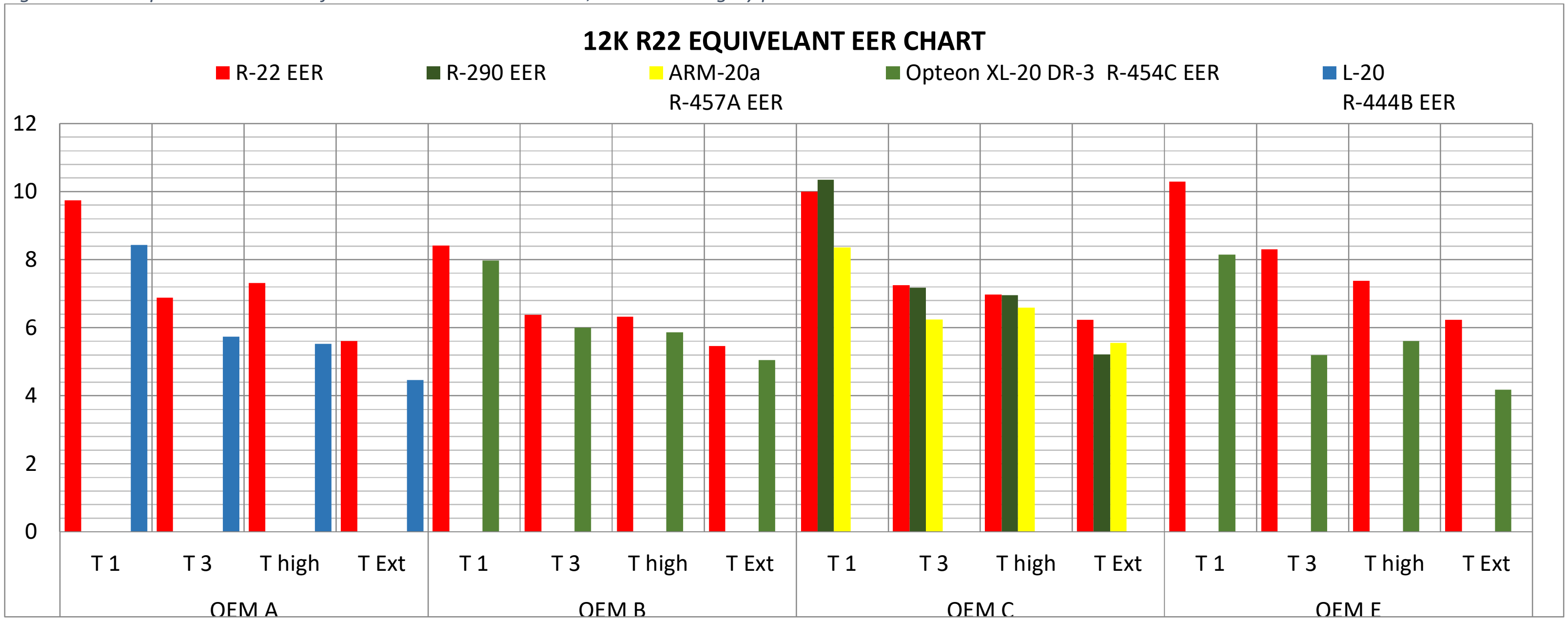


Table 20 A1- Capacity and EER results for HCFC-22 alternatives in 18,000 Btuh category

HCF-22 eq. 18,000 Btuh		OEM A				OEM B				OEM C				OEM D			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-22	CAP	18659	16799	17543	15046	16433	14545	13718	15350	18160	16182	17632	16292	17548	16422	14624	13948
	EER	9.410	7.260	6.980	5.550	8.930	6.650	6.370	5.330	10	7.372	7.371	6.445	10.500	8.750	7.220	6.00
R-290	CAP	16111	14067	15343	13442												
	EER	9.310	7.090	7.170	5.860												
R-457A	CAP					15257	12672	13418	12149								
	EER					9.260	6.590	6.310	5.330								
R-454C	CAP									16510	14327	15619	14250				
	EER									9.312	6.972	7.011	6.015				
R-444B	CAP													17098	15746	13498	13047
	EER													10.000	7.780	6.320	5.400

Figure 17 A1 - Equivalent capacity charts for HCFC-22 alternatives in 18,000 Btuh category plotted vs HCFC-22 results

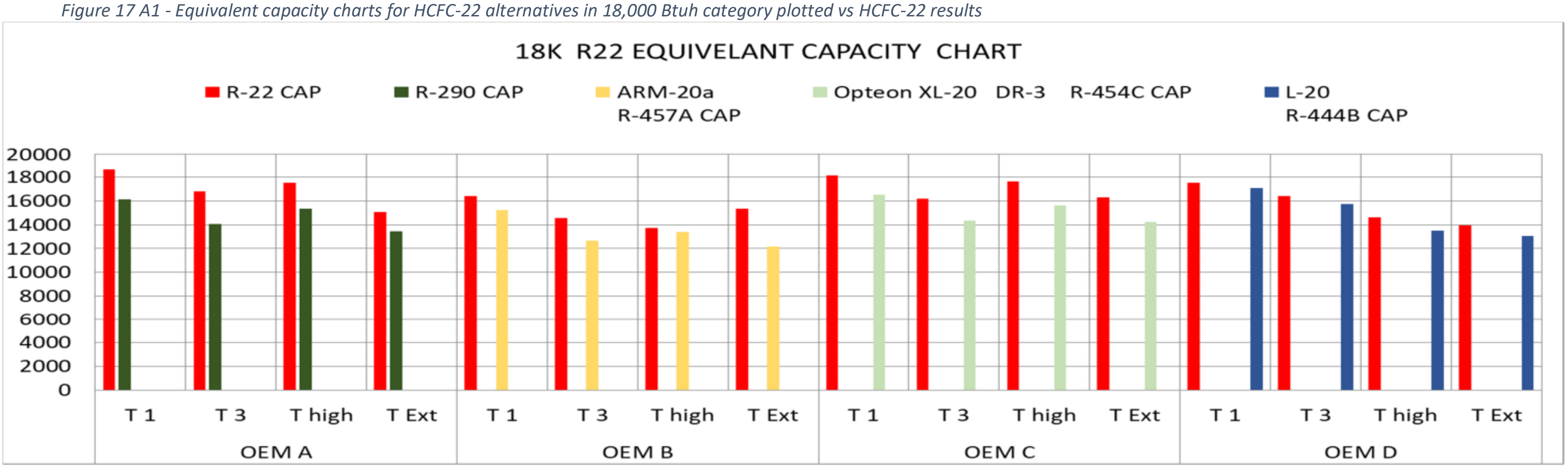


Figure 187 A1 - Equivalent EER charts for HCFC-22 alternatives in 18,000 Btuh category plotted vs HCFC-22 results

