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Low-GWP Refrigerant Evaluation in AC Systems for High Ambient Temperature Applications - Select Components and Finish System Design of a Window Air Conditioner with Propane (Regular)– FY17 2nd Quarter Milestone Report

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Select Components and Finish System Design of a Window Air Conditioner with Propane

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FY17 2nd Quarter Milestone Report

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Executive Summary

This report describes the technical targets for developing a high efficiency window air conditioner (WAC) using propane (R-290). The baseline unit selected for this activity is a GE R-410A WAC. We established collaboration with a Chinese rotary compressor manufacturer, to select an R-290 compressor. We first modelled and calibrated the WAC system model using R-410A. Next, we applied the calibrated system model to design the R-290 WAC, and decided the strategies to reduce the system charge below 260 grams and achieve the capacity and efficiency targets.

Introduction

In air conditioning application, packaged terminal air conditioners (AC) have the best chance to apply flammable (Class A3) hydrocarbon refrigerants, due to their small inner volumes and refrigerant charges. US EPA (2014)[1] proposed that the maximum design charge size for a 10,000 BTU/hr window air conditioner Unit would amount to 260 g of propane (R-290). The GWP of R290 is 3.3. Asian countries, e.g. China and India, have been marketing R-290 room air conditioners. R-290 AC compressors have already been available on the market. Therefore, we will develop a high efficiency WAC for the US and mid-east market, using R-290 instead of isobutene, to meet the US efficiency and safety standard. We will collaborate with a Chinese rotary compressor manufacturer, i.e. Shanghai Hitachi Electrical Appliances Co. Ltd, to select an R-290 rotary compressor optimized for the WAC design.

Shanghai Hitachi is a subsidiary of Johnson Controls Inc. US, a company founded in 1993 and headquartered in Shanghai, China. It is a world leading manufacturer of rotary compressors. It produces 18 million compressors annually, covering wide categories of air conditioning, water heating and refrigeration. It has a capital of 1.2 billions of dollars, and multiple manufacturing sites in China and India. In fact, 1/7 compressors in the world were made by the company.

The system is designed to meet the following three technical goals:

1. System refrigerant charge < 260 g as proposed by EPA.
2. Rated cooling capacity > 10,000 Btu/hr, at the AHRI A condition (95°F ambient temperature, 80°F indoor dry bulb/67°F indoor wet bulb temperature).
3. Rated EER reaches 12.0 (Energy Star), at the AHRI A condition.

Baseline Unit

We selected a GE WAC, using R-410A, as the baseline. The model number is AEC12AV. Some general features of the WAC are listed below:

- Power supply: single-phase, 115 V/60 HZ
- Rated capacity: 12,050 Btu/hr
- Rated EER: 12.1
- Indoor air flow rate: 614.5 CFM (29 Liter/s)
- Fan power: 100 W to drive both indoor and outdoor air flow
- Fan speed: 3 speeds
- Dehumidification rate: 3.4 pts/hour, i.e. equivalent SHR – 68%.
- System charge: 750 grams, i.e. 1.65 lbms

The schematic diagram of the WAC and its P-h diagram are shown in Figures 1 and 2 respectively. The open WAC unit is shown in Figure 3. The condenser fan blade is specially configured, to pick up water from the water collection pan and to spray it in the air stream flowing over the condenser coil surface. The water droplets evaporate and cooling the air drawn across the coil, and enhance the condenser heat transfer. This feature is called the "sling" effect. Figures 4 and 5 respectively show the single axis fan, and the "slinger ring". A subcooler downstream of the condenser coil is submerged in a water collection pan, which collects condensed water from the indoor evaporator coil.

