Technical Assistance to Plotter-Racks to Develop a Modular Chiller using the R-290

Second Deliverable: Design of Modular R-290 Chiller

Task 2: Technical assistance to develop a modular chiller, including performance, components specifications, safety requirements.

By

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August 17th, 2018

Report Submitted to

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In partial fulfilment of the duties for the TOR “Expert on modular chiller, based on R-290, for commercial refrigeration equipment”

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1 Introduction

There exists a global effort to limit the use of conventional fluorinated refrigerants that cause ozone depletion and contribute to global warming. Natural refrigerants, such as propane or R-290, are considered good replacement refrigerants as they pose no ozone depletion potential and have very low global warming potential. Furthermore, R-290 is considered as an efficient refrigerant; resulting in additional lifetime energy savings and indirect emission reduction. However, R-290 is a flammable refrigerant, classified as an A3[1,2] refrigerant. Therefore, R-290 can't be used as a drop-in refrigerant and equipment will need to be specifically designed to handle the refrigerant flammability. This report highlights the technical assistance offered to Plotter Racks to develop a modular chiller, the system modelling efforts to evaluate the expected performance, the components specifications, and safety requirements.

2 R-290 Modular Chiller Design

A design workshop was held at Plotter-Racks facilities in Curitiba, São Paulo, Brazil during the week of July 2nd, 2018. During the design workshop, the project team decided on the system design, circuit capacity, baseline for comparison, operating conditions, and required safety standards. The following sections provides the relevant details for each.

2.1 R-290 Modular Chiller Conceptual Design

The modular chiller concept is envisioned to be based on the current Plotter-Racks line of Chillpack with vertical air flow configuration as shown in Figure 1. The refrigeration and glycol diagram for this system is shown in Figure 2. The current system employs R-410A as the working refrigerant and 25% propylene glycol for the secondary circuit. This design was selected as it greatly reduces the refrigerant charge and minimizes the potential for refrigerant leaks. The only difference between the existing product and the R-290 system would be in the design of refrigerant circuit and the additional safety features required per applicable codes.

Figure 1: Chillpack chiller by Plotter-Racks

[1] ANSI/ASHRAE Standard 34-2016, Designation and Safety Classification of Refrigerants, 2016, with Addenda, American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 25 West 43rd Street, 4th Floor, New York, New York 10036 U.S.A., 1791 Tullie Circle N.E., Atlanta, GA 30329, U.S.A.

[2] ISO 817:2014, Refrigerants -- Designation and safety classification, 2014, ISO.

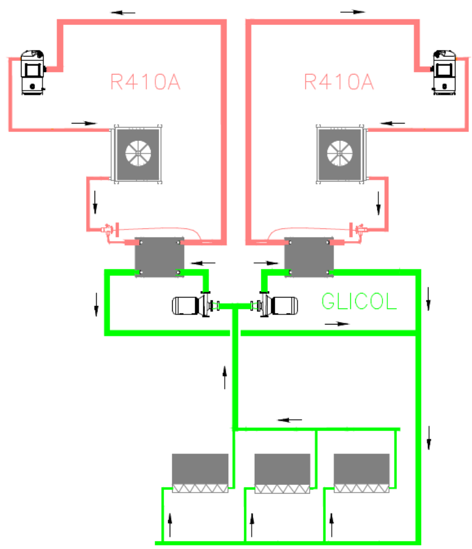


Figure 2: Chillpack refrigerant and glycol circuit configuration

2.2 System Modelling Efforts

The U.S. DOE, ORNL Heat Pump Design Model HPDM[3] was used to evaluate the expected performance of R-290 in comparison with the baseline refrigerant, e.g. R-410A. the modelled system configuration is shown in Figure 3 below. The selected components for both systems are summarized in Table 1.

