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# Performance of an R-410A Room Air Conditioner Modified for Use with R-1234ze

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- Introduction
- Objective
- Mathematical Model
- System Modifications
- Experimental Results
- Conclusions



# Introduction

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- Senior design project to reduce the environmental impact of room air conditioners (RACs)
- 23% of households in the United States possess window or wall RACs <sup>[1]</sup>
  - » 25.9 million households
- Reductions in either direct or indirect greenhouse gas emissions can have a large impact



# Introduction

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- Focus on direct greenhouse gas emissions as requested by project sponsor
  - » Phasing out of hydrofluorocarbons (HFCs)
- Current refrigerants possess a high global warming potential (GWP)
  - » R-410A → GWP of 2,088 [2]



# Introduction

- GWP is the ratio of heat trapped by one unit mass of the greenhouse gas relative to one unit mass of gaseous carbon dioxide (CO<sub>2</sub>) over a specified time period [3]
- In mathematical terms:

$$GWP_i = \frac{\int_0^{TH} a_i x_i(t) dt}{\int_0^{TH} a_{CO_2} x_{CO_2}(t) dt}$$



# Introduction

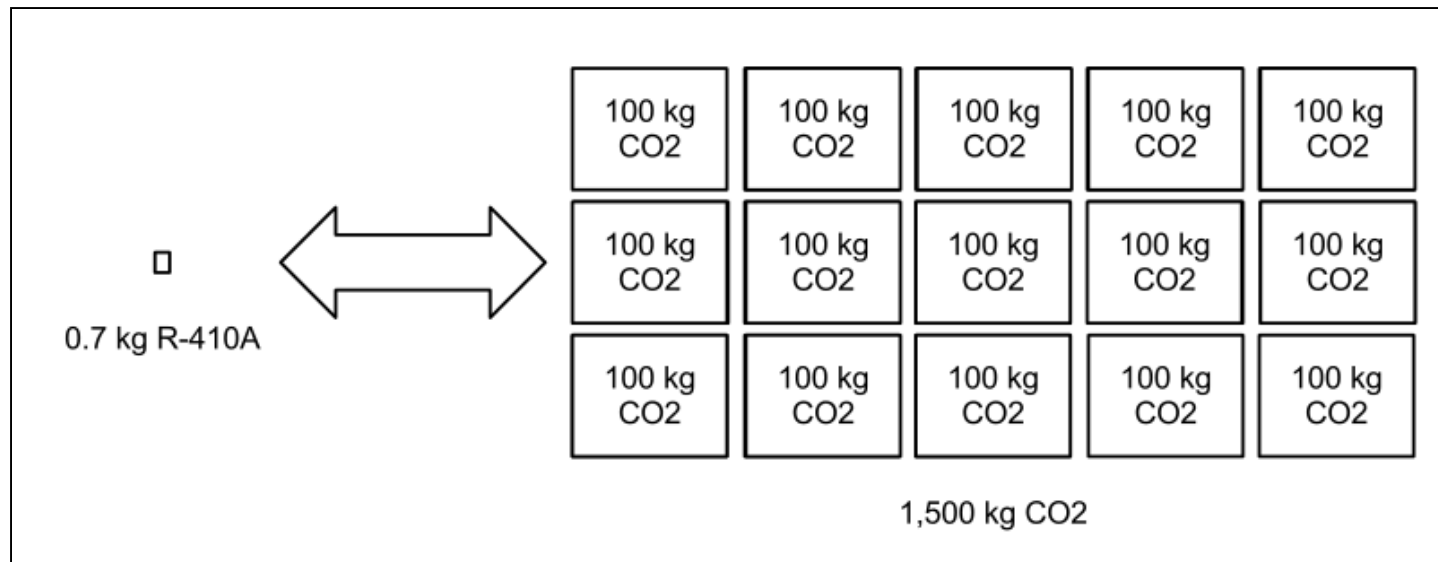
- Classification of GWP Values

<b>GWP Value (100 yrs.)</b>	<b>Designation</b>
1-30	Ultra Low
31-100	Very Low
101-300	Low
301-1000	Moderate
1001-3000	High
3001-10000	Very High
> 10000	Ultra High



