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(RESEARCH ARTICLE)

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Design and performance evaluation of a cold storage room for bakery and frozen foods using coolselector®2 Software

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Abstract

Efficient cold storage design is essential to preserve the quality and safety of perishable food products, especially in tropical environments. This study presents a simulation-based design of a cold storage room using Danfoss Coolselector®2 software to store a combination of bakery and frozen food products. The cold room was configured to operate continuously at 4 °C and 80% relative humidity, with a daily load of 2000 kg. Cooling load calculations included product cooling, conduction, and internal heat gains from lighting and equipment, resulting in a total required capacity of 2006 W. The selected system consists of an Optyma Plus condensing unit and a thermostatic expansion valve using R-404A refrigerant. Performance was evaluated through pressure drop analysis, refrigerant flow characteristics, and thermodynamic behavior on P-h diagrams. Results showed that the system met the cooling demand under ambient temperatures up to 35 °C with a COP ranging from 1.0 to 2.5 depending on evaporating conditions. This study demonstrates the value of integrating manufacturer-verified simulation tools for practical cold storage design in hot and humid climates.

Keywords: Cold storage design; Bakery and frozen food; Cooling load calculation; Coolselector®2; COP.

1. Introduction

The preservation of perishable food products such as bakery items and frozen food requires strict environmental control, particularly in terms of temperature and humidity. These products are highly susceptible to microbial spoilage, texture degradation, and nutrient loss when stored outside optimal thermal conditions. Cold storage systems, therefore, serve as a critical infrastructure in the food supply chain, ensuring food safety, product quality, and compliance with food standards [1,2]. In tropical climates where ambient temperatures often exceed 30 °C, the design and operation of efficient refrigeration systems become increasingly complex and energy-intensive.

Thermal load analysis and system component selection are fundamental steps in designing an effective refrigeration system. Improper sizing of the system—either overdimensioning or underdimensioning—not only leads to increased energy consumption but also affects the reliability and service life of the equipment [3]. Moreover, the choice of insulation materials, such as polyurethane panels with appropriate thickness, plays a crucial role in limiting conductive heat transfer and achieving thermal efficiency [4,5]. These aspects must be integrated within a comprehensive design process that takes into account operational load patterns, internal heat gains, and environmental boundary conditions.

While a growing body of research has explored optimization strategies for cold storage systems—ranging from empirical studies to numerical simulations—many of these analyses lack integration with industrial-standard design tools. Several researchers have focused on computational fluid dynamics (CFD) or thermal modeling [6,7], but few studies have demonstrated the practical application of manufacturer-endorsed software in real-world cold room design

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scenarios. One such tool, Coolselector®2 developed by Danfoss, provides users with a validated platform to calculate refrigeration loads, simulate operating conditions, and select matching components such as compressors, expansion valves, and condensers. Despite its widespread use in the HVAC-R industry, the academic use of Coolselector®2 as an integrated design aid remains underrepresented in literature, particularly for applications involving mixed food product storage under tropical conditions.

This study aims to design a cold storage room with dimensions of 10 m × 8 m × 3.5 m, intended to store a combination of bakery and frozen food products with a daily input of 2000 kg. The system operates continuously for 24 hours and is expected to maintain an internal temperature of 4 °C with a relative humidity of 80%. Thermal load calculations incorporate not only product and infiltration heat loads but also additional gains from lighting, fans, and electrical equipment. The design process utilizes Coolselector®2 to select key refrigeration components, including the Optyma Plus condensing unit and a thermostatic expansion valve made of stainless steel. Structural elements, such as 15 cm-thick polyurethane-insulated walls, are considered in calculating heat transmission from surrounding environments, which range from 10 °C under the floor to 35 °C ambient air temperature.

The novelty of this research lies in the integration of a comprehensive thermal load assessment with component selection via Coolselector®2, tailored to real operational parameters and environmental conditions typical in tropical developing countries. This contrasts with prior studies that often assume static or idealized conditions without industrial tools or field constraints.

