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Assessing the Thermal Load of Low-Cost Cold Storage for Perishable Agricultural Products Used in Rural Areas of Bangladesh

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Abstract: Bangladesh is an agricultural country with limited food storage facilities. As a result, more than 20-40% of perishable products go to waste, amounting to an estimated loss of $2.4 billion annually. Field surveys indicate that consumers prefer fresh, nutrient-rich goods, while farmers need sufficient time to sell their harvested produce at fair prices. Additionally, supply chain authorities aim to reduce perishable waste to maximize their profits. To ensure food safety and improve supply chain management, implementing low-cost cold storage solutions emerges as an immediate and viable solution. Districts without adequate storage facilities, such as Khagrachari, Brahmanbaria, Mymensingh, and Narail, could benefit significantly from being developed into storage-rich zones, aligning with government initiatives. With this goal in mind, a low-cost cold storage unit has been designed, offering 28 m^3 of storage space with a capacity of 5,000 kg for perishable fruits and vegetables. The daily intake rate is 1,000 kg, and rice husk particles are used as insulating material to minimize costs. In the design process, cooling loads for various perishable fruits and vegetables were calculated using MATLAB coding. Based on their perishability rates and availability in local markets, potatoes, mangoes, watermelons, and cauliflowers were selected for this study.

Keywords: **low-cost cold storage, agricultural products, rural areas, Bangladesh.**

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1. Introduction

Efficient food storage and supply chain management are essential for any country to ensure food distribution to its population and reduce waste. Bangladesh, primarily an agricultural nation, employs over 43% of its population in agriculture, which accounted for 14.2% of GDP in 2017. With its favorable climate conditions, Bangladesh stands out as one of the leading vegetable and fruit-producing nations in South Asia (Bhuiyan, et al., 2012). The country ranks among the top global producers of rice (third), potatoes (seventh), tropical fruits (sixth), and farmed fish (fifth) (UNCTAD, 2017). Additionally, the country produced 4.384 million metric tons of fish in 2018-19 (Chakraborty, 2021). Notably, Bangladesh produced 13,592 metric tons of shrimp in 2022-2023, generating USD 422.3 million in revenue, according to the Bangladesh Department of Fisheries. However, significant quantities of these perishable goods are reportedly lost due to inadequate packaging, processing, and conversion technologies (Bhuiyan, et al., 2012). These shortcomings contribute to unintended food losses during production and significant post-harvest losses, which remain major concerns for the country. Furthermore, agricultural losses and waste management issues place a considerable burden on the nation.

Bangladesh is a highly populated country with a population of 170 million, which is increasing daily (Bangladesh Bureau of Statistics, 2022). Despite this agricultural abundance, one-third of Bangladesh's horticultural produce—mainly fruits and vegetables—is wasted due to inadequate post-harvest management, including preservation, storage facilities, and efficient transportation systems (Noman, 2021). The country faces an urgent need to ensure food security for all its citizens. Proper cold storage facilities can reduce post-harvest losses. In other words, maintaining the desired temperature of the food during processing is crucial (Ndraha, et al. 2018). The lack of cold storage facilities also encourages the use of harmful chemicals to artificially extend the shelf life of food, leading to serious health and nutritional issues for consumers. Refrigeration stops or reduces changes in foods, those being microbiological, physiological, biochemical, or physical. The most effective cold chain systems refrigerate food to temperatures that inhibit these changes for as long as possible, enhancing food quality and extending shelf life (Ndraha et al., 2018; James & James, 2010; Gullpart, 2018). Introducing low-cost cold storage solutions could significantly reduce post-harvest losses and mitigate food adulteration, improving food safety and public health. Motivated by this challenge, this study aims to develop a MATLAB algorithm to support the design of a farmer-friendly cold storage facility. This facility is intended to simplify the preservation of perishable products and shield farmers from exploitation by opportunistic intermediaries.