# Introduction

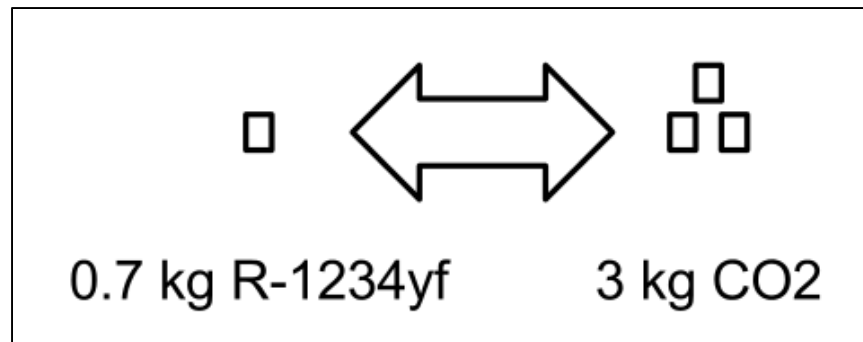
- Average RAC charge of 0.7 kg of a high-GWP refrigerant in the atmosphere (R-410A) [2]





# Introduction

- Average RAC charge of 0.7 kg of an ultra low-GWP refrigerant in the atmosphere (R-1234yf)



- Ultra low-GWP refrigerants offer a significant reduction in the environmental impact of RACs





# Objective

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- Analyze the operating performance of a 2.93-kW RAC with R-410A (current) and R-1234yf.
  - » Develop a mathematical model of the current RAC using data from the manufacturer
  - » Determine the system modifications necessary to achieve a 2.93-kW cooling capacity with alternative working fluid, R-1234yf
  - » Evaluate the model by comparing predicted results with experimental results



# Mathematical Model

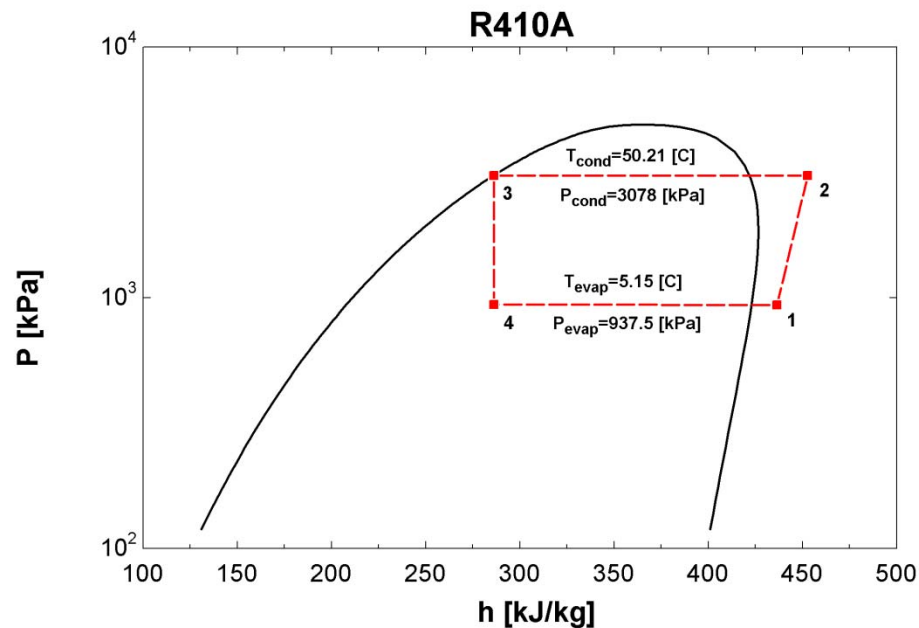


- Developed in Engineering Equation Solver (EES)
- Assumptions:
  - » System is operating at steady-state
  - » Pressure drop across each heat exchanger is negligible
  - » Refrigerant leaves condenser as a saturated liquid
  - » Volumetric efficiency of the compressor is 100%
  - » Changes in kinetic and potential energies of fluid are negligible
  - » Heat exchanger performance does not vary with fluid
  - » Pinch temperatures are constant
    - Evaporator: 22°C below indoor ambient
    - Condenser: 15°C above outdoor ambient



# Mathematical Model

- Predicted thermodynamic states of RAC with R-410A
  - » Derived from assumptions, test data from the manufacturer, and lab measurements of power into and heat lost from the compressor





