INTEGRATING ENERGY MANAGEMENT STRATEGIES INTO THE COLD CHAIN FOR HERB STORAGE

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Article History: Received 20 January 2025; Revised 5 September 2025;
Accepted 12 October 2025

ABSTRACT: The increasing demand for locally cultivated sweet basil as a prospective antiviral herb has resulted in the implementation of cold storage to preserve its quality. From a financial perspective, however, storage costs are also a significant concern. An important factor in operating costs is the energy consumption required for chilling the basil. Thus, this study examined energy management strategies for a cold storage system with an evaporative condenser used in the production of chilled sweet basil. The system features a 15 HP compressor (380 V) operating with R22 refrigerant, with an upper-wall-mounted evaporator connected to a water-cooled pad evaporative condenser. Experiments were conducted at five precooling temperatures (8°C, 10°C, 12°C, 14°C, and 16°C) and three product mass fractions (50%, 75%, and 100%). The results showed that, while precooling temperature had a significant impact on the coefficient of performance (COP), COP decreased with increasing temperature under cooling load. A mass fraction increase from 50% to 75% slightly improved COP, with a marginal gain at 100%. The optimal condition, balancing energy efficiency and product quality, was observed at 12°C precooling temperature and 75% mass fraction. Under this setting, the system not only maintained favorable thermal performance but also achieved cost-effective operation with a chilling cost of 11.8 baht per kilogram of sweet basil, demonstrating its economic viability for commercial applications.

KEYWORDS: *Energy management; Cold Storage; Evaporative Condenser; Chilling process; Sweet Basil*

1.0 INTRODUCTION

Thai exports of agricultural and agro-industrial products have seen substantial growth, rising 17.4% year-over-year, driven in part by a remarkable 233.6% increase in herbs, vegetables, and oils [1]. This success in exports highlights the growing global demand for high-quality agricultural products. Further compounding this opportunity, research suggests that sweet basil, a key component of this category, may possess valuable antiviral properties, increasing its market potential [2]. However, manufacturers must prioritize preserving the quality of sweet basil during warehousing and transportation to capitalize on its growing demand and unique potential.

Inadequate handling, storage, or transportation can drastically reduce shelf life and diminish flavor, negatively impacting the marketable quality of the product. Therefore, investigating and implementing effective cold storage configurations is essential to minimize spoilage, maintain market value, and ensure that exported sweet basil reaches consumers with its desirable qualities intact. A successful postharvest storage strategy for basil in a manufacturing setting involves a combination of temperature and humidity control, modified atmosphere packaging, sanitation, and potentially light exposure as well as other treatments [3]. The optimal chilling conditions for sweet basil, including the appropriate setting of temperature, humidity, and precooling duration, can extend product shelf life [2]. Additionally, effective energy management strategies can reduce production costs for post-harvest preservation and storage, enhancing overall manufacturing efficiency [3].

The use of modified atmosphere packaging (MAP) has shown promise in extending the shelf life of various herbs [4, 5]. However, the effectiveness of MAP depends heavily on the specific gas composition, packaging material, and storage temperature [4]. While some studies suggest that MAP can significantly reduce spoilage when combined with cold storage [5], others have found limited benefits for basil, particularly in terms of maintaining volatile aroma compounds. These conflicting results highlight the need for further research to optimize MAP protocols for sweet basil and to understand the underlying mechanisms by which MAP affects basil quality. Maintaining a temperature range of 10–13°C is crucial for basil storage to prevent chilling injury and dehydration [3–4]. However, it should be noted that these recommendations are often based on small-scale laboratory experiments, and their applicability to large-scale commercial operations may be limited. The impact of refrigeration time on product longevity [6-8] underscores the need for predictive models that can accurately estimate shelf life under varying storage conditions. Furthermore, studies by Thanwit et al. [9] and Yuzainee et al. [10] have highlighted the importance of product placement and quantity, but these studies may not be directly transferable to evaporative cooling systems, which exhibit different airflow patterns and temperature gradients compared to conventional refrigeration systems.

Therefore, further research is needed to optimize storage conditions for sweet basil specifically within evaporative cooling environments. Evaporative cooling offers a promising avenue for energy-efficient herb preservation, with research focusing on factors such as pad characteristics and water flow [11-13]. However, a critical evaluation reveals that the cost-effectiveness of these systems can be highly variable, depending on local water availability and quality, as well as the energy required to pump and treat the water. Moreover, advanced designs involving falling films around specialized tube geometries [14-15] may offer improved heat transfer coefficients, but their complexity and increased capital costs may limit their widespread adoption in practical herb storage applications. There is a need for studies that rigorously assess the lifecycle costs and environmental impacts of evaporative cooling technologies for herb preservation, considering the specific context of small and medium-sized agricultural enterprises.