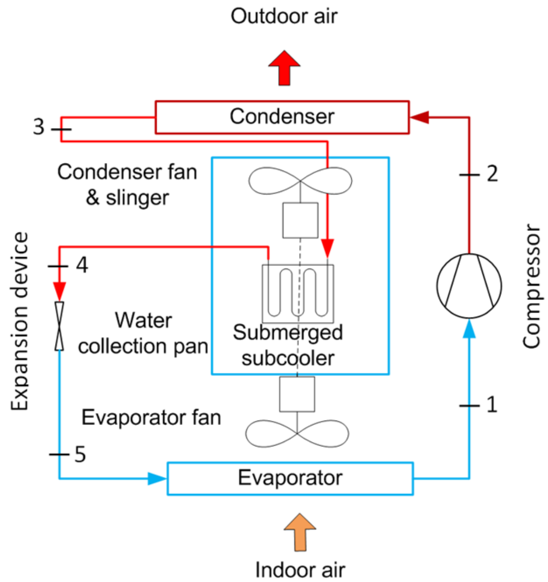

Figure 1: Schematic of Window Air Conditioner

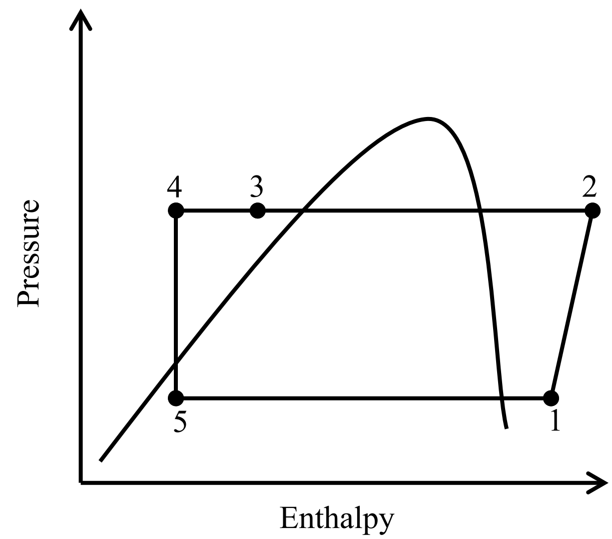

Figure 2: P-h diagram of Window Air Conditioner

Figure 3: Baseline GE Window Air Conditioner

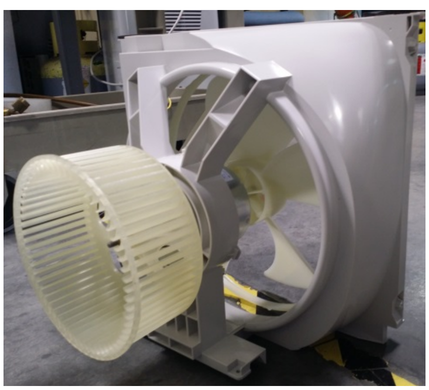

Figure 4: Single axis blower/fan

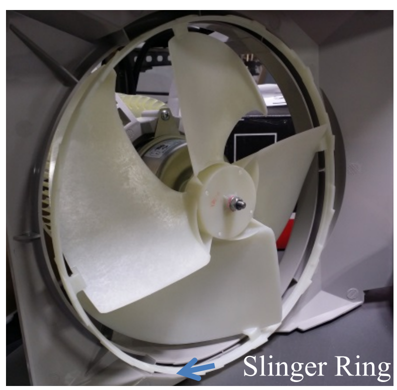

Figure 5: Slinger on condenser fan

The WAC uses fin-and-tube coils for the evaporator and condenser. Some basic parameters of the heat exchangers are given in Table 1.

Table 1: Condenser and Evaporator of Window Air Conditioner

Parameters	Fin-&-Tube Condenser Coil	Fin-&-Tube Evaporator Coil
Face area [ft^2]	1.44	0.94
Total Tube Number	56	48
Number of rows	3 (cross counter-flow)	4 (cross counter-flow)
Tube outside diameter [in]	0.2 (5 mm)	0.33
Finned tube length [in]	18.2	15.0
Tube pitch [in]	0.6	0.75
Row pitch [in]	0.5	0.7
Fin density [fins/in]	20	22
Fin length [in]	11.4	9.0
Fin depth [in]	1.5	2.8

Tube connection patterns of the condenser and evaporator can be seen in Figures 6 and 7, where green cells represent numbered tubes, arrows indicate refrigerant flow direction, and “JUNC#” means a refrigerant flow intersection port. The condenser coil has seven circuits and five refrigerant flow intersections, as numbered from zero and described in Figure 6. The evaporator coil has six circuits (with two feeds in and four out) and four refrigerant flow intersections.

