Parametric Study of a Walk-in-Freezer Renewable Energy Heat

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Abstract

Motivated by the imperative to enhance energy efficiency and environmental sustainability, this parametric study delves into the optimization of a walk-in freezer system for a fictional restaurant situated in Hamburg. Our goal is to identify the most efficient combination of refrigerant; condenser, and evaporator temperatures tailored to the specific operational context. Hamburg's climate, characterized by fluctuating temperatures, necessitates a nuanced parameter selection for optimal performance. This study aims to provide a customized solution aligning with the restaurant's cooling requirements and our commitment to energy conservation and responsible refrigerant choices.

Table of Parameters

Dimension of walk-in freezer	4x3x2 [m]	Condenser temperature midpoint	+20 ℃
Total surface area	52 m^2	Evaporator temperature midpoint	-10 ℃
Desired room temperature	-18 ℃	Selected condenser temperature	29.8 ℃
Heat pump model	JAE-200P (fictional)	Selected evaporator temperature	-28 ℃
Compressor efficiency	80 %	Selected cooling demand (Q_{demand})	411.55 W
Wall material	Polyurethane (10 cm)	Selected refrigerant	R290 (Propane)
Ceiling material	Polyurethane (13 cm)	Selected compressor power	200 W
Floor material	Concrete (20 cm)	Average yearly COP	2.06
Average yearly temperature	9.83 ℃	Average yearly refrigerator efficiency	0.5
NH_3 Post-compression T	163.1 ℃	R290 Post-compression T	50.1 ℃
NH_3 Post-compression S	6709.78 J/kg K	R290 Post-compression S	2480.54 J/kg K
Thermal coeff. k of Concrete	0.11 W/mK	Thermal coeff. k of Polyurethane	0.022 W/mK

1. Introduction

This study analyzes temperature distributions in the region of Hamburg, as depicted in **Figure 1**, indicating an average yearly temperature of approximately 10 ℃. The objective of our parametric study is to optimize a walk-in freezer system for a Hamburg-based restaurant by considering key factors such as refrigerant, condenser, and evaporator temperatures. The relevant data is detailed in the accompanying table above.

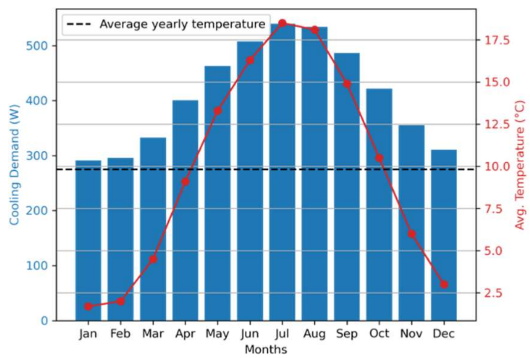

Figure 1: Monthly cooling demand and average monthly temperatures in Hamburg.

2. Power Demands

In a walk-in freezer or refrigerator, the cooling demand refers to the thermal load imposed on the refrigeration system to maintain the desired low temperature within the freezer enclosure (-18 ℃). To calculate this cooling demand Q_{demand} we use the following equation,

$$Q_{demand} = \frac{k}{L} \cdot A \cdot \Delta T$$

where k is the thermal conductivity coefficient, L the thickness of the freezers walls, A the entire surface of the insulator area and ΔT the difference between the desired freezers temperature and the outside temperatures we saw in **Figure 1**. Also in this figure, the calculation of the cooling demand can be observed for the different months of the year with our selected key parameters.

To improve our room insulation, the thermal conductivity k of different insulation materials for walls and ceiling were investigated. Three common types of materials used in Industrial Refrigeration Systems (polystyrene, cellular glass and polyurethane) were analyzed using both the upper and lower limit of typical k values. The cooling demand obtained from the analysis indicated that the best insulating material for the range of k values used was polyurethane, offering the lowest Q_{demand} values necessary to cool the walk-in freezer to our desired temperature.