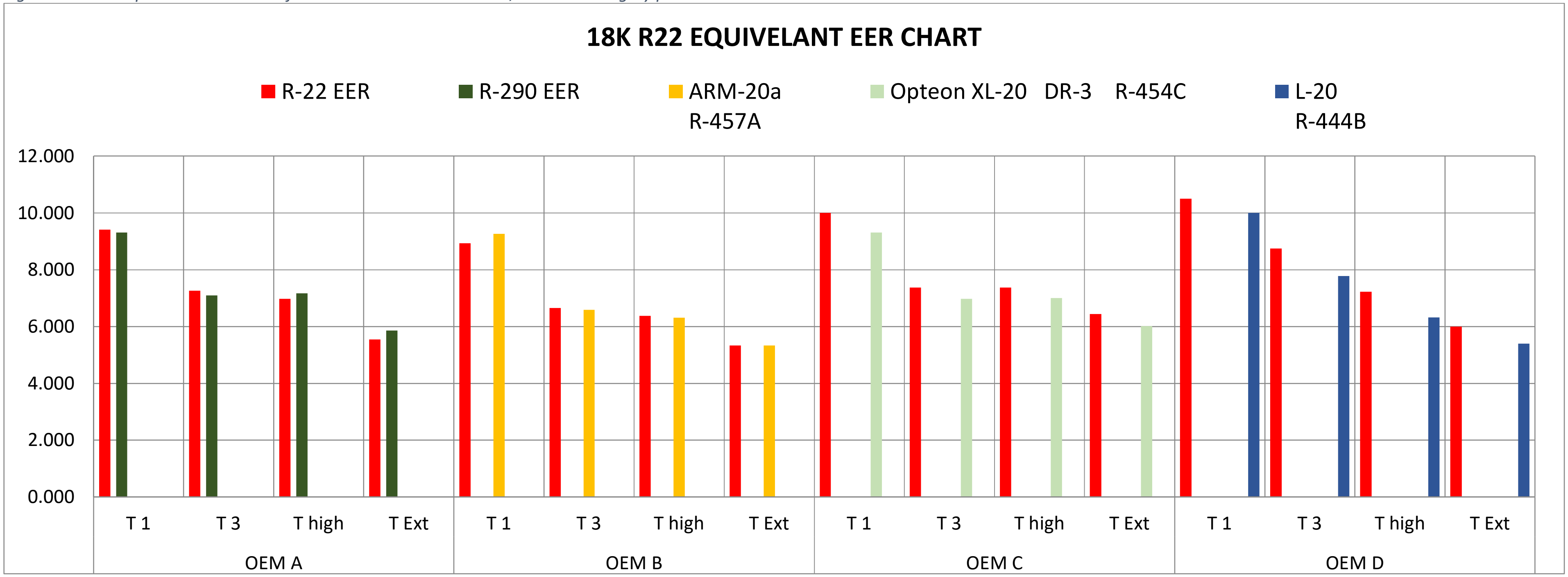


Table 21 A1 - Capacity and EER results for HCFC-22 alternatives in 24,000 Btuh category

HCFC-22 eq. 24,000 Btuh		OEM B				OEM D			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-22	CAP	22782				22318	21202	20144	19148
	EER	9.270				9.300	7.320	6.100	5.73
R-290	CAP								
	EER								
ARM-20a R-457A	CAP					21758	20670	19636	18657
	EER					8.78	6.85	5.82	5.25
Opteon XL-20 DR-3 R-454C	CAP								
	EER								
L-20 R-444B	CAP	23436							
	EER	7.38							

Figure 19 A1 - Equivalent capacity charts for HCFC-22 alternatives in 24,000 Btuh category plotted vs HCFC-22 results

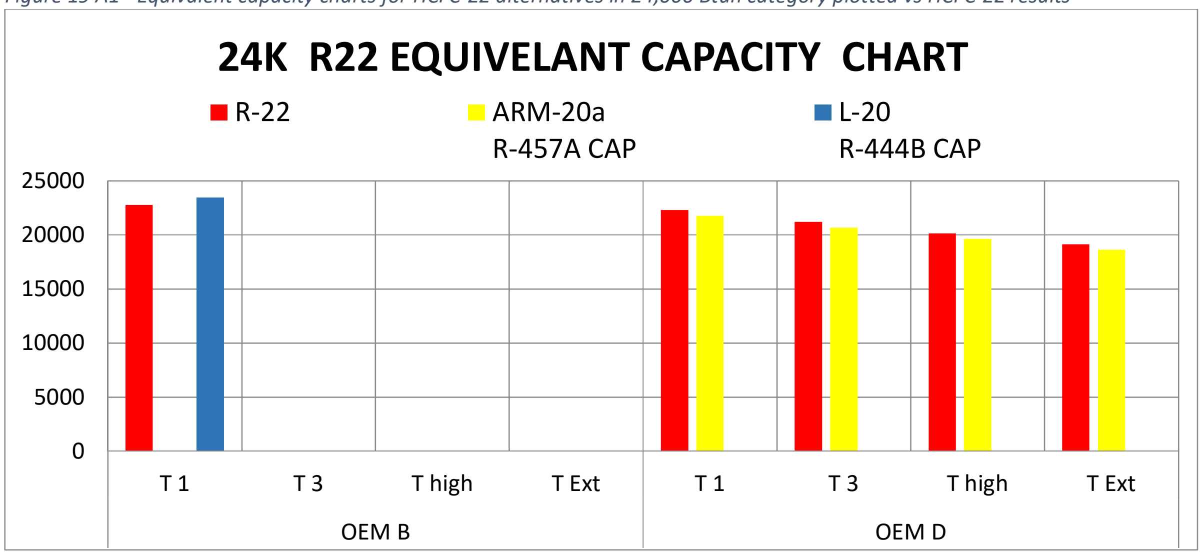


Figure 20 A1 - Equivalent EER chart for HCFC-22 alternatives in 24,000 Btuh category plotted vs HCFC-22 results