Nonetheless, sweet basil has been predominantly neglected in prior research about energy management. Specifically, the effects of precooling temperature, mass fraction, and water flow rate on the energy performance of cold storage systems using evaporative condensers remain unexplored. Therefore, this research aims to determine effective energy management strategies for sweet basil cold storage by specifically investigating the influence of precooling temperature, mass fraction, and water flow rate on the energy performance of the system. This study is novel in that it directly addresses a previously identified gap by focusing on sweet basil and its unique requirements in relation to evaporative cooling. The significance of this research lies in its potential to fill a critical knowledge gap in energy-efficient sweet basil preservation and to provide data-driven, practical solutions for optimizing cold storage, minimizing spoilage, and promoting sustainable post-harvest management in the agricultural sector.

2.0 METHODOLOGY

This section details the experimental setup and procedure used to investigate the effects of precooling temperature, water flow rate, and mass fraction on the Coefficient of Performance (COP) of a sweet basil cold storage system. The approach in this study integrates fundamental energy conservation principles with a carefully designed experimental protocol. This allows for the precise modeling of the complex interactions between these parameters and their combined effect on the energy performance of the cold storage system. Furthermore, the experimental design incorporates real-world conditions specific to sweet basil storage, unlike previous studies that relied on generalized models or simulated environments, enabling a more accurate and applicable assessment of energy conservation strategies. Finally, the economic analysis further enhances the practical value of this study by quantifying the potential cost savings associated with the optimized operating conditions identified through its integrated experimental and analytical approach.

2.1 Experimental Setup and Procedure

The sweet basil leaves utilized in this study were obtained from Songkhla Province, demonstrating freshness and an average leaf length of 5 ± 0.5 cm. Before each experimental trial, it is essential to eliminate contaminants and allow the basil leaves to acclimatize at room temperature for 30 min before sealing them in vacuum bags for the analysis of mass ratio characteristics. The cold storage system is designed with a 15 Hp (11.18 kW) compressor, operating on a power supply voltage of 380 V and utilizing R22 refrigerant. The dimensions of the storage chamber are 2.4 m x 3.5 m x 2 m (Width x Length x Height), equipped with a stainless-steel trolley capable of accommodating nine trays. Inside the cold room, an evaporator unit is installed on the upper wall of the room, connected to a hose system that transports the refrigerant to an evaporative condenser unit, leveraging a cooling pad water system for effective heat dissipation. The cold storage with evaporative condenser is depicted in Figure 1.

The experimental study will begin by investigating the optimal water flow rate for the evaporative condenser, testing four levels: 0, 2, 4, and 6 L/min. Following this, the focus will shift to two variables, comprising the precooling temperature and mass fraction for packaging basil leaves. The set precooling temperatures will include five specific values of 8 °C, 10 °C, 12 °C, 14 °C, and 16 °C, encompassing the operational temperature range employed for chilling leafy green vegetables [5]. The mass fraction of the packaged basil leaves (m*) will be categorized into three levels: 50%, 75%, and 100%. It corresponds to the specified mass proportional value, as indicated in Equation (1):

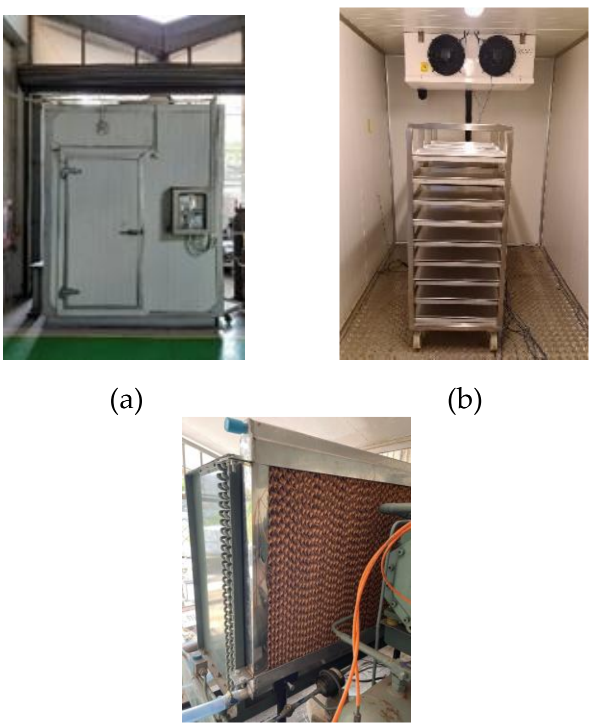
$$m^* = \frac{m_{basil}}{m_{total}} \tag{1}$$

where m_{basil} is the mass of the filled basil, and m_{total} is the total mass that the vacuum bag can accommodate.