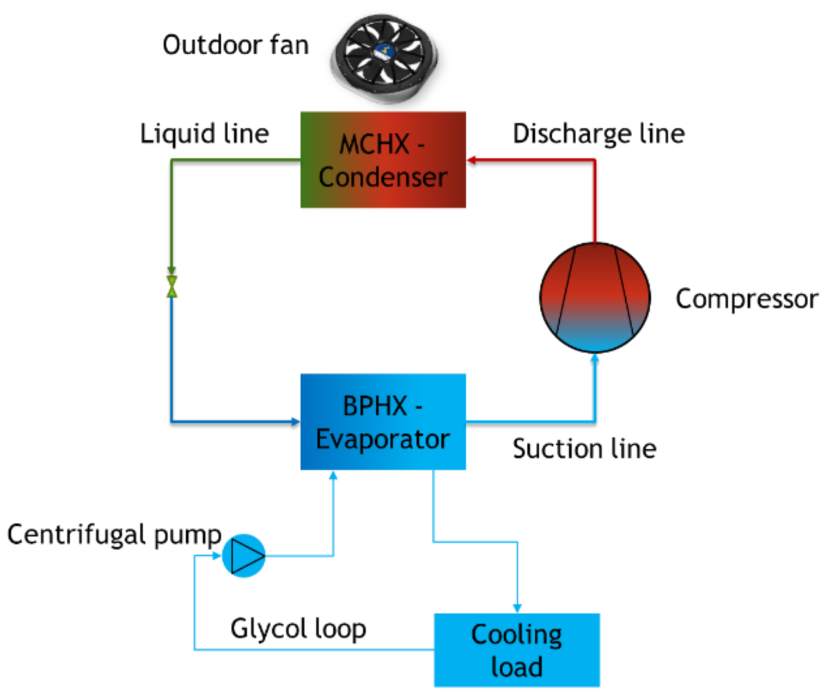


Figure 3: Modelled system configuration

[3] https://hpdmflex.ornl.gov/hpdm/wizard/welcome.php

Table 1: System components for the baseline R-410A and the R-290 systems

Component	Baseline (R-410A)	R-290
Compressor	Danfoss variable speed VZH44CG	Mitsubishi Carel variable speed APB52FA1MT, or Emerson ZB49KCU-TFM
Condenser	Microchannel condenser: Danfoss DF0071 (1074 ×1196 mm)	
Evaporator	Brazed plate heat exchanger: SWEP V80Hx40/1P (40 plates, 526 × 119 mm)	
Outdoor Fan	ZIEHL-ABEGG ZN071ZIL.GG.V7P4	
Pump	Generic variable speed (assumed rated at 500 W)	

2.2.1 Compressor model

The variable speed AHRI 540-IP[4] 10 coefficient model was used in HPDM to model the 3 different compressors. HPDM model these compressors by evaluating the mass flow rate and power consumption using the 10-coefficients provided by the component supplier as shown in the following equations

$$P_{comp} = C_{1,P} + C_{2,P} \times T_{suc,\ sat} + C_{3,P} \times T_{dis,\ sat} + C_{4,P} \times T_{suc,\ sat}^2 + C_{5,P} \times T_{suc,\ sat} \times T_{dis,\ sat} + C_{6,P} \times T_{dis,\ sat}^2 + C_{7,P} \times T_{suc,\ sat}^3 + C_{8,P} \times T_{suc,\ sat}^2 \times T_{dis,\ sat} + C_{9,P} \times T_{suc,\ sat} \times T_{dis,\ sat}^2 + C_{10,P} \times T_{dis,\ sat}^3$$

$$\dot{m}_{comp} = C_{1,M} + C_{2,M} \times T_{suc,\ sat} + C_{3,M\ P} \times T_{dis,\ sat} + C_{4,M\ P} \times T_{suc,\ sat}^2 + C_{5,M} \times T_{suc,\ sat} \times T_{dis,\ sat} + C_{6,M} \times T_{dis,\ sat}^2 + C_{7,M} \times T_{suc,\ sat}^3 + C_{8,M} \times T_{suc,\ sat}^2 \times T_{dis,\ sat} + C_{9,M} \times T_{suc,\ sat} \times T_{dis,\ sat}^2 + C_{10,P} \times T_{dis,\ sat}^3$$

Where P_{comp}, $\dot{m}_{comp}$, $T_{suc,\ sat}$, $T_{dis,\ sat}$, $C_{1..10,P}$, $C_{1\ ..10,M}$ are the compressor power in W, flow rate in lbm/hr, saturated suction temperature in °F, saturated discharge temperature in °F, 10 coefficients for the Power curve fit, and 10 coefficients for the mass flow curve fit respectively.

The component suppliers provided these coefficients to Plotter Racks in SI units, as such, code was developed in Python to translate those coefficients to IP values and the results were within ±2.5% for the operating region of interest for the chiller.

The VZH44CG compressor coefficients at different compressor speeds are summarized in Table 2. The APB52FA1MT compressor coefficients at different compressor speeds are summarized in Table 3, and finally, the ZB49KCU-TFM compressor coefficients at 50 Hz are summarized in Table 4.