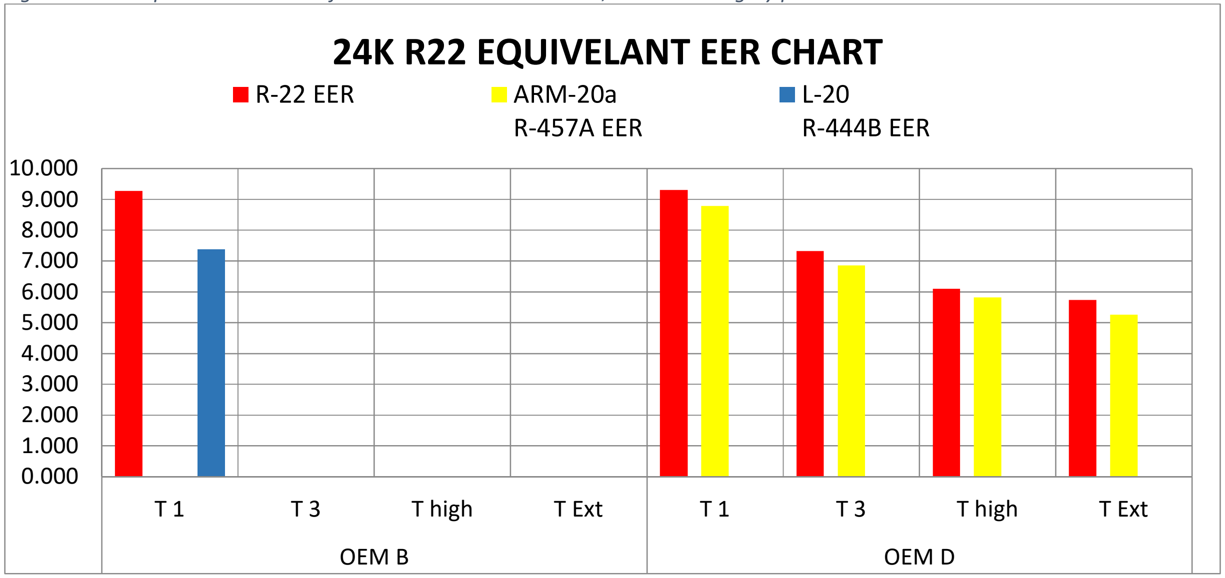


Table 22 A1 - Capacity & EER results for R-410A alternatives in 12,000 Btuh category

R-410 A eq.		OEM A				OEM B				OEM E			
12,000 Btuh Ambient		T 1	T 3	T high	T Ext	T 1	T 3	T high	T Ext	T 1	T 3	T high	T Ext
R-410A	CAP	10307	-	8313	-	12068	10343	11089	9968	11905	9369	10848	9299
	EER	8.77	-	5.43	-	10.17	7.31	7.15	5.93	10.88	7.29	7.42	5.89
ARM-71a R-459A	CAP												
	EER												
R-32	CAP					11355	9249	9822	8499				
	EER					11.51	7.53	7.26	5.69				
Opteon XL-41 DR-5 R-454B	CAP									11987	11130	12257	11094
	EER									9.92	7.95	7.66252	6.7676
L-41 R447A	CAP	9963	-	8539	-								
	EER	8.38	-	5.55	-								

Figure 21 A1 - Equivalent capacity chart for R410A alternatives in 12,000 Btuh category plotted vs R-410A results

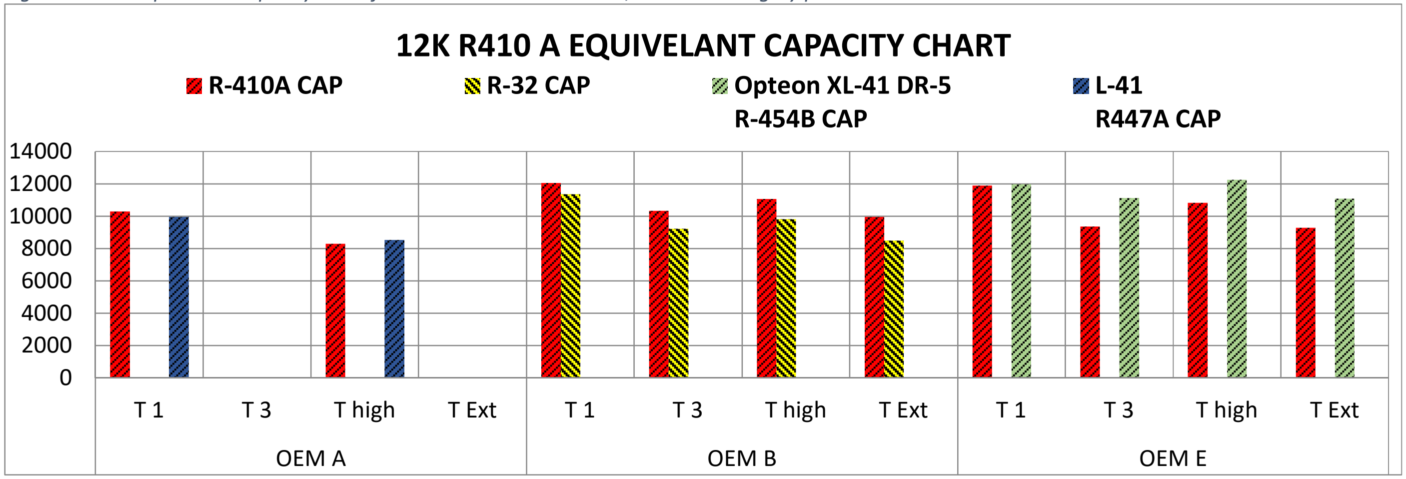


Figure 22 A1 - Equivalent EER chart for R-410A alternatives in 12,000 Btuh category plotted vs R-410A results