The results of this work are expected to contribute practical design insights for engineers, technicians, and food facility planners by demonstrating how advanced design software can bridge the gap between theoretical load calculations and practical system implementation. Furthermore, this study serves as a reference model for similar applications requiring cold chain integrity, especially in regions where climate conditions, energy availability, and food preservation needs intersect. Future work may expand this model to include energy optimization, system life cycle analysis, and the integration of renewable energy sources to further enhance sustainability and operational resilience.

2. Materials and Methods

This research employs a simulation-based approach to design and evaluate the performance of a cold storage room intended for bakery and frozen food products using Coolselector®2, a refrigeration system design tool developed by Danfoss. The design process involves setting spatial parameters, environmental conditions, heat gain components, and refrigeration specifications to calculate the required cooling capacity and validate component selection.

The cold room is designed with dimensions of 10 meters in length, 8 meters in width, and 3.5 meters in height, resulting in an internal volume of 280 m^3. The construction utilizes polyurethane insulation panels with a thickness of 0.15 meters on the walls, ceiling, and floor due to their low thermal conductivity and high insulation performance. The target room temperature is 4 °C (278 K) with 80% relative humidity, conditions deemed suitable for both bakery products and frozen foods.

The surrounding ambient temperature is 35 °C (308 K), while the sub-floor temperature is assumed to be 10 °C (283 K). The cold room operates 24 hours daily, receiving approximately 2000 kg of products per day, which are to be cooled from ambient temperature down to storage temperature. These inputs were used to calculate the product load by assuming typical specific heat values and cooling time per kilogram of food mass. The internal heat load includes several components: lighting load: 60 W, fan load: 20 W, other electrical equipment: 300 W.

Additionally, a defrost cycle was accounted for, with 30 minutes of operation estimated per cycle, contributing additional latent and sensible heat into the system.

The heat gain through conduction is computed based on the temperature gradient across the walls, ceiling, and floor using the known insulation thickness and material properties. The infiltration load was considered negligible due to minimized door openings in this preliminary study, although acknowledged as a potential contributor in operational settings.

All data were then input into Coolselector®2, where the system was modeled using the Optyma Plus condensing unit, a reliable and efficient solution for medium-sized commercial applications. A thermostatic expansion valve made of stainless steel was selected to control the refrigerant flow precisely, matching load variability during operation. The final output of the simulation provided the required cooling capacity of 2006 W.

Additional operational parameters used in the Coolselector®2 configuration include: evaporation dew point temperature: 268 K, useful superheat: 6.5 K, return gas temperature: 271 K, condensation ambient temperature: 305 K, subcooling: 3.0 K, altitude: 0 m.

The system was simulated under steady-state conditions, assuming ideal installation and uniform thermal load distribution. This methodology ensures that the sizing and component selection are not only based on theoretical estimations but are supported by reliable simulation tools grounded in thermodynamic and heat transfer principles.

The results of this simulation will be analyzed to validate the feasibility of the selected configuration and to determine its capability in maintaining the desired environmental conditions under continuous operation. This methodology sets the foundation for performance evaluation and potential system optimization.

3. Results and Discussion

A computational analysis was conducted using Coolselector®2 software to evaluate the performance and reliability of the refrigeration components in a cold room designed to operate at 4 °C with a relative humidity of 80%. The system operates continuously for 24 hours and is intended to store 2000 kg of product daily. The total cooling capacity is 2006 W, with polyurethane-insulated walls (0.15 m thick) and ambient conditions of 35 °C surrounding temperature and 10 °C subfloor temperature. The evaluation includes both the liquid and suction lines, focusing on pressure drops, flow velocities, and component compatibility.

3.1. Liquid Line Analysis

The liquid line comprises several components arranged in sequence: a copper pipe (DIN-EN 6), a copper reducer (DIN-EN 8 × 6), a solenoid valve (EVR 3 v2), a thermostatic expansion valve (TU – 6 N S), and a refrigerant distributor. Most components in this line demonstrated acceptable performance, as indicated by “Connection = OK” and successful result validation in the software output.

The thermostatic expansion valve (TU – 6 N S) experienced the highest pressure drop of 119,500 Pa, with a corresponding subcooling temperature difference (ΔT_{sat}) of 39.5 K. These values indicate the component is functioning properly under a high thermal load and contributing effectively to expansion and vaporization control.