2. Methodology

To assess the cooling load of a low-cost cold storage system, the study first analyzed the post-harvest losses of fruits and vegetables. A field survey was then conducted among stakeholders, farmers, and fishermen to gather comprehensive data reflecting the necessity of low-cost cold storage. Based on this study, a MATLAB algorithm was developed to calculate cooling loads and was validated against published results (Bredesen, 2019). Using the survey data, the algorithm was applied to calculate the cooling load for a low-cost cold storage unit with a product capacity of 5,000 kg.

2.1 Post-Harvest Loss

It is deeply distressing for growers to be unable to protect their harvested crops. Post-harvest losses not only result in wasted produce but also represent a significant loss of labor, money, and resources. In Bangladesh, post-harvest losses account for nearly 40% of the total produce. Efforts to minimize these losses are crucial for ensuring better food security. Various factors contribute to post-harvest losses, including improper handling, inadequate packaging, biodegradation, unfavorable climatic conditions, premature or over-mature harvesting, and damage caused by insects and birds. These losses prevent growers from maximizing their profits despite their hard work (Noman, 2021). Figure 1 illustrates the post-harvest losses of some common fruits and vegetables.

For example, in Bangladesh, about 81% of the total potato harvest occurs between January and April, but only 28% of these potatoes are consumed during this period. This results in a surplus of 53% that needs to be stored and consumed over the next six months (Akter et al., 2022). According to Khadiza Akter (2022), several issues contribute to the post-harvest losses of potatoes: inadequate storage facilities (48.94%), poor packaging systems (32.37%), rain during harvesting (17.63%), loading and unloading challenges (0.2%), and poor transportation (0.51%). Given these challenges, cold storage presents a viable solution to reduce post-harvest losses of fruits and vegetables. By lowering the temperature of harvested crops, cold storage can significantly extend their shelf life, providing growers with more time to market their produce effectively.

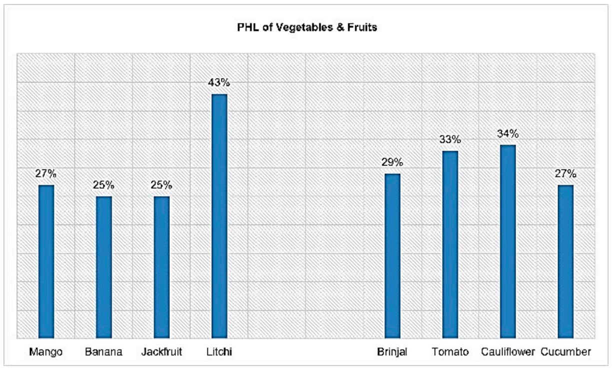

Figure 1. Percentages of post-harvest loss of some common fruits and vegetables (Rahman, 2023).

2.2 Field Survey

A field survey was conducted to gather feedback from food supply chain stakeholders on the refrigerated storage of vegetables and fruits, including its impact on profit margins and nutrient retention. The survey took place at the Uttara Sector 10 vegetable market in Dhaka, with participation from 10 *arathdars* (intermediate storers), 10 *beparis* (wholesalers), and 10 general consumers outside the food supply chain. The findings revealed that while *beparis* and *arathdars* currently do not refrigerate vegetables, they believe doing so could increase their profits. Furthermore, all stakeholders—*beparis*, *arathdars*, and consumers—agreed that refrigeration does not compromise the nutritional value of vegetables. With access to proper storage facilities, farmers could bypass *farias* and *beparis*, thereby enhancing their bargaining power (Hasan, 2022).

A second survey was conducted among 10 farmers and 10 fishermen to understand their perspectives on using refrigeration systems to store their products. Both groups agreed that refrigeration could help reduce post-harvest losses and increase profits. However, fishermen noted that they primarily keep freshwater fish in ponds or lakes until sold, reducing their immediate need for cold storage. Nevertheless, they acknowledged that refrigerated storage is essential for export purposes, particularly for vegetables and fish. These surveys underscore the critical need for cold storage facilities to preserve products, minimize post-harvest losses, and improve profitability for all stakeholders in the food supply chain.