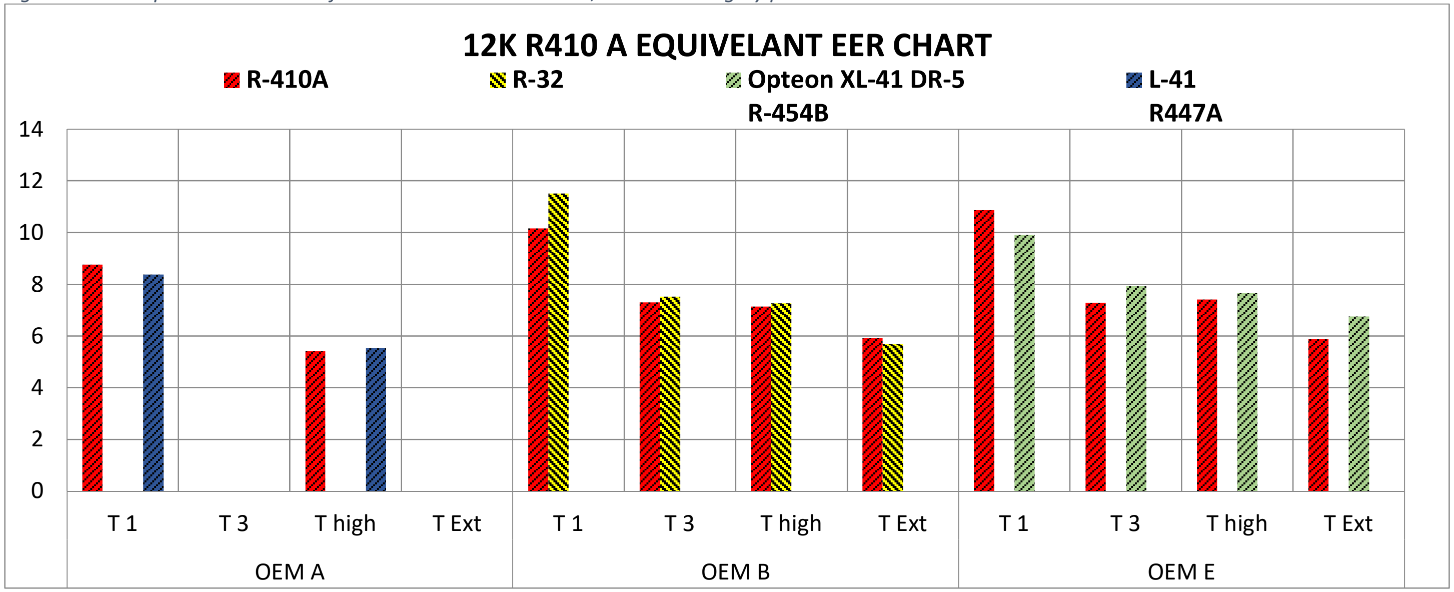


Table 23 A1 - Capacity & EER results for R-410A alternatives in 18,000 Btuh category

R-410 A eq. 18,000 Btuh		OEM A				OEM C			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-410A	CAP	16938	14337	14123	12441	17800	14924	16075	13746
	EER	9.8	6.8	6.3	5.1	9.152	6.497	6.485	5.116
ARM-71a R-459A	CAP					17115	14430	15392	14023
	EER					9.282	6.544	6.265	5.32
R-32	CAP	17616	15255	15761	13809				
	EER	10.03	7.1	6.65	5.29				
Opteon XL-41 DR-5 R-454B	CAP	15167	13229	13782	11800				
	EER	9.5	6.9	6.5	5.2				
L-41 R447A	CAP								
	EER								

Figure 23 A1- Equivalent capacity charts for R-410A alternatives in 18,000 Btuh category plotted vs R-410A results

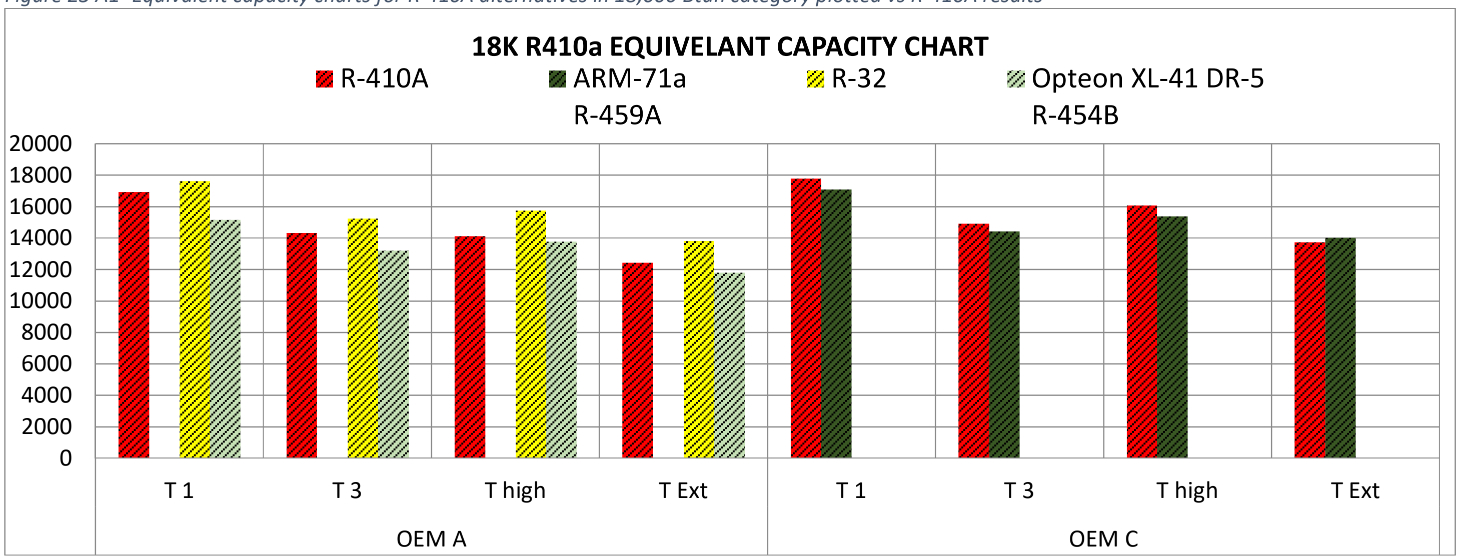


Figure 24 A1 - Equivalent EER chart for R-410A alternatives in 18,000 Btuh category plotted vs R-410A results

