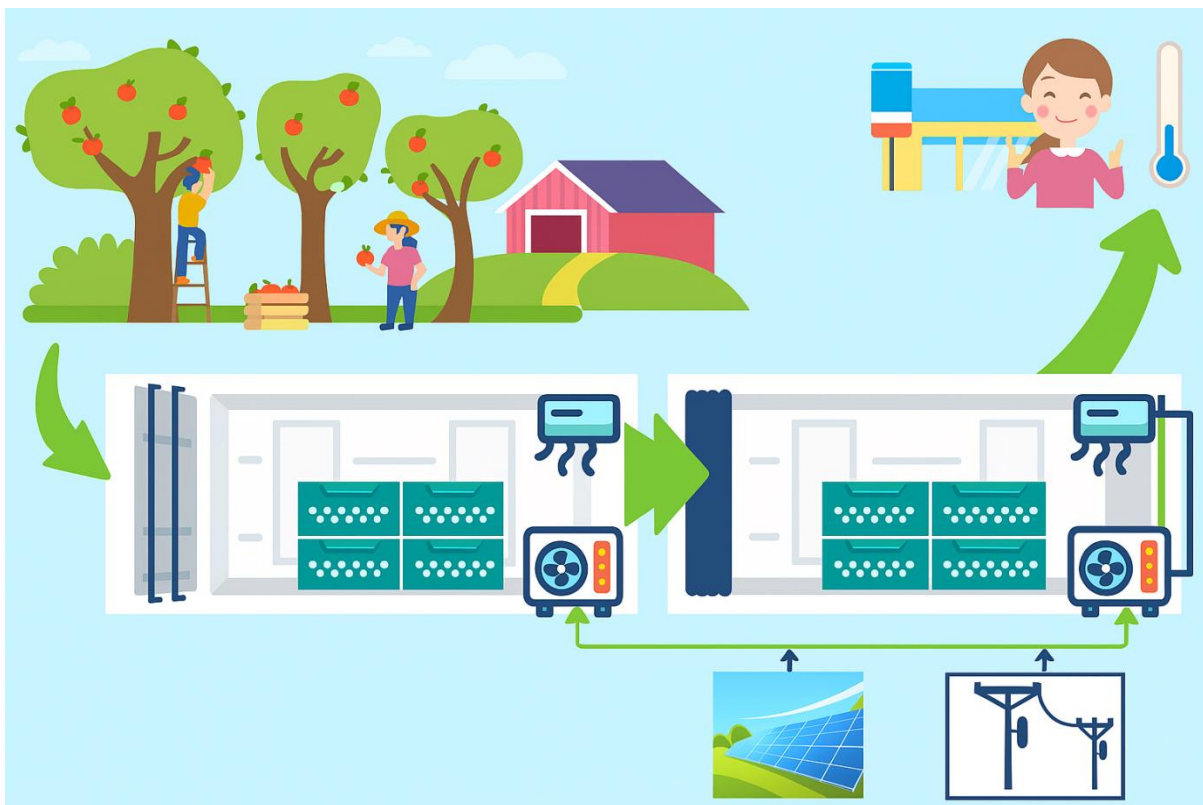


Feasibility research of Solar Electric-Based Cold Warehouse equipped with Low-temperature Latent Heat Material for Fruit Storage in Bangladesh Climate Conditions



Design of 20-ft cold warehouse for agricultural product by solar power system

November, 2025 |

1. Background and objective

Bangladesh's subtropical monsoon climate, characterized by high temperatures and high humidity with hot-season peaks often exceeding 30°C, poses serious challenges for the post-harvest management of temperature-sensitive agricultural products such as mango. To maintain quality and extend shelf life, mangoes require controlled conditions of around 15°C and 90–95% relative humidity—requirements that are difficult to meet in rural areas with limited cold chain infrastructure and unstable power supply. In response, the UNEP CTCN technical assistance project in Bangladesh is promoting the development of PV-based low-temperature refrigeration systems that integrate latent heat materials (LHM) and insulated containers. The objective of this report is to present an integrated design and implementation plan for a PV-based low-temperature refrigeration system tailored to Bangladesh's climatic and operational conditions, with a focus on mango cold storage at 15°C. The report summarizes the technical basis for determining refrigeration and PV capacities, the detailed design of insulated containers (including PU foam/XPS composite insulation, door configuration, and panel connection methods), and design refinements made following on-site surveys and modified load calculations. It also describes numerical heat flow analyses that evaluate the impact of evaporator location, loading patterns, and product respiration heat on the internal temperature and air velocity distribution, providing guidance for system optimization.

2. Design of PV-based cold refrigeration system in Bangladesh

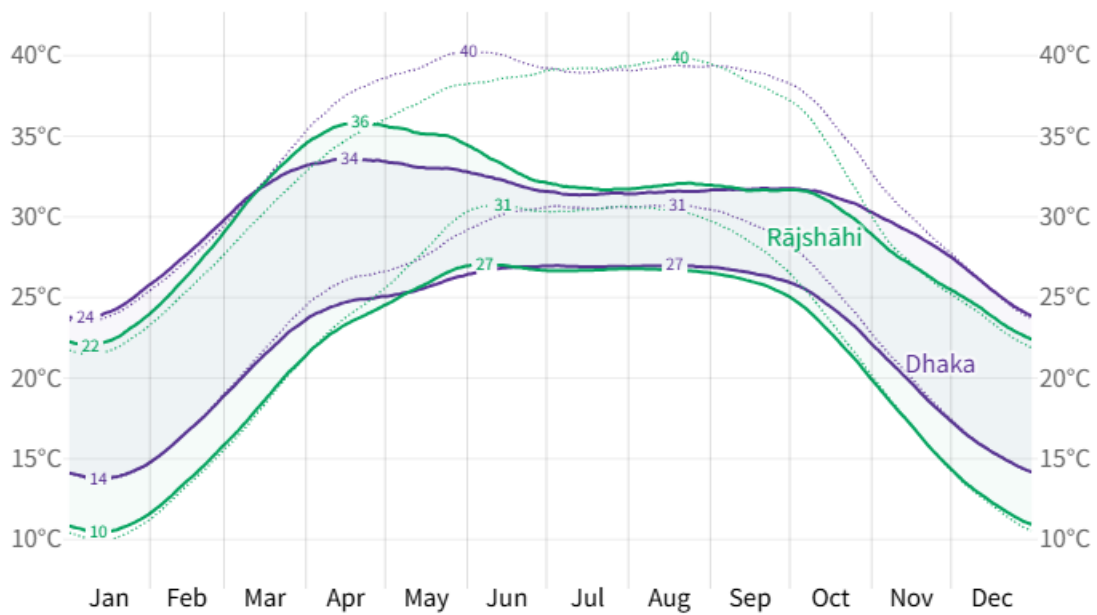
An overall review of the design of a solar-based refrigeration system to maintain the internal temperature of a cold storage warehouse at 15°C under external temperature conditions (35°C) in Bangladesh was conducted, with additional considerations identified.

2.1 Weather condition in Bangladesh

Bangladesh has a subtropical monsoon climate, with a high and humid climate with an average annual temperature of about 25°C

- Monthly average temperature (Dhaka):
 - Hot season : April - September (average 28°C - 29°C, high 31°C - 34°C)
 - Cold season : January (average 22°C, low 14°C, high 28°C) Winters are short, with an average temperature of 15°C, never dropping below zero.

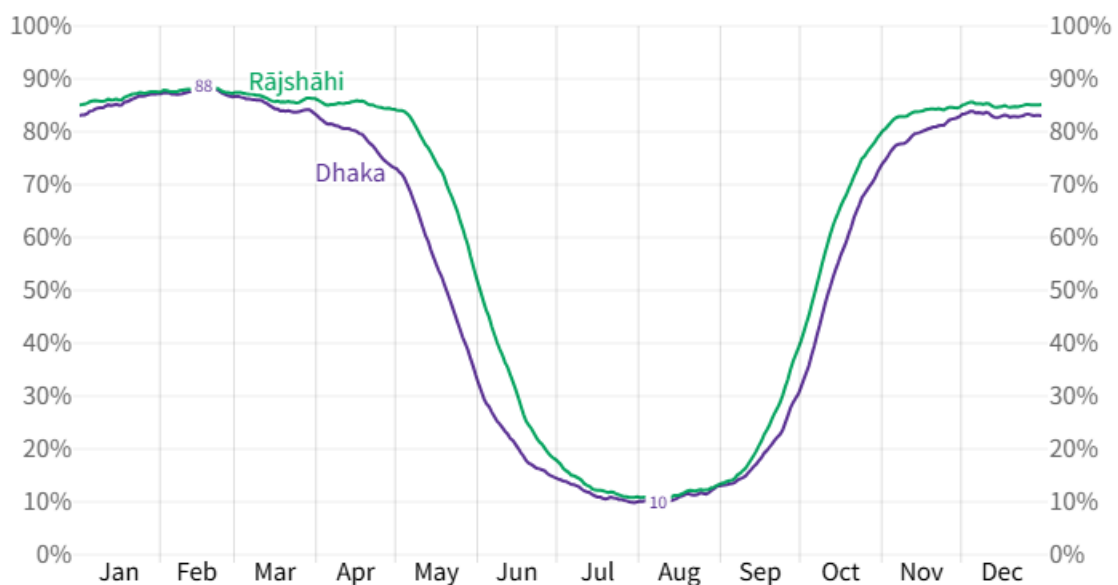
When designing refrigerated containers, it is important to secure sufficient refrigeration capacity, especially considering the high temperature and humidity in summer.



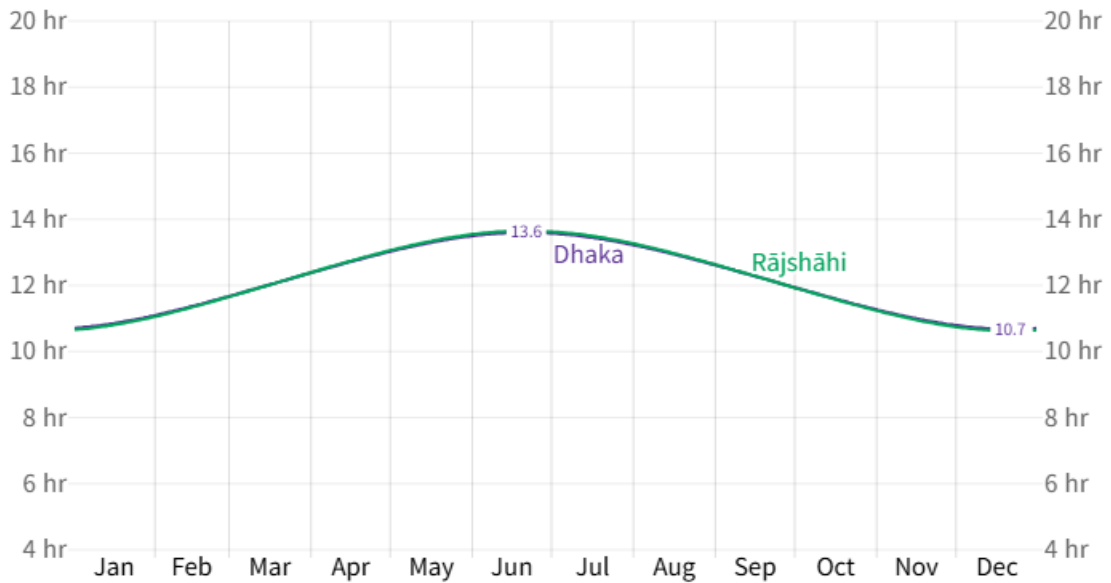
< Compare the Average High and Low Temperature in Dhaka and Rājshāhi, Ref. : <https://weatherspark.com/>>