However, the copper reducer exhibited a connection error (“Connection = No”), signaling a mismatch in capacity or sizing that could hinder refrigerant flow. This component may require resizing or replacement with a more suitable transition fitting to ensure system integrity.

The velocity of the refrigerant within the copper pipe and across the expansion valve remained within recommended ranges, between 0.46 and 1.78 m/s. These values minimize the risk of pressure shock and cavitation, thereby supporting stable liquid-phase refrigerant flow to the evaporator.

3.2. Suction Line Analysis

The suction line configuration includes a 1-meter copper pipe (DIN-EN 18) from the evaporator to the compressor. The measured pressure drop in this line was 255.4 Pa, with a refrigerant velocity of 4.38 m/s. These values are within the acceptable limits for maintaining efficient refrigerant return and oil circulation.

All connections in the suction line were validated by the software, and the valve state was “Open,” indicating uninterrupted flow of low-pressure refrigerant vapor to the compressor. This confirms that the suction side of the system is operating effectively without bottlenecks or excessive pressure loss.

3.3. Overall System Performance

In summary, the refrigeration system—comprising a condenser, EVR solenoid valve, thermostatic expansion valve, evaporator, and compressor—demonstrates thermodynamic and hydraulic viability under the given operational conditions. The identified issue with the copper reducer must be addressed to avoid potential flow disturbances and ensure long-term reliability [8].

The system was designed while accounting for thermal transmission through polyurethane insulation, internal heat loads from lighting (60 W), fans (20 W), and electronic devices (300 W), as well as external heat gains due to ambient temperature. Based on the calculated parameters, the system performance aligns with the cooling requirements and energy efficiency targets for medium-scale cold storage facilities.

3.4. Cooling Capacity Performance of the Optyma Plus System

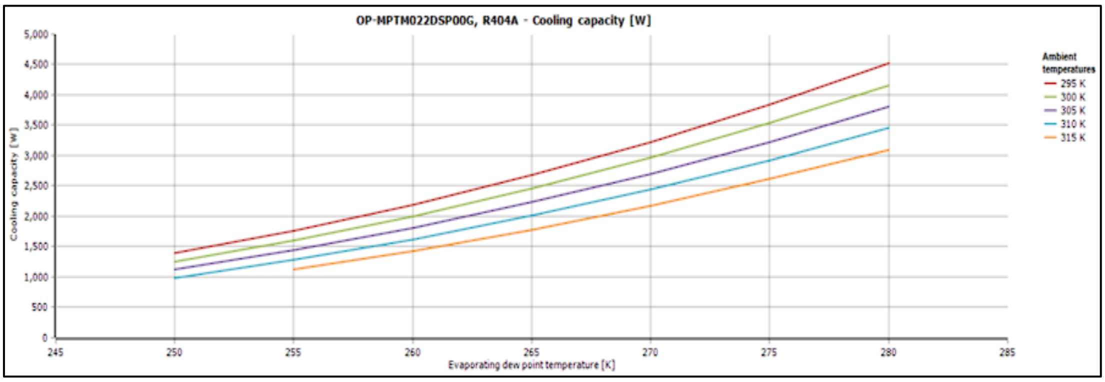

Figure 1 Cooling capacity

Figure 1 illustrates the cooling capacity performance of the Optyma Plus OP-MPTM022DSP00G compressor using R404A refrigerant across a range of evaporating dew point temperatures (from 248 K to 282 K) and ambient temperatures (295 K to 315 K). As shown, the cooling capacity increases with both higher evaporating temperatures and lower ambient temperatures. This trend is consistent with the thermodynamic behavior of vapor-compression refrigeration systems, where an increase in the evaporator temperature enhances the enthalpy difference across the evaporator, leading to improved cooling performance [9].

At an evaporating temperature of 278 K (corresponding to 4 °C, which is the target cold room temperature), the system achieves a cooling capacity close to 2000 W under an ambient condition of approximately 308 K (35 °C), which aligns well with the operational parameters designed for this study. This observation confirms the suitability of the selected compressor model under realistic field conditions.

