Albatross Energetics - LP - HVAC System Design

Date: December 7, 2024

Contents

1. Model Details

1.1. Air Conditioner

The model uses refrigeration cycle with R-290 (Propane) as refrigerant. There are four equipments in the refrigeration cycle. Namely, evaporator, compressor, condenser and the expansion valve. The evaporator and condenser and fin tube heat exchangers. In evaporator the coolant absorbs heat from the indoor air and turn into superheated vapor phase form liquid vapor mixture. This superheated vapor is compressed in a screw compressor where the pressure of vapor is increased up to the operating pressure of condenser. In condenser the coolant fluid exchanges heat with the outdoor air. Thereby transitioning to the sub-cooled liquid of same pressure. The high pressure sub-cooled liquid undergoes isentropic expansion in the expansion valve to a vapor liquid mixture which goes to evaporator.

In the simulink model apart form these four blocks a liquid receiver and flow resistance are used. The liquid receiver represents the coolant holdup present in the system which will account for the unsteady flow rates of coolant at different locations in the coolant circuit. The flow resistance represents the pressure drop due to piping in the coolant circulation loop for real system.

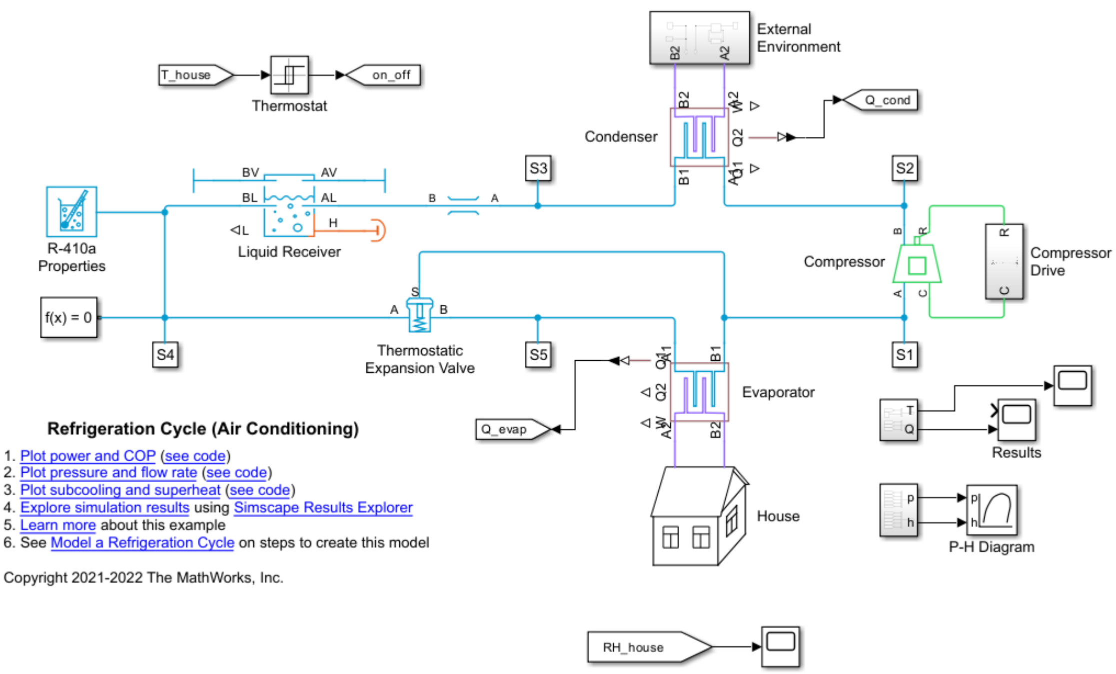

Figure 1: Model of a vapor compression-based air conditioning (AC) system [1]

1.2. Dehumidifier

The moist air stream returning from the evaporator is the coldest moist air stream in the system. Thus the capacity to hold moisture is lowest in this stream. Thus moisture will condense into droplets which is removed by a dehumidifier is present in this stream. The dehumidifier block removes the condensed water droplets in the stream and some amount of water vapor present.

1.3. Indoor Environment

The indoor environment is modeled with a house volume which exchanges heat with surrounding through walls, roof, windows. Heat transfer takes place between the indoor environment and outdoor through the wall, window and roof from exterior to interior side. Heat exchange in the room occurs through a combination of convection and conduction. The rooms volume affects the rate of change in temperature and humidity as a larger volume which will slow down the variations due to the higher air capacity thus increasing the time constant of the process. Apart from that the indoor heat generation due to various activities and the presence of occupants is modeled using heat flow rate source block in simulink. Overall the heat exchange in the room is the continuous process and there is the dynamic thermal interactions between the room's surface and its air.