2.2. Average daily solar generation hours

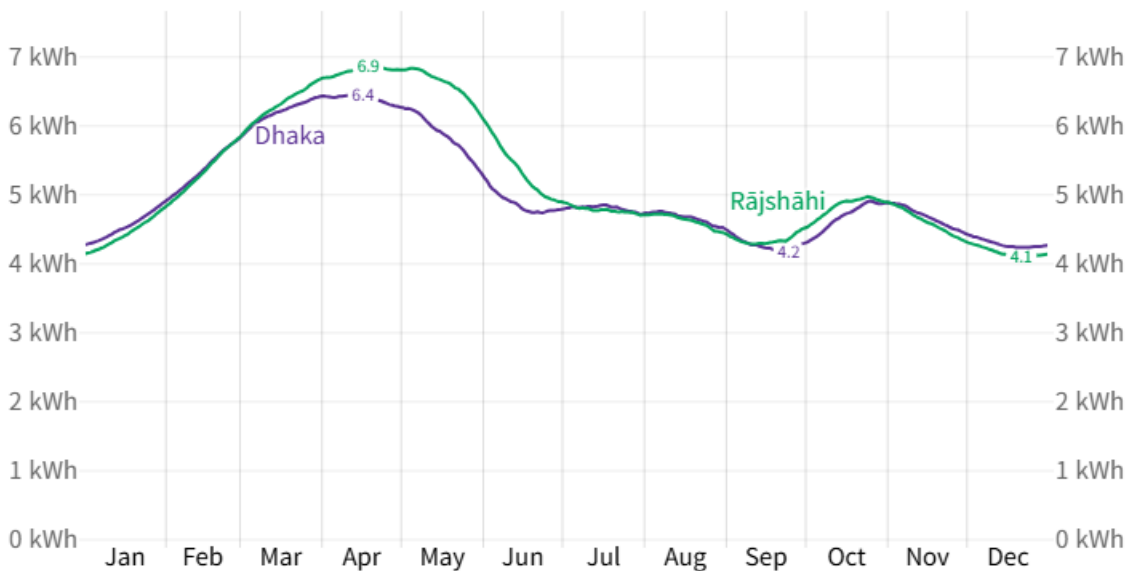
A refrigerator can be operated for up to 6 hours and 30 minutes during the day using solar power. Since at least 4 hours of solar power is required to effectively maintain the temperature inside a cold storage, the refrigerator can be operated for the time that satisfies this condition to secure the necessary cooling effect. Consider the time when power supply is available, which is a key factor in stable operation of a cold storage.



<Compare the Chance of Clearer Skies in Dhaka and Rājshāhi, Ref. : <https://weatherspark.com/>>



<Compare the Hours of Daylight in Dhaka and Rājshāhi, Ref. : <https://weatherspark.com/>>



<Compare the Average Daily Incident Shortwave Solar Energy in Dhaka and Rājshāhi, Ref. : <https://weatherspark.com/>>

2.3. Storage temperature of fruits and vegetables in cold storage

For example, mango, the inside of the cold storage should be maintained at a storage temperature of 15°C and a relative humidity of 90-95%. These are essential conditions for optimizing the freshness of fruits and vegetables and extending their storage period.

Table 3: Recommended temperature and relative humidity for fruits and the approximate storage life under these conditions.

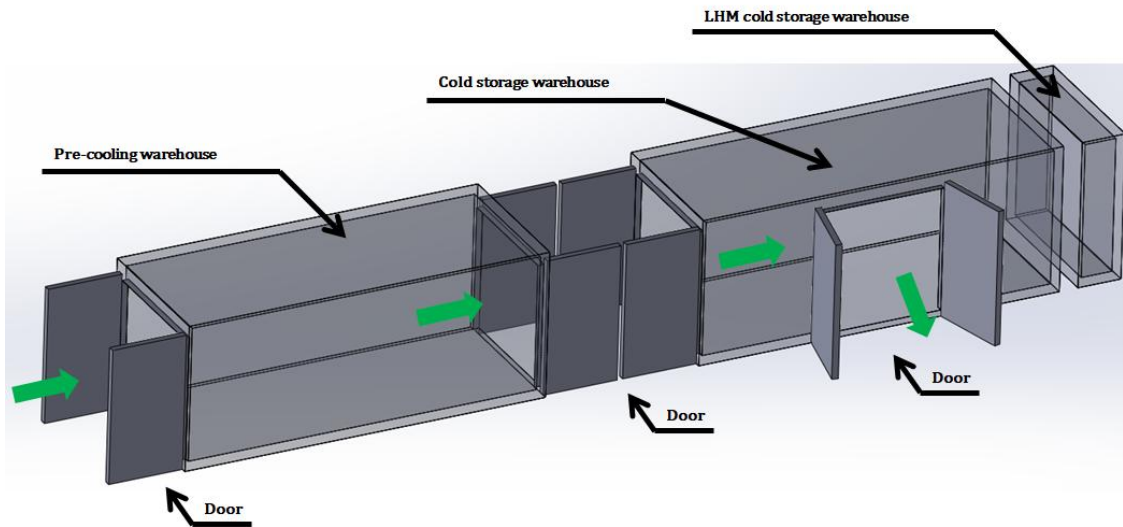
Fruit	Storage (°C)	Temperature	Storage (%)	Relative Humidity	Storage (days)	life
Apple	-1-4		90-95		30-180	
Apricot	-0.5-0		90-95		7-21	
Asian pear	1		90-95		150-180	
Atemoya	13		85-90		28-42	
Avocado	3-13		85-90		14-56	
Babaco	7		85-90		7-21	
Banana /Plantain	13-15		90-95		7-28	
Barbados cherry	0		85-90		49-56	
Blackberry	-0.5-0		90-95		2-3	
Black sapote	13-15		85-90		14-21	
Blueberries	-0.5-0		90-95		14	
Breadfruit	13-15		85-90		14-42	
Caimito	3		90		21	
Calamondin	9-10		90		14	
Cantalupo	0-2		95		5-15	
Carambola	9-10		85-90		21-28	
Cashew apple	0-2		85-90		35	
Chayote	7		85-90		28-42	
Cherimoya	13		90-95		14-28	
Cherries	-1-0.5		90-95		14-21	
Chicory	0		95-100		14-21	
Coconut	0-1.5		80-85		30-60	
Cranberries	2-4		90-95		60-120	
Cucumber	10-13		95		10-14	
Currants	-0.5-0		90-95		7-28	
Custard apple	5-7		85-90		28-42	
Dates	-18-0		75		180-360	
Durian	4-6		85-90		42-56	
Feijoa	5-10		90		14-21	
Fig	-0.5-0		85-90		7-10	
Grape	-0.5-0		90-95		14-56	
Grapefruit	10-15		85-90		42-56	
Guanabana	13		85-90		7-14	
Guava	5-10		90		14-21	
Jaboticaba	13-15		90-95		2-3	
Jackfruit	13		85-90		14-42	
Kiwano	10-15		90		180	
Kiwifruit	-0.5-0		90-95		90-150	
Kumquat	4		90-95		14-28	
Lemon	10-13		85-90		30-180	
Lime	9-10		85-90		42-56	
Longan	1-2		90-95		21-35	
Loquat	0		90		21	
Lychee	1-2		90-95		21-35	
Mamey	13-18		85-95		14-42	
Mandarin	4-7		90-95		14-28	
Mango	13		90-95		14-21	
Mangosteen	13		85-90		14-28	
Melon	7-10		90-95		12-21	
Nectarine	-0.5-0		90-95		14-28	
Olives, fresh	5-10		85-90		28-42	
Orange	0-9		85-90		56-84	
Papaya	7-13		85-90		7-21	
Passionfruit	7-10		85-90		21-35	
Peach	-0.5-0		90-95		14-28	

2.4. Cold storage configuration plan

The cold storage warehouse comprises the following components:

- Pre-cooling using an electric fan: Contributes to reducing the load on the cold storage by removing the initial heat of harvested agricultural products.
- Pre-cooling using a freezer: Used when more powerful pre-cooling is required, and can be applied selectively depending on the item.
- Cold storage: A core storage space that maintains a constant set temperature and humidity.

- Cold storage using LHM (Latent Heat Material): LHM is a cold storage material that helps to maintain the temperature inside the cold storage stably during times when solar power generation is not possible. It is an important element that allows for a constant temperature to be maintained even at night or on cloudy days.



2.5. Calculation of heat load and chiller/solar panel capacity

The heat load calculation was performed to maintain the temperature inside the cold storage at 15°C at an outside temperature of 35°C in Bangladesh. Based on the calculation results, the capacity of each refrigerator required for the pre-cooling warehouse, cold storage, and cold storage using LHM was calculated. The total capacity and layout plan of the solar panels were established to meet the required refrigerator capacity and secure a minimum operating time of 4 hours.

2.6. Calculating and comparing heat loads by refrigerated warehouse size

The heat load was calculated and compared based on 20-ft and 40-ft containers. The energy demand according to container size was clearly identified.

2.7. Design of a low-temperature refrigeration system based on a 20-ft container

The design of a low-temperature refrigeration system based on a 20-ft container was conducted according to the presented conditions.

3. Consultation on the detailed design of the insulated container and the refrigeration system

3.1. Consultation on the detailed design of the insulated container

3.1.1 Insulation structure: Consultation on the PU foam/XPS composite structure

Insulated containers are important for minimizing the inflow of external heat into the interior. PU (polyurethane) foam and XPS (extruded polystyrene) composite structures offer the following advantages:

- PU foam (polyurethane foam):
 - Features: Very low thermal conductivity (0.022~0.033W/(m*K)) and has the best insulation performance among existing insulation materials. The fine independent bubbles formed inside during foaming maximize the insulation performance.
 - Advantages: Excellent insulation, airtightness, adhesiveness, lightweight.
- XPS (extruded polystyrene):
 - Features: Has a perfect closed-cell honeycomb structure, very low water absorption (almost no water absorption), low thermal conductivity (0.027~0.03W/mK), high compressive strength, and aging resistance.
 - Advantages: Excellent waterproofing, moisture resistance, no rot or mold, high strength contributes to structural stability, soundproofing effect.
- Advantages of composite structures (examples):
 - The container walls can be constructed in the form of sandwich panels.
 - The exterior is finished with FRP (glass fiber reinforced plastic) or aluminum sheets, and the interior is layered with PU foam and XPS to maximize the advantages of each material.
 - The form in which XPS prevents moisture penetration and provides structural support, and PU foam provides excellent insulation performance.
 - This can increase thermal efficiency and enhance the durability of the container.

3.1.2 Negotiate the location of containers for pre-cooling and storage

Container doors can be a major path for heat inflow, so they should be carefully designed.

- Minimize heat loss: Doors should be airtight and sufficiently insulated, including the door itself. Consider installing double doors or air curtains to minimize heat inflow when opened.
- Consider air circulation: To ensure efficient circulation of cooling air, a certain gap should be left between the cargo, the freezer, and the door. Cargo should not be loaded higher than the red line indicated on the inside wall of the refrigerated container to avoid impeding air circulation.
- Work efficiency: Consider the number and location of doors by considering the movement of mangoes in and out, and design them to facilitate loading and unloading.

3.2. Discussion on detailed design plan for refrigeration system

3.2.1 Refrigeration system specifications

The specifications of the refrigeration system are determined by the size of the container, insulation performance, type of fruit to be stored (mango), external temperature conditions, target internal temperature, etc.

- Refrigerator type: Generally, a compression refrigerator is used. Scroll compressors or reciprocating compressors can be selected considering efficiency and maintenance.
- Refrigerant: Considering environmental regulations and efficiency, it is common to use eco-friendly and high-efficiency refrigerants such as R-404A and R-134a.
- Refrigeration capacity: Calculate the refrigeration capacity based on the total heat load of the container. All of the respiration heat of the mango, heat penetration through the outer wall, and heat loss due to opening the door must be considered.
- Temperature control range: A precise temperature control system is required to maintain the optimal storage temperature for the mango (typically 10°C to 13°C).
- Dehumidification function: Considering the high humidity in Bangladesh, a dehumidification function that removes excessive moisture inside the container must be considered.

- Automatic control and monitoring system: It is necessary to build a system that can monitor and control the internal temperature, humidity, and refrigerator operation status in real time to support stable operation.