2.3 Important Products and Locations

The low-cost cold storage system is designed to accommodate all types of fruits and vegetables harvested in Bangladesh. However, this study focuses on some of the most common and widely produced varieties. According to the BBS Handbook, Jhenaidah and Rajbari are the top producers of bananas, yet neither district has cold storage facilities. Similarly, Jamalpur leads in the production of brinjal (winter variety) and cauliflower, but only three small cold storage units (with capacities of less than 6,000 MT) are available for use. Many other districts lack any cold storage facilities despite having significant fruit and vegetable production. This highlights a critical gap in post-harvest infrastructure that adversely affects the preservation and profitability of produce in these regions. Table 1 lists the districts with the highest fruit and vegetable production. Table 2 highlights notable examples of common fruits and vegetables produced in large quantities in districts without adequate storage facilities.

Table 1. Maximum vegetable- and fruit-producing districts (Bangladesh Bureau of Statistics 2023).

Vegetable and fruit name	District	Production (MT)
Banana	Jhenaidah	21041
	Rajbari	11565
	Jashore	8577
	Rajshahi	8150
Pineapple	Tangail	129640
	Rangamati	24844
	Gajipur	8562
	Khagrachari	24844
Ripe papaya	Bogura	11175
	Rajshahi	9038
	Natore	7828
	Jamalpur	6815
Litchi	Dinajpur	11143
	Natore	8097
	Pabna	7958
	Kushtia	4169
Brinjal (summer)	Rajshahi	18397
	Jashore	17440
	Pabna	16074
	Jhenaidah	13481
Green papaya	Jashore	17344
	Rajshahi	75809
	Mymensingh	23215
	Rangamati	7893

Cauliflower	Jamalpur	30200
	Dinajpur	22112
	Mymensingh	20566
	Rangpur	15372

Table 2. Production of some fruits and vegetables in districts without storage facilities (BBS, May 2023 [17]).

District Name	Mango (MT)	Guava (MT)	Orange (MT)	Melon (MT)
Mymensingh	22773	4029	0	225
Narshingdi	5029	4332	0	428
Bagerhat	1987	1863	0	925
Chuadanga	7141	2005	27.4	590
Narial	7775	2013	0	441
B. Baria	10045	3445	0	492
Noakhali	8703	1970	0	395
Khagrachari	9643	1488	1291	137
Bandarban	3764	651	1392	181
Rangamati	6251	6329	2665	336
District Name	Lady's Finger (MT)	Bitter Gourd (Karalla) (MT)	Indian Spinach (Puishak) (MT)	Chili (winter) (MT)
Mymensingh	4256	2456	3171	15201
Narshingdi	751	1392	558	6592
Bagerhat	620	1337	1404	486
Chuadanga	1692	870	2167	938
Narial	1114	617	1889	1100
B. Baria	3168	351	2028	10475
Noakhali	789	296	1015	24662
Khagrachari	1053	1245	898	2435
Bandarban	548	550	316	1357
Rangamati	798	788	787	3947

2.4 Storage of Fruits and Vegetables

Cooling is an effective food preservation method that slows physical changes, chemical reactions, and microbiological activity in food, thereby extending its shelf life (ASHRAE, 2018). The perishability of fruits and vegetables varies depending on their type. The perishability of fruits and vegetables varies depending on their type. Most perishable horticultural commodities last the longest when stored at temperatures close to 0 °C. However, chilling-sensitive products such as bananas, mangoes, melons, and tomatoes are best stored at 5–15 °C, depending on their ripeness and the intended storage duration. In contrast, non-chilling-sensitive products like apples, grapes, and pears are optimally stored at temperatures ranging from -2 °C to -0.5 °C, and up to 2 °C (Kader, 2013). For "very high" perishable products such as tomatoes, brinjal, amaranth, and okra, the potential storage life is less than two weeks. In contrast, "high" perishable products like mangoes, bananas, papayas, and cabbages can be stored for 2–4 weeks. "Moderate" perishables, such as apples, carrots, radishes, and potatoes, can last for 4–8 weeks under proper storage conditions. Meanwhile, "low" perishable products like potatoes, dry onions, garlic, and pumpkins have a potential storage life of 8–16 weeks (Kitinoja & Kader, 2015).