The leaves will be vacuum-packed in bags with dimensions of 20 × 30 cm (width × length), allowing a maximum packing capacity of 20 kg (100%). These vacuum-sealed bags will be positioned on each shelf of the stainless-steel tray system. The experiment will maintain an initial temperature control of 28 ± 0.5 °C. The cooling process will terminate across all experimental scenarios when the average internal temperature of the product stabilizes at a predetermined value for five minutes. Data acquisition will utilize a Yokogawa MV1000 data logger. Temperature measurements will be taken using a Chromel-Alumel thermocouple (type K) with an uncertainty of ±0.5°C. Relative humidity will be measured with a Primus HM-005-01 sensor, also offering an uncertainty of ±0.5%. Electrical consumption will be monitored using a Schneider Electric PM 2100 digital power meter, with an uncertainty of ±0.1 kWh. To evaluate the quality of basil leaves packaged in a modified atmosphere, oxygen concentration will be maintained at approximately 20% using a Uyigao UA6070B oxygen meter, which has an uncertainty of ±0.1%. This comprehensive data collection strategy will enable a thorough analysis of the factors affecting the storage and quality of basil leaves.

All tests involved measuring the same position at least three times, with recorded parameter points monitored every minute. The air-cooling temperature was calculated as the average of two temperature points (T_{17} and T_{18}). The temperatures of the sweet basil on the upper tray were determined by averaging eight temperature points: (T_5 to T_8) for the front zone and (T_9 to T_{12}) for the back zone. Similarly, the temperatures of the sweet basil on the lower tray were calculated using the average temperature points from T_1 to T_4 (front zone) and from T_{10} to T_{16} (back zone). The relative humidity of the evaporator was measured at two points (RH_{19} and RH_{20}).

Additionally, the temperature of the evaporative condenser was recorded at three locations, including the inlet temperature (T_{21}), the water temperature (T_{22}), and the outlet temperature (T_{23}). All data points are shown in Figure 2.



(a) (b) (c)

Figure 1: Cold storage specifications of (a) exterior, (b) interior, and (c) evaporative condenser

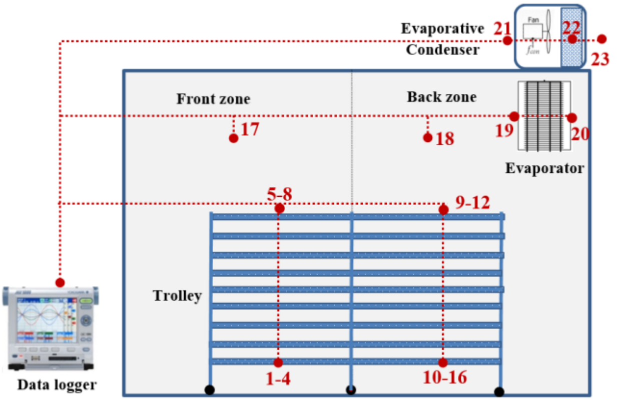


Figure 2: Experimental apparatus

To assess the quality of chilled sweet basil, the oxygen content in the vacuum bag is initially adjusted to 20 ± 0.1% before introducing the basil to each experimental configuration. Small holes are drilled in the bag to allow for the insertion of thermocouple wires, which are then sealed with silicone to maintain the integrity of the packaging. The basil is arranged evenly across all layers.

Experiments are conducted to evaluate the effects of varying precooling temperature drops and mass proportions. This process continues until a stable state is achieved, defined as temperature differences within ±0.5 °C for five minutes. Following this stabilization period, the oxygen concentration in the vacuum bag is measured again to determine the effectiveness of the modified atmosphere packaging for preserving the quality of the basil. All experiments were replicated three times, and the uncertainties of parameters throughout the experiments are presented in Table 1.