3.2.2 Refrigeration System Configuration (General Configuration)

A general refrigeration system consists of the following main components:

1. Compressor: Compresses low-temperature, low-pressure refrigerant vapor to high-temperature, high-pressure refrigerant vapor.
2. Condenser: High-temperature, high-pressure refrigerant vapor condenses through heat exchange with outside air (or cooling water) and changes into liquid refrigerant.
3. Expansion Valve: Expands high-pressure liquid refrigerant to low pressure and sends it to the evaporator. At this time, the temperature of the refrigerant drops rapidly.
4. Evaporator: Low-temperature, low-pressure liquid refrigerant absorbs heat inside the container and evaporates, cooling the inside of the container. The evaporated refrigerant vapor returns to the compressor.
5. Fan: Circulates the cooled air from the evaporator into the container to maintain the temperature.

These components are connected by piping so that the refrigerant circulates and forms a refrigeration cycle. The refrigerator is usually installed as an integral part at one end of the container or as a separate unit installed outside.

3.3. Calculating heat load according to container size and thermal conductivity

When designing a refrigeration system to store mangoes inside a container, accurate heat load calculation is essential. Heat load refers to the total amount of heat that the refrigerator must remove, and is largely composed of the following factors:

- Mango selection: Select mango as the fruit to be stored inside the container. Since mangoes generate respiration heat even after harvest, this heat must also be included in the heat load calculation.

3.3.1 The main components of the heat load calculation.

1. Transmission Load (Q_T):
 - Concept: The amount of heat transferred from the outside to the inside through the walls, roof, and floor of the container
 - Calculation: $Q_T = U \times A \times \Delta T$
 - U (Overall Heat Transfer Coefficient): Varies depending on the type of insulation (PU foam, XPS) and thickness. The lower the U value, the better the insulation performance. It is important to minimize this value through a composite insulation structure.
 - A (Surface Area): Determined by the external surface area of the container (length, width, height). As the container size increases, the heat transfer area increases, which increases the heat load.
 - ΔT (Temperature Difference): The difference between the outside air temperature (local temperature in Bangladesh) and the target temperature inside the container (mango storage temperature). The larger the temperature difference, the greater the heat load.
2. Product Load (Q_P):

- Concept: The amount of heat generated by the stored mango (respiration heat) and the amount of heat required for the mango to cool to the target temperature inside the container
- Calculation:
 - Respiration heat: The amount of heat generated per hour varies depending on the type, ripeness, and temperature of the mango. This value is calculated using the weight and respiration rate data of the mango.
 - Cooling heat: Calculated by considering the specific heat of the mango, weight, and the difference between the initial temperature and the target temperature. This is especially important in pre-cooled containers.
- 3. Infiltration Load (Q_I):
 - Concept: Heat and moisture load generated when the door is opened or outside air flows into the container through a gap.
 - Influencing factors: Varies depending on door opening and closing frequency, opening time, and airtightness of the container.
- 4. Internal Load (Q_L):
 - Concept: All heat generated inside the container, such as fans, lighting, and body heat of workers installed inside the container.

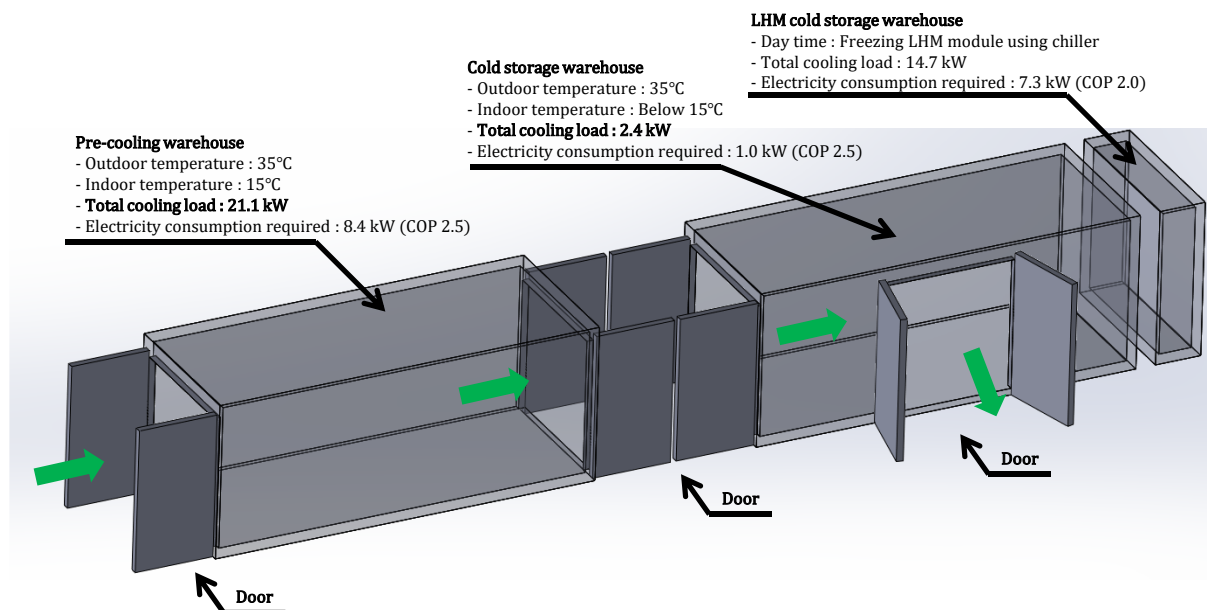
3.3.2 Total heat load calculation equation

Total heat load (Q_{total}) is the sum of all loads mentioned above.

$$Q_{total} = Q_T + Q_P + Q_I + Q_L$$

In order to quantitatively calculate each of these factors, specific data such as the exact drawing of the container, the thermal conductivity of the insulation, the characteristics of the mango (specific heat, respiration rate), and the operating plan (door opening frequency, etc.) are required.

This allows the optimal refrigeration system capacity to be calculated and an energy-efficient container to be designed.



CALCULATING LOAD												
Structure	Bangladesh						Room size (m)			Area (m ²)	Volume (m ³)	Clearance meters (m)
	Room name	Room condition		Length	Width	Height	5.90	2.35	2.39			
Temperature condition (°C)						Thermal transmittance (kcal/m ² h°C)						
Dry bulb temperature	Wet bulb temperature	Relative humidity	Absolute humidity	Inside temperature	Direction	East	West	South	North	Floor	Roof	
35.0		80.0	0.02890	15.0		0.259	0.259	0.259	0.259	0.258	0.259	
Stored goods		Capacity of products	Mass of added products	Product incoming temperature	Product outgoing temperature	Product average	Specific heat capacity of the products (kcal/kg°C)		Before freezing	Freezing	After freezing	Freezing point
Mango		5000	30	15	22.5	2.2810		0.863	65.78	0.448	-1.1	
						Infiltration load (kcal/24h, Ton)		2.2810				
Contents	Direction	Surface area (m ²)			Thermal transmittance (kcal/m ² h°C)	Temperature difference (°C)	Directional temperature correction factor	Heat load (kcal/h)	Subtotal (kcal/h)			
		Length	Width	Surface area								
1. Transmission loads	East	2.35	2.39	5.61	0.259	23.5	0	34.1	406.2			
	West	2.35	2.39	5.61	0.259	23.5	0	34.1				
	South	5.90	2.39	14.10	0.259	22.5	0	82.1				
	North	5.90	2.39	14.10	0.259	22.5	0	82.1				
	Floor	5.90	2.35	13.85	0.258	20.0	0	71.5				
	Roof	5.90	2.35	13.85	0.259	28.5	0	102.2				
2. Infiltration load		Energy per cubic meter		Cold storage volume		Number of volume change		Time		Subtotal (kcal/h)		
		17.94		33.10		1.083333333		4		160.9		
3. Worker heat load		Heat losses per person		Number of people working		Working time		Time		Subtotal (kcal/h)		
		232.2		2		0.166666667		4		19.4		
4. Cooling load		Classify	Mass of added products (kg)	Specific heat (kcal/kg°C)	Temperature difference (°C)	Cooling time (hr)	Total cooling time (hr)	Heat load (kcal/h)	Subtotal (kcal/h)			
		Before freezing	5000	0.86	15	4	4	16181.3	16,181.3			
		Freezing		65.78	1	24	24	0.0				
		After freezing		0.45	1	24	24	0.0				
5. Respiration		Capacity of products (Ton)	Respiratory heat (0°C)	Amount of product(Ton)	Respiratory heat (15°C)	Time (hr)		Subtotal (kcal/h)				
				5	2,281.0	4		475.2				
6. Internal load		Classify	Power rating	Number	Operating time	Time	Heat load (kcal/h)	Subtotal (kcal/h)				
		Lamp	860	0.1	2	4	43	903.0				
		Equipment	860	0	0							
		Forklift	860	0	0							
		Fans	860	1	4	4	860					
7. Total cooling load		7. = (1. + 2. + 3. + 4. + 5. + 6.) × (Safety factor 120 %)					25.32	kW	21,775.0	kcal/h	6.56	RT

4. Insulated Container Manufacturing Consultation

When manufacturing insulated containers, the door shape and location, as well as the selection of insulation materials, should be discussed as key factors.

These two factors have a significant impact on the performance, efficiency, and usability of the container.

4.1. Door shape and location

The door directly affects the accessibility and insulation performance of the container. The main points to consider are as follows:

- **Shape:** In addition to the general swing door, there are various types such as sliding doors and roll-up doors. Select the optimal shape considering the purpose of use and space efficiency. For example, if it is for a logistics warehouse, a roll-up door that can be opened and closed quickly may be advantageous, and if it is for research that requires precise temperature maintenance, a swing door with high sealing power is suitable.
- **Location:** The location of the door should consider the movement line inside the container and the external environment. It should be installed on one side only, both sides, or on the side, etc., and should be tailored to the user's work flow.
- **Size:** Determine the appropriate size considering the size of the items to be transported and the convenience of workers' entry and exit. If it is too small, it is difficult to take items in and out, and if it is too large, insulation loss may be large.

- Sealing: To maximize insulation performance, door gaps should be minimized and materials that increase sealing power, such as rubber packing, should be used to block the inflow of outside air.

4.2. Final Selection of Insulation Materials (PU Foam + Ten)

Polyurethane (PU) foam is a widely used material for manufacturing insulated containers due to its excellent insulation performance. The following materials can be considered with PU foam, which is commonly applied to insulated containers:

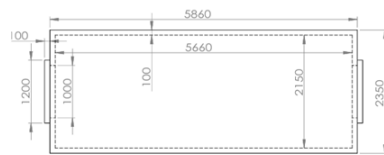
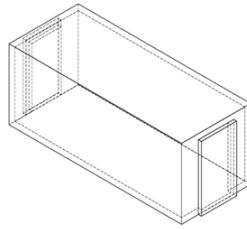
- PU foam: It is lightweight and has excellent insulation effects, so it is mainly injected or attached to the container walls, ceilings, and floors. Since insulation performance varies depending on density and thickness, appropriate specifications should be selected according to the required insulation grade.
- Thermal Reflective Insulation: It is a material composed of aluminum foil, etc., that reflects radiant heat to increase the insulation effect. When used with PU foam, it can block heat exchange more effectively.
- Variable vapor retarder/barrier: Used to prevent moisture penetration, prevent deterioration of insulation performance, and prevent condensation
- Flame retardant/non-combustible material: Auxiliary material with flame retardant or non-combustible performance that can be used with PU foam to enhance fire safety

Therefore, when selecting the final insulation material, the density and thickness of the PU foam, as well as the optimal insulation performance for the intended use of the container, must be secured.