In general, most vegetables experience a high initial respiration rate during the first one to two days after harvest. This rate decreases rapidly within a few days, reaching an equilibrium level (Ryall & Lipton, 2012)). Table 3 provides an overview of the storage temperatures, relative humidity levels, and potential storage times for various perishable products.

Table 3. Storage requirements of fresh fruits and vegetables (Kitinoja &Kader, 2015).

Product	Storage Temp., °C	Relative Humidity, %	Approximate Storage Life
Fruits			
Bananas (green)	13-14	90-95	1-4 weeks
Jackfruit	13	85-90	2-6 weeks
Litchi	1.5	90-95	3-5 weeks
Mango	13	85-90	2-3 weeks
Papaya	7-13	85-90	1-3 weeks
Pineapple	7-13	85-90	2-4 weeks
Watermelon	10-15	90	2-3 weeks
Vegetables			
Amaranth	0-2	95-100	10-14 days
Cauliflower	0	95-98	3-4 weeks
Cucumber	10-13	95	10-14 days
Eggplant	12	90-95	1 week
Tomato (mature, green)	10-13	90-95	2-5 weeks
Tomato (firm, ripe)	8-10	85-90	1-3 weeks
Potato (early crop)	10-15	90-95	10-14 days
Potato (late crop)	4-12	95-98	5-10 months
Onion (dry)	0	65-70	1-8 months

2.5 Cold Room Dimensions

Before determining the dimensions of the storeroom, several key parameters were taken into consideration: the mass of the products to be stored, the number of crates required, the arrangement of racks for holding the crates, and the appropriate spacing between crates to ensure proper ventilation. Based on these considerations, the final dimensions of the storeroom were determined to be 4.10 m (L) × 3.18 m (W) × 2.14 m (H). A hinged door measuring 1.98 m × 0.8 m was selected. The construction plan includes a 60 mm thick PUB slab laid over a Kota and PCC floor, with 100 mm rice husk particle board insulation for thermal efficiency. Both the external and internal finishes will use a 0.5 mm pre-painted CRCA sheet to ensure durability and ease of maintenance.

The specifics of the products to be stored are as follows:

- Fresh fruits and vegetables: 5000 kg
- Intake rate: 1000 kg/day
- Intake product temperature: +36 °C
- Product entry temperature: 25-31 °C
- Storage temperature: +4 °C
- Relative humidity: 85-90%
- Pull-down time: 24 h/ batch

2.6 Cooling Load Calculation for the Proposed Cold Storage

To calculate the cooling load, the following parameters must be considered: heat transmission through the walls, roof, and floor; heat infiltration through the door; removal of heat from the stored products; equipment loads; respiratory heat generation from the stored products; and safety factors. Together, these factors determine the total cooling load required for the storage facility.

2.6.1 Transmission Loads

Heat transmission through the walls, roof, and floor of the refrigerated space accounts for heat loss. The transmission load is typically the largest component of the cooling load and can be calculated as follows:

$$Q_T = UA(T_{amb} - T_{room}) \quad (1)$$

Here, Q_T is the heat gain in W; A is the outer surface area of the room in m^2; T_{amb} is the ambient temperature in K; T_{room} is the storage room temperature, U is the overall heat transfer coefficient of the wall, floor, or ceiling in W/m^2-K. U can be calculated by the following equation:

$$U = \frac{1}{\frac{1}{hi} + \frac{\delta ins}{kins} + \frac{1}{ho}} \quad (2)$$