[4] AHRI 2015, AHRI Standard 540, 2015 Standard for Performance Rating Of Positive Displacement Refrigerant Compressors and Compressor Units, AHRI, 2015, http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_540_I-P_and_SI_2015.pdf

Table 2: VZH44CG compressor coefficients

*	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S	900 RPM									
P	3.60E+02	-3.89E+00	2.23E+00	9.67E-03	4.13E-04	1.63E-02	1.40E-05	-3.27E-04	-9.66E-05	4.06E-04
M	6.74E+01	1.94E+00	-5.00E-02	6.37E-03	-5.48E-03	4.38E-03	-1.25E-05	1.65E-04	1.52E-06	-4.03E-05
S	1800 RPM									
P	-7.13E+01	-4.77E-01	2.08E+01	-4.59E-01	2.28E-02	-7.03E-02	-2.02E-03	5.47E-03	-3.56E-04	3.15E-04
M	1.64E+02	3.66E+00	-1.65E-01	2.98E-02	-6.87E-04	-1.41E-03	9.97E-05	2.57E-05	-2.80E-05	5.62E-06
S	4800 RPM									
P	4.58E+02	-1.16E+00	3.98E+01	-1.08E+00	1.47E-02	-3.50E-02	-3.25E-03	1.07E-02	6.11E-04	1.17E-04
M	4.25E+02	8.88E+00	-3.13E-01	8.64E-02	2.81E-03	3.32E-03	4.09E-04	-1.65E-04	2.59E-05	-3.17E-05
S	5400 RPM									
P	2.46E+03	-4.74E+01	-6.99E+00	-1.21E-01	4.37E-01	3.88E-01	2.32E-03	-6.65E-03	3.65E-03	-1.02E-03
M	4.52E+02	1.07E+01	7.84E-01	9.01E-02	-8.20E-03	-1.10E-02	4.44E-04	-8.78E-05	6.14E-05	2.41E-05

* S: Speed, P: Power Coefficients, M: Flow Rate Coefficients

Table 3: APB52FA1MT compressor coefficients

*	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S	1200 RPM									
P	4.44E+01	-2.50E-01	5.29E+00	-5.67E-02	-3.03E-03	3.93E-03	-6.47E-04	6.98E-04	-1.89E-06	7.85E-05
M	4.90E+01	8.84E-01	-9.37E-02	3.81E-03	6.21E-04	1.45E-04	3.89E-05	3.35E-06	-2.95E-06	-4.77E-07
S	3600 RPM									
P	3.69E+02	-1.64E+01	1.88E+01	9.57E-02	1.19E-01	-6.77E-02	-1.76E-03	-2.37E-04	1.20E-04	5.11E-04
M	1.25E+02	2.65E+00	3.52E-01	1.41E-02	1.80E-03	-4.83E-03	1.04E-04	4.02E-07	-1.00E-05	1.34E-05
S	6000 RPM									
P	4.62E+02	-1.46E+01	3.29E+01	9.49E-03	1.20E-01	-5.69E-02	-1.94E-03	3.18E-04	6.73E-05	5.64E-04
M	2.30E+02	4.61E+00	1.01E-02	2.30E-02	-1.29E-03	-2.11E-03	1.50E-04	2.89E-05	-2.90E-06	3.34E-06

* S: Speed, P: Power Coefficients, M: Flow Rate Coefficients

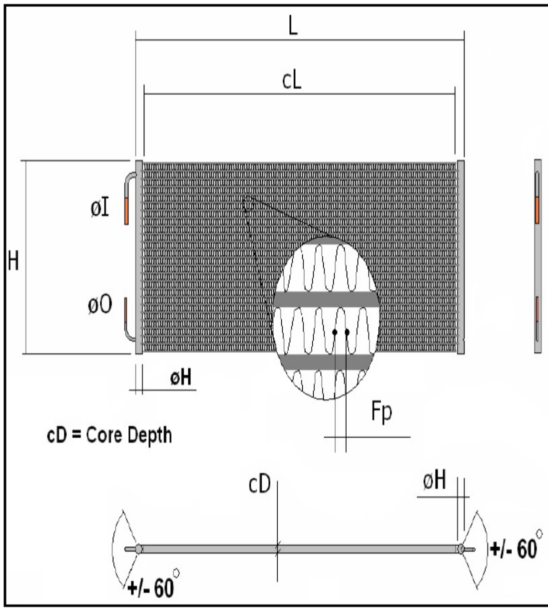
Table 4: ZB49KCU-TFM compressor coefficients

*	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S	3000 RPM									
P	1.43E+03	5.53E+00	1.33E+01	-6.73E-02	1.11E-02	2.51E-02	-4.23E-04	1.22E-03	-2.54E-05	6.40E-04
M	2.45E+02	5.16E+00	3.25E-01	3.73E-02	-3.26E-03	-4.12E-03	9.49E-05	2.08E-05	1.12E-05	1.11E-05