4.3. Consultation on the shape and location of the door and final selection of insulation material in relation to the production of insulated containers

- Door shape and location of pre-cooled warehouse and cold storage
 - Pre-cooled warehouse: Install doors on both sides of the side considering efficient entry/exit of goods and movement path
 - Cold storage: Install doors on the left side and front considering work efficiency
- Consultation on insulation material
 - In order to maximize insulation performance and secure energy efficiency, a combination of PU foam (polyurethane foam) and 'Tian' was finally selected as the insulation material
 - Expected to provide high insulation effect
- Based on these consultations, the production of insulated containers will be specified

20ft container



<Top View>



<Side View>

External size

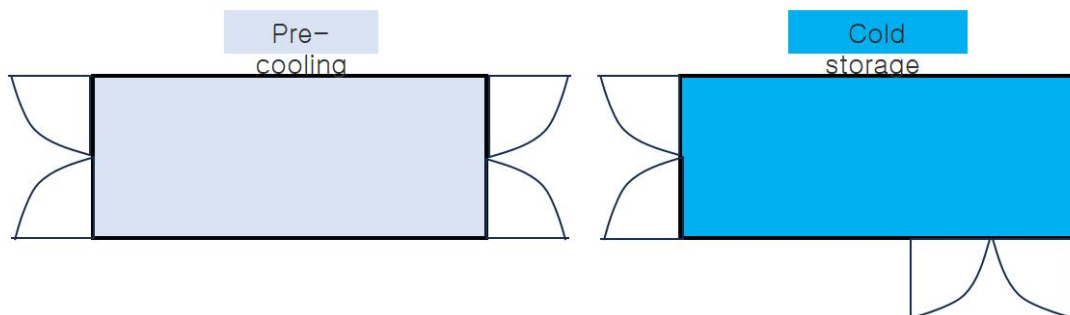
1. Width : 2.35 m
2. Height : 2.38 m
3. Length : 5.86 m

Internal size

1. Width : 2.15 m
2. Height : 2.18 m
3. Length : 5.66 m

Insulation

1. Thickness : 100 mm



5. Study on modification and analysis of design of PV-based low-temperature refrigeration system in Bangladesh

The refrigeration load calculation was modified through the first on-site survey, and the solar panel capacity design and expected drawing were created based on this..

5.1. Modified Load Calculation Details

- Inlet temperature of goods: Changed from 35°C to 30°C
- Amount of goods received: Changed from 5,000 kg to 4,500 kg

5.2. Solar Panel System Design

The following solar panel system was configured according to the modified load calculation

- Total system size: 17010 mm×4960 mm×30 mm
- Total power: 19.2 kWh

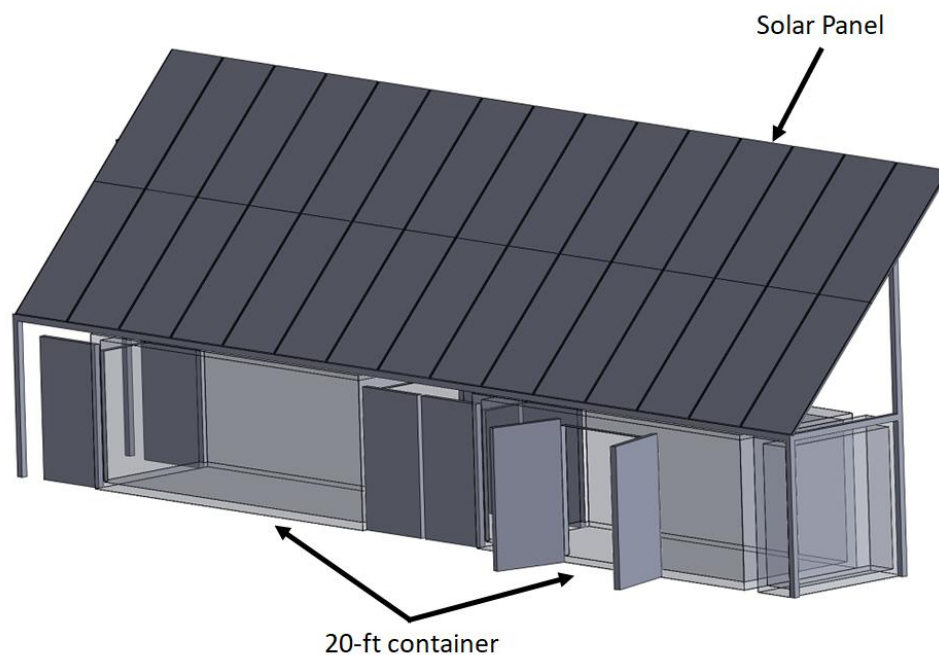
The solar panel will be mounted on the top of a 20-foot container and must be installed at a height higher than 2380 mm at least

5.3. Solar panels referenced

The solar panels used in the design are as follows.

- Model: Q.TRON XL-G2R Series
- Individual panel size: 2465 mm×1134 mm×30 mm
- Maximum power(MPP): 640 W

Solar panel and 20ft container installation concept



Additional discussion of decisions related to the design of new pre-cooling and cold storage

6.1. Determination of door height and securing of indoor unit space

- Determine the door height of the pre-cooling and cold storage to secure sufficient space for installing indoor units inside the refrigeration unit
- Consider efficient installation and maintenance of the unit

6.2. Modification of the number and size of cold storage doors

- Initially, it was decided to install two doors of the same size in the pre-cooling and cold storage, but the door located at the front of the cold storage was adjusted to one
- Change the number and size of doors considering the overall layout and operational efficiency

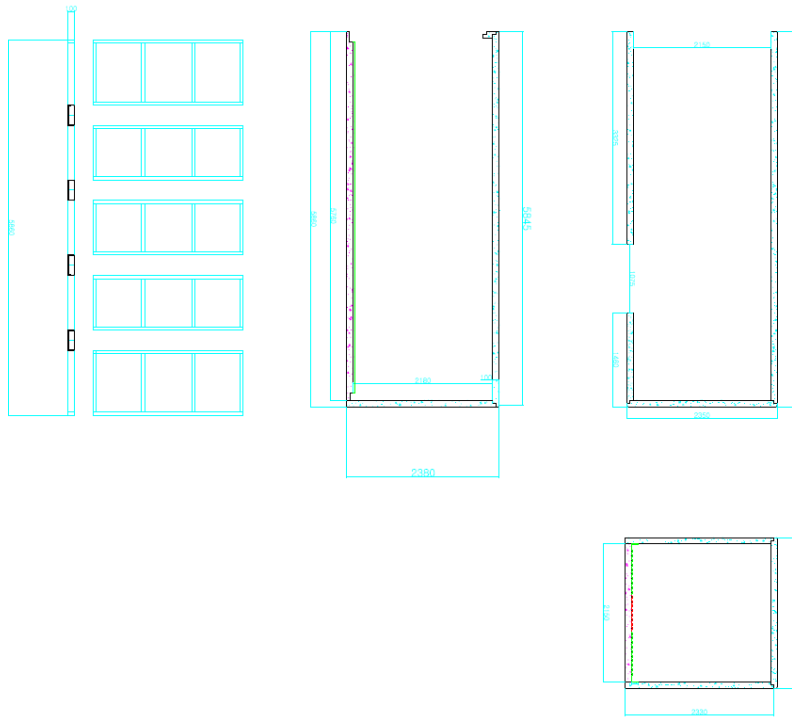
6.3. Installation of indoor unit support reinforcement bar and reinforcement panel

- Reinforcement bar is required to stably support indoor units installed inside pre-cooling warehouses and cold storages
- Discussion of method of installing reinforcement panel at indoor unit location based on design of refrigeration unit installed in warehouse
- Consideration of securing stability and structural reinforcement of unit

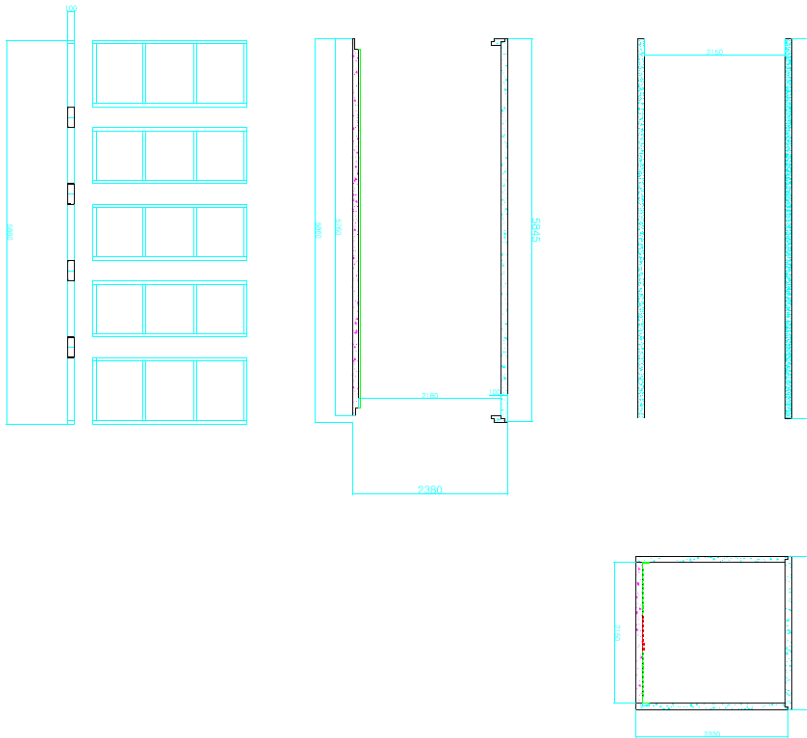
6.4 Selecting panel connection method to minimize heat loss

- Sharing panel connection method to minimize heat loss when installing pre-cooling warehouses and cold storages
- Consideration of method to maximize insulation performance and increase energy efficiency of warehouse





<Cold storage warehouse>



<Pre-cooling warehouse>

7. Performing heat flow analysis inside an insulated container

7.1. Temperature and velocity distributions according to changes in evaporator location

The heat flow inside an insulated container was analyzed to analyze the effect of changes in the location of the evaporator on the temperature and velocity distribution inside the container. The heat flow analysis was performed under stationary conditions.

- Analysis conditions and models

- Inside the container: Applying the properties of air
- Loaded goods: Assigning the properties of mango
 - Specific heat at constant pressure: 1470 J/kg-K
 - Thermal conductivity: 0.021 W/(m-K)
 - Density: 35 kg/m³

- Evaporator conditions

Each evaporator is installed with two fans, and the following boundary conditions are applied

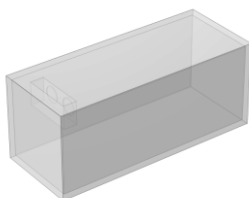
- Fan speed: 5 m/s per fan
- Fan outlet temperature: 15 °C
- Evaporator inlet passage: One passage, and a pressure condition of 0 Pa is set

- Model classification according to evaporator location

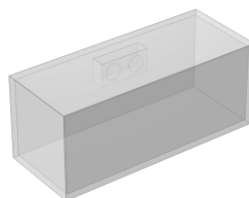
The analysis was performed by changing the evaporator location for three cases.

1. Container side evaporator: Model with the evaporator placed on the side of the container
2. Container back evaporator (1 unit): Model with one evaporator installed on the back wall of the container
3. Container back evaporator (2 units): Model with two evaporators installed on the back wall of the container
 - In the case of a model with two evaporators, the total flow inside the container is calculated by comparing it to the single evaporator model. To maintain similarity, the outlet speed of each fan was adjusted to 2.5 m/s.

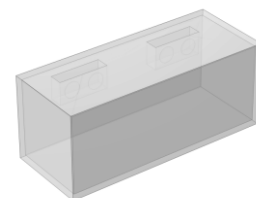
Through this analysis, the temperature and velocity distribution changes inside the container according to each evaporator arrangement were confirmed.