In this context, δ_{ins} represents the thickness of the insulation in meters, k_{ins} is the thermal conductivity of the wall insulation in W/m-K, h_i is the inner surface conductance in W/m^2-K, and h_o is the outer surface conductance in W/m^2-K. For thick walls with low conductivity, the resistance term $\frac{\delta ins}{kins}$ significantly reduces the overall U-value, making the terms $\frac{1}{hi}$ and $\frac{1}{ho}$ negligible and may be omitted from the calculation [12]. When multiple insulation layers are used, the value of $\frac{\delta ins}{kins}$ increases with the number and types of insulation materials.

$$T_{wall} = T_{amb} + \Delta T_{sun} \quad (3)$$

Additionally, solar irradiation affects heat transmission through walls. To account for this, a sun-air temperature difference, ΔT_{sun} is included based on the orientation of the wall and surface characteristics. In this study, ΔT_{sun} values for light-colored surfaces were used. For additional clarification, we have included a table (Table 4) derived from Chapter 24.2 of the ASHRAE Handbook [3]. The sun-air temperature differences are taken following the guidelines of ASHRAE 2018. Instead of using the ambient temperature in Equation 1, the wall temperature, T_{wall}, must be used. This adjustment ensures accurate compensation for the effects of solar irradiation.

Table 4. Allowance for sun effect [12].

Typical Surface Types	East/ West Wall, (K)	South Wall, (K)	Flat Roof, (K)
Dark-colored surfaces: Slate or tar roofing, black paint.	5	3	11
Medium-colored surfaces: Unpainted wood, brick, red tile, dark cement, red, gray, and green paint.	4	3	9
Light-colored surfaces: White stone, light-colored cement, white paint.	3	2	5

2.6.2 Infiltration Loads

Infiltration loads refer to the heat gains caused by infiltrating air [12]. When the door of the refrigerated room is opened, air flows between the refrigerated space and the ambient area, leading to heat exchange. The heat load through doorways due to air exchange can be calculated as follows:

$$Q_D = Q_S D_t D_f (1\text{-}E) \quad (4)$$

Where Q_S represents the sensible and latent refrigeration load resulting from air exchange. For fully established airflow, Q_S is expressed as

$$Q_S = 0.221 A_D (h_{amb} - h_{room}) \rho_R \left(1 - \frac{\rho_{amb}}{\rho_R}\right)^{0.5} (g H_D)^{0.5} F_m \tag{5}$$

In Equation 5, g is the acceleration due to gravity in m/s^2; A_D is the doorway area in m^2; H_D is the doorway height in m; h_{amb} is the enthalpy of ambient air in kJ/kg; h_{room} is the enthalpy of cold storage room air in kJ/kg, ρ_{amb} is the density of ambient air in kg/m^3; ρ_R is the density of cold storage room air in kg/m^3 and F_m is the density factor. The enthalpy and density of air were determined using the open-source software *CoolProp* [2], as both are functions of pressure and temperature. In this study, while pressure was kept constant at 1 atm, the temperature was varied multiple times. To account for this variation, a suitable MATLAB command was integrated into the algorithm to extract the corresponding enthalpy and density values from *CoolProp*. These values were dynamically updated based on temperature and subsequently used for cooling load calculations. The density factor Fm is

$$F_m = \left(\frac{2}{1 + \left(\frac{\rho_R}{\rho_{amb}}\right)^{\frac{1}{3}}}\right)^{1.5} \tag{6}$$

For cyclical, irregular, and constant door usage, alone or in combination, the doorway open-time factor, D_t, can be calculated as:

$$D_t = \frac{N\theta_p + 60\theta_o}{3600\theta_d} \tag{7}$$

Where Θ_d is the daily time period in hr; Θ_o is the time the door simply stands open, min; Θ_p is the door open-close time in seconds per passage; N is the number of doorway passages. The typical time Θ_p for conventional pull-cord-operated doors ranges from 15 to 25 s per passage [12]. Θ_d and Θ_o vary with the usage of passage. The doorway flow factor D_f is the ratio of actual air exchange to fully established flow which is 1.1 when T_{amb}–T_{room} < 11 and 0.8 when T_{amb}–T_{room} > 11. This depends on the temperature difference between the refrigerated room and the ambient space. The effectiveness of the doorway protective device, E, is 0.95 or higher for newly installed strips, fast-fold, and other non-tight-closing doors [12].