# Mathematical Model

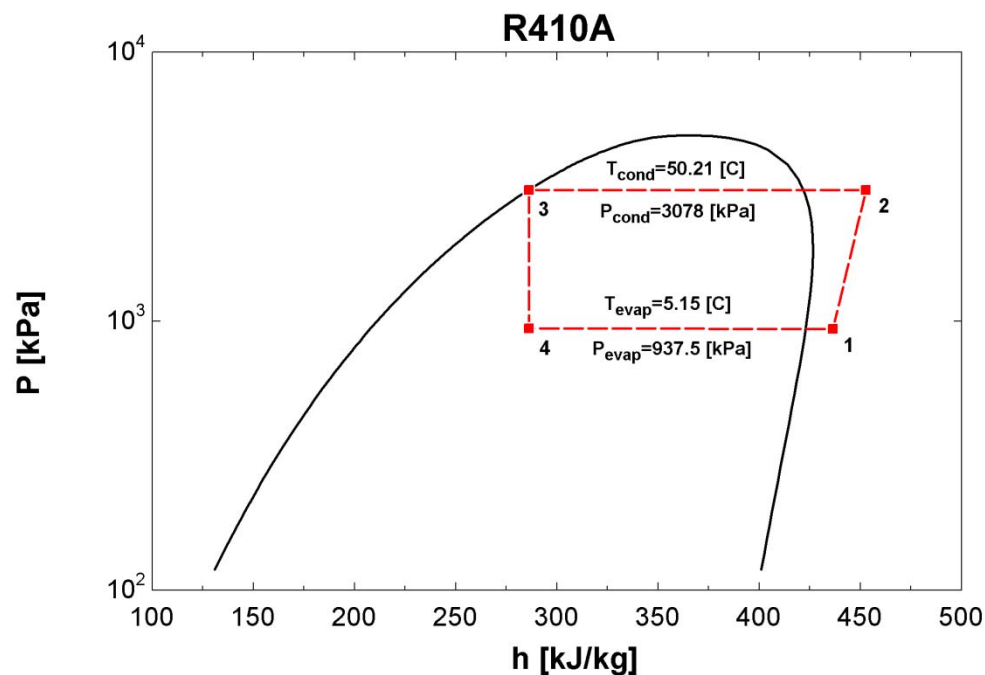
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- Based on the operating points, the mass flow rate of refrigerant was estimated using three different mass and energy balances:
  1. Energy balance on the compressor
    - Adiabatic operation
    - Isentropic efficiency of 68%
  2. Energy balance on the condenser
    - Saturated liquid at exit
  3. Energy balance on the evaporator
    - Isenthalpic expansion from condenser exit to evaporator inlet



# Mathematical Model

- Flow rates had a standard deviation of 7.4%
- The energy balance on the evaporator is expected to provide the most accurate estimate of flow rate

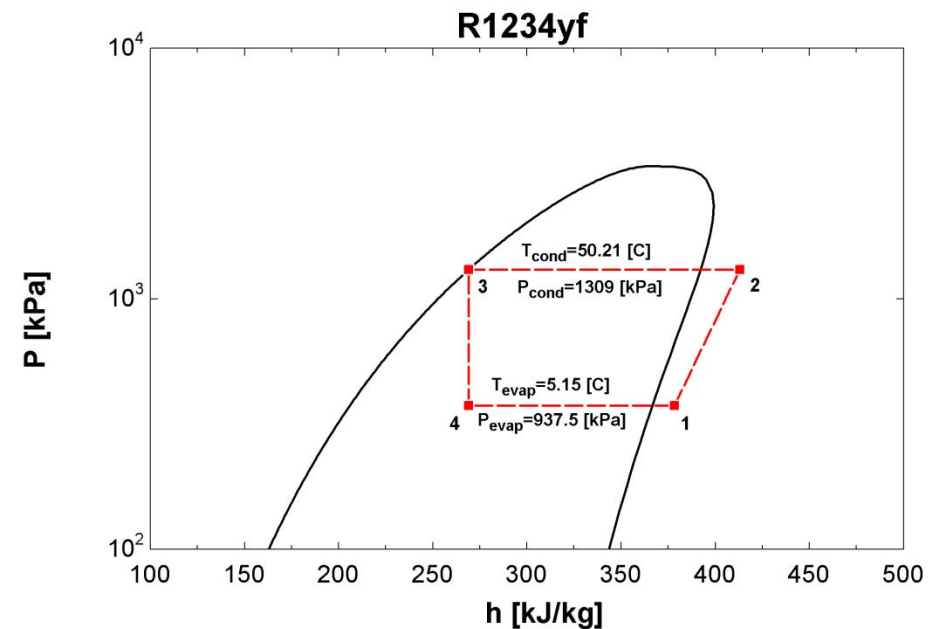
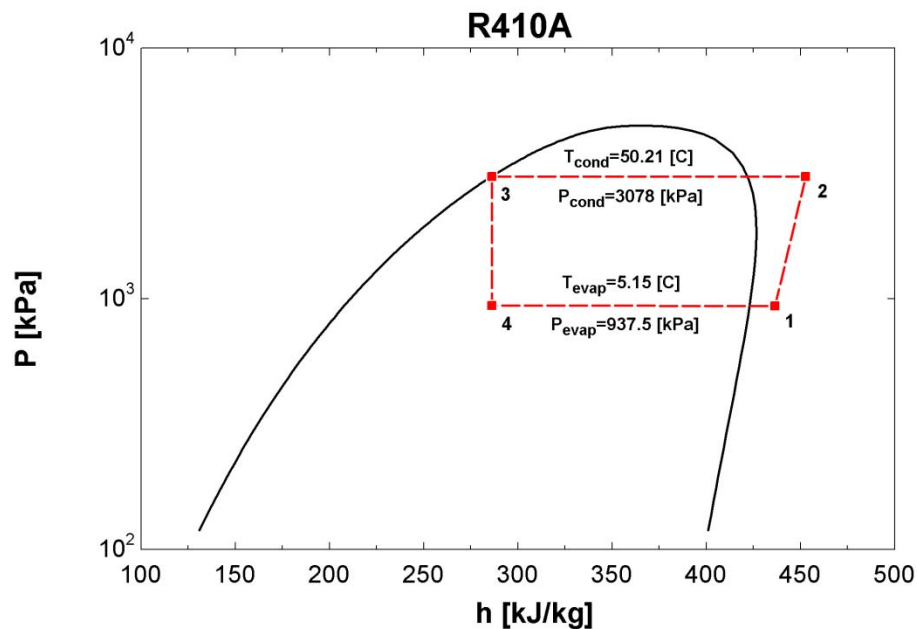