* S: Speed, P: Power Coefficients, M: Flow Rate Coefficients

2.2.2 Microchannel heat exchanger model

The selected microchannel heat exchanger (MCHX) for the system design is the Danfoss DF071. This microchannel heat exchanger was selected as it offers easy integration with the current Chillpack system chassis and provide sufficient heat exchange area for both the baseline R-410A and the R-290 systems. The geometry of the microchannel heat exchanger is outlined in Figure 4. The microchannels used in this MCHX are 25.4 mm and 1.3 mm thick with 26 ports and wall thickness of 0.28 mm. The microchannel ports are 0.86 mm wide and 0.74 mm high. The MCHX uses folded multi-louver fins, 8.1 mm high, 25.4 mm wide, and 0.08 mm thick. The fin pitch is 23 fins per inch. Finally, the microchannel headers are made of 32 mm outside diameter tube with wall thickness of 2.5 mm. The MCHX max operating pressure is 13.5 MPa. The performance of this condenser at the design condition, 37°C ambient temperature, are summarized in Table 5.



GUI Version	3.1
Engine Version	5.1
Customer	Projeto Unido
Project	DF071 710mm
Sales Contact	fmarchioro
Refrigerant	R410A
Number of Slabs	1
Overall Length (L)	1074 [mm]
Total Height (H)	1196 [mm]
Tube Width (cD)	25,4 [mm]
Manifold Outer Dia (ΦH)	32 [mm]
Tube ID	2G25
Fin ID	B31
Manifold ID	J31
Pass Distribution	76,50

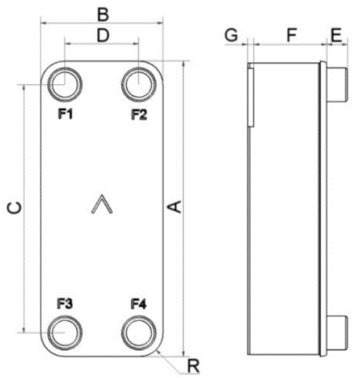
Figure 4: Danfoss microchannel condenser design

Table 5: DF071 Microchannel condenser performance

Parameter	R-410A	R-290
Capacity [kW]	18.18	19.58
ΔPair [Pa]	58	48
ΔPref [kPa]	9.63	14.08
$\dot{m}_{ref}$ [kg/hr]	318.9	193.22
Qair [m3/hr]	11008	9707
Tair, out [°C]	42.84	44.12
Tref, in [°C]	75	75
Tsat, out [°C]	44.73	44.59
Subcool [°C]	5.77	0

2.2.3 Brazed plate heat exchanger model

A 12.5 kW brazed plate heat exchanger (BPHX) was sized by SWEP. The BPHX design and dimensions are shown in Figure 5. It consists of 40 plates with a total heat transfer area of 2.28 m^2 and total refrigerant hold-up volume is 1.9 litre. The performance of this BPHX at the design stipulated design conditions are summarized in Table 6Table 5.



A	=	526 ±2	mm
B	=	119 ±1	mm
C	=	470 ±1	mm
D	=	63 ±1	mm
E	=	27 ±1	mm
F	=	93.60 ±2,5%	mm
G	=	2 to 6 ±1	mm
O	=	4	mm
R	=	23	mm

Figure 5: Brazed plate heat exchanger sketch

Table 6: SWEP V80Hx40/1P performance at design conditions

Parameter	**R-410A**		**R-290**	
	Inner side R-410A	**Outer side Glycol**	**Inner side R-290**	**Outer side Glycol**
Capacity [kW]	12.5			
Inlet temperature, °C	-7.77	0	-5.47	0
Superheating, °C	7		5	
Outlet temperature, °C	-1	-2	-1	-2
Flow rate, kg/s	0.08157	1.618	0.0478	1.618
Total pressure drop, kPa	7.14	55	7.52	37.5
Port diameter, mm	33/33	33/33	33/33	33/33
Recommended inlet connection, mm	7.99 – 12.6		9.13 – 14.4	
Recommended outlet connection, mm	13.6 – 30.4		16.9 – 37.7	

Glycol: 25% Propylene Glycol by mass

2.2.4 Auxiliary components

A fan model was modelled attached to the MCHX. The fan can be modelled as a variable speed if the correlation between the power and flow rates are provided. In the current model, the fans were modelled as fixed speed with constant power consumption according to data provided from ZIHEL-ABEGG FANselect software. The variable speed fan (ZN071ZIL.GG.V7P4) was modelled as follows:

- R-410A: 11000 m^3/hr, 58 Pa, 477 W
- R-290: 9700 m^3/hr, 48 Pa, 320 W

The pump used for the propylene glycol was assumed to provide a fixed flow rate of 1.618 kg/s and require 500 W of power.