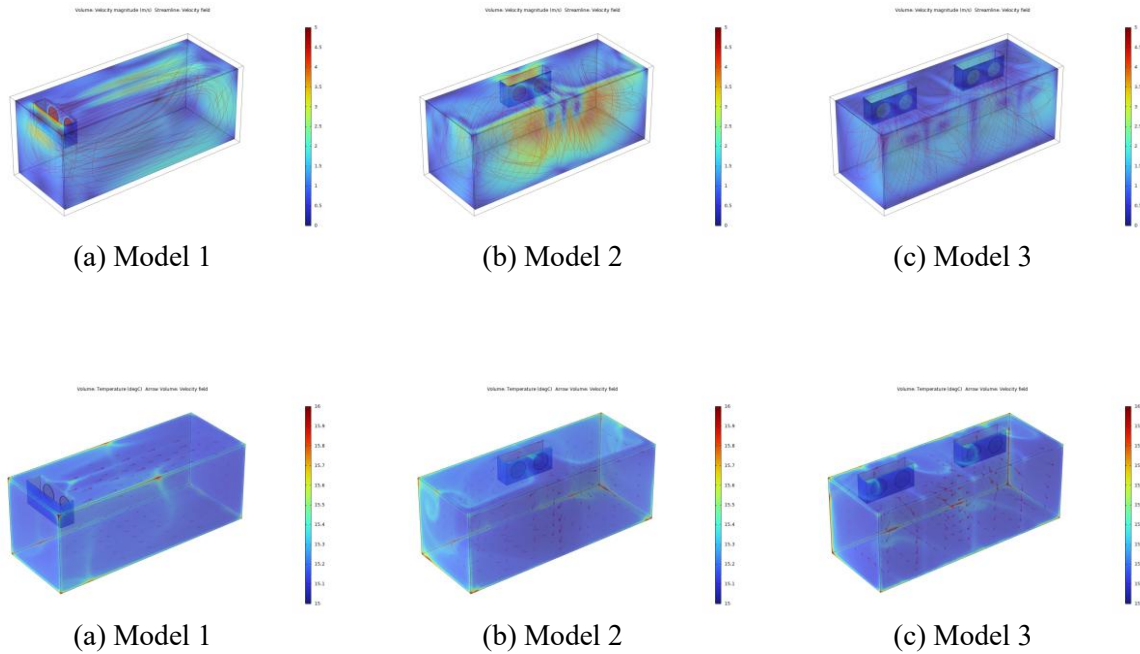
(a) Model 1



(b) Model 2



(c) Model 3



7.2. Temperature and velocity distribution according to change in loading shape of goods

The heat flow inside the insulated container is analyzed to analyze the effect of change in loading shape of stored goods on the temperature and velocity distribution inside the container. The evaporator is analyzed for various loading shapes based on the reference model placed on the side of the container.

- Analysis conditions and model settings

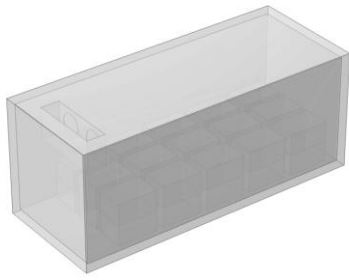
- Item shape: Assumed to be a box shape, and treated as a solid material property during analysis.
- Evaporator location: Fixed to the side of the container
- Evaporator inlet/outlet: Pressure condition set to 0 Pa
- Fan boundary conditions: The following conditions are given for each fan.
 - Exit velocity: 5 m/s
 - Exit temperature: 15 °C

- Loading shape change model

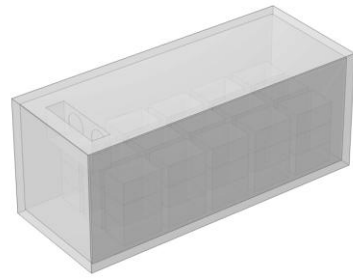
The loading shape of the goods is analyzed by changing the following four cases (based on width, length, and height):

1. 5×3×2 layout: Model with goods loaded with 5 widths, 3 depths, and 2 heights
2. 5×3×3 layout: Model with goods loaded with 5 widths, 3 depths, and 3 heights
3. 5×3×4 layout: Model with goods loaded with 5 widths, 3 depths, and 4 heights
4. 6×3×4 layout: Model with goods loaded with 6 widths, 3 depths, and 4 heights

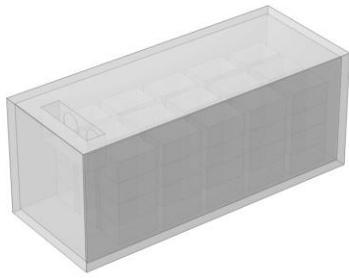
Through this analysis, the effects of different loading shapes on the temperature and speed distribution inside the container are analyzed.



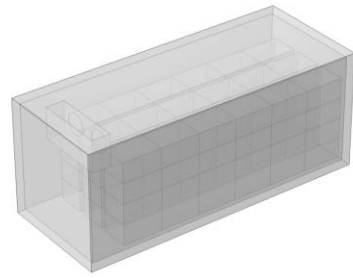
(a) $5 \times 3 \times 2$



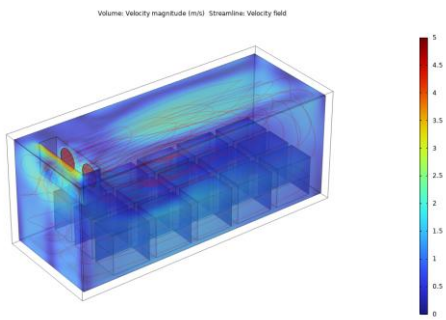
(b) $5 \times 3 \times 3$



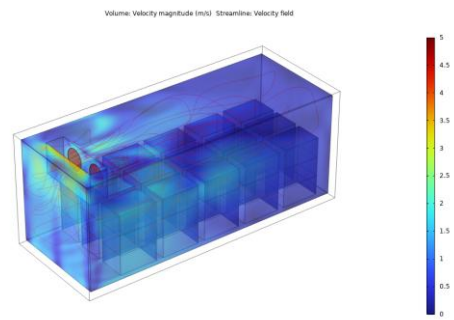
(c) $5 \times 3 \times 4$



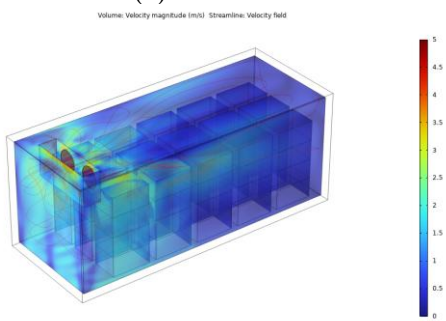
(d) $6 \times 3 \times 4$



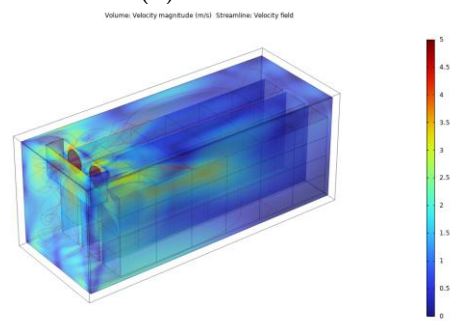
(a) $5 \times 3 \times 2$



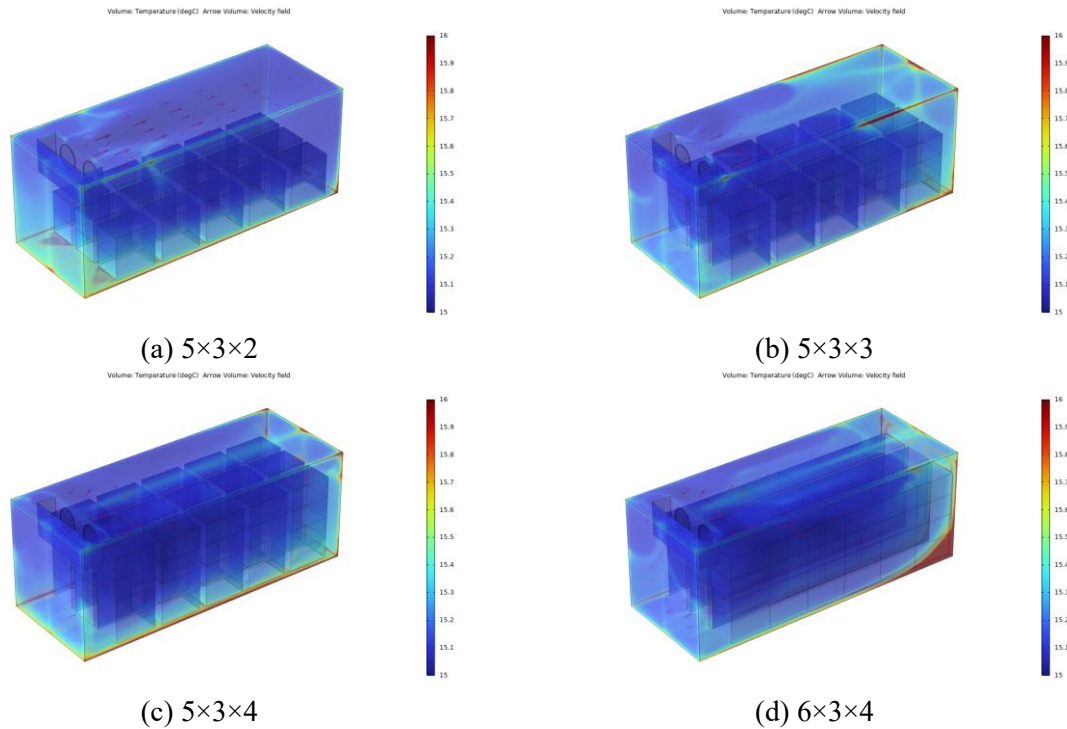
(b) $5 \times 3 \times 3$



(c) $5 \times 3 \times 4$



(d) $6 \times 3 \times 4$



7.3. Temperature and velocity distribution according to the change in evaporator position considering the heat of respiration of the product

The heat flow inside the insulated container is analyzed considering the heat of respiration of the product, and the temperature and velocity distribution inside the container are analyzed according to the change in evaporator position.

- Analysis conditions and model settings

- Standard item loading: Items are placed in a $5 \times 3 \times 3$ (width \times length \times height) configuration inside the container
- Item shape: Assumed to be a box shape and treated as a solid property during analysis
- Item respiration heat: The respiration heat of mango is assumed to be 500 W and set to be generated in proportion to the volume of the item placed inside the container

- Evaporator location change model

The analysis was performed by changing the evaporator location for three cases.

1. Container side evaporator: Model where the evaporator is placed on the side of the container
2. Container back evaporator (1 unit): Model where one evaporator is installed on the back wall of the container
3. Container back evaporator (2 units): Model where two evaporators are installed on the back wall of the container
 - In the case of a model with two evaporators, the outlet speed of each fan was adjusted to 2.5 m/s to maintain the total flow inside the container similar to the single evaporator model

Through this analysis, the temperature and velocity distribution changes inside the container according to the placement of each evaporator along with the generation of the item's respiration heat were confirmed.