$$\dot{m} = \frac{\dot{Q}_{\text{evap}}}{h_1 - h_4}$$



# System Modifications

- Model was modified to use R-1234yf with the same cooling capacity and evaporator and condenser temperatures as the R-410A cycle





# System Modifications

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- Conditions of the refrigerant entering and leaving the evaporator are primarily a function of the heat source and sink temperatures
  - » Cooling capacity can be adjusted with mass flow rate
- Fixing the source and sink temperatures, R-1234yf experiences a smaller change in specific enthalpy than R-410A as it evaporates
  - » Mass flow rate must be increased to retain original cooling capacity
  - » Compressor is the single most important component to modify



# System Modifications



- New mass flow rate:

$$\dot{m} = \frac{\dot{Q}_{evap}}{h_1 - h_4}$$

- New volumetric flow rate:

$$\dot{V}_s = \frac{\dot{m}_s}{\rho_s}$$

- New required swept displacement for the compressor, assuming that it operates with 100% volumetric efficiency:

$$V = \frac{\dot{V}_s}{\dot{N}}$$





# System Modifications



- Final Design Changes
  - » Model recommended change in compressor's swept displacement:
    - $10.1 \text{ cm}^3 \rightarrow 23.61 \text{ cm}^3$
  - » Due to the similar properties of R-134a and R-1234yf, an R-134a compressor was chosen with a swept displacement of  $26.11 \text{ cm}^3$
  - » Model predicted new cooling capacity of 3.37 kW (15% increase)
  - » Capillary tubes were resized and replaced according to recommendations provided in compressor literature