Moreover, the moisture gain due to occupants in the room are taken into account using a moisture source block in simulink.

1.4. Outdoor Environment

The outdoor environment is modeled using two reservoirs at specified environment temperature and relative humidity. A fan is used which facilitates the flow of outdoor air to exchange heat from the coolant at the condenser.

1.5. System Parameters

Parameter	Symbol	Value
Refrigerent Mass flow rate	$\dot{m}$	0.0852671 kg/s
Condenser pressure	P_{cond}	1.88202 MPa
Evaporator pressure	P_{evap}	0.848185 MPa
Thermostatic expansion valve opening fraction	–	1

Table 1: Key operating parameters of the refrigeration system.

Parameter	Symbol	Value
Initial environment temperature	T_{env}	30 °C
environment relative humidity	RH_{env}	0.5
Initial house temperature	$T_{\text{house, init}}$	30 °C
Initial house relative humidity	$RH_{\text{house, init}}$	0.5
DBT set point	T_{set}	27 °C
Relative Humidity set point	RH_{set}	0.4658
Refrigerant tube diameter	D_{tube}	0.02 m
Air duct width	W_{duct}	0.4 m
House length	L_{house}	20 m
House width	W_{house}	10 m
House height	H_{house}	6 m
Roof pitch angle	θ_{roof}	40°

Table 2: Key system parameters for the refrigeration simulation.

2. Controller Logic

The wet bulb temperature is the measure of humidity instead of wet bulb temperature the relative humidity is calculated and controlled. For the wet bulb temperature set point of 19^0C and dry bulb temperature set point of 27^0C the corresponding relative humidity set point will be 0.4658.

2.1. Compressor Fan RPM

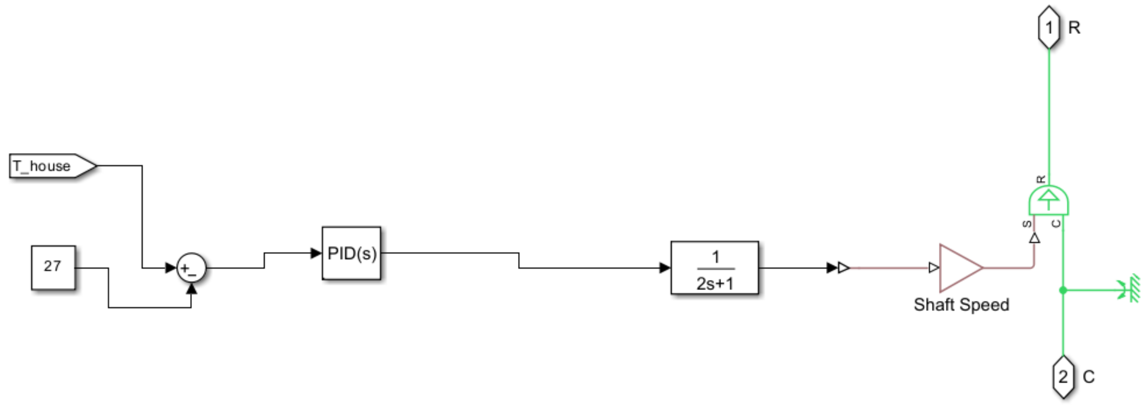

Figure 2: Compressor Driver Control Loop

Higher the compressor RPM higher will be the circulation of coolant thus the AC will be able to transfer more heat from the indoor. Thus if the indoor temperature is higher than its set point then the compressor RPM should be increased. Therefore a direct PID controller as shown in figure 2 is implemented.

2.2. Evaporator Fan RPM

The evaporator fan speed controls the flow rate of air from indoor exchanging heat with the coolant and the air which is getting dehumidified. Thus higher evaporator fan speed will decrease the indoor temperature and the indoor relative humidity. Out of which the effect of relative humidity is higher thus a direct PID controller is implemented as shown in the figure 3 is implemented. Moreover to ensure that there is enough flow rate of air exchanging heat with the coolant for temperature control a minimum threshold is provided for the evaporator fan control action.