Finally, the discharge, liquid, and suction lines were all modelled to evaluate the expected refrigerant side pressure drop through them. Furthermore, the heat loss/gains through these lines were estimated at 0.55°C each.

2.3 Curitiba Weather Data

In order to properly evaluate the performance of the proposed R-290 chiller it is important to understand its performance at off-design conditions and get an annual weighted average for the results. The Curitiba typical weather data was obtained from EnergyPlus web portal[5]. The temperature bins are summarized in Figure 6 below. The HPDM parametric evaluation tool was used to evaluate the system performance at all temperature conditions (from 5 to 37 with 1°C increment). An annual weighted average capacity and coefficient of performance (COP) were evaluated at the different compressor speeds in light of unavailability of cooling loads. Ultimately, the compressor speed will change at the different ambient conditions to match the cooling load, thereby reducing the performance degradation associated with the On/Off controls.

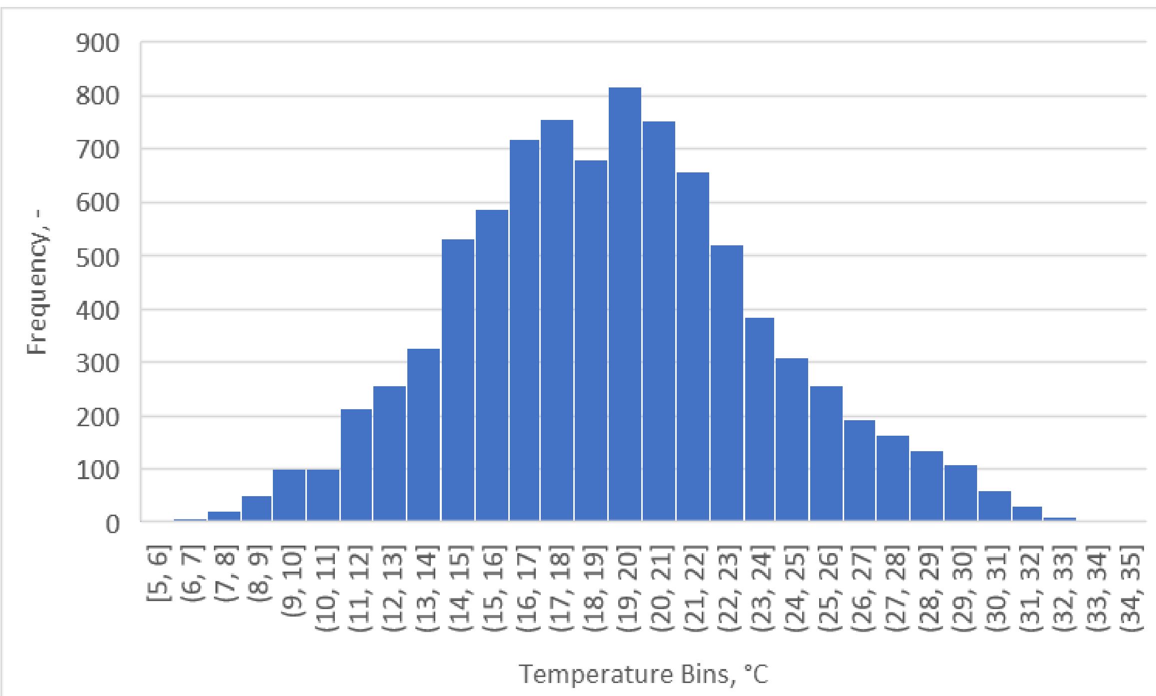


Figure 6: Curitiba weather profile

[5] https://energyplus.net/weather-location/south_america_wmo_region_3/BRA//BRA_Curitiba-Afonso.Pen.838400_SWERA

2.4 Required Safety Standards

In order to safely introduce the R-290 chiller to the market, Plotter-Racks has to follow the following international standards[6 and 7] and ensure that the chiller is properly marked with the flammable refrigerant signage.