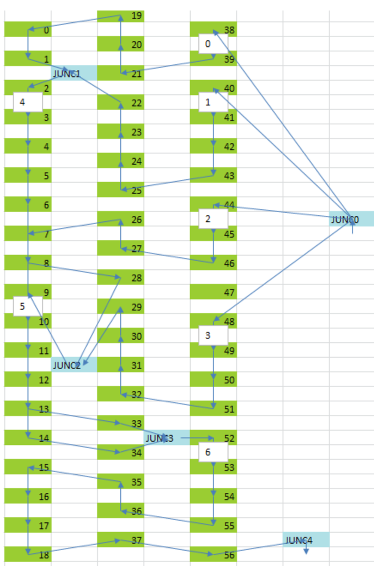

Figure 6: Tube connections in condenser

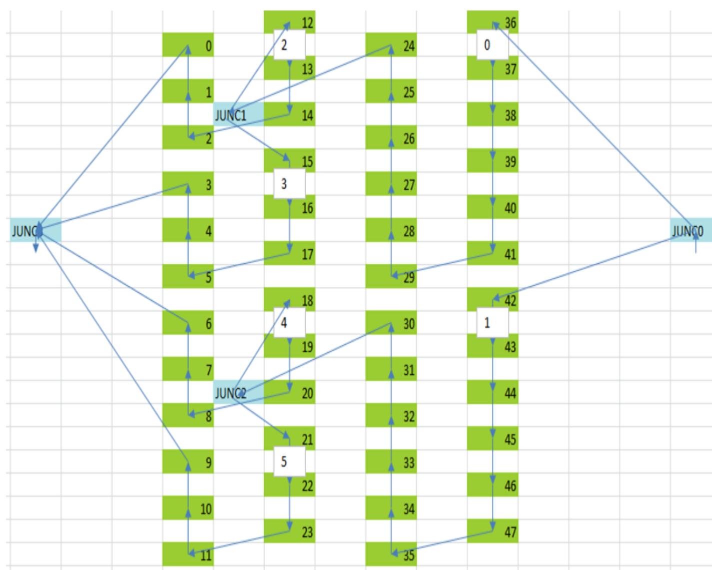

Figure 7: Tube connections in evaporator

The submerged subcooler has eight tubes, having an outside diameter (OD) of 0.28 inch and total length of 12.7 feet. The liquid line is one-foot long and has an OD of 0.28 inch. The discharge line has a length of 3.3 feet and an OD of 0.32 inch. The length and inner volume of the suction line can be ignored as containing only low density vapor.

Compressor Selection

The baseline WAC uses a single-speed, rotary compressor, made by Shanghai Hitachi with the brand name of “Highly”. We worked with the compressor manufacturer and selected an R-290 compressor to achieve the similar capacity and efficiency. A side-to-side comparison between the two compressors is given in Table 2.

Table 2: Comparing Compressors

Model No	ASD100HW-H6KUN (Highly)	PSD162XW (Highly)
Refrigerant	R-410A	R-290
Power supply	115 V/60 HZ/single-phase	115 V/60 HZ/single-phase
Displacement [ml]	10.0	16.2
Amount of oil charge [ml]	230	270
Space volume of inner case [ml]	1175	1175
Rated capacity* [Btu/hr]	9,827	10,014
Motor input* [W]	970	894
Rated COP* [W/W]	2.97	3.28
Volumetric efficiency* [%]	87%	91%
Isentropic efficiency* [%]	67%	67%
Estimated refrigerant mass in oil [g]	40	40

*the rated values were obtained at a standard test condition: evaporating temperature 7.2°C (45°F); condensing temperature: 54.4°C (130°F); liquid temperature entering expansion valve: 46.1°C (115°F); compressor return gas temperature: 35°C (95°F); ambient temperature: 35°C (95°F).