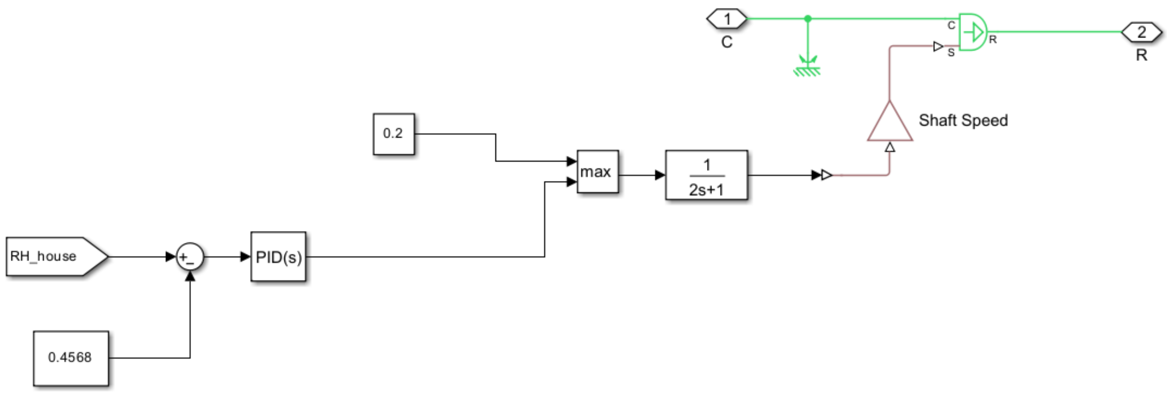

Figure 3: Evaporator Fan Driver Control Loop

2.3. Condenser Fan RPM

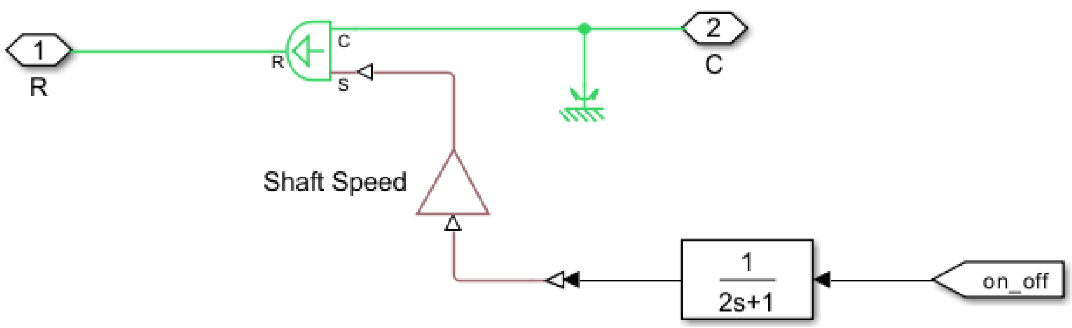

Figure 4: Condenser Fan Driver Control Loop

The condenser fan flow rate affects the heat transfer between the outdoor environment and the coolant. Thus an on-off controller is used which will control the RPM of condenser fan as shown in figure 4.

3. Performance Metrics

3.1. ISEER Methodology

To calculated ISEER the steady state values of evaporator heat duty, compressor power consumption, condenser fan and evaporator fan power consumption are obtained at different environmental temperatures as provided in the table. Then Cooling Seasonal Total Load (CSTL) and Cooling Seasonal Energy Consumption (CSEC) is calculated by taking the sum product of evaporator duty and total power consumption with bin hours for corresponding environment temperature. Then the ISEER ratio i.e. of CSEL by CSTC is calculated.

ISEER for full load is 0.03508. Which is below 1 star rating.