Table 1: Uncertainties of parameters throughout the experiments

Parameters	Uncertainty	Unit
Temperature	±0.5	°C
Relative humidity	±0.1	%
Time measurement	±0.1	min
Air velocity	±0.1	m/s
Water flow rate	±0.2	L/min

2.2 Performance analysis

The efficiency of refrigeration systems, including refrigerators and heat pumps, is quantified by a metric known as the coefficient of performance (COP) [6-7]. The COP is defined as the ratio of the work input to the compressor (W) to the useful cooling delivered at the evaporator (Q_c). The COP can be calculated using Equation (2):

$$COP = \frac{Q_c}{W} \tag{2}$$

The useful cooling at the evaporator was assessed by calculating the rate of heat transfer to the ambient air, employing the conservation of energy principle for a heating process at constant specific humidity [7]. This relationship is represented by Equation (3):

$$Q_C = \dot{m}_{air}\left(h_{in} - h_{out}\right) \tag{3}$$

where $\dot{m}_{air}$ is the mass flow rate of dry air, and h_{out} and h_{in} are the enthalpies per unit mass of dry air at the exit and the inlet of the evaporator section, respectively.

The cost per unit of energy consumption represents the electricity expense incurred in processing a given mass of sweet basil. This metric reflects the economic efficiency of the cooling process by directly relating energy usage to the quantity of product handled [16]. This relationship is represented by Equation (4):

$$Cost = \frac{E_e \times C}{m_{basil}} \tag{4}$$

where E_e is the total energy consumption in kilowatt-hours (kWh), and C is the cost of electricity per kilowatt-hour (THB/kWh). This parameter provides a practical basis for comparing the operational cost efficiency under different cooling conditions and system configurations.

3.0 RESULTS AND DISCUSSION

3.1 The optimal water flow rate for evaporative cooling system

In preparing the cold storage for the sweet basil chilling process, it is essential to investigate the optimal water flow rate for the evaporative condenser to enhance energy efficiency. The air temperature difference between the inlet (T_{21}) and outlet (T_{23}), water temperature (T_{22}), and COP for the evaporative condenser at different water flow rates are shown in Figure 3. The temperature difference between air and water decreases as the water flow rate increases, with higher flow rates improving cooling efficiency in the condenser. This further increase has a minimal impact on temperature difference, as noted in previous work [14-15]. By enhancing convective heat transfer, evaporative cooling systems can provide efficient cooling solutions, especially in hot and dry climates where low humidity allows for greater evaporation rates. Additionally, the coefficient of performance (COP) increases with water flow rate, peaking at 4 L/min before declining slightly at 6 L/min, indicating an optimal flow rate for maximizing COP. This pattern reflects that an increased water flow improves performance; too high a flow can lead to a falling income. This condition can be tested in the next section for the cooling process of the sweet basil.

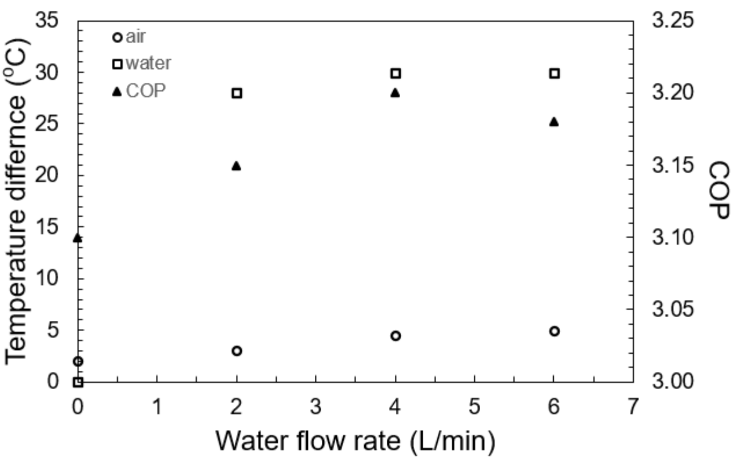


Figure 3: Temperature difference and COP at different water flow rates

3.2 Effect of precooling temperature on the COP

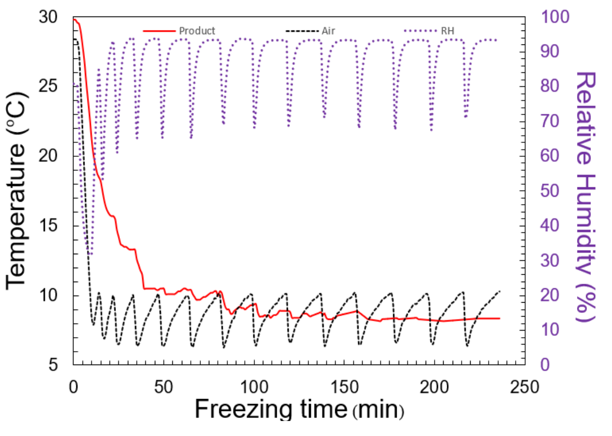
This study investigated the effects of precooling temperature on the cooling performance of basil in a cold storage room with a cooling load (sweet basil pack). Experiments investigating basil leaf precooling under five temperature conditions (8°C, 10°C, 12°C, 14°C, and 16°C) demonstrated that both temperature and relative humidity exhibited predictable and consistent trends over time, providing a crucial baseline for optimizing the cold storage environment. Further experiments loading the cold storage with basil leaves (75% mass ratio) and assessing cooling performance alongside leaf quality revealed significant insights into the trade-offs between cooling speed, energy consumption, and product preservation. Specifically, the data presented in Figures 4(a) to 4(e) illustrate that increasing the controlled cooling temperature from 8°C to 16°C resulted in a 40% reduction in cooling time (from 244 min to 146 min).