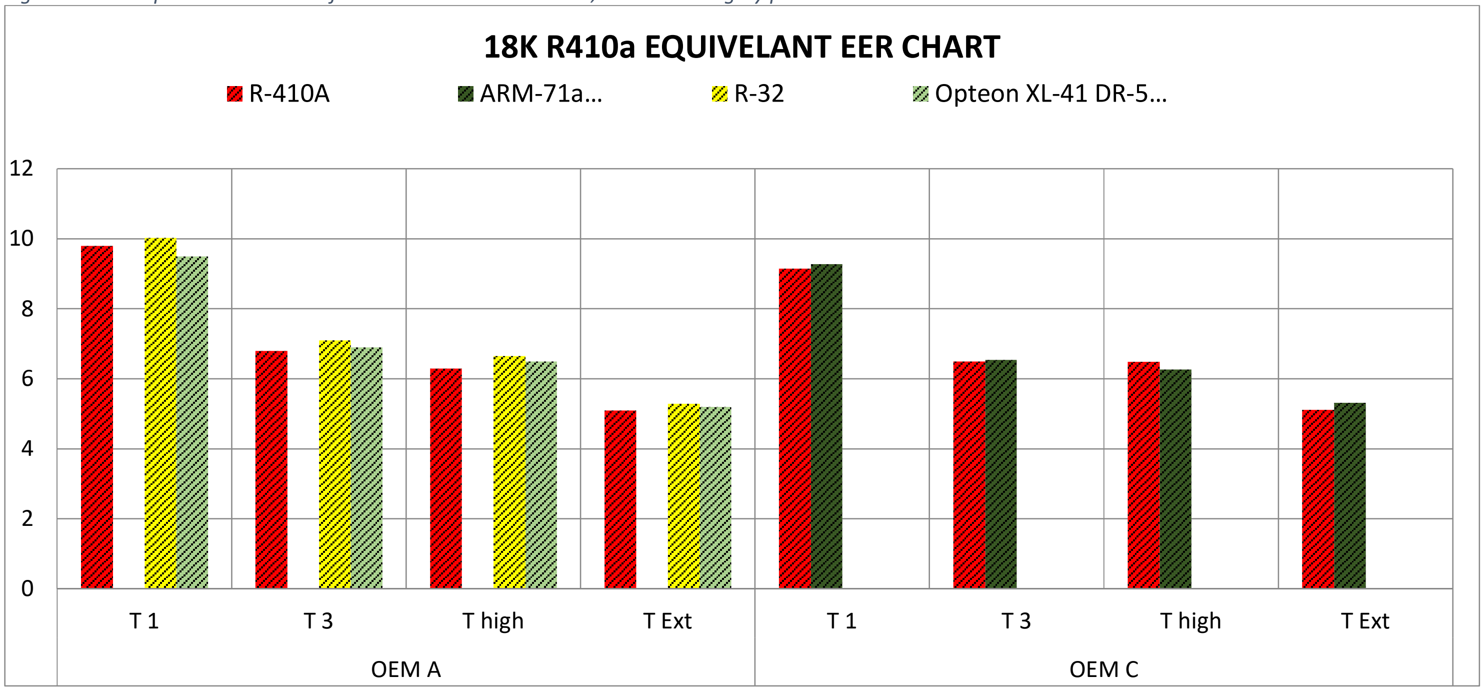


Table 24 A1 - Capacity & EER results for R-410A alternatives in 24,000 Btuh category

R-410 A eq. 24,000 Btuh		OEM C			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**
R-410A	CAP	23022	19531	20534	18379
	EER	10.57	7.518	7.376	6.161
ARM-71a R-459A	CAP				
	EER				
R-32	CAP	23310	19522	21876	19035
	EER	10.62	7.228	7.459	5.988
Opteon XL-41 DR-5 R-454B	CAP	23766	20241	22268	20160
	EER	10.653	7.516	7.515	6.224
L-41 R447A	CAP				
	EER				

Figure 25 A1 - Equivalent capacity charts for R-410A alternatives in 24,000 Btuh category plotted vs R-410A results