3. COP Analysis

To determine the optimal refrigerants for our cold room, a comprehensive analysis of the Coefficient of Performance (COP) and the efficiencies was integral to our parametric investigation. Seven potential refrigerants underwent scrutiny across a specified scenario, encompassing a range of evaporator and condenser temperatures deviating by ±10°C from estimations of +20°C and -10°C relative to the average yearly temperatures for our condenser and evaporator, respectively. The CoolProp library in Python facilitated this evaluation, allowing COP calculation through a detailed assessment of the heat cycle within our system. Employing thermodynamic principles, COP was defined as the ratio of heat absorbed during evaporation to the power input, expressed as $COP = \frac{heat_{evap}}{power}$, where power is represented by $P = m \cdot (h_3 - h_2)$. Here, $\boldsymbol{heat_{evap}}$ corresponds to the previously computed cooling power demands, m signifies the mass flow rate of the compressor, and h_3 and h_2 denote the enthalpies at points 3 and 2 of the thermodynamic cycle. Also, the efficiencies were calculated using the formula $\eta = \frac{COP}{COP_{carnot}}$, in which η is the efficiency (ranging from 0 to 1) and COP_{carnot} is the calculated COP for an ideal scenario, depending only in the selected evaporator and condenser temperature. The resulting values were visualized in **Figure 2**, providing a comparative framework for the refrigerants. Ammonia and propane emerged as highly efficient options, surpassing others eliminated due to environmental concerns. Consequently, the refrigerant selection was refined to include only ammonia and propane, with ammonia exhibiting marginal efficiency advantages and the additional benefit of non-flammability, albeit with toxicity considerations.

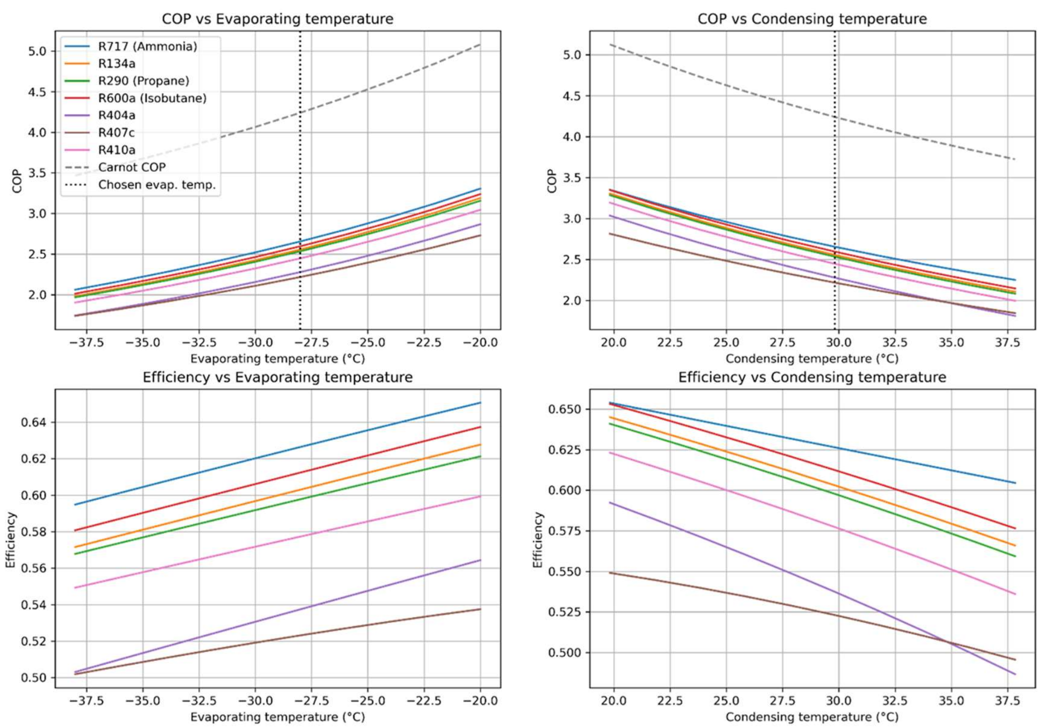

Figure 2: COP/efficiency comparison for different refrigerants

4. T-s Diagrams

To finalize the choice of refrigerant, we conducted T-s and P-h analyses. The T-s diagram **(Figure 3)** highlighted ammonia's post-compression temperatures exceeding its critical point and extremely high entropies and enthalpies, necessitating a potential system redesign. This led us to opt for propane, as its T-s diagram indicated lower post-compression temperatures and entropies, avoiding the need for extensive modifications and potential infrastructure cost increases associated with ammonia's higher temperature differences.