Standard	Scope/Title	Technical Aspects	Relevant Information	Applies to				
				Equipment / system design	Installation of new equipment/system	Operation	Maintenance	Decommissioning
IEC 60335-2-89	Household and similar electrical appliances – Safety	Requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor	CDV circulated in April 2018 with new upper limit on refrigerant charge approx. 500 g of propane and 1,2 kg of A2L refrigerant.	X	X	X		
ISO 5149-1	Refrigerating systems and heat pumps — Safety and environmental requirements	Requirements, definitions, classification and selection criteria	Major revision of refrigerant charge limits in 2014	X				
ISO 5149-2		Design, construction, testing, marking and documentation		X	X			
ISO 5149-3		Installation site and personal protection			X			
ISO 5149-4		Operation, maintenance, repair and recovery				X	X	X
ANSI/ASHRAE 15	Safety Standard for Refrigeration Systems	Design, construction, installation, and operation of refrigeration systems	Work is ongoing on adding requirements for A2L refrigerants to the standard	X	X	X	X	

Furthermore, the following standards are also important;

- ISO 817/ASHRAE34: Refrigerant classification
- IEC 60079-10-1: Classification of areas - Explosive gas atmospheres
- IEC 60079-13: Equipment protection by pressurized room "p" and artificially ventilated room "v"
- IEC 60079-14: Explosive atmospheres - Part 14: Electrical installations design, selection and erection
- IEC 60079-15: Explosive atmospheres – Part 15: Equipment protection by type of protection "n"
- IEC 60079-29-1: Explosive atmospheres - Part 29-1: Gas detectors – Performance requirements of detectors for flammable gases
- IEC 60079-29-2: Explosive atmospheres - Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen

[6] Corberán, J.M., Segurado, J., Colbourne, D., Gonzálvez, J., 2008. Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment. International Journal of Refrigeration 31, 748-756

[7] http://conf.montreal-protocol.org/meeting/oewg/oewg-40/presession/backgroundnote/safety-standards_tabular-overview_background-note.pdf

Also, it is important to ensure that the active mitigation plan employed is effective in minimizing the risks such:

- Using properly designed ATEX compressor
- Minimize any potential for sparks from fan and pump motors (using ECM motors)
- Minimize any potential for sparks associated with fan operation
- Avoid any potential sparks from electrical components (e.g. replace conventional contactors with solid-state contactors)
- Completely isolate the electrical panel from the refrigeration circuit using Gas-tight enclosure
- Braze all fittings to avoid leakage
- Blow-out pipe for safety relief valves
- Safety valve piping to evacuate refrigerant in case of overpressure

An evolving technic for refrigerant leak detection is the use of ultrasonic sensors that detect ultrasonic signal associated with a leaking vapor compression system[8].

3 Modelling Results

3.1 Baseline R-410A system

The baseline R-410A system was modelled at various ambient conditions, compressor speeds, and superheat. The summary of the results is shown in Table 7 and Table 8 for the performance at the design conditions and the weather weighted average values respectively.

Table 7: R-410A system performance at the design conditions, 37°C ambient conditions

Compressor RPM	Evaporator Superheat, °C	Suction Sat. Temp, °C	Discharge Sat. Temp, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
5400	8	-8.5	44.3	2.546	12.9	1.94
5400	7	-8.2	44.4	2.686	13.0	1.95
5400	6	-8.0	44.5	2.772	13.1	1.96
5400	5	-7.9	44.5	2.837	13.1	1.96
4800	8	-8.2	43.8	2.504	11.6	2.03
4800	7	-7.8	43.9	2.697	11.8	2.05
4800	6	-7.6	44.0	2.794	11.9	2.06
4800	5	-7.5	44.0	2.862	11.9	2.07
1800	7	-7.1	43.3	2.261	4.0	1.45
900	7	-7.1	43.3	2.243	1.6	0.70

[8] http://conf.montreal-protocol.org/meeting/oewg/oewg-40/events-publications/Observer%20Publications/DEVELOPMENT%20OF%20THERMOTAR%20R290%20DUCTED%20SPLIT%20AND%20ROOFTOP%20AIR-CONDITIONING%20UNITS.pdf

Table 8: R-410A system weather-weighted average performance

Compressor RPM	Evaporator Superheat, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
5400	8	2.566	14.9	2.90
5400	7	2.680	15.1	2.92
5400	6	2.755	15.1	2.93
5400	5	2.809	15.2	2.94
4800	8	2.524	13.5	2.92
4800	7	2.673	13.6	2.95
4800	6	2.762	13.7	2.96
4800	5	2.824	13.8	2.97
1800	7	2.414	4.9	2.15

3.2 Propane system using the Mitsubishi Carel Compressor

The R-290 system was modelled at various ambient conditions, compressor speeds, and superheat using the Mitsubishi-Carel compressor. The summary of the results is shown in Table 9 and Table 10 for the performance at the design conditions and the weather weighted average values respectively.