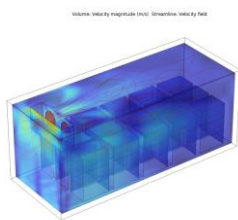
(a) Model 1



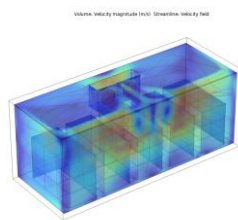
(b) Model 2



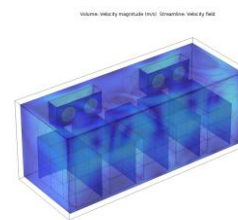
(c) Model 3



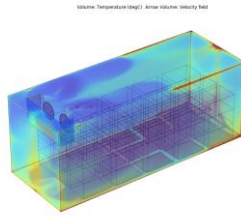
(a) Model 1



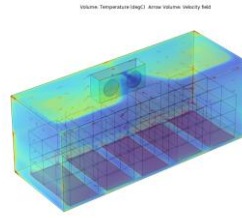
(b) Model 2



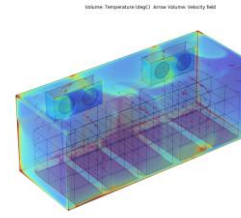
(c) Model 3



(a) Model 1



(b) Model 2

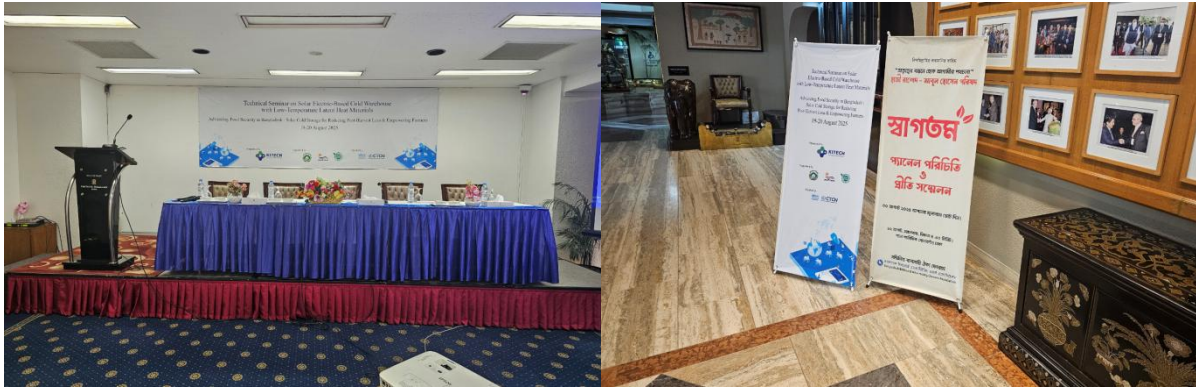


(c) Model 3

8. Technical seminar and survey of local factory for container assembly

8.1. Technical seminar and technical meeting

- A technical seminar was held to introduce the key technologies related to solar-powered, latent-heat-material-based low-temperature container systems for cold storage of agricultural products in Bangladesh, in connection with the UNEP CTCN technical assistance project in Bangladesh.



- Dr. Jeongyeol Kim (KITECH) explained the ongoing project to design and demonstrate a 20 ft-class refrigerated container based on solar power generation and LHM (latent heat material), which is being promoted in response to the cold chain technology request from the Bangladesh NDE under the UN CTCN project. He also introduced several case studies where KITECH's LHM technology has been applied.

- Dr. Daegyul Lee (KITECH) presented on heat load calculation for the efficient operation of low-temperature containers (maintaining product freshness, optimizing refrigeration system efficiency, and avoiding unnecessary capital expenditure). He explained the main factors of heat load calculation and the process of estimating the heat load for the pre-cooling warehouse and storage warehouse under the UN CTCN project. Using simulation tools, he analyzed changes over time in internal air and product temperature, as well as temperature uniformity, under various conditions such as evaporator location, product placement, and outdoor temperature variation, demonstrating that the system can be optimized based on the heat load calculation results.

- Director Yongjin Shin (EST) gave a presentation on cold chain logistics technology based on LHM. LHM acts as a “thermal battery” that stores and releases energy while maintaining a constant temperature during phase change, enabling more energy-efficient and stable temperature control than conventional refrigeration systems. This technology can maintain frozen and refrigerated temperatures over an extended period and can be applied to various transportation modes—such as road trucks, rail, and maritime shipping—as well as cold storage systems. He explained that it reduces dependence on fossil fuels, lowers greenhouse gas emissions, extends product quality and shelf life, and reduces operating costs. In addition, he emphasized that LHM-based cold chain infrastructure can contribute to carbon emission reduction, resource waste minimization, public health improvement, and increased local income.

- Executive Director Sangman Yoon (Seongwoo S.P) emphasized the importance of insulation performance, a core factor for special-purpose panels such as refrigerated/freezer vehicles. In particular, he explained that XPS (extruded polystyrene) foam provides superior insulation performance and durability compared to polyurethane foam, especially in humid environments. The newly developed high-impact GRP (glass fiber reinforced plastic) sheet has 2–3 times higher impact and flexural strength than aluminum or steel, does not corrode, and has very low thermal conductivity, thereby maximizing insulation performance. The “Liner Tuff” panel, which combines a high-strength high-impact outer sheet with XPS foam insulation, improves the shortcomings of conventional sandwich composite panels by significantly reducing weight (thus improving fuel efficiency and reducing carbon emissions), enhancing refrigeration performance through improved heat transfer coefficient, and further strengthening insulation through increased insulation thickness. He also explained that it reduces blistering caused by differential thermal expansion and contraction of dissimilar materials, improves adhesion, and provides high durability and appearance retention,

presenting it as an optimal solution in terms of the temperature, insulation, durability, strength, and weight required for special-purpose panels.



- A technical meeting was held on low-temperature container technology based on solar power and latent heat materials for agricultural cold storage in Bangladesh, in connection with the UNEP CTCN technical assistance project in Bangladesh.

- Discussions focused on the local applicability and future development direction of solar power-based refrigerated warehouses using low-temperature latent heat materials for cold storage of agricultural products in Bangladesh.

- In addition to the need to build refrigerated warehouse infrastructure, options for designing refrigerated containers suitable for local conditions in Bangladesh and for their pilot operation were also discussed.



8.2. Survey of local factory for container assembly

- A site visit and inspection were conducted at a container assembly factory responsible for assembling refrigerated warehouses and installing refrigeration systems for deployment at farms in Bangladesh.

- Leader Engineering Cooling System Limited (LECS) is a refrigeration and air-conditioning specialist company headquartered in Bangladesh, providing total solutions for the design, construction, and maintenance of industrial and commercial cold storage facilities, cold rooms, chillers, cooling towers, clean rooms, and HVAC/VRF systems.

- The company has carried out various projects for customers in sectors such as seafood and meat processing, poultry, food and agriculture, vaccines, and retail, including major local companies such as Partex Group and Provita Group.

- By using components from leading global brands such as Bitzer, Copeland, Carrier, Emerson, Hanbell, Schneider, Alfa Laval, Samsung, and Hitachi, LECS supplies reliable systems to local customers and offers end-to-end services from design and installation to commissioning and maintenance.

- LECS has expertise in both ammonia- and Freon-based refrigeration solutions and also has strengths in cleanroom engineering and the supply of high-efficiency chiller systems.



9. Annex

9.1. List of attendees

Attached is the list of attendees for the technical seminar.

List of attendees

	Name	Organization	Positions	E-mail
1	Dr Syed Rafiqul Anis	Honin Foundation	Managing Director	hartin@hartin.org
2	Mant. Israd Jalani	DAM	Assistant Director	paprinradydian1974@gmail.com
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5	Md Saifur Rahman	JB Biotech	CEO	info@jbbiotechbd.com
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14	Mahfuz Chowdhury	Mashim	ED	mahfuzen.Chowdhury@nusliuaid.org.bd
15	Sayeeda Akter	"	Fisheries Sect.	- do -
16	Sayeed M. Bayin	NORWAY EMBASSY	ADVISOR	-
17	Alouzir	Herlium	Allied with E	-

List of attendees

	Name	Organization	Positions	E-mail
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4	MA Sayem	UKBET	EO	SAYEMB H@M UKBET-BP.ORG
5	Md. Abu Jafar	GPS	ASS. M	abujafarsiddiq@gmail.com
6	NO MAZHARUL ISLAM	POWER DIVISION	senior Assistant secretary	magharsohel@gmail.com
7	Jaydeweka Joy	EDCOL	Manager	joy@idcol.org
8	MD. SHABUJ ALI	IDF	SM	shabujali000@gmail.in
9	KIM Jeongyeol	KITECH	Principal Researcher	esperant@kitech.re.kr
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11	Aekhaul Jilom	Bachdadi	Business M	aeckhaul@bachdadi.org
12	Md. Wahiduzzaman Sarkar	DOE	Climate Change Expert	wahid_ms07@yahoo.com
13	Fozal Lodi	STAVIA	Deputy Manager	
14	Tazmilur Rahman	KfW	Deputy Diver	tazmilur.rahman@kfw.de
15	Dr. Tarlima Julia			tarlima.julia@yahoo.com
16	Raisa Lodi			locliraisa@gmail.com
17	Md. Enamul Karim Paul	IDCOL	Head of RE	ekarim@idcol.org
18	A F M Shaked	Intellecap	Country manager	afm.shaked@intellecap.net

List of attendees

	Name	Organization	Positions	E-mail
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③	Hassan M. Aziz	UN	Consultant	hassan.aziz@un.org
④	Mohiddin	Incom IT	CEO	mohin.ece@gmail.com
⑤	Mourshed	Mitsubishi	Biz. Manager	mourshed.karim@mitsubishi.com
⑥	ARIF AHMED	UNDP	Program Specialist	arif.ahmed@undp.org
⑦	Abdul Anit	UNDP	Program Associate	abdul.anit@undp.org
⑧	Mirza Sherif	MAS	owner	Ahmad
⑨	Ahmad Habis	Global IT Forum	Chairman	Ahmad
⑩	Mofruza	RWA	Country Manager	Mofruza
⑪	Kulbawa		Advisor	
⑫	'Tuhin	Kulbawa		
⑬	DR MD HARUN RASHID	Ministry of Agriculture	Deputy Secretary	harun@minat.gov.bd
14.	MS. MOFIDUL HAN	DAM	D.S	12.8.25
15.	Sohag Samken	DAM	AD	SohagSamken108@gmail.com

9.2. Technical seminar material

The technical seminar material is attached in a PPT format..

UN CTCN Project in Bangladesh

Efficient Operation of Cold Storage using LHM Technology

19th Aug. 2025

Korea Institute of Industrial Technology
(KITECH)

Dr. KIM Jeong-Yeol

Contents

- I ----- Introduction of KITECH
 - II ----- Overview Project
 - III ----- LHM Technology
 - IV ----- Case Study
-

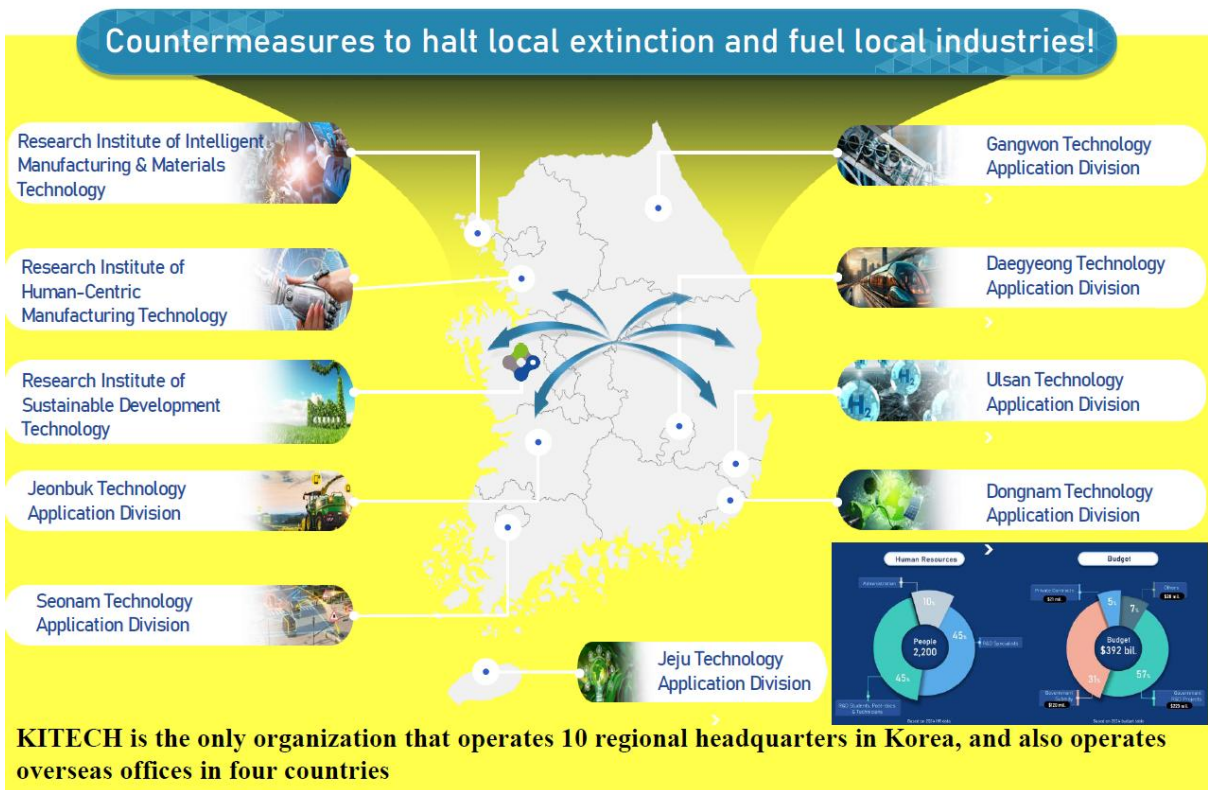
Introduction

About KITECH



KITECH operates various programs to foster the manufacturing ecosystem in South Korea

About KITECH



Overview of Project

The UN CTCN supports developing countries by matching their technology requests with institutions capable of providing technical support and education. CTCN serves as a cooperative platform to facilitate technology transfer among stakeholders in developing nations. KITECH joined as a member in 2015.