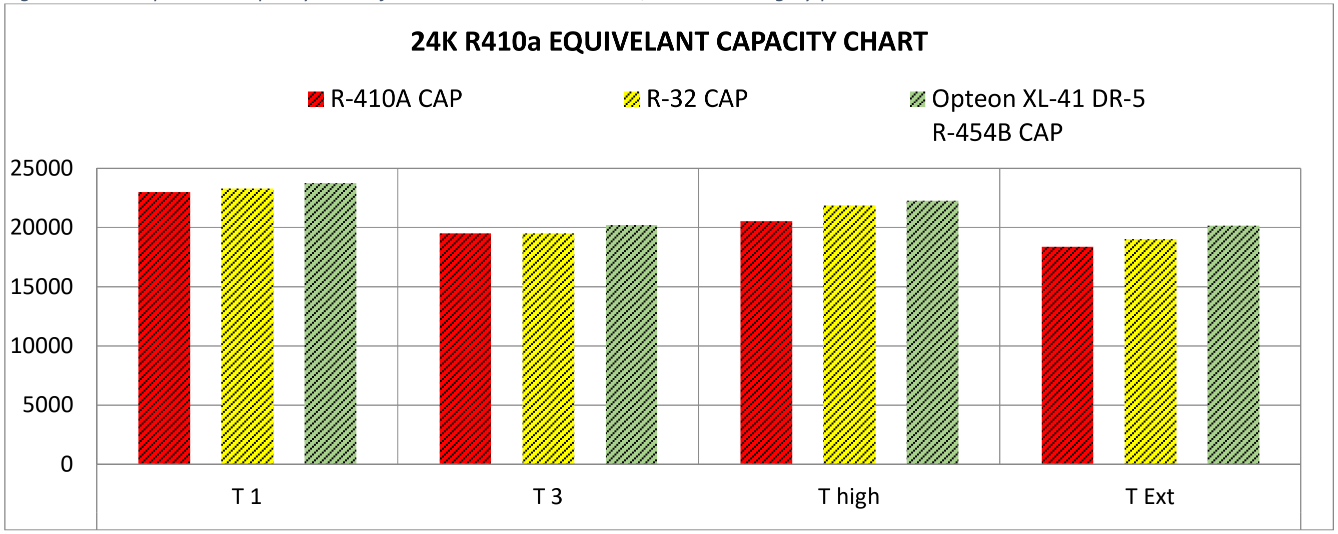
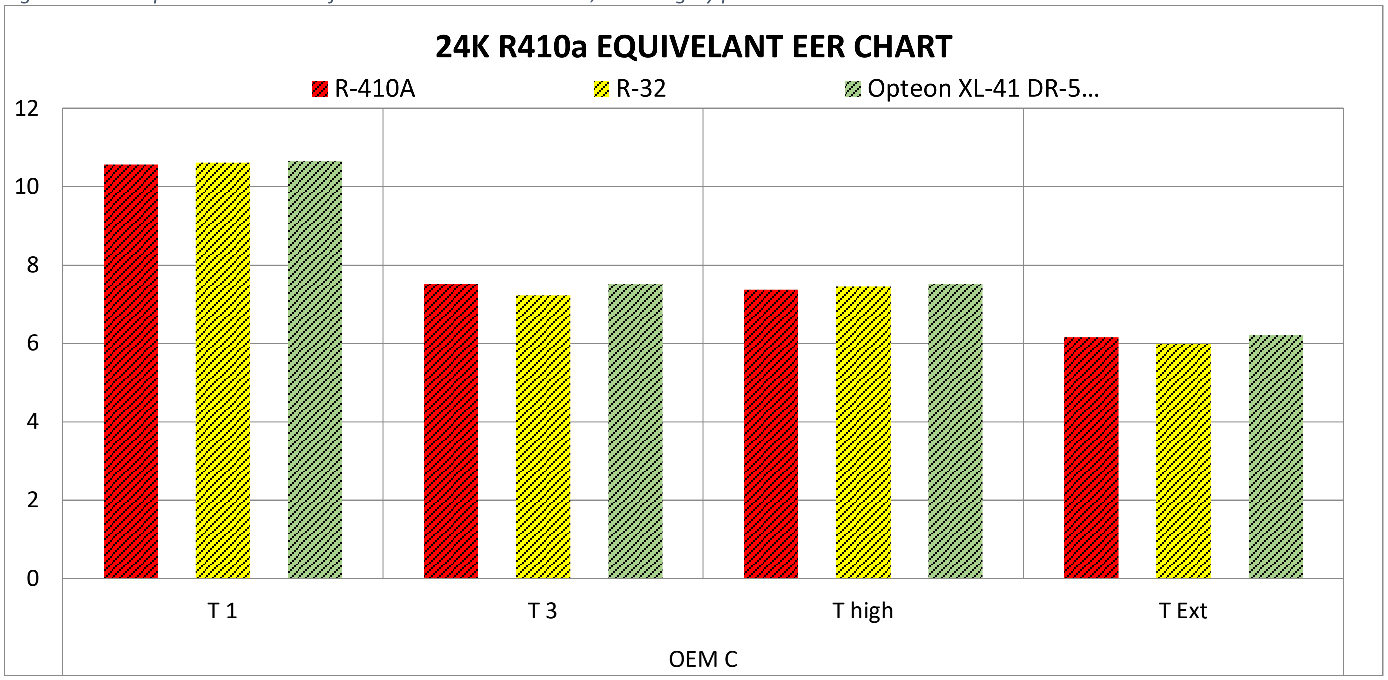


Figure 26 A1 - Equivalent EER chart for R-410A alternatives in 24,000 category plotted vs R-410A results



Annex 2: Sample Questionnaire for Local Manufacturers

Goal:

The Initiative objective is to test prototype air-conditioning units using low-GWP alternative technologies and share recommendations with manufacturers and decision makers in Egypt

Questionnaire:

This questionnaire is aimed at selected air-conditioning manufacturers in Egypt. The purpose of the questionnaire is to ask the preferences of the selected manufacturers in as far as technology selection and partnership with other stakeholders as well as getting a confirmation on their willingness to participate. All information complied of this questionnaire will be treated as confidential.

A. General Conditions	**Participant response**
My company is willing to participate in the project. If you answer YES, please proceed to rest to questionnaire.	YES NO

B. Technology Selection	**Participant response**
1. Do you have a preference for the alternative refrigerant?	YES NO
2. Alternative refrigerant choice (*you can provide more than one selection by deleting what is not applicable)*	➢ HFO Honeywell ➢ HFO DuPont ➢ R-32 ➢ Hydrocarbon
3. Do you have a preference for the compressor manufacturer?	YES NO
4. Provide name of compressor manufacturer(s)	

C. Application Selection	**Participant response**
5. Do you have a preference for the type and capacity of equipment for which you will build the prototype?	YES NO
6. My selection of equipment: (*you can provide more than one selection)*	➢ Decorative split ➢ Ducted split ➢ Rooftop package ➢ Self-contained
7. My selection of cooling capacity	➢ 1 – 5 tons ➢ 6 – 10 tons ➢ No preference

D. Building Prototypes	**Participant response**
8. My company can design and/or build prototypes	YES NO
9. How many prototypes are you willing to build?	➢ One ➢ More (*pls specify number)*

E. Testing Prototypes	**Participant response**
10. Which type of testing do you prefer?	➢ Independent 3rd party Testing ➢ Witness Testing at own premises
11. If you answered **3rd Party Testing**, are you willing to pay the cost for the test?	YES NO

12. If you answered **Witness Testing**, is your lab certified and by whom?	YES NO Certified by:

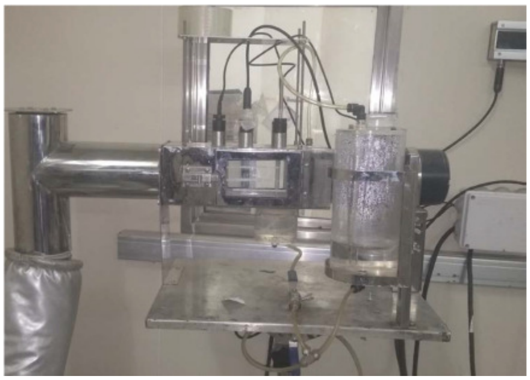
F. Logistics	Participant response
13. My company will allow independent consultants appointed by UNEP/UNIDO to oversee the development of the prototypes.	YES NO
14. If NO, pls describe what limitations you want to impose.	
15. My company will allow independent consultants appointed by UNEP/UNIDO to oversee the testing of the prototypes.	YES NO
16. If NO, pls describe what limitations you want to impose.	