This performance behavior supports earlier which reported that R404A-based systems exhibit better cooling efficiency at moderate ambient conditions, especially when combined with thermostatic expansion valves [10]. Similarly, other study demonstrated that for cold storage applications operating in tropical climates, compressor performance degrades as ambient temperature exceeds 310 K due to reduced condenser efficiency [11]. The same phenomenon is seen in the plotted data, where cooling capacity diminishes with increasing ambient temperature, indicating the importance of maintaining adequate condenser ventilation or integrating secondary cooling loops in extreme environments.

The current results reaffirm that the Optyma Plus system, under the prescribed loading and environmental conditions, meets the thermal demands of the cold room. Furthermore, considering the heat load contributions from lighting, fans, and product load, the available capacity ensures operational reliability with a reasonable safety margin.

3.5. Power consumption

Furthermore, as depicted in Figure 2, the power consumption of the compressor system increases progressively with rising evaporating temperatures and ambient conditions. This behavior is expected, as higher evaporating temperatures require the compressor to circulate a greater volume of refrigerant vapor, thus demanding more electrical input. Additionally, elevated ambient temperatures reduce the heat rejection efficiency at the condenser, which causes the compressor to operate at higher compression ratios, further increasing the energy input.

At an evaporating temperature of 278 K, the system consumes approximately 1350 W of power under 308 K ambient conditions. This corresponds well with the cooling capacity values shown in Figure 1, yielding a coefficient of performance (COP) of approximately 1.48. This result is within the typical performance range for medium-temperature commercial refrigeration systems using R404A, as reported by earlier study which found that COP values between 1.3 and 1.6 are common for such systems under tropical and subtropical ambient conditions [12].

The observed increase in power consumption can be reduced effectively by improving ambient heat exchange, particularly through the application of subcooling methods or by utilizing more efficient condenser designs [13]. In this study, without any additional heat recovery or economizer strategies, the system's energy efficiency remains dependent on ambient fluctuations, indicating a possible area for future optimization.

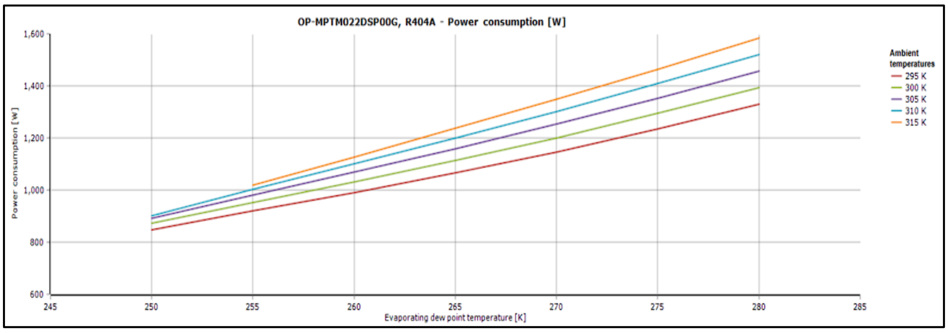

Figure 2 Power consumption

Combining the insights from Figures 1 and 2, it is evident that the system operates efficiently within the thermal and electrical bounds defined by its manufacturer, offering reliable cooling output with manageable power consumption. However, prolonged operation under high ambient temperatures (>310 K) may lead to increased energy costs and reduced system lifetime if not accompanied by adequate thermal management strategies.