4. Performance and Output Requirements

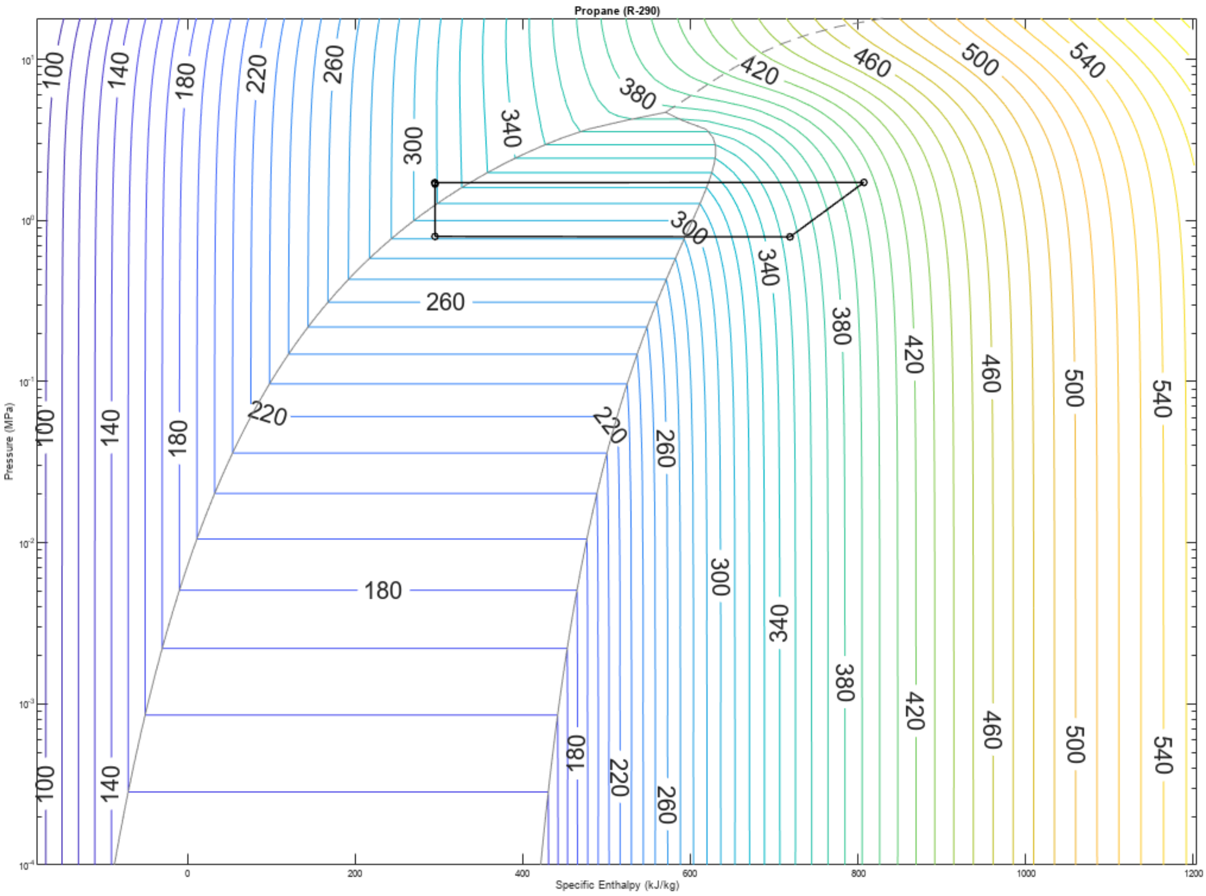

Figure 5: Pressure-Enthalpy (P-h) Chart of the Refrigeration Cycle

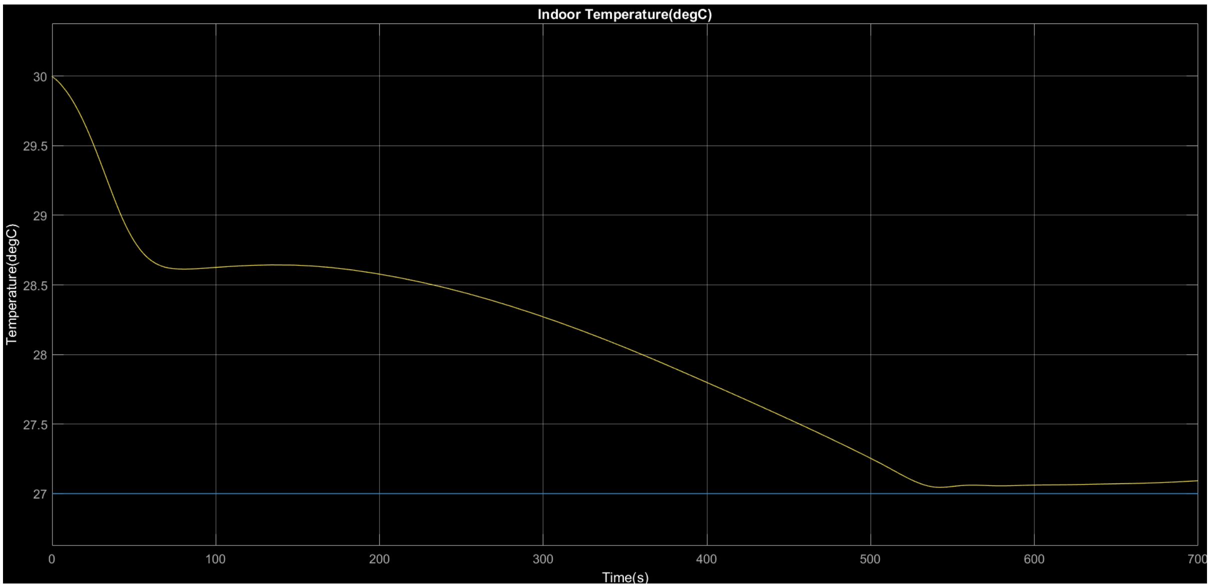

Figure 6: Dry Bulb Temperature Plot