2.6.3 Product Loads (Pulldown Load)

Product loads refer to the heat loads associated with the products stored in the facility. These loads arise either from the products entering the cold storage at a temperature higher than the storage temperature or from the respiration heat generated by stored items (primarily fruits and vegetables). In this study, freezing of products is not considered; therefore, only sensible heat gain is accounted for. If freezing were involved, the latent heat of fusion would also need to be included in the calculations. The quantity of heat to be removed can be determined using the following equation.

$$Q_P = \frac{m C_p (t_i - t_R)}{3600 t} \tag{8}$$

Where Q_p is the heat removed from the product in KW; m is the mass of the product in kg; C_P is the specific heat of the product above freezing in kJ/kg-K; t_i is the initial loading temperature of the product above freezing, in °C; t_R is the cold storage room temperature in °C and t is the staying time of the product in hours. The specific heat (C_p) values used in this study were derived from Sections 19.3 and 19.4 of the ASHRAE Handbook (2018). Table 5 provides the specific heat values for the products considered in this study.

Table 5. The specific heat of some of the investigated products above freezing (ASHRAE, 2018).

Food Item	Specific Heat Above Freezing, (kJ/kg-K)
Mangoes	3.74
Watermelon	3.97
Cauliflower	4.02
Potatoes	3.67
Onion	3.95

2.6.4 Equipment Loads

Heat gains associated with the operation of refrigeration equipment consist essentially of heat generated by the fan motor used for forced-air circulation and humidity control. The heat from defrosting where the refrigeration coil operates at a temperature below freezing point must be defrosted periodically, regardless of the room temperature. Equipment heat gain is generally minimal at space temperatures above approximately -1 °C, contributing to 5% or less of the total load. At lower refrigeration temperatures, like -30 °C, the equipment heat gain can become as high as 15% or more of the total refrigeration load (ASHRAE, 2018).

2.6.5 The Heat of Respiration

Respiration is a chemical change as it involves the formation of new substances such as CO_2 and H_2O. Additionally, there is a change in mass as glucose is oxidized by O_2, releasing heat. This process is permanent, further confirming that respiration is a chemical change. For most stored plant products, cellular development is negligible. Instead, the majority of respiration energy is released as heat, which must be accounted for during the cooling and storage of these living commodities. The respiration load can be found by the following equation.

$$Q_S = m \times q_{resp} \tag{9}$$

Here, m is the mass of the product in kg and q_{resp} is the heat of respiration (ASHRAE, 2018) in W/kg. The respiration rates for some common fruits and vegetables are provided in the ASHRAE Handbook (2018).

2.7 Safety Factor

When calculating the total refrigeration load, it is common to add a safety factor to allow for possible discrepancies between the design and actual operation. This factor will vary depending on the quality of the cold storage, but generally, a safety factor of 10% of the total refrigeration load is used (ASHRAE, 2018).

3. Results and Discussion

MATLAB is utilized to calculate the cooling load for selected fruits and vegetables. Figure 2 compares the published results [9] against the data obtained from our algorithm. The input boundary conditions of Bredesen et al. [9] are taken as input conditions of our code and the graph shows the comparison between the total output load. The curves of Figure 2 ensure the reliability of our algorithm as our results follow the trend of the results of Bredesen (2019). The deviation of quantitative results is also less. We calculated the average deviation between the following $\frac{\sum_{day1}^{day6}\frac{|Bredesen-Dip|}{Dip}x100\%}{NumberofDays}$ and found that the average deviation is 1.7%. The sources of this deviation are the selection of different models and the variations in the calculation approach.