This acceleration in cooling came with a substantial 27% decrease in electricity consumption (from 6.3 kWh to 4.5 kWh), highlighting direct and quantifiable energy saving. The observed cyclical pattern in relative humidity (75%-93%), linked directly to compressor operation and temperature regulation, underscores the importance of understanding the interplay between these factors for maintaining stable and optimal storage conditions. The strong correlation between temperature, humidity, and compressor operation offers a valuable diagnostic tool: deviations quickly flag system inefficiencies, enabling proactive maintenance to prevent spoilage and downtime. This has considerable practical implications for the herbal cold chain. Strategically adjusting precooling temperatures can demonstrably reduce energy consumption (a 27% reduction in this study) for more sustainable, cost-effective basil storage. While further quality analysis is needed, the potential for optimized energy usage is clear. Understanding the interplay between cooling parameters, energy consumption, and humidity empowers operators to fine-tune systems, minimizing waste, ensuring quality, and potentially extending shelf life. Readily available temperature and humidity data become critical, real-time indicators of cooling system efficiency.

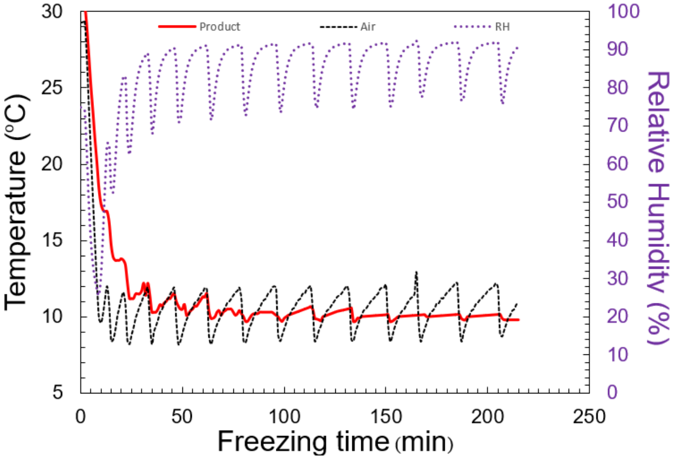
While Table 2 might suggest a direct proportionality between the COP and controlled temperature, aligning with some previous research [3-

9], this relationship is an oversimplification for vapor-compression refrigeration cycles common in HVAC systems. The Coefficient of Performance (COP) is fundamentally constrained by thermodynamics; these systems operate on cycles where efficiency is inversely related to the temperature lift between the evaporator and condenser. Larger temperature lifts require higher compressor work, reducing the COP. The relatively minor changes in COP observed at higher controlled temperatures (12°C to 16°C), falling within the experimental uncertainty range, suggest diminishing returns for increasing the evaporating temperature in this specific setup. This implies that, while precooling temperature does impact COP, the benefits plateau beyond a certain point, highlighting the need for a balanced approach that considers both energy efficiency and the specific temperature requirements for optimal herb preservation.

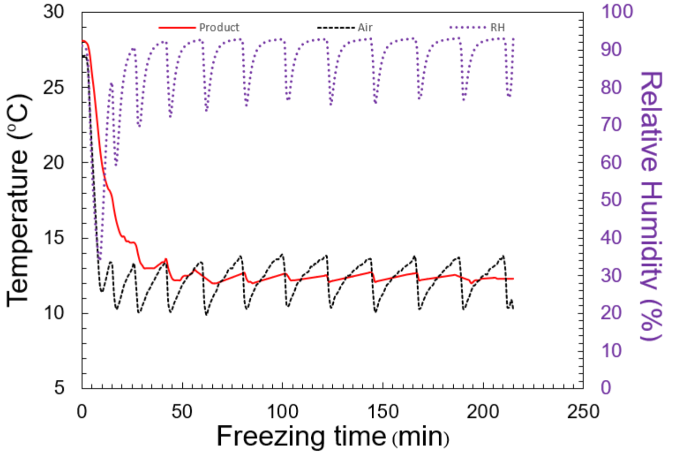
Further investigation is needed to fully reconcile these findings with prior studies and to determine the optimal temperature range for maximizing COP without compromising product quality. Therefore, the potentially reduced compressor power consumption at 16 °C may be offset by the fact that this higher temperature may not be ideal for preserving produce quality. The decreasing residual oxygen levels at higher temperatures accelerate respiration in the stored sweet basil, potentially leading to spoilage and cold shock [7-8]. Considering both energy efficiency (COP) and product quality, an optimal cooling condition for chilling sweet basil at a mass ratio of 75% is a controlled temperature of 12°C. Further studies are needed to investigate the impact of mass ratios, which will be addressed in the following section.