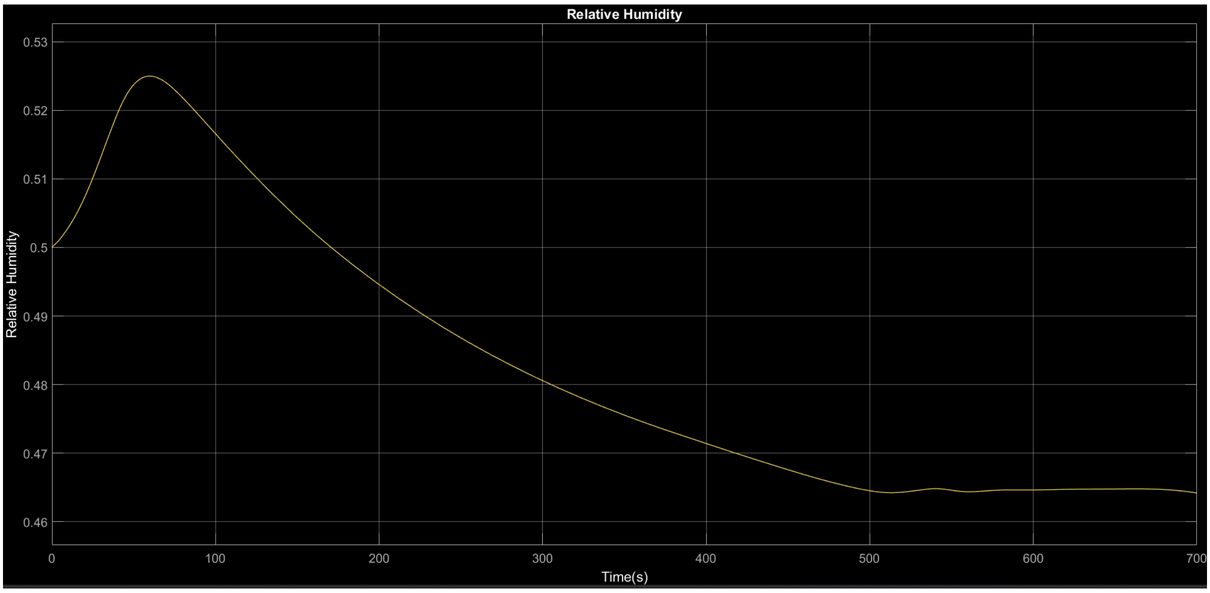

Figure 7: Relative Humidity Plot

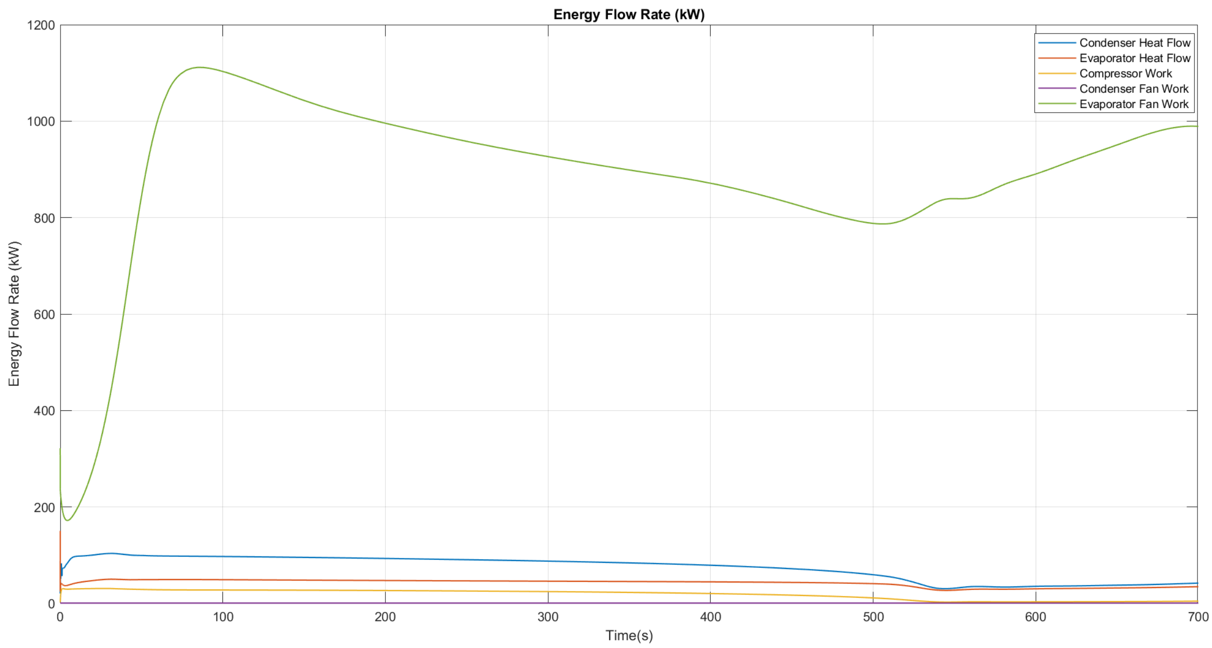

Figure 8: Cooling Delivered, Power Consumption, and Energy Efficiency Ratio (EER)