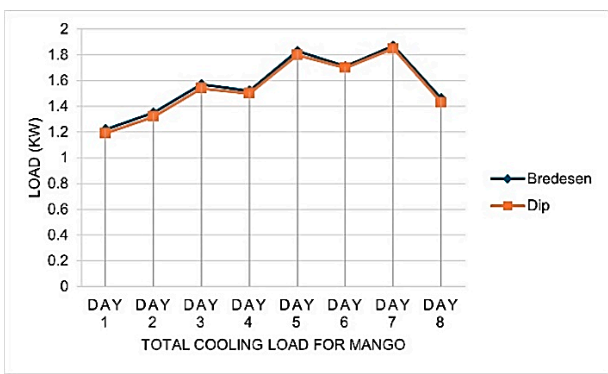

Figure 2. Comparison of the total cooling load for mango between Bredesen 2019 and the present study.

In this study, mango, watermelon, cauliflower, potato, and onion are chosen, with a daily storage rate set at 1000 kg. As Kharif crops, the loading temperatures for mango and watermelon are set at 31 °C, while for Rabi crops such as cauliflower, potato, and onion, the loading temperature is set at 25 °C, reflecting the average temperature during their respective cropping seasons. The ambient temperature is assumed to be 36 °C, which corresponds to the average highest temperature in Bangladesh. The cold room temperature is determined based on the optimal storage temperatures for the selected perishable fruits and vegetables. Table 3 illustrates the storage temperatures and the corresponding relative humidity for these fruits and vegetables.

3.1 Total Refrigeration Load

The product load is found to be one of the most crucial components of the total refrigeration load. According to our algorithm, 1,000 kg of product is loaded daily at the initial temperature. It was observed that reducing the product's temperature to the storage temperature requires approximately 1 hour and 20 minutes according to the lumped method of transient heat conduction. This process is repeated daily until the total storage capacity of 5,000 kg is reached. Importantly, products loaded on previous days require minimal transmission load to maintain their temperature. The type and quantity of goods are the most important factors while the usage conditions—such as door opening, weather, the number of electrical equipment, personnel, among others—associated with the cold storage stay constant. Additionally, our calculations indicate that the equipment load constitutes 10% of the combined transmission, infiltration, and respiration loads. Nonetheless, many of the important factors are connected. The cold storage can be operated with the lowest possible overall refrigeration load without accounting for losses.

3.2 The Status of Cooling Loads for Kharif Crops (Mango and Watermelon)

Figure 3 illustrates the cooling load status, which includes the equipment load, respiration load, infiltration load, pulldown load, and transmission load while the products are mango and watermelon. For both mango and watermelon, respiration, infiltration, and equipment load increase according to the mass, but pulldown and transmission loads stay constant until day five. When the product is mango, the pulldown load is significantly decreased from 0.78 kW to almost 0 kW on day 6 because of the least temperature variance. On the other hand, the pulldown load for watermelon at full load condition dropped down from 0.96 kW to almost 0 kW due to the minimum temperature difference meanwhile the transmission load and the respiration load are constant at the value of 0.86 kW and 0.15 kW, respectively. Both the respiration load and the transmission load for mangoes are fixed at 0.67 kW and 0.78 kW, respectively. The equipment and infiltration load variations are negligible.

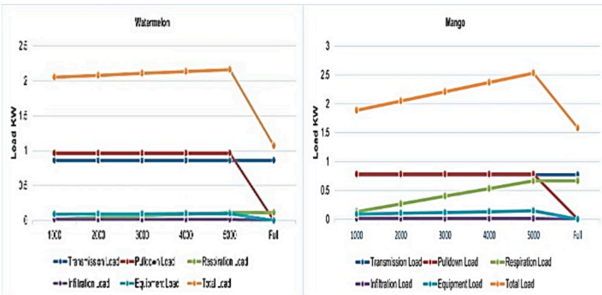

Figure 3. Status of cooling loads for Kharif crops (mango and watermelon).

3.3 The Status of Cooling Loads for Rabi Crops (Potato, Cauliflower and Onion)

Figure 4 shows the current state of the cooling load, which includes the pulldown, infiltration, respiration, transmission, and equipment loads for potatoes, cauliflower, and onions. All of these loads are retaining the same properties as those listed in section 3.2.