3.6. Coefficient of performance

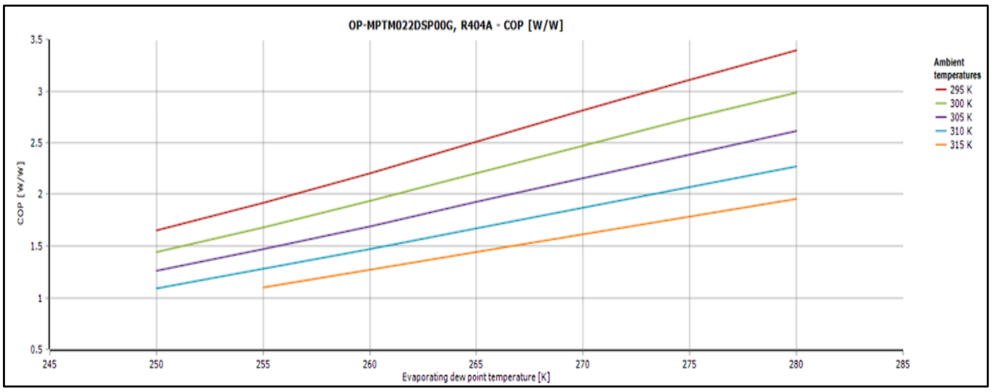

Figure 3 Coefficient of performance

Figure 3 shows the variation of the coefficient of performance (COP) of the refrigeration system as a function of the evaporating dew point temperature for different ambient conditions. As expected, COP increases with increasing evaporating temperature and decreases with increasing ambient temperature. This trend is consistent with the thermodynamic principle that a smaller temperature lift (difference between condensing and evaporating temperatures) leads to a more efficient refrigeration cycle.

At an ambient temperature of 295 K, the COP increases from approximately 1.6 at 250 K evaporating temperature to over 3.3 at 280 K. Conversely, at 315 K ambient, the COP only ranges from 1.0 to about 2.1 over the same evaporating temperature range. This degradation in COP at higher ambient conditions reinforces the conclusion drawn earlier from Figures 1 and 2—namely, that system efficiency is strongly dependent on environmental temperature.

These results align with earlier observations indicating that the efficiency of commercial refrigeration systems declines noticeably when ambient temperatures rise above 308 K [14]. Their study highlighted the importance of selecting appropriate refrigerant and system design for applications in warm climates. In addition, it has been noted that although R404A operates effectively under moderate conditions, its performance tends to decrease in high-temperature environments, particularly when compared to other refrigerants with lower global warming potential (GWP) [15].

Overall, the observed COP behavior in this study confirms the compressor manufacturer's specifications and indicates that optimal operating conditions occur at higher evaporating temperatures and lower ambient temperatures. In practical applications, this insight indicates that incorporating adequate subcooling and ensuring proper condenser ventilation are important strategies to reduce the negative impact of elevated ambient temperatures on system performance [16].

3.7. Vapor-compression refrigeration system

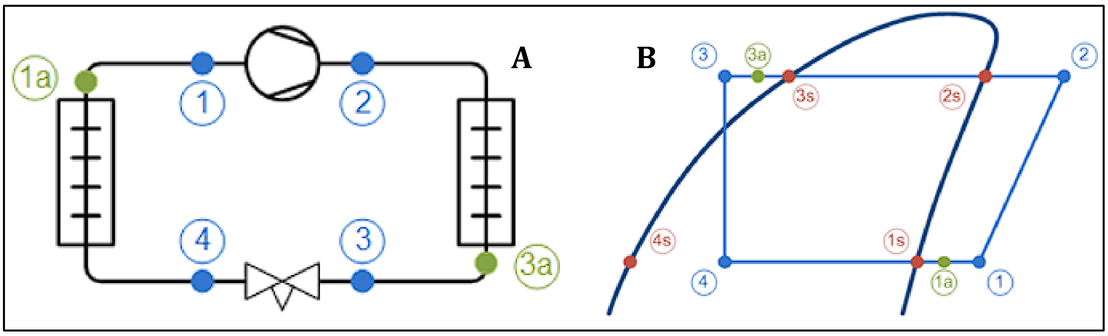

Figure 4 a) Schematic diagram of a vapor-compression refrigeration system, b) pressure-enthalpy (P-h) diagram

Figure 4 illustrates the schematic diagram of a vapor-compression refrigeration system (a) and its corresponding representation on a pressure-enthalpy (P-h) diagram (b). The key thermodynamic states are marked numerically (1–4) along with the actual and isentropic points on the compression and expansion processes. This representation provides deeper insight into the energy interactions and losses that occur in each component of the system, particularly in the compressor and expansion valve.

From the schematic diagram, the process begins at point 1, where low-pressure saturated vapor enters the compressor. The fluid is compressed isentropically (ideally) to point 2s but in reality reaches point 2 due to irreversibilities, such as mechanical losses and non-ideal behavior, resulting in entropy generation. This deviation indicates a loss in compressor efficiency. The compressed high-pressure superheated vapor then enters the condenser (state 2 to 3), where it releases heat to the surroundings and condenses into a high-pressure liquid.