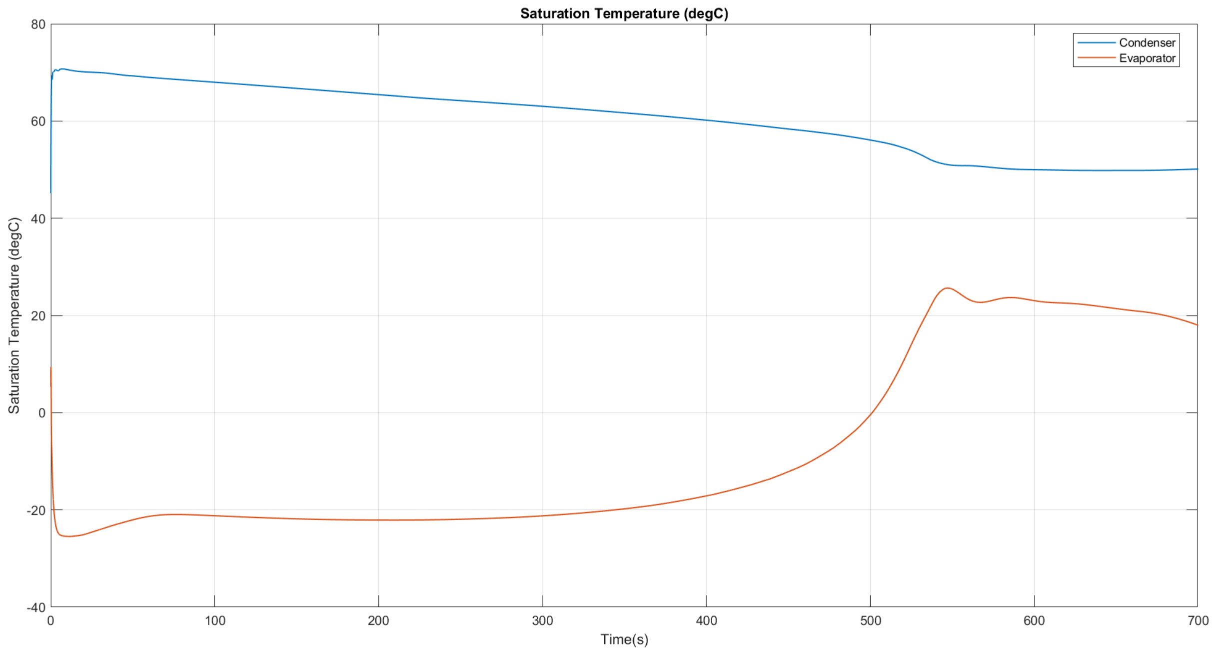

Figure 9: Condenser and Evaporator Saturation Temperatures

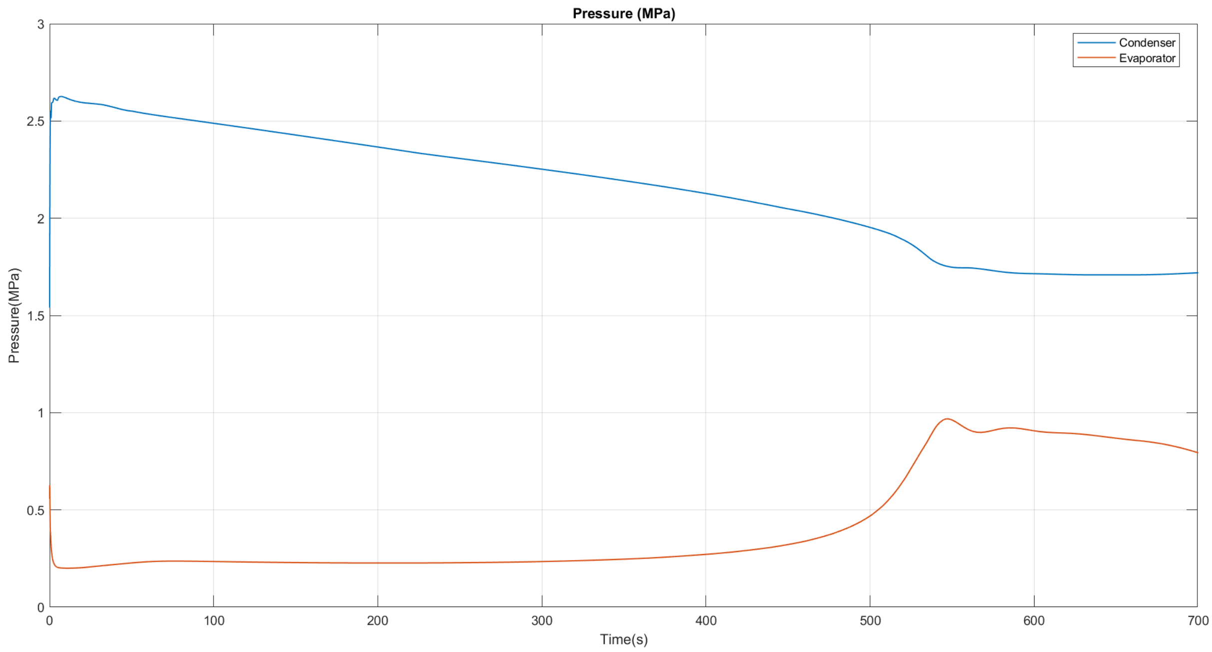

Figure 10: Condenser and Evaporator Pressures

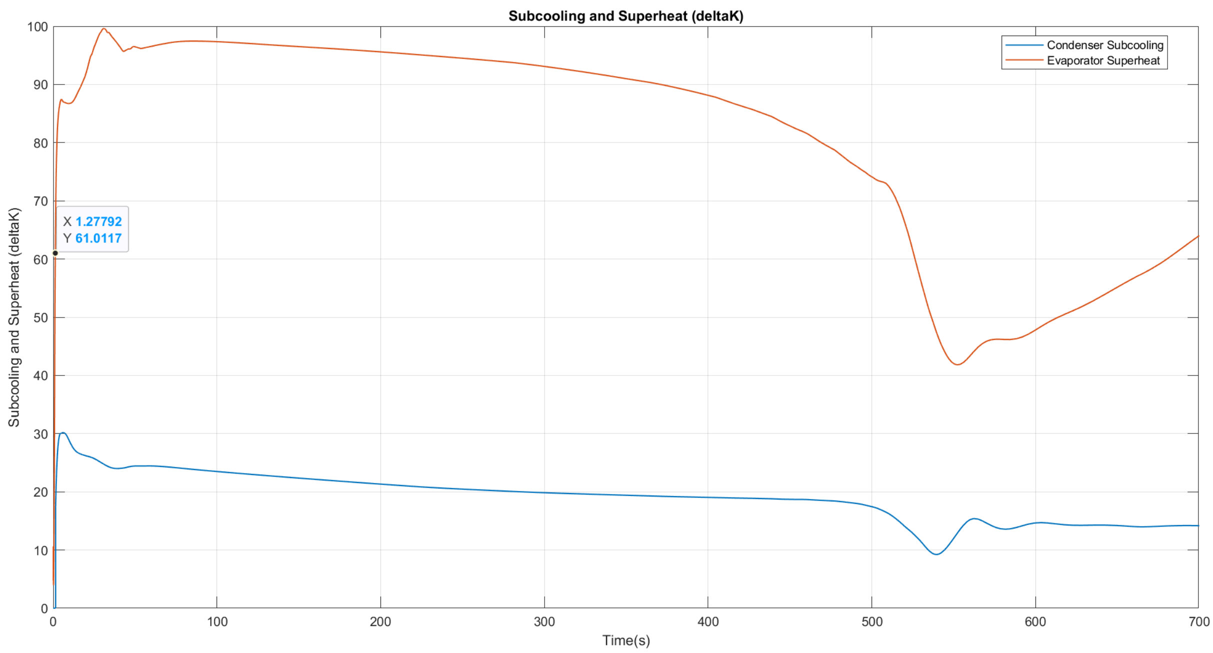

Figure 11: Superheating and Subcooling

5. Key Innovations and Environmental Considerations

The controller logic developed is robust and simple. In this project Propane (R-290) is used as the refrigerant. It has GWP of 3 which is very less compared to widely used industrial refrigerants such as (R-134a, R-410a, etc.) making the developed model environment friendly. [2]. R-290 is non toxic but highly flamable thus falls under safety classification of A3 [3].

6. Cost Analysis

The operational cost analysis focuses on the total energy consumed to maintain the desired indoor conditions. The total work done (in kW) represents the energy consumed by the air conditioning system, including the compressor fan, Evaporator fan and Condenser fan. As a standard cost of INR 6.47 per kWh, the total operational cost is calculated as Total Cost = Total Work Done × Bin Hours × INR 6.47. Here, "bin hours" refers to the number of hours the AC operates under specific conditions. This approach provides an accurate estimate of the energy expenditure based on the system's workload and the electricity rate.