# System Modifications



- Modified RAC





# System Modifications

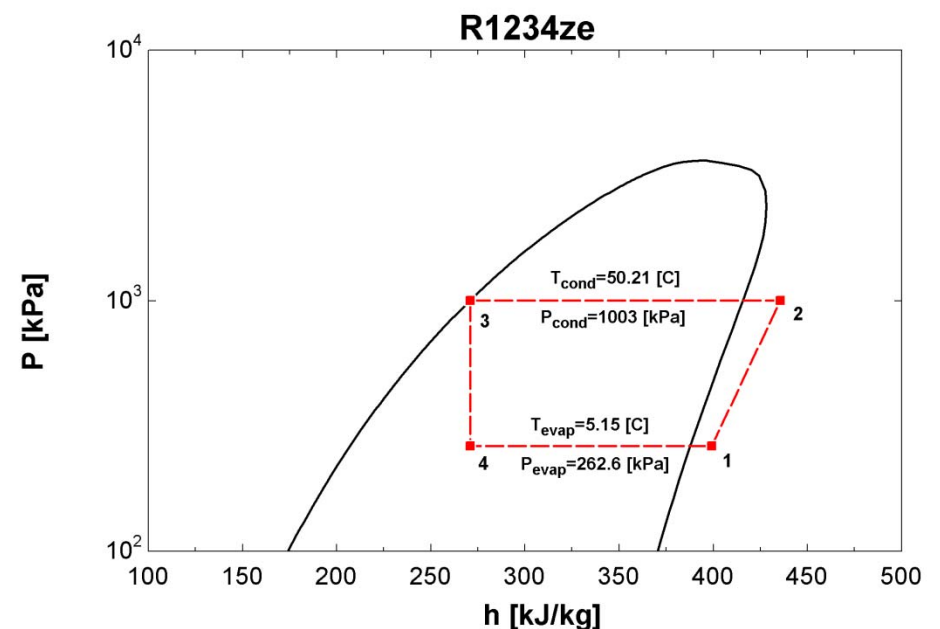
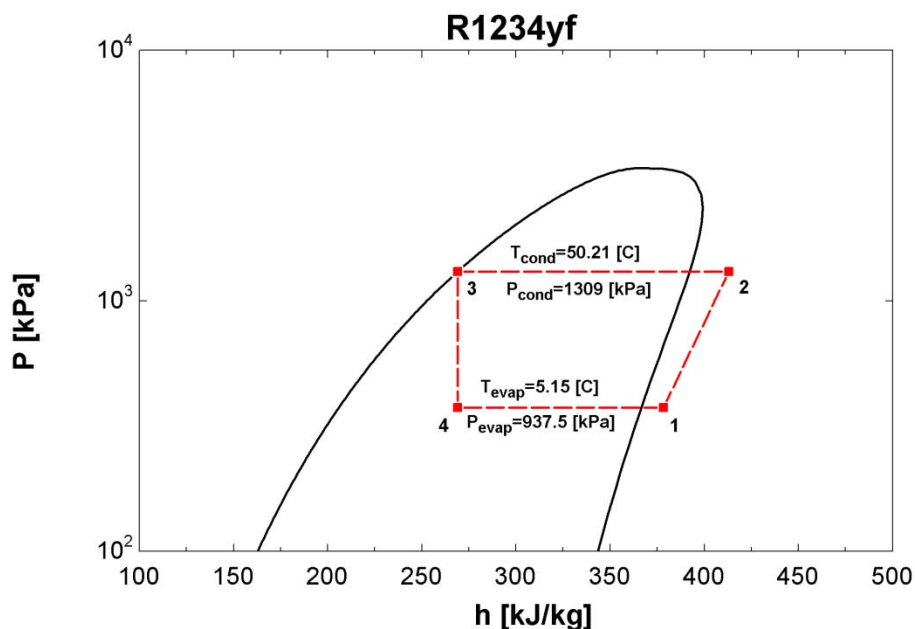


- Refrigerant change as per sponsor request
  - » R-1234yf → R-1234ze
    - Availability of refrigerant
    - Cost and flammability concerns
  
- Revised predicted cooling capacity
  - » 3.37 kW → 2.68 kW



# System Modifications

- Reduction in cooling capacity results primarily from a decrease in mass flow rate due to a lower density
  - » Density of R-1234ze at state 1 =  $9.92 \text{ kg/m}^3$
  - » Density of R-1234yf at state 1 =  $14.8 \text{ kg/m}^3$





# Experimental Results

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- In order to verify the model, RAC performance was tested using a single environmental chamber
- Chamber provided control over heat sink (outdoor space) temperature but not humidity
- Laboratory served as heat source (indoor space)
- Tests conducted with two different heat sink temperatures
  - » 11 °C and 28 °C above the indoor environment's temperature