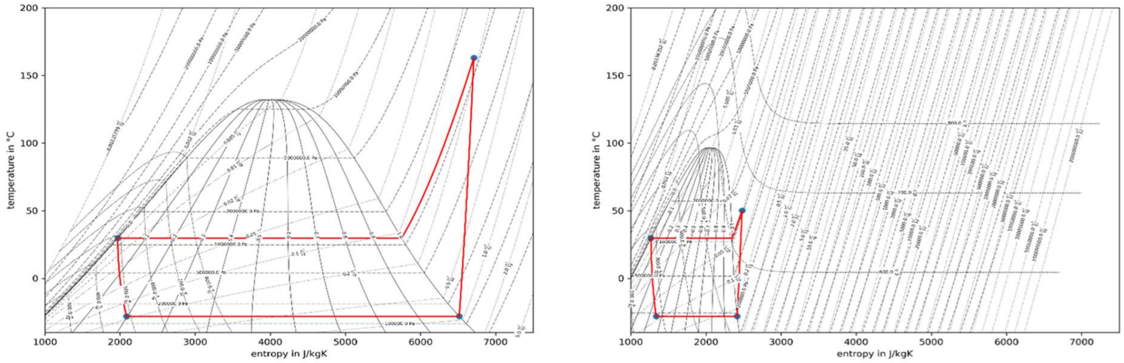

Figure 3: T-s diagrams of Ammonia and Propane respectively

5. Monthly COP

Selecting R290 as the refrigerant and maintaining the compressor power at 200 W, we recalculated the Coefficient of Performance (COP) based on average monthly cooling demands over the year. The results, depicted in **Figure 5**, reveal an annual average COP of 2.06 and an efficiency of 0.50.

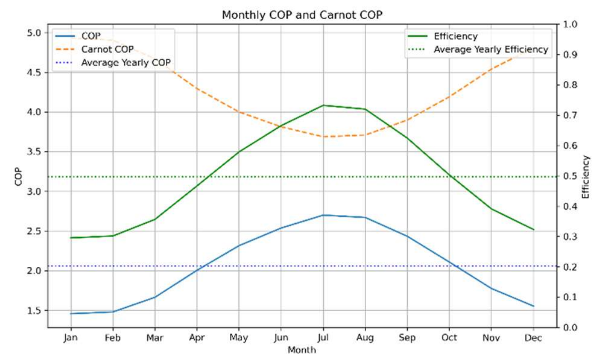

Figure 4: Monthly COP and efficiency

6. Conclusion

In our thorough assessment of three insulation materials, Polyurethane (PU) emerged as the optimal choice due to its narrow thermal conductivity coefficient range, providing superior energy efficiency and reducing cooling demands.

The selection of R290 (Propane) as the refrigerant for our walk-in freezer system is a prudent decision, driven by its environmentally friendly nature, commendable energy efficiency, and non-toxic properties.

Our extensive analysis of Coefficient of Performance (COP) and system efficiency has revealed nuanced relationships between temperature variations, cooling demands, and refrigerant selection. These findings highlight crucial considerations for optimizing energy efficiency in refrigeration systems.

Future optimization efforts focus on enhancing energy efficiency, refining temperature control mechanisms, and integrating intelligent technologies for advanced monitoring and management capabilities. These initiatives aim to promote sustainability and operational excellence in refrigeration systems.

7. Sources

[1] Drisdelle, T. (2022). *What Refrigerant is Used in Commercial Refrigerators?* [online] HABCO. Available at: https://habcomfg.com/what-refrigerant-is-used-in-commercial-refrigerators/.

[2] INTARCON (2019). *Substitute natural refrigerants*. [online] INTARCON. Available at: https://www.intarcon.com/en/substitutive-natural-refrigerants/ [Accessed 7 Feb. 2024].

Parametric Study of a Walk-in-Freezer "Exploring Sustainable Solutions for Cold Storage" by JM Boullosa, A. Jimenez and E. Atalan, 2024 [Presentation and code] Also available in Github: https://github.com/boujuan/Renewable_Energy_Heat