Table 9: R-290 system using the Mitsubishi-Carel performance at the design conditions, 37°C ambient conditions

Compressor RPM	Evaporator Superheat, °C	Suction Sat. Temp, °C	Discharge Sat. Temp, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
6000	8	-8.1	43.9	0.688	10.0	1.94
6000	7	-7.1	44.0	0.749	10.4	2.01
6000	6	-6.1	44.2	0.855	10.7	2.08
6000	5	-5.2	44.3	1.042	11.1	2.14
3600	8	-8.1	43.3	0.772	5.8	1.78
3600	7	-7.1	43.5	0.805	6.0	1.84
3600	6	-6.1	43.5	0.842	6.2	1.91
3600	5	-5.1	43.5	0.921	6.5	1.99
1200	8	-8.1	43.4	0.976	1.5	0.88
1200	7	-7.1	43.4	0.982	1.6	0.93
1200	6	-6.1	43.4	0.991	1.7	0.97
1200	5	-5.1	43.4	1.016	1.8	1.02

Table 10: R-290 system using the Mitsubishi-Carel weather-weighted average performance

Compressor RPM	Evaporator Superheat, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
6000	8	0.694	11.9	2.90
6000	7	0.772	12.3	3.00
6000	6	0.906	12.7	3.10
6000	5	1.097	13.0	3.18
3600	8	0.777	6.9	2.59
3600	7	0.803	7.1	2.70
3600	6	0.853	7.4	2.81
3600	5	0.953	7.7	2.92
1200	8	1.016	1.9	1.26
1200	7	1.022	2.0	1.32
1200	6	1.034	2.1	1.38
1200	5	1.057	2.2	1.44

3.3 Propane system using the Emerson Compressor

The baseline R-410A system was modelled at various ambient conditions, compressor speeds, and superheat. The summary of the results is shown in Table 11 and Table 12for the performance at the design conditions and the weather weighted average values respectively.

Table 11: R-290 system using the Emerson compressor performance at the design conditions, 37°C ambient conditions

Compressor RPM	Evaporator Superheat, °C	Suction Sat. Temp, °C	Discharge Sat. Temp, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
3000	8	-8.1	44.6	0.705	11.6	2.22
3000	7	-7.1	44.8	0.790	12.1	2.28
3000	6	-6.1	44.9	0.923	12.5	2.35
3000	5	-5.3	45.1	1.103	12.8	2.40

Table 12: R-290 system using the Emerson compressor weather-weighted average performance

Compressor RPM	Evaporator Superheat, °C	System Charge, kg	Refrigeration Capacity, kW	System COP, W/W
3000	8	0.726	13.6	3.18
3000	7	0.825	14.0	3.27
3000	6	0.986	14.5	3.36
3000	5	1.135	14.8	3.41

4 Results analysis

In order to be able to analyse the simulation results, the system capacity and COP were plotted against the ambient temperature at various conditions as shown in Figure 7 and Figure 8. In Figure 7, it can be noted that the Mitsubishi-Carel (APB) compressor has the smallest refrigeration capacity, about 10% lower on average compared with the baseline R-410A system running at 4800 RPM (optimal conditions). The Emerson (ZB49) compressor matches the capacity of the baseline compressor when operated with 8°C superheat and can even exceed the capacity and almost matches the baseline capacity when running at 5400 RPM by reducing the superheat to 5°C.

On the other hand, Figure 8 clearly indicate the superior performance of the Emerson compressor at moderate and high ambient conditions. The Emerson compressor results in even higher savings when the superheat degree is reduced to 5°C with weather-weighted average COP improvement of 17% over the baseline R-410A system operating at 4800 RPM and 8°C superheat.