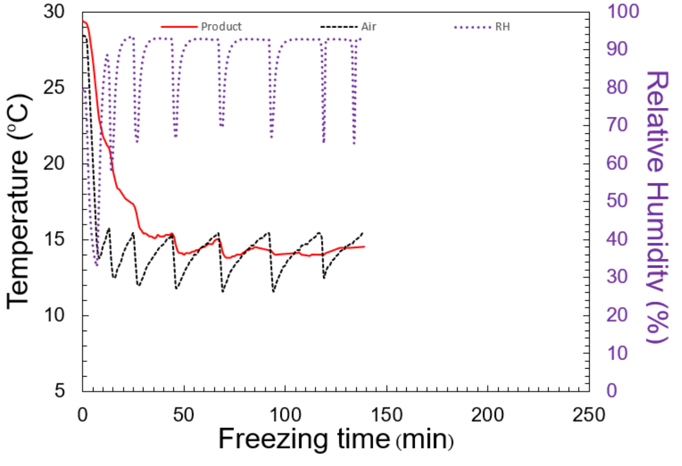
(a)


Product
Air
RH
Temperature (°C)
Relative Humidity (%)
Freezing time (min)

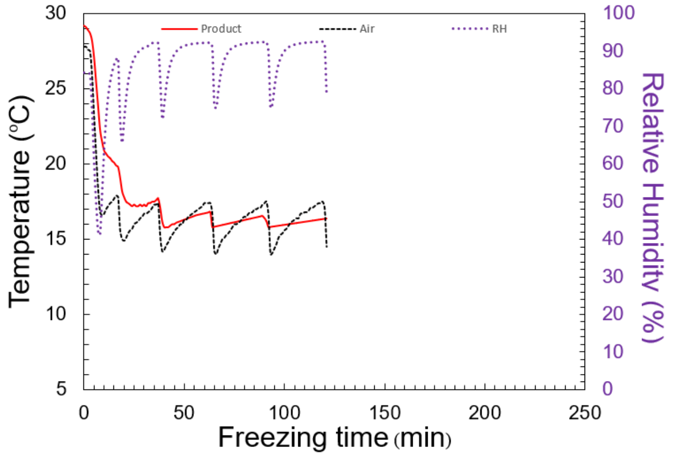
(b)


Product
Air
RH
Temperature (°C)
Relative Humidity (%)
Freezing time (min)

(c)


Product
Air
RH
Temperature (°C)
Relative Humidity (%)
Freezing time (min)

(d)



(e)

Figure 4: Temperatures and relative humidity variation at different precooling temperatures of (a) 8°C, (b) 10°C, (c) 12°C, (d) 14°C and (e) 16°C

Table2: COP and oxygen levels at different precooling temperatures

Controlled temperature (°C)	COP	O2 level (%)
8	2.14	18.9
10	2.19	18.5
12	2.27	18.3
14	2.30	16.2
16	2.31	15.1

3.3 Effect of mass fraction on the COP

Figure 5 presents COP and oxygen levels at different mass fractions. While the experimental results suggest a slight decrease in COP (around 3%) as the mass ratio increased from 50% to 75%, this difference is not statistically significant due to experimental uncertainty. Therefore, it is difficult to draw definitive conclusions about the impact of mass fraction on COP within this range. However, the COP dropped significantly to 2.05 when the mass ratio increased from 75% to 100%, representing a 10% reduction, which aligns with prior research findings [10]. This is consistent with the principle that the cooling load of a cold room varies directly with the mass and type of refrigerated products [17]. Additionally, examining the changes in residual oxygen levels after the precooling process revealed that the residual oxygen decreased gradually as the mass ratio increased, reaching a minimum of 17.2% (Figure 5), which still falls within acceptable limits for maintaining product quality [5]. The results also confirm that a precooling temperature of 12 °C is optimal for chilling sweet basil while preserving its quality, even with an increased mass of product. Thus, the ideal conditions for efficiently chilling basil are a precooling temperature of 12 °C and a mass ratio of 75%, resulting in a COP of 2.27. While a mass ratio of 50% provides the highest COP and residual oxygen levels, the 75% mass ratio offers better economic returns, with only slight differences in COP and oxygen levels. This condition maintains residual oxygen at 18.3%. This condition can be adapted for manufacturing planning in the next section.

