# 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 m² | 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 |
| NH₃ Post-compression T | 163.1 ℃ | R290 Post-compression T | 50.1 ℃ |
| NH₃ 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 °C. 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.
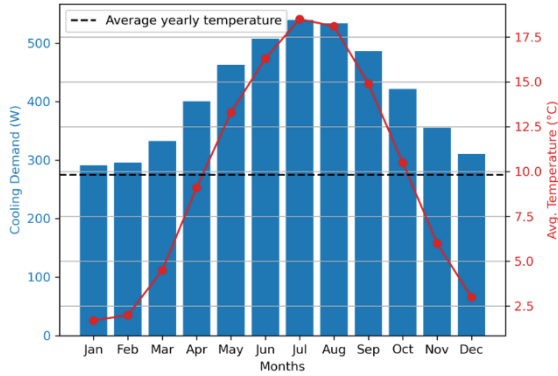


*Figure 1: Monthly cooling demand and average monthly temperatures in Hamburg.*

# 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 °C). 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 $\Delta T$ 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, $heat_{evap}$ 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 $\eta$ 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.
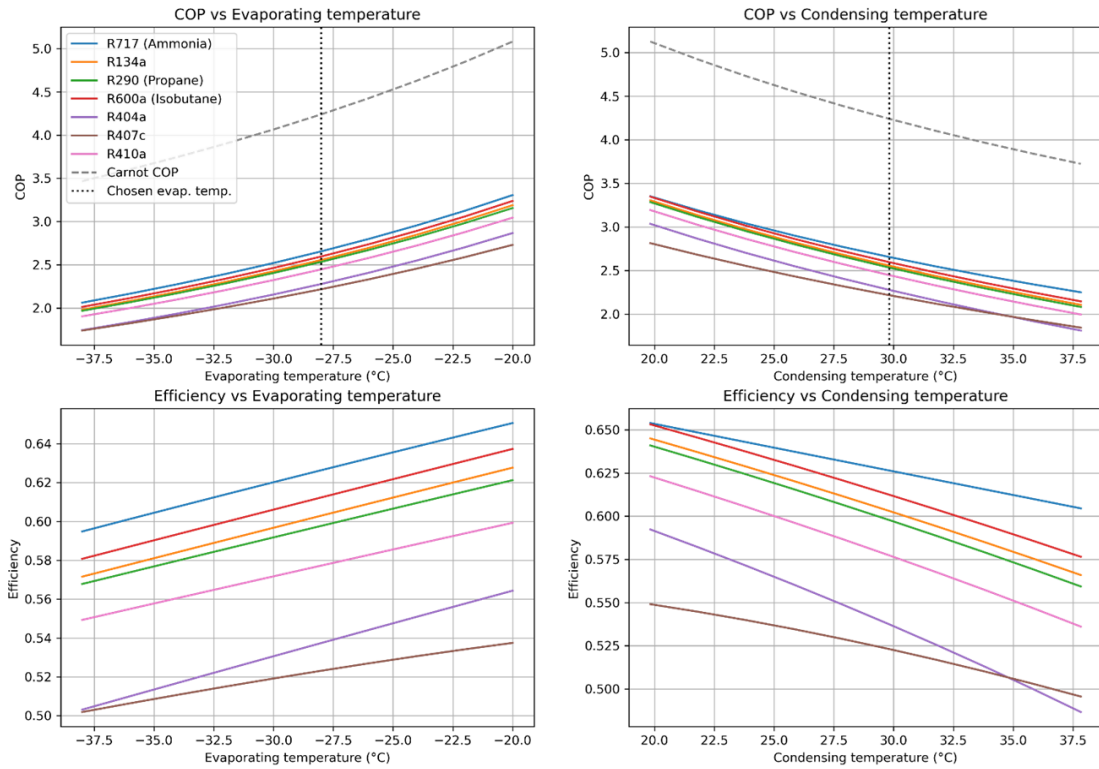


*Figure 2: COP/efficiency comparison for different refrigerants*

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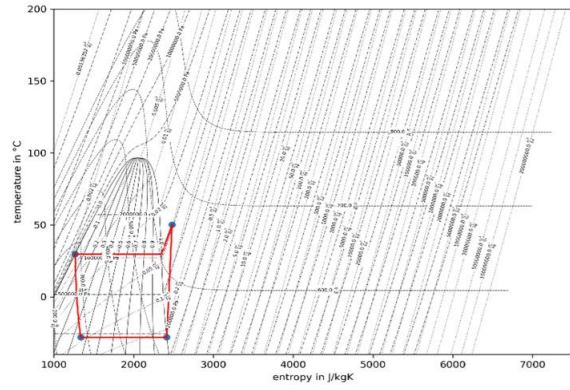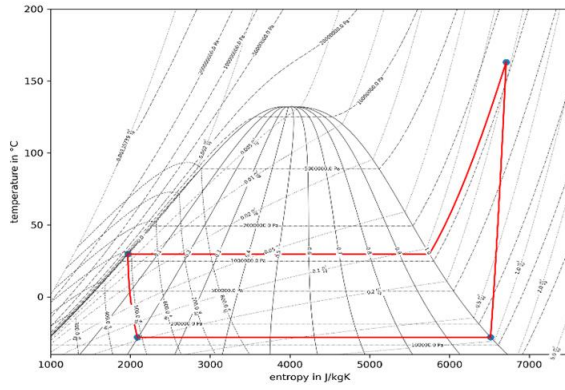
**Figure 3**: T-s diagrams of Ammonia and Propane respectively

## 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.
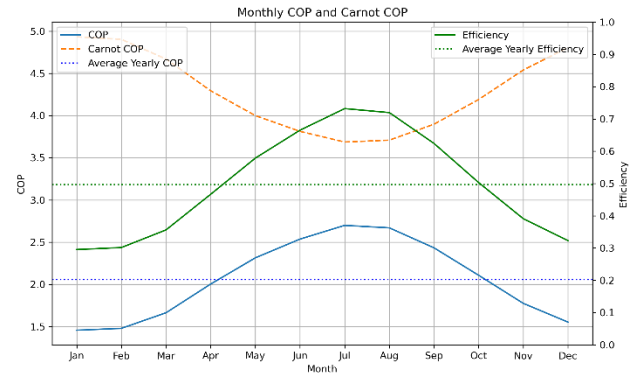


**Figure 4**: Monthly COP and efficiency

## 6. Conclusion

In our initial assessment for the selection of insulation materials for our walk-in freezer, Polyurethane (PU) emerged as the optimal choice due to its narrow thermal conductivity coefficient range, providing superior energy efficiency and reducing cooling demands.

Our extensive analysis of the Coefficient of Performance (COP), refrigerator efficiency and T-s diagram cycles of different refrigerator fluids, resulted with the selection of R290 (Propane) for our cold room. This was due to its high efficiency, non-toxic nature, and positive environmental impact.

With the conclusion of the selection process, a suitable compressor power was selected (200 W) and the monthly COP and efficiencies gave an annual average of 2.06 for COP and 0.50 for refrigerator efficiency.

## 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 https://github.com/boujuan/Renewable_Energy_Heat