The high-pressure liquid then passes through the expansion valve (point 3 to 4), experiencing a rapid drop in pressure and temperature, resulting in a low-pressure, low-temperature mixture of liquid and vapor. This mixture enters the evaporator (point 4 to 1), where it absorbs heat from the refrigerated space and completes the cycle.

The P-h diagram on the right visualizes these processes, with 1a–2s–3s–4s representing the ideal cycle, and 1–2–3–4 showing the actual cycle. The deviation between ideal and actual states (especially at compression and expansion) reflects the system's irreversibility and thus affects the COP discussed earlier in Figures 2 and 3.

These findings are in line with previous analyses showing that deviations from the ideal refrigeration cycle—particularly during the compression phase—are a significant factor in decreased system efficiency [17]. Additionally, examining the pressure-enthalpy (P-h) diagram is crucial for identifying sources of entropy generation and proposing enhancements, such as the adoption of high-efficiency compressors or the integration of economizers [18].

The inclusion of this P-h analysis validates the earlier COP trend (Figure 3) by linking the reduced performance at high ambient temperatures to the increased entropy generation in compression and reduced effectiveness in condensation. In practical terms, reducing the gap between the actual and ideal refrigeration cycle curves can result in significant improvements in system efficiency [19].

3.8. Pressure-enthalpy (P-h) analysis

Figure 5 presents the pressure-enthalpy (P-h) diagram specific to refrigerant R-404A, which provides a more detailed thermodynamic representation of the cycle analyzed in Figure 4. Each state point (1–4) is plotted based on the enthalpy and pressure conditions derived from the experimental or simulated data. The P-h diagram not only confirms the refrigerant phase transitions throughout the cycle but also allows for precise evaluation of energy quantities such as refrigeration effect, compressor work, and heat rejected in the condenser.

State (1) corresponds to low-pressure, low-enthalpy vapor entering the compressor. The vertical line from point (1) to (2) represents the compression process, where enthalpy increases significantly due to work input. The position of point (2) slightly right of the isentropic line once again indicates entropy generation due to irreversibilities. The high-pressure superheated vapor at (2) then undergoes heat rejection in the condenser, transitioning from superheated to saturated liquid at point (3), with a corresponding enthalpy decrease.

The vertical drop from (3) to (4) illustrates the isenthalpic expansion process through the expansion valve. Despite being isenthalpic, this process results in a significant pressure drop and partial vaporization, forming a liquid-vapor mixture. The cycle closes as the refrigerant absorbs heat in the evaporator from point (4) to (1), causing the enthalpy to increase as it changes phase from saturated mixture to vapor.

The cycle's performance can be evaluated by measuring the enthalpy differences between these key states. Specifically, the refrigeration effect is calculated from h_1-h_4, and compressor work from h_2-h_1, both of which are visualized clearly in this chart. These values are fundamental to computing the COP (Coefficient of Performance), as discussed in Figures 3 and 4.