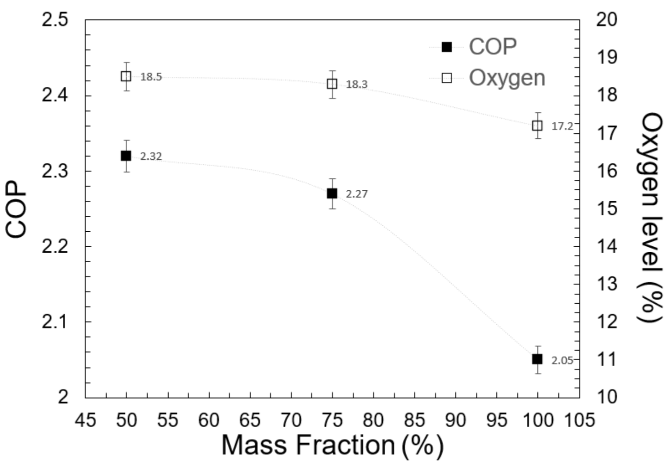


Figure 5: COP and oxygen levels at different mass fractions

3.4 Manufacturing planning

To optimize manufacturing planning for a vegetable chilling factory focusing on sweet basil, this experiment investigated the impact of precooling temperature and mass fraction of vacuum-sealed sweet basil on a cooling system with an evaporative condenser. The goal was to maximize cooling efficiency and product quality for industrial-scale postharvest handling. The findings indicate that an optimal water flow rate of 4 L/min in the evaporative condenser maximizes the Coefficient of Performance (COP), with diminishing returns at 6 L/min.

For precooling, 12°C is the recommended temperature. This balances energy consumption and product quality, yielding a COP of 2.27 and a residual oxygen level of 18.3% within the vacuum bag, preserving freshness. Temperatures of 8°C risk cold shock, while those above 14°C, although faster, accelerate quality degradation. A 75% fill rate for the vacuum bags is the most effective regarding product mass fraction, balancing energy efficiency and economic viability. A 50% fill rate has a slightly higher COP but is less economical, while a 100% fill rate reduces cooling performance. Under these optimized conditions, the chilling cost is approximately 11.8 baht per kilogram of sweet basil, indicating a cost-effective operation. Table 3 summarizes the recommended conditions for efficient sweet basil chilling using an evaporative condenser system, which should be integrated into the factory's manufacturing plan for optimal performance.

Table 3: The optimization for setting precooling system

Item	Value	Unit
Precooling temperature	12	°C
Mass fraction of basil in the packaging	75	%
Water flow rate	4	L/min
Cost per unit	11.8	Baht/kg

4. CONCLUSION

This study examines innovative energy management strategies for cold storage systems employing evaporative condensers, specifically in the context of chilled sweet basil production, to improve efficiency and sustainability. It examines the impact of precooling temperature and mass ratio on the Coefficient of Performance (COP) of the system during the cooling process. The investigation aims to determine optimal chilling conditions that balance energy efficiency and product quality in a small-scale industrial cold storage setting. The results show that the water flow rate significantly influences the COP, with 4 L/min being the most effective. Precooling temperature also affects the COP under the chilling load condition of 12°C, providing the highest COP while preserving basil leaf quality. Both COP and residual oxygen levels are inversely related to precooling temperature and mass ratio. The recommended conditions for efficiently chilling basil include a precooling temperature of 12°C and mass ratio of 75%, yielding a COP of 2.27 and a residual oxygen level of 18.3%. Integrating this approach into the sweet basil chilling process can enhance energy management and economic efficiency, maximizing cost-effectiveness within the overall production framework. Under these conditions, the estimated chilling cost is 11.8 baht per kilogram of sweet basil. Further research should focus on modeling airflow conditions within the cold storage system to improve cooling efficiency in future applications.

ACKNOWLEDGMENTS

This research was supported by the Department of Mechanical Engineering, Faculty of Engineering, Rajamangala University of Technology Srivijaya, and granted by university research funds.

AUTHOR CONTRIBUTIONS

P. Inthararak: Investigation and Writing—Original Draft Preparation; T. Naemsai: Conceptualization, Methodology, Writing – Original Draft Preparation and Supervision; J. Jareanjit: Conceptualization; K. Thongkaew: Writing-Reviewing and Validation.