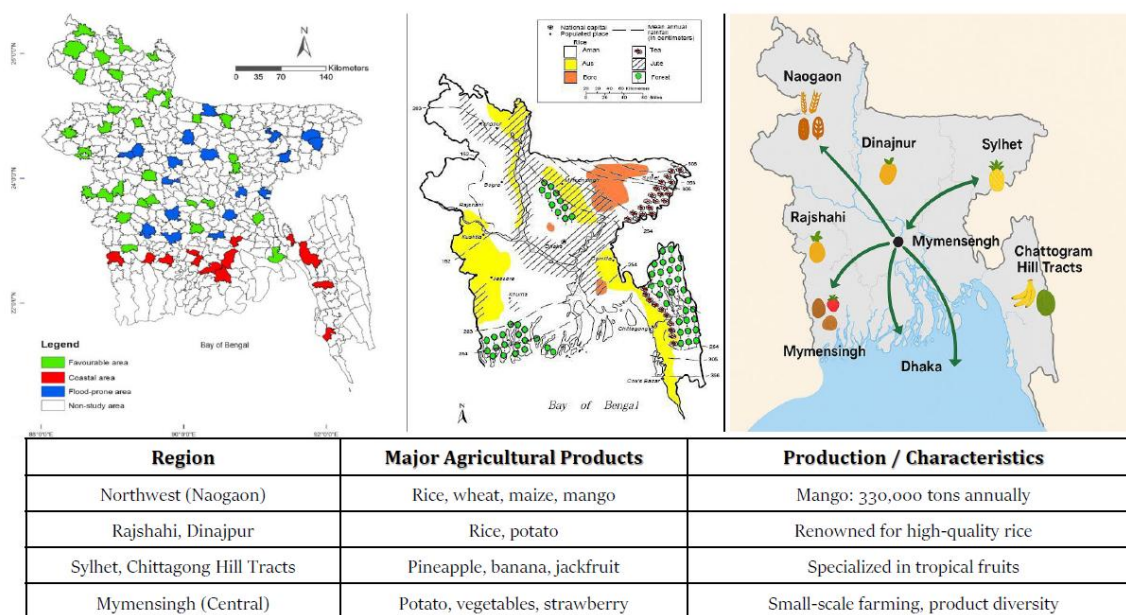
Based on a cold chain technology request submitted by Bangladesh's NDE (National Designated Entity), we proposed a revised project to UN CTCN and Bangladesh NDE, utilizing Latent Heat material (LHM)-based cold chain technology. This project is now underway with multilateral agreement.

The project consists of three main areas:

1. Manufacturing and local demonstration in Bangladesh of a 20ft-class cold storage container using solar power and LHM,
2. Technical training and guidance,
3. Promoting gender equality through the involvement of a gender expert.

The project is expected to foster local commercialization through collaborative R&D with cold chain-related companies and lay a foundation for Korean companies to enter and expand in the Bangladeshi market.

Major agricultural production areas and transport routes in Bangladesh



Market Potential of 20ft Solar-Powered Cold Storage Container

1. Market Demand Drivers

- Post-harvest losses in developing countries reach 30–45%
- Rural areas lack access to conventional cold storage
- High need for modular, off-grid, small-scale storage units
- Suitable for fruits, vegetables, roots, and grains

2. Technical Feasibility & Cost

- Solar + Battery or Solar + Diesel hybrid systems
- Power usage: 4–8 kWh/day
- Capacity: 3–5 tons (20ft insulated container)
- Lifespan: Solar (20 yrs), Compressor (5–10 yrs)
- Cost: USD \$9,000–\$20,000
- Optional: IoT remote monitoring

3. Geographical Opportunities

- High-Potential Markets:
 - South Asia: Bangladesh, India
 - Africa: Kenya, Nigeria
 - Southeast Asia: Myanmar, Cambodia
- Enablers:
 - Donor support (WB, ADB, FAO, GCF)
 - Climate finance and carbon offset programs

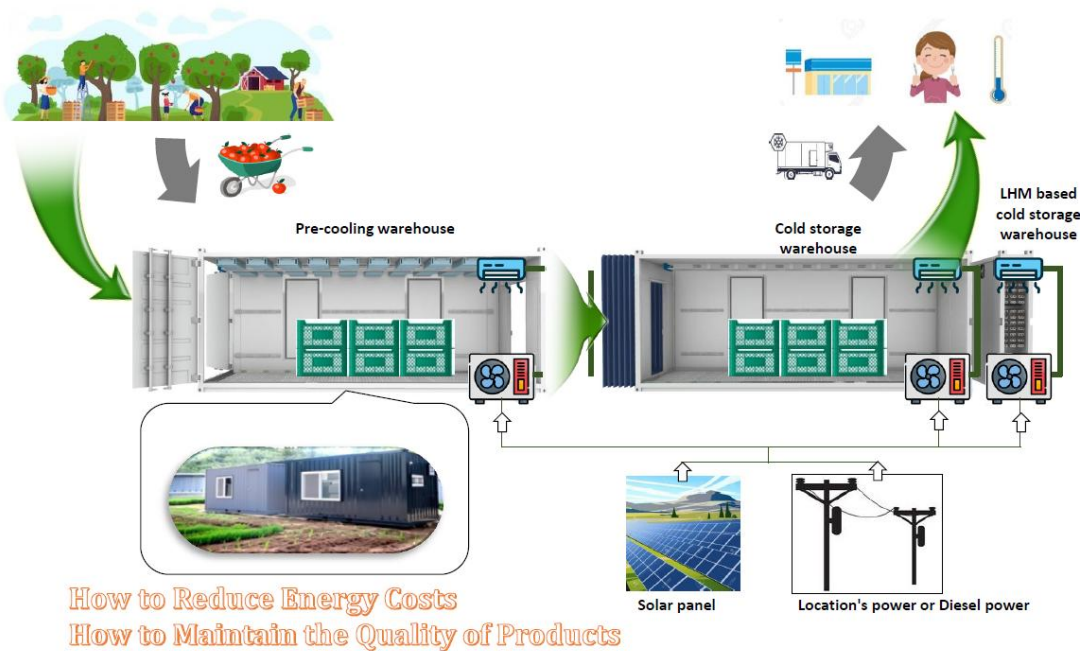
4. Market Outlook (Bangladesh Example)

- Estimated demand: 50,000–100,000 units by 2030
- Initial deployment: 2,000–5,000 units (5 years)
- Rental revenue: \$200–\$350/month per unit
- Annual revenue potential (5,000 units): \$12M–\$20M

What should we do?

Final Goal

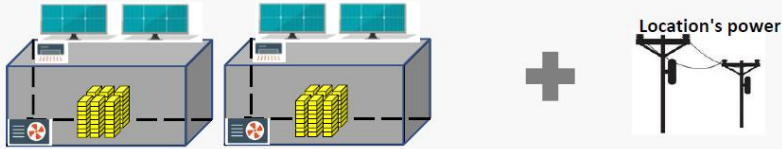
Development of a pilot scale cold warehouse system for stable storage of harvested agricultural products



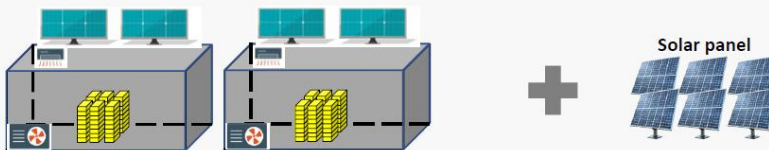
What to do verify?

Determining the Optimal Driving Strategy for Bangladesh Through 6 Scenarios

Scenario 1_Cold storage warehouse operation using location's power



Scenario 2_Cold storage warehouse operation using solar panel



Scenario 3_Cold storage warehouse operation using location's power and solar panel

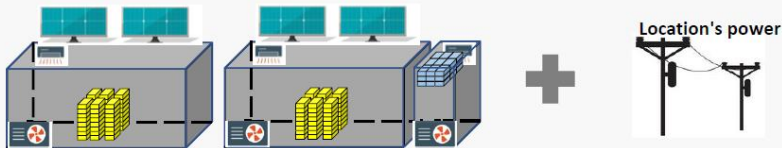


9

What to do verify?

Determining the Optimal Driving Strategy for Bangladesh Through 6 Scenarios

Scenario 4_Cold storage warehouse operation with LHM storage warehouse using location's power



Scenario 5_Cold storage warehouse operation with LHM storage warehouse using solar panel



Scenario 6_Cold storage warehouse operation with LHM storage warehouse using location's power and solar panel



10

Technology transfer through verification

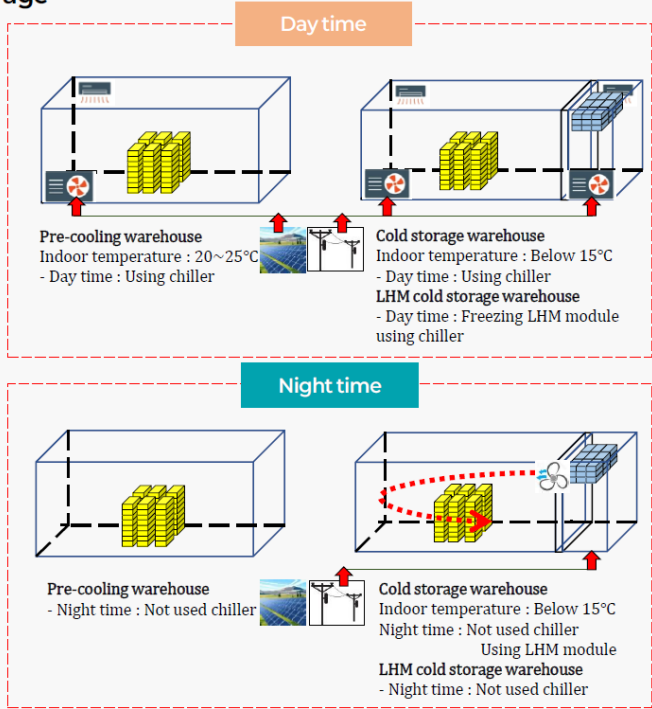
System Operation from Harvest to Storage



Mango farm
Atmospheric temperature : 35°C

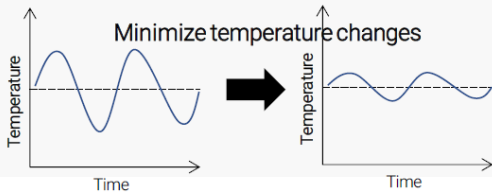


Put harvested mangoes (fruits)
into boxes of a constant size



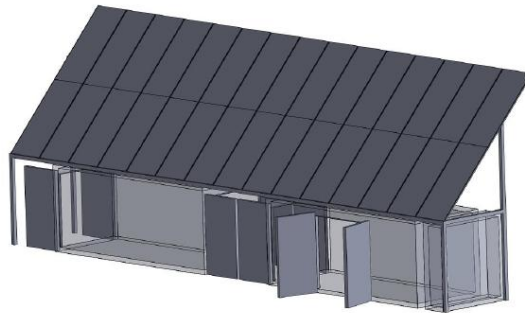
Electricity energy cost ↓

Maintain good quality ↑



Latent Heat Materials (LHM) Technology

KITECH has developed various types of LHM and is conducting research and development for industrial application.