G. Information about the Company	Participant response
17. Company Name	
18. Brand names used in market	
19. Company headquarters location	
20. Manufacturing location where prototype will be built	
21. Ownership percentage pertaining to the nationality where prototype is manufactured (*This information is needed to determine whether the limitations for project participation set by the Ozone Secretariat of the Montreal Protocol are applicable)*	
22. Name and title and Contact details of designated contact person for this project	

Annex 3: Brief description of Manufacturers' testing labs

The test labs of the different OEMs had varying capabilities. The best equipped labs have the following characteristics:

- Psychrometric type laboratory in which the air enthalpy test method is used to determine the cooling and heating capacities from measurements of entering and leaving wet-and dry-bulb temperatures and the associated airflow rate;
- Air sampling devices in each room (indoor room, code tester and outdoor room) are used to measure an average temperature. The airflow induced using blower through the tree (photo on left) and insulated duct passing over the temperature instruments (photo on the right) at velocity of 4-5 m/s.



- Air flow measuring apparatus (code tester) is attached to air discharge of UUT by insulated duct. The first section (receiving chamber) delivers air from UUT and contains the static pressure measuring instrument. The air is then mixed by a mixer in next section to measure its temperature by the air sampling device installed inside the code tester.

- Nozzles section, consisting of a receiving chamber and a discharge chamber separated by a partition in which four nozzles are located (see photo below). Air passes through the nozzles and is then exhausted to the test room. The pressure drop across the nozzles is measured using differential pressure transmitter. Air flow rate is calculated according to ISO 5151:2017.

- Voltage stabilizer(photo on left) is used to adjust the applied voltage for UUT, and the Power meter device is used to measure electrical parameters for it like applied voltage, power consumption, current consumption and power factor.

- Most labs are capable of testing up to 5 TR capacity (17.5 kW of cooling) measuring unit working pressure, super-heat, sub-cooling, and various temperature points on the refrigeration cycle;
- Lab consists of two well thermally insulated rooms: indoor room and outdoor room. In both rooms, temperature and humidity can be controlled preciously to achieve the required environment, as per different standards, thru refrigeration units, humidifiers and electric heaters;
- The accuracy of temperature control for dry and wet bulb temperature is 0.01 °C;
- In the indoor room there is a thermal insulated code tester where outlet air dry bulb, wet bulb and volume are measured;
- Wires sensors with accuracy of 0.1 °C are used for measuring surface temperatures at various points;
- Information gathered during the test are monitored on a computer screen;

The table below shows the parameters that are shown on the monitor

Table 25 A3: Typical parameters shown on a testing lab monitoring screen

Test Screen Display
Inlet DB
Inlet WB
Inlet Enthalpy
Outlet DB
Outlet WB
Outlet Enthalpy
Enthalpy Differential
Specific Density
Air velocity
Air volume
Standard air volume
Atmospheric pressure
Differential pressure
Heat Loss
Total capacity
Capacity ratio
EER
EER ratio
COMPRESSOR
FM surface temperature
high pressure
low pressure
Super-heat
Sub-cooling
ADDITIVE TEMP.
Accumulator outlet temp
Outlet air temperature
Evaporator coil sensor temp
Compressor inlet
O/D Motor surface
OUTDOOR UNIT
Inlet DB
Inlet WB
POWER
Voltage
Current
Wattage
Power Factor
Frequency

Annex 4: Other Research Programs

Research at High Ambient Temperature

The dedicated research on the performance of refrigerants at High Ambient Temperatures (HAT) was driven by the need to find low-GWP alternative refrigerants that have a better degradation of capacity and efficiency than the commercial HFCs that are replacing HCFCs in the HAT countries. The need to meet higher Minimum Efficiency Performance Standards (MEPS) while phasing out the current production of HCFC-based units was a challenge facing both the local industry in the HAT countries and the global exporters to those markets.

Three research programs were announced and completed in the time period between 2013 and 2016. While the three programs had a common goal in testing the refrigerant alternatives at temperatures higher than the standard T1 testing conditions, they were distinct in their protocols, approach, and the entity who was behind the project.

The PRAHA program mentioned in Chapter 1 is a Multilateral Fund financed project to test custom-built prototypes in four equipment categories that built by manufacturers located in HAT countries and testing them all at one independent lab. The results were compared to base units running with HCFC-22 and R-410A refrigerants.

The AREP (Alternative Refrigerant Evaluation Program) is an industry association program by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) to test various categories of equipment, by various manufacturers, at their own labs by either dropping in the refrigerant or "soft" optimizing the unit.

The Oak Ridge National Laboratory (ORNL) program by the United States Department of Energy (DoE) tested two similar capacity standard units running with HCFC-22 and R-410A and soft optimizing them for the various alternative refrigerants. All tests were carried on at ORNL labs.

A comparison of the three program design criteria and testing protocols is found in table xx below. In the next sections of this chapter is a resume of the test results for the three programs and a comparison of these results.

PRAHA program

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 ^{0}C and a relative humidity of 50 % as per AHRI test procedures for T1 conditions (35 ^{0}C), and 29 ^{0}C and 50% for T3 (46 ^{0}C and 50 ^{0}C) conditions. A memorandum of understanding (MOU) was 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.

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 were all required to meet the minimum energy efficiency (EER) of 7 at 46 °C. Tests were performed at an independent reputable lab for result consistency; Intertek was selected through competitive bidding. Verification for repeatability was performed to ensure that results are within the acceptable accuracy levels.