As described in Table 2, R-290 requires 62% larger displacement volume for the similar cooling capacity. The two compressors have the same rated isentropic efficiency, i.e. 67%, but the rated COP of the R-290 compressor is 10% higher than the R-410A compressor, because R-290 is a more efficient refrigerant based on its thermodynamic cycle properties.

System Modeling and Heat Exchanger Selection

We used the DOE/ORNL Heat Pump Design Model to model the GE baseline WAC using R-410A, and calibrated the system to match the available product data. Table 2 compares the simulation with the product data, at the AHRI A condition,

Table 3: R-410A WAC model validation at the AHRI A condition

	Predicted by calibrated model	Published product data
Cooling Capacity [Btu/hr]	12,069	12,050
EER [Btu/hr/W]	12.1	12.1
SHR [%]	69%	68%
System charge [lbm]	1.61	1.65
Evaporating temperature [F]	50.0	N/A
Condensing temperature [F]	124.0	N/A
Evaporator exit superheat degree [R]	10	N/A
Condenser subcooling degree [R]	15	N/A
Subcooler temperature drop [R]	6.4	N/A

It should be mentioned, the predicted system balance points result in smaller pressure ratio than the compressor rated condition given in Table 2. A rotary compressor tends to have higher volumetric and isentropic efficiency with decreasing the pressure ratio. Thus, at the system balance points of 50°F/124°F suction and discharge saturation temperatures, it is assumed that the R-410A compressor volumetric efficiency would increase from 87% (rated) to 90%, and the isentropic efficiency would increase from

67% to 70%. Uncertainty of system charge prediction is 1.61 lbms (prediction) versus 1.65 lbms (product), i.e. 2.5% under-predicted.

Using the same heat transfer calibration factors as above, the system model was used to model the R-290 WAC, by changing the refrigerant to R-290 and replacing the compressor with Highly PSD162XW. For the R-290 compressor, we specified the known displacement volume and set the volumetric efficiency as 94% and the isentropic efficiency as 70%. Table 4 below gives the predicted values with and without the submerged subcooler, at 15°R condenser subcooling and 10°R evaporator exit superheat.

Table 3: R-290 system predictions with/without the submerged subcooler at the AHRI A condition

	With submerged subcooler	Without submerged subcooler
Cooling Capacity [Btu/hr]	11792	11415
EER [Btu/hr/W]	12.5	12.0
SHR [%]	70%	71%
System charge* [g]	328	263

* The system charge predictions were adjusted by adding 2.5% uncertainty.

It can be seen from Table 3, to match the charge target below 260 grams, the submerged subcooler has to be eliminated. Without the submerged subcooler, we can still achieve an EER >= 12.0, and cooling capacity > 10,000 Btu/h. The predicted charge is 263 grams, slightly higher than required.

In addition to eliminating the submerged subcooler, we have two measures to decrease the charge further, one is to reduce the subcooling degree and charge in the original system and the other is to modify the evaporator coil by using the same 5 mm (0.2 inch OD) tube size as for the condenser, while keeping the number of evaporator coil tubes unchanged.

Figure 8 shows EER and cooling capacity changes with system charge, using 0.2 inch tubes and 0.33 inch tubes in the evaporator respectively. Using 0.2 inch tubes will reduce the system charge effectively, but at the expense of decreasing the cooling EER and capacity due to the reduced evaporator tube surface area and larger refrigerant side pressure drop. Using 0.33 inch tubes with a lower design subcooling of 14 R results in 260 grams of R-290 charge. The predicted EER for a 260 g charge is roughly 12.0 with a capacity of 11 kBtu/hr.