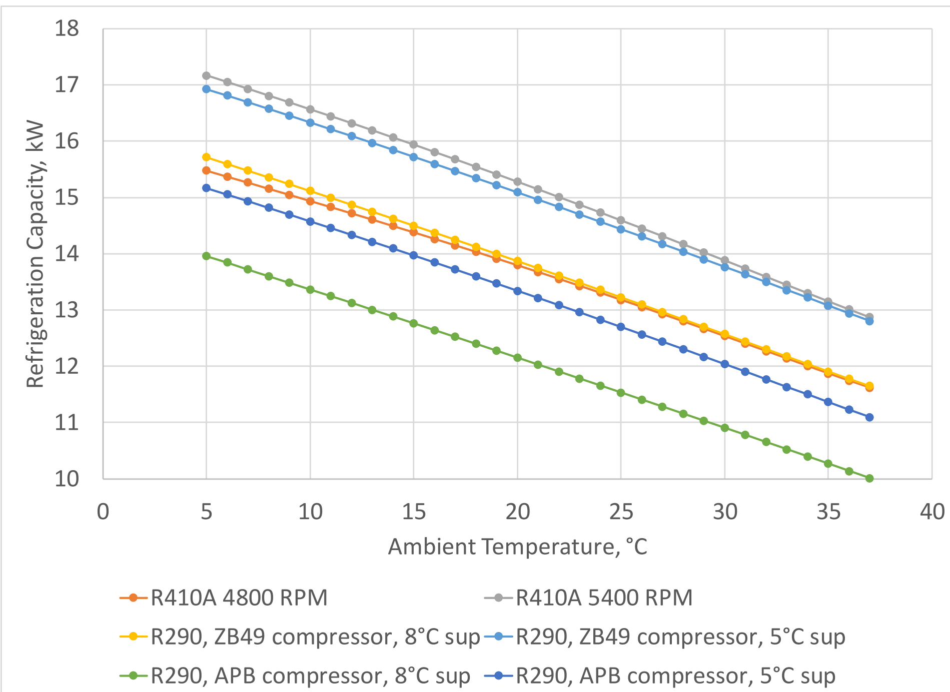


Figure 7: Refrigeration capacity at various operating conditions with different compressors

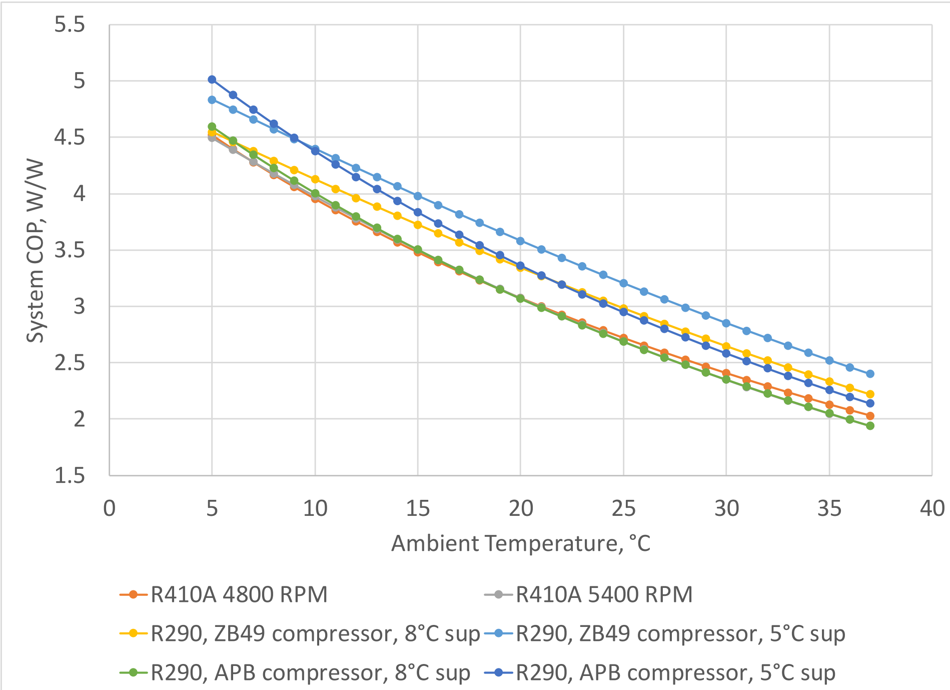


Figure 8: System COP at various operating conditions with different compressors

5 Conclusions

This document details the modelling efforts pursued to design a modular R-290 chiller. The analysis was based on actual components that can be sourced in Brazil and require minimum modification to the existing baseline Chillpack system. The R-290 system design employs the same MCHX and BPHX used in the baseline 12.5 Chillpack; however, 2 different compressors where investigated

- The Mitsubishi-Carel variable speed APB52FA1MT
- Emerson ZB49KCU-TFM

The model results showed that the Emerson ZB49KCU-TFM compressor has the potential for up-to 17% COP improvement compared with the baseline system. It should be noted that the Emerson compressor currently doesn't allow for variable speed operation. As such, we expect a performance degradation of about 5% due to the compressor cycling. The expected energy efficiency gains after all consideration would be at least 10% over the baseline system.

Finally, it is important to follow the required international safety standards that pertains to the use of flammable refrigerants in commercial refrigeration systems. Furthermore, it is important to include the required mitigation strategies such as the refrigerant leak detector, proper leakage handling through compartmentalization and ventilation, and use of properly design components such as ATEX certified compressors and electrical components, ECM fans and pumps, gas tight electrical enclosures, and minimize the refrigerant leakage potential.