REFERENCE

[1] Trade Policy and Strategy Office "Thai International Trade in August 2024." Ministry of Commerce, Bangkok, Thailand. Aug. 2024.

[2] N. S. Azizah, B. Irawan, J. Kusmoro, W. Safriansyah, K. Farabi, D. Oktavia, F. Doni and M. Miranti, M. "Sweet Basil (*Ocimum basilicum L.*)—A Review of Its Botany, Phytochemistry", *Pharmacological Activities, and Biotechnological Development*, vol. 12, no. 24, pp. 4148, 2023.

[3] L. J. Brindisi and J. E. Simon, "Preharvest and postharvest techniques that optimize the shelf life of fresh basil (*Ocimum basilicum L.*): a review", *Frontiers in Plant Science*, vol. 14, p. 1237577, 2023.

[4] T. Niamthong, S. Sittipod, and V. Chonhenchob, "Development of Holy Basil Storage Using Low Temperatures and Modified Atmosphere Packaging,". *Agriculture and Natural Resources*, vol. 41, no. 5. pp. 286-293. 2007.

[5] Y. Fang and M. Wakisaka, "A Review on the Modified Atmosphere Preservation of Fruits and Vegetables with Cutting-Edge Technologies," *Agriculture*, vol. 11, no. 10, pp. 992, 2021.

[6] A. Biglia, L. Comba, E. Fabrizio, P. Gay, and D. R. Aimonino, “Case Studies in Food Freezing at Very Low Temperature,” *Energy Procedia*, vol. 101, pp. 305–312,.2016.

[7] M. Bulut, Ö. Bayer, E. Kırtıl, and A. Bayındırlı, “Effect of freezing rate and storage on the texture and quality parameters of strawberry and green bean frozen in home type freezer,” *International Journal of Refrigeration*, vol. 88, pp. 360–369, 2018.

[8] C. Zilio, G. Righetti, G. Pernigotto, and G. A. Longo, “Analysis of the freezing time of chicken breast finite cylinders,” *International Journal of Refrigeration*, vol. 95, pp. 38–50, 2018.

[9] T. Naemsai, B. Niyomvas, and J. Jareanjit, "Energy management of precooling process for green cabbages," in The 11th International Conference on Applied Energy (ICAE 2021), Bangkok, Thailand, 2021, pp. 012067.

[10] M. Y. Yuzainee, N. H. N. Zafira, and J. Nurulnadiah, “Cooling Load Calculation for Efficient Cold Storage of Fresh-Cut Yam Bean”, *International Journal of Recent Technology and Engineering*, vol. 8, no. 4, pp. 6506–6513, 2019.

[11] M. C. Ndukwu, M. I. Ibeh, G. E. Akpan, E. Ugwu, L. Akuwueke, L. Oriaku, V. E. Ihediwa, F. I. Abam, H. Wu, C. A. Kalu, A. E. Ben, and J. Mbanasor, “Analysis of the influence of outdoor surface heat flux on the inlet water and the exhaust air temperature of the wetting pad of a direct evaporative cooling system,” *Applied Thermal Engineering*, vol. 226, pp. 120292, 2023.

[12] W. Shi, H. Yang, X. Ma, and X. Liu, “Techno-economic evaluation and environmental benefit of hybrid evaporative cooling system in hot-humid regions,” *Sustainable Cities and Society*, vol. 97, pp. 104735, 2023.

[13] N. Kapilan, A. M. Isloor, and S. Karinka, “A comprehensive review on evaporative cooling systems,” *Results in Engineering*, vol. 18, pp. 101059, 2023.

[14] R. Li, W. Wang, Y. Shi, C. Wang, and P. Wang, “Advanced Material Design and Engineering for Water-Based Evaporative Cooling,” *Advanced Materials*, vol. 36, no. 12, pp. 2209460, 2024.

[15] H. Zhang, J. Liu, Y. He, and Y. Zhou, “Convective heat transfer of falling film around the horizontal half-oval tube with reverse airflow in an evaporative condenser,” *International Journal of Heat and Mass Transfer*, vol. 225, pp. 125429, 2024.

[16] P. Intararak, R. Dejchanchaiwong, and P. Tekasakul, "Optimization of operating parameters for rubber sheet fast drying in a forced-convection

rubber smoking room," in The 1st International Conference on Applied Science and Technology, Krabi, Thailand, 2021, p. 012010.

[17] F. Polonara, Ed., *Refrigeration, Air Conditioning and Heat Pumps: Energy and Environmental Issues*. Basel, Switzerland: MDPI - Multidisciplinary Digital Publishing Institute, 2021.