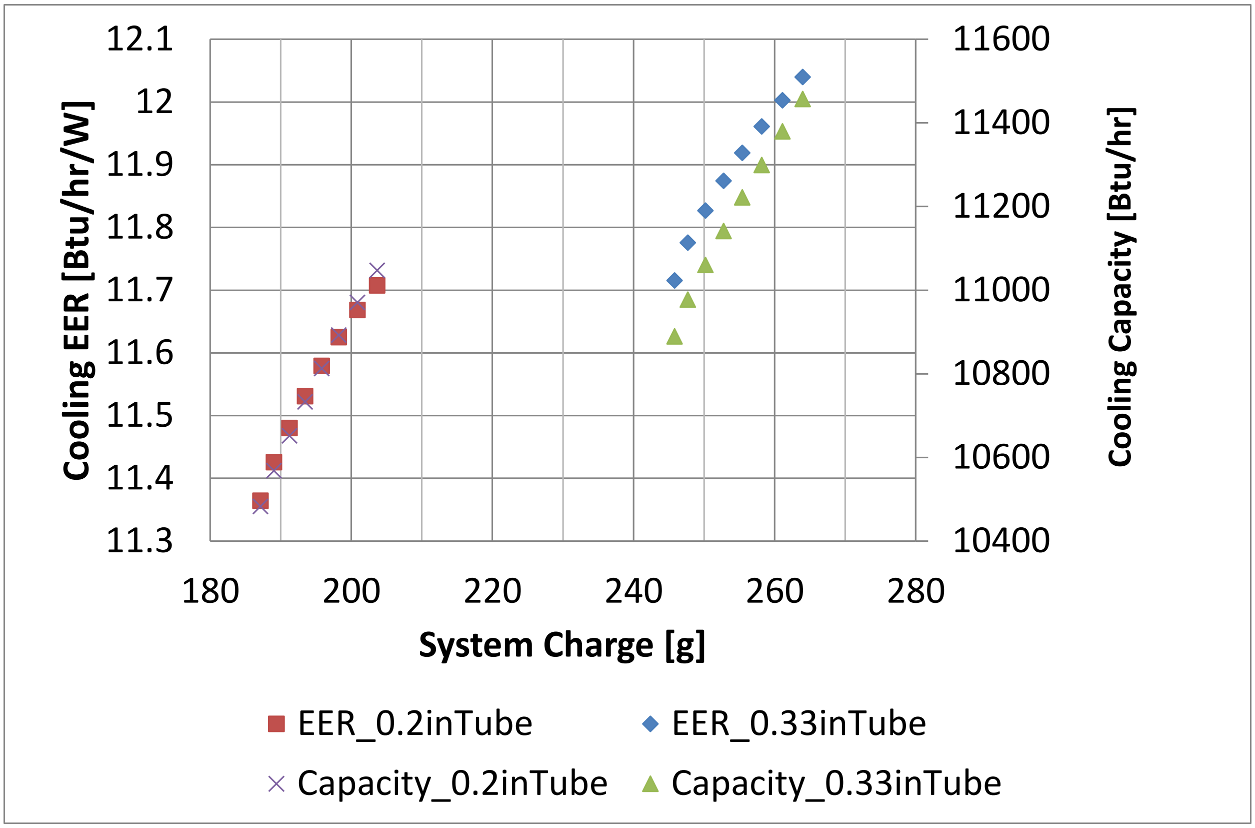

Figure 8: Predicted EER and Capacity as a function of the system charge, using 0.2 inch tubes and 0.33 inch tubes in the evaporator

The condenser coil won't be changed, as it already has 5 mm (0.2 inch) tubes and we want to maintain the water sling effect via keeping its connection with the water slinger and fan.

Summary

The calibrated R-290 WAC model demonstrates that the design goals, i.e. < 260 g charge, reaching 12 EER and > 10,000 Btu/hr cooling capacity can be achieved by eliminating the submerged subcooler and reducing the design subcooling level in the original GE WAC. If further charge reduction is needed, the evaporator can be modified by using 5 mm (0.2 inch) tubes at the expense of reducing the EER to 11.5 if using the same number of tubes. On the other hand, we can increase the tube number and redesign the evaporator to optimize the system efficiency to control the system charge to < 260 g. The evaporator optimization will be performed after the first round of lab testing using the baseline evaporator, if the lab testing demonstrates that the efficiency and capacity goals can't be met without violating the charge limit.

Reference

1. http://hydrocarbons21.com/articles/5417/us_epa_proposes_approval_of_4_hcs_in_6_ac_r_applications, U.S. EPA, 2014