Table 26 A4 - Results for PRAHA-I program

Equipment type	Baseline refrigerant	Refrigerant tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 50°C	Capacity % comp to baseline @ 50°C
18,000 Btu/hr. Window Unit	HCFC-22 COP = 3.14 (35°C), 2.26 (50°C) for OEM A COP = 2.76 (35°C), 2.02 (50°C) for OEM B	L-20 (OEM A)	-11%	9%	-10%	7%
		L-20 (OEM B)	-2%	-6%	-5%	-10%
		DR-3 (OEM A)	-9%	2%	-2%	1%
24,000 Btu/hr. split system	HCFC-22 COP = 2.75 (35°C), 1.94 (50°C) for OEM C COP = 2.52 (35°C) for OEM D	HC-290 (OEM C)	4%	8%	-2%	5%
		L-20 (OEM D)	-19%	7%	-76%	-78%
		DR-3 (OEM D)	-27%	-33%	-28%	-31%
24,000 Btu/hr. split system	R-410A COP = 3.52 (35°C), 2.30 (50°C) for OEM E COP = 3.08 (35°C), 2.02 (50°C) for OEM F	HFC-32 (OEM E)	-1%	15%	-2%	16%
		HFC-32 (OEM F)	-9%	8%	-22%	-1%
		L-41 (OEM E)	-10%	20%	-7%	22%
36,000 Btu/hr. Ducted Split	HCFC-22 COP = 2.83 (35°C), 1.91 (50°C) for OEM G	L-20 (OEM G)	0%	-7%	2%	-5%
		DR-3 (OEM G)	-18%	-25%	-13%	-21%
36,000 Btu/hr. Ducted Split	R-410A COP = 2.79 (35°C), 1.84 (50°C) for OEM G	HFC-32 (OEM G)	-1%	-4%	-12%	-18%
90,000 Btu/hr. Rooftop	HCFC-22 COP = 2.95 (35°C), 2.07 (50°C) for OEM H	L-20 (OEM H)	1%	6%	-3%	5%
		DR-3 (OEM H)	-3%	-1%	-6%	-4%

AREP Program

The Alternative Refrigerant Evaluation Program (AREP) by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) tested several refrigerants either as a drop-or in soft optimized units built and tested at various manufacturers who are members of AHRI (AREP 2014). Testing was done in two phases for several applications including refrigeration and at various temperatures.

Table 27 A4 - Results for the AREP program

Equipment type	Base-line refrigerant	Modifications (test-type)	Refrigerant tested	COP % compared to baseline @ 35 °C	Capacity % compared to baseline @ 35 °C	COP % compared to baseline @ 51.6 °C	Capacity % compared to baseline @ 51.6 °C
36,000 Bu/hr. Split heat pump. AREP report 52(6)	R-410A COP = 3.55 at 35C and 1.87 at 51.6C	Criteria: Drop-in. Matching superheat and sub cooling to base unit. Charge level determined by criteria and held constant for all temperatures tested.	ARM-71A	-1%	-8%	7%	-3%
			R-454A (DR-5A)	-1%	-6%	6%	-1%
			HPR2A	-4%	-11%	3%	-4%
			R-446A (L-41-1)	-2%	-10%	-1%	-3%
			R447A (L-41-2)	-1%	-7%	-1%	-4%
48,500 Btu/hr. Rooftop AREP report 56(11)	R-410A COP = 3.31 at 35C, 2.00 at 48.9C and 1.80 at 51.6C	Soft optimization. Adjustable expansion device, Variable Frequency drive matching the capacity with base unit. Varying indoor conditions.	DR-55	4%	0%	3%	0%
			HFC-32	6%	1%	NA	NA
			DR-5A	5%	1%	7%	3%
72,000 Btu/hr. Rooftop AREP report 55(10)	R-410A COP = 3.57 at 35 C and 2.06 at 51.6C	Soft Optimization. Same superheat and sub cooling as base, changing expansion devise and adjusting charge. Oil is also different.	HFC-32	2%	9%	10%	16%
34,000 Btu/hr. split AREP Report 42(5)	R-410A COP = 3.53 at 35C and 1.82 at 51.6C	Tested HFC-32 unit with POE oil and withy prototype oil for the same expansion devise and charge determined by superheat.	HFC-32 with prototype oil	3%	7%	13%	14%
60,000 Btu/hr. Rooftop AREP reports 47 & 53 (8, 9)	R-410A COP = 3.87 at 35C and 2.07 at 51.6C	Soft optimization. Matching superheat and sub cooling.	L-41-2	3%	-7%	10%	-1%
			ARM-71A	3%	-4%	10%	2%
			HPR2A	1%	-5%	8%	1%
			DR-5A	1%	-4%	2%	-3%
			HFC-32	-10%	-4%	-9%	-1%

ORNL Program

The Oak Ridge National Laboratory (ORNL) program consisted of testing alternatives of HCFC-22 and R-410A in two units of the same capacity (Abdelaziz 2015). Testing was done at the ORNL labs at various temperatures. Table below shows the criteria and a comparison of the result.

Table 28 A4 - Results for the ORNL program

Equipment Type	Lab utilized	Baseline Refrigerant	Equipment Criterion	Refriger. Tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 52°C	Capacity % comp to baseline @ 52°C
18,000 Btu/hr. Split unit (Carrier)	ORNL	HCFC-22 COP = 3.07 at 35°C and 1.98 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	N-20B	-13%	-14%	-11%	-15%
				DR-3	-16%	-12%	-14%	-12%
				ARM-20B	-12%	-3%	-11%	-3%
				R-444B (L-20A)	-11%	-9%	-7%	-4%
				HC-290	7%	-8%	7%	-4%
18,000 Btu/hr. split unit (Carrier)	ORNL	R-410A COP = 3.4 at 35°C and 2.07 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	HFC-32	4%	5%	5%	11%
				DR-55	3%	-3%	3%	0%
				R-447A (L-41)	-5%	-14%	3%	-6%
				ARM-71a	-1%	-8%	2%	-4%
				HPR-2A	-2%	-9%	5%	-1%