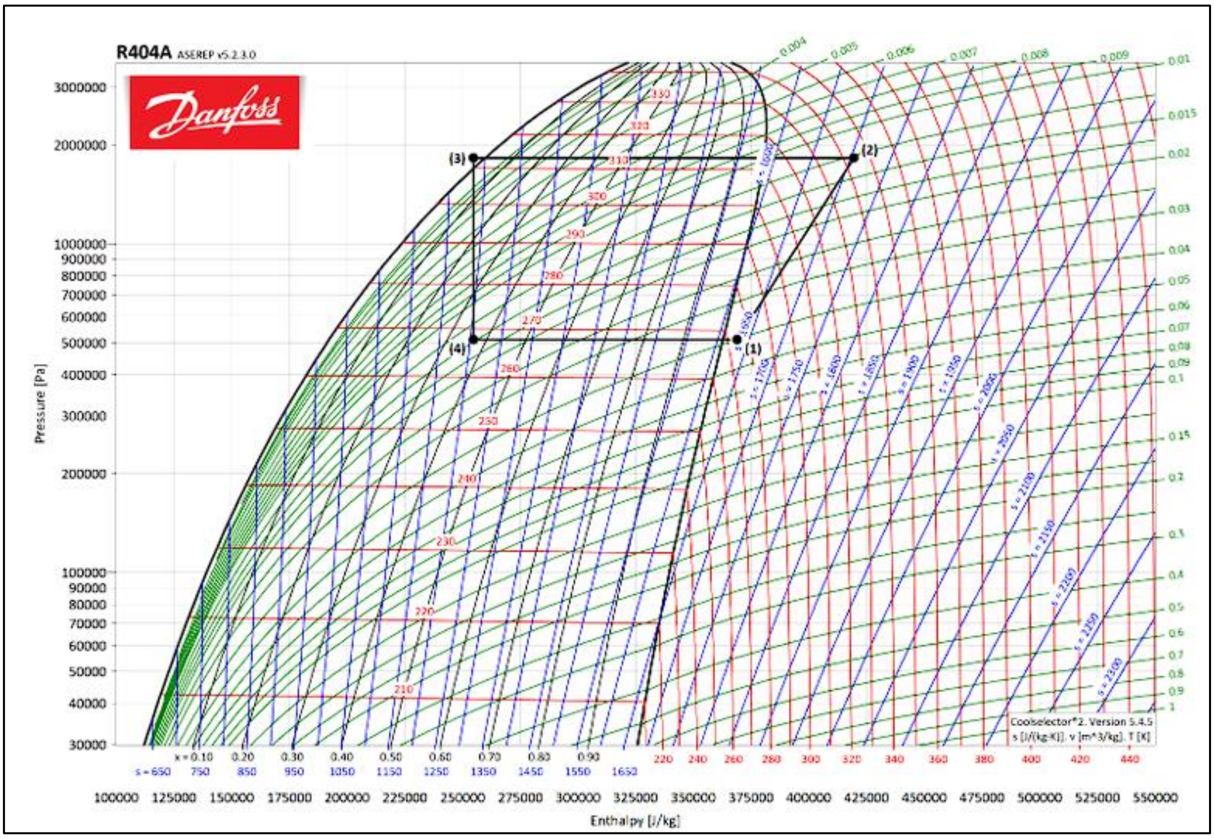

Figure 5 Pressure-enthalpy (P-h) diagram specific to refrigerant R-404A

The patterns illustrated in this diagram align with earlier research on the thermodynamic behavior of R-404A, highlighting the importance of minimizing superheat and subcooling regions to enhance the coefficient of performance (COP) [20]. Additionally, the use of pressure-enthalpy (P-h) diagrams has proven valuable in performance evaluation, demonstrating that operational modifications—such as implementing suction line heat exchangers—can effectively alter enthalpy values to increase system efficiency [21].

By analyzing this refrigerant-specific P-h diagram, it is evident that any deviation from ideal behavior—especially during compression and expansion—leads to reduced energy efficiency. Thus, using this tool enables not only visualization of the working cycle but also quantification of inefficiencies, as reflected in the declining COP at elevated ambient conditions reported earlier.

4. Conclusion

This study successfully demonstrated the design and evaluation of a cold storage system using Coolselector®2 software for storing bakery and frozen food products under tropical environmental conditions. The integration of thermal load analysis, component selection, and performance simulation enabled the system to meet cooling demands of 2006 W with satisfactory thermodynamic efficiency. The selected Optyma Plus condensing unit with R-404A refrigerant maintained stable operation with COP values ranging between 1.0 and 2.5, depending on evaporating and ambient conditions. Thermodynamic cycle visualization using pressure-enthalpy diagrams revealed system irreversibilities that affect overall efficiency, particularly at higher ambient temperatures. These findings underscore the importance of precise component matching and operational optimization in refrigeration systems. Future work should explore the incorporation of alternative low-GWP refrigerants, renewable energy integration, and lifecycle energy analysis to enhance sustainability in cold chain infrastructure.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. No financial, personal, or professional relationships with individuals or organizations have influenced the outcome or content of this manuscript.

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