Onion, cauliflower, and potato have pulldown loads of 0.72 kW, 1.17 kW, and 1.72 kW, respectively, and transmission loads of 0.92 kW, 1.17 kW, and 1.17 kW, respectively. Compared to watermelon, mango, and potato, cauliflower has a substantially higher transmission burden. In contrast to other perishable goods, the storage temperature is kept lower at 0 °C. Additionally, cauliflower has a higher specific heat than the other products covered in this article.

Onions yield the most pulldown refrigeration load, whereas potatoes yield the lowest. Mangoes have a lower initial refrigeration load (1.89 kW) than watermelons (2.05 kW). However, after two days, their load rises rapidly. The overall refrigeration load may be impacted by the thickness of the insulation. In general, there should be a negative correlation between insulation thickness and the overall refrigeration load. However, at a certain thickness—which is outside the purview of this study—the impact of insulation thickness may decrease.

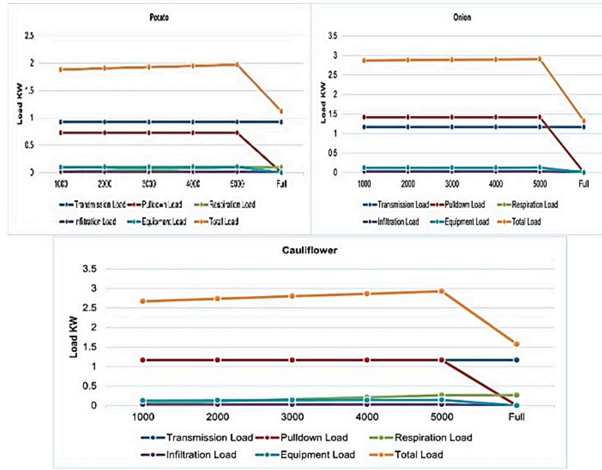

Figure 4. Status of cooling loads for Rabi crops (potato, cauliflower, and onion).

Table 6 illustrates how the transmission load varied during the summer and winter of 2020 in Rangpur, Bangladesh, for different crops. August was chosen to represent the summer season, and the highest and lowest recorded temperatures of a specific day were analyzed. Similarly, January was selected for the winter season using the same criteria. The results show that the transmission load for all crops is approximately 53% higher in summer than in winter. Additionally, the difference in transmission load between day and night is smaller in summer compared to winter, highlighting seasonal variations in cooling demands.

Table 6. The maximum and minimum temperatures in Rangpur district for August and January 2020 (Open-Meteo, 2026).

	August (summer)		January (winter)	
Temperature (°C)	Maximum (day)	Minimum (night)	Maximum (day)	Minimum (night)
	36	30	22	14
Transmission load for onions (kW)	1.17	0.98	0.74	0.49
Transmission load for potatoes (kW)	0.92	0.74	0.49	0.25
Transmission load for mangoes (kW)	0.77	0.59	0.34	0.1

4. Conclusion

Bangladesh is one of the largest producers of vegetables and fruits, yet inadequate storage facilities result in significant post-harvest losses, ranging from 3.5% to 9.03% at the farmers' level and 20.5% to 27.64% at the traders' level. This study evaluates factors relevant to Bangladesh, including local weather conditions, product types, and consumer needs, to address these challenges.

Rice husk particle board is used as an insulating material to lower the construction costs of cold storage. A MATLAB algorithm was developed and validated to ensure accurate cooling capacity calculations. The validated code was applied to determine and analyze the cooling load for a 5,000 kg cold storage facility. The cooling loads for Rabi and Kharif crops were calculated, revealing that Kharif crops have a lower total cooling load compared to Rabi crops. Among the various loads, transmission and pulldown loads were found to be higher than respiration, infiltration, and equipment load. Notably, the transmission load decreases by approximately 20% at night in summer and by 50% in winter compared to daytime. These findings provide valuable insights for designing and fabricating low-cost cold storage solutions tailored to rural areas in Bangladesh.

Conflict of Interest

The authors have no conflicts of interest to declare.

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