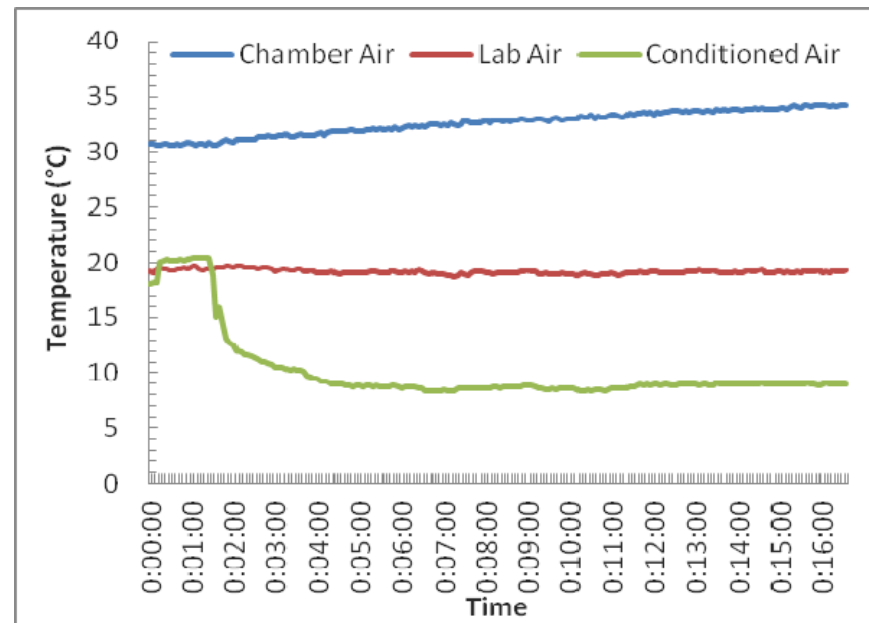


# Experimental Results



Assume pseudo-steady state operation due to inability to precisely control room temperatures and humidities

- Lab large enough to serve as the conditioned reservoir
- Temperature of the conditioned air did not vary by more than 0.83 °C over 12 minutes of RAC operation
- Humidity of indoor air was 30% at beginning and end of test





# Experimental Results

Conditions	Unconditioned Air Temperature (°C)	Unconditioned Relative Humidity (%)	Conditioned Air Temperature (°C)	Conditioned Relative Humidity (%)	Outdoor Temperature (°C)	Outdoor Relative Humidity (%)
$\Delta T=11\text{ }^{\circ}\text{C}$	19.1 $\pm$ 0.56	31 $\pm$ 2.5	9.06 $\pm$ 0.56	73.7 $\pm$ 2.5	30 $\pm$ 0.56	23.3 $\pm$ 2.5
$\Delta T=28\text{ }^{\circ}\text{C}$	19.1 $\pm$ 0.56	31 $\pm$ 2.5	10.4 $\pm$ 0.56	68.5 $\pm$ 2.5	47 $\pm$ 0.56	15.4 $\pm$ 2.5

Conditions	Cooling Capacity (kW)		Percent Difference Between Measured and Predicted (%)
	Predicted	Measured	
$\Delta T=11\text{ }^{\circ}\text{C}$	2.13	2.48	16.35%
$\Delta T=28\text{ }^{\circ}\text{C}$	1.74	1.94	11.62%



# Conclusions

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- The refrigeration cycle of a 2.93-kW RAC that utilizes R-410A (High GWP) was successfully modeled
- The model was successfully used to determine the system modifications required for the use of R-1234yf (Ultra Low GWP)
- The model was used to predict performance with the new compressor and capillary tubes with R-1234ze as the working fluid





# Conclusions

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- From experimental results it was determined that the model predicted the cooling capacity to within 16%, warranting further testing
- Despite the modified RAC being too large and heavy for practical use, the feasibility of utilizing an alternative, ultra low GWP in place of a high GWP HFC refrigerant was demonstrated



# Acknowledgments



- The team would like to thank both Whirlpool Corporation, for the resources they provided as the project sponsor, and Bob Cristan, for the knowledge he shared with the team and his donations to the project.



# Questions?

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# References

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- [1] "Residential Energy Consumption Survey Data: Fuel used and end uses by type of housing unit," 2009. [Online]. Available: <http://www.eia.gov/consumption/residential/data/2009/>
- [2] Environmental Protection Agency, "Transitioning to Low-GWP Alternatives in Unitary Air Conditioning," October 2010. [Online]. Available: [http://www.epa.gov/ozone/downloads/EPA\\_HFC\\_UAC.pdf](http://www.epa.gov/ozone/downloads/EPA_HFC_UAC.pdf)
- [3] P. Blowers, "Environmental Foresight: Estimating Global Warming Potentials with Published Data," Syracuse University College of Engineering and Computer Science, [Online]. Available: [http://lcs.syr.edu/centers/SustainableEngineering/modules/08-3\\_Blowers.pdf](http://lcs.syr.edu/centers/SustainableEngineering/modules/08-3_Blowers.pdf)