As per the given bin condition we got the operational cost upto INR 1,02,29,892.06. Therefore, INR 184.437 will spend for the 1kW of work done by AC.

The expenditure cost analysis for the AC system includes components such as the compressor, evaporator, condenser, and refrigerant, like isopropane. These components have associated costs for procurement and installation. The variable costs stem from ongoing energy consumption, maintenance, and potential repairs.

Price of the element as per our model:

- Evaporator and Condenser Coil price INR 12000 (INR 6000 $\times$ 2) [4]
- Compressor price INR 30,000 [5]

Therefore, after estimating cost of other equipments our model price will cost INR 50,000.

7. Conclusion

In conclusion, while our model demonstrates unique and simplified controller logic, it falls short in terms of energy efficiency as indicated by a low Coefficient of Performance (COP) and ISEER value, which is significantly below the benchmark for even a 1-star rating. This inefficiency implies higher operational costs, making the model less cost-friendly.

However, our choice of propane (R-290) as the refrigerant contributes significantly to environmental sustainability. Propane has a Global Warming Potential (GWP) of just 3, which is negligible compared to conventional refrigerants like R-134a or R-410a. This makes our system an environmentally friendly alternative while aligning with global efforts to reduce greenhouse gas emissions.

Additionally, our model successfully reached the set point temperature value within the stipulated time of 600 seconds (10 minutes), demonstrating effective and responsive performance under the defined operational conditions.

Despite the limitations in energy efficiency, the innovative and robust controller logic ensures operational simplicity and reliability. With further optimization, particularly in energy efficiency aspects, this model has the potential to be both cost-effective and eco-friendly.

References

[1] [Online]. Available: https://in.mathworks.com/help/hydro/ug/residential-refrigeration-unit.html

[2] M. S. Ciprés, "Six reasons to use propane as refrigerant," Mar 2020. [Online]. Available: https://www.carel.com/blog/-/blogs/six-reasons-to-use-propane-as-refrigerant

[3] "R290 | product information." [Online]. Available: https://www.agas.com/au/products-services/refrigerants/r290/

[4] "Ac condensor evaporator coil." [Online]. Available: https://www.indiamart.com/proddetail/ac-condenser-2854344640855.html

[5] "Ac compressor." [Online]. Available: https://www.indiamart.com/proddetail/air-conditioning-compressors-27477473430.html