What is Thermal Energy Storage?

Thermal energy storage is largely divided into sensible heat storage and latent heat storage

◆ **Sensible heat storage**

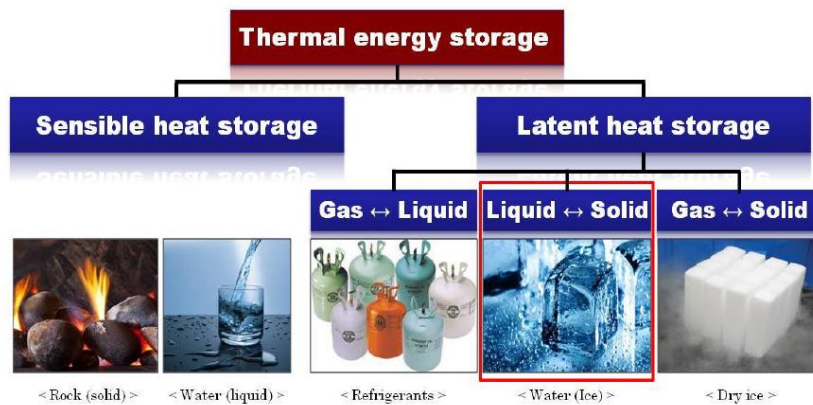
- Heat storage by temperature difference of sensible heat materials (rock, water etc.)

$$\Delta Q = C \cdot \Delta T = m \cdot c \cdot \Delta T$$

◆ **Latent heat storage**

- Heat storage by heat of fusion during phase changing process

$$\Delta Q = \Delta H = m\Delta h$$

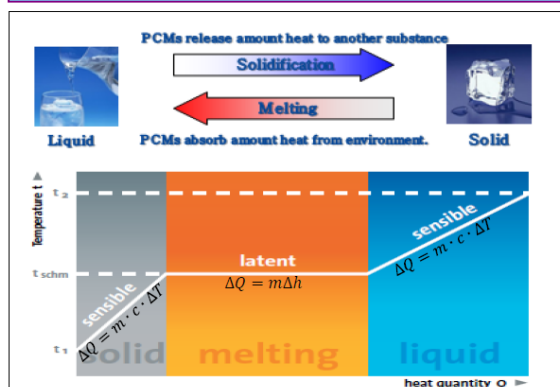


Thermal Energy Storage using LHM

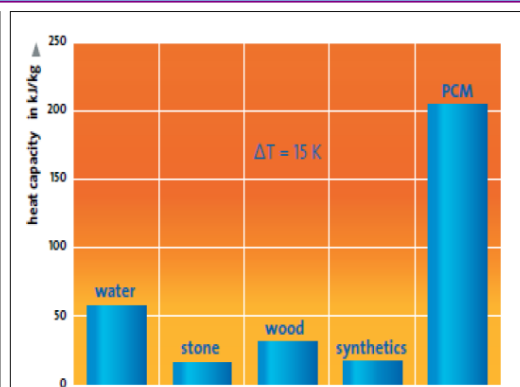
What is the latent heat material (LHM) ?

- ◆ High thermal storage density (latent heat)
- ◆ Constant temperature during the phase change process
- ◆ But, Low thermal conductivity, Supercooling Behavior, Corrosion,

Water 1 kg, 80°C + Ice 1 kg, 0°C = Water 2 kg, 0°C		
* Water	: 1 kg x 1.0 kcal/kg°C x (80-0)°C	= 80kcal (Emission)
* ICE(LHM)	: 1 kg (Ice → Water)	= 80kcal (Absorption)



< Heat capacity and temperature for phase changing process >



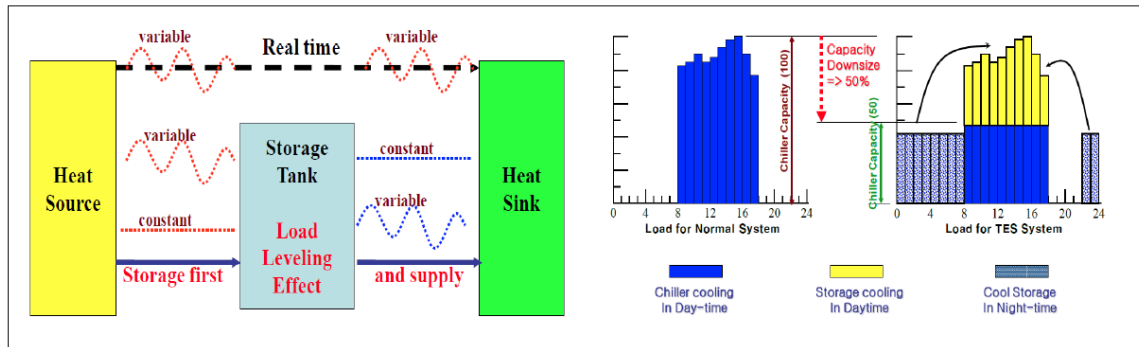
< Heat storage capacity in various materials >

Thermal Energy Storage

How to use the Thermal Energy Storage (TES) Technology?

To store the HEAT from **heat source** and Supply the **heat to demand**

In most of the generation and utilization of heat energy, there is a mismatch between supply and demand

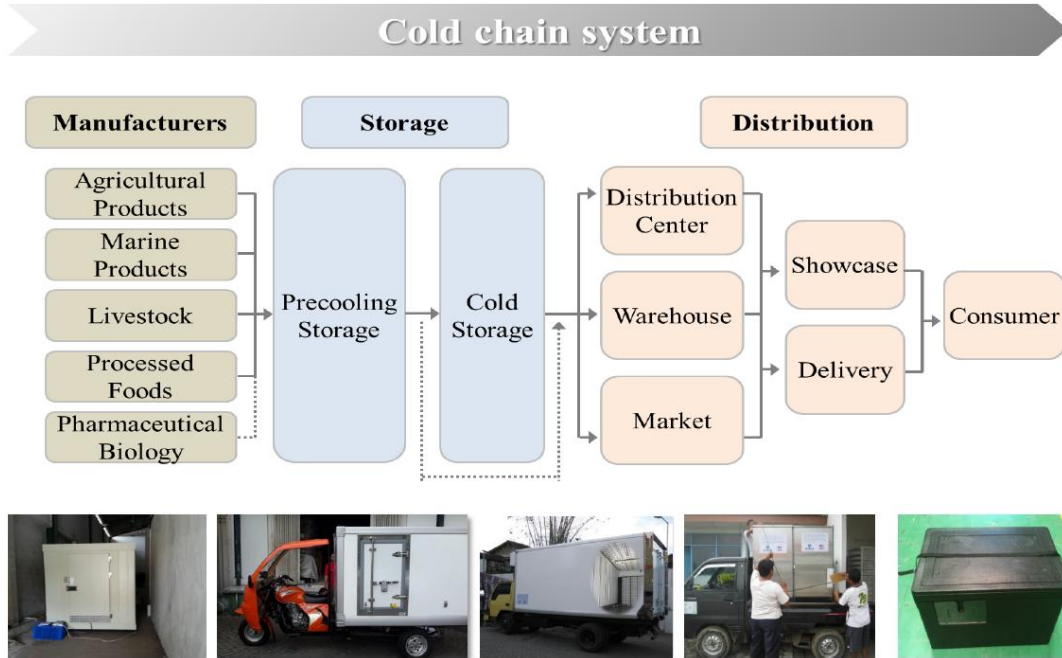


- ◆ Resolving the mismatch between supply and demand in time, space, quality, quantity
- ◆ Load cutting, sharing and leveling effect by thermal storage technology
- ◆ Possible to electricity rate down by variable electricity rate rates
- ◆ Design and operating conditions for the required heat quantity for heat demand/supply
- ◆ Low quality energy source → High quality and high performance



Case Study

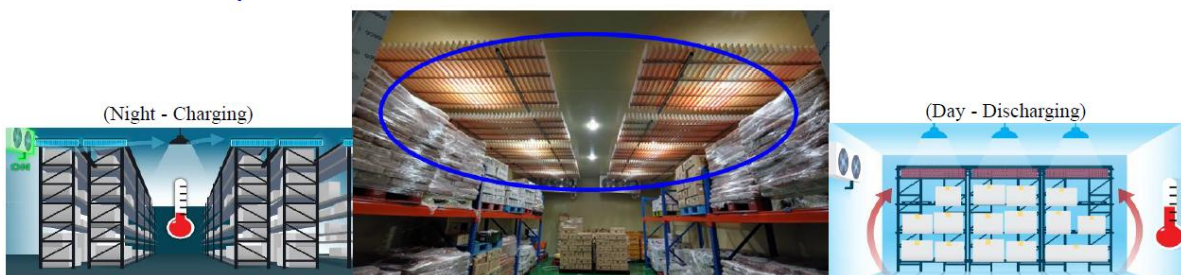
Overview of cold chain system



Case Study

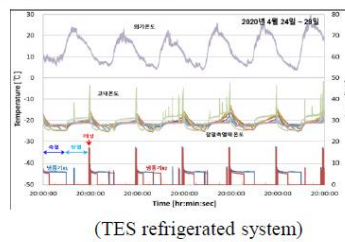
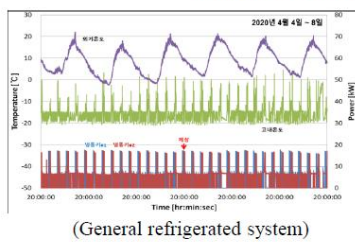
Cold warehouse

- ◆ Raw material (frozen meat, vegetable, etc.) storage for food manufacturing
- ◆ Internal temperature of cold warehouse: $-18\text{ }^{\circ}\text{C}$ or less



36.31% reduction of power consumption

42.21% reduction of electricity cost in Korea

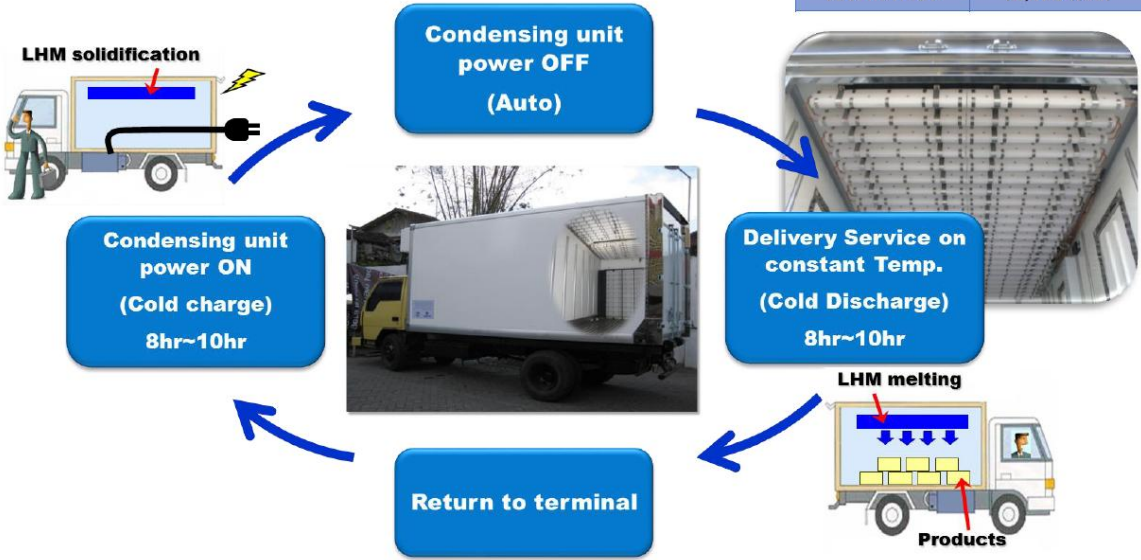


Case Study

Holdover refrigerated truck System (Indonesia)

- ◆ Target temperature range : below -10 °C
- ◆ Maintaining time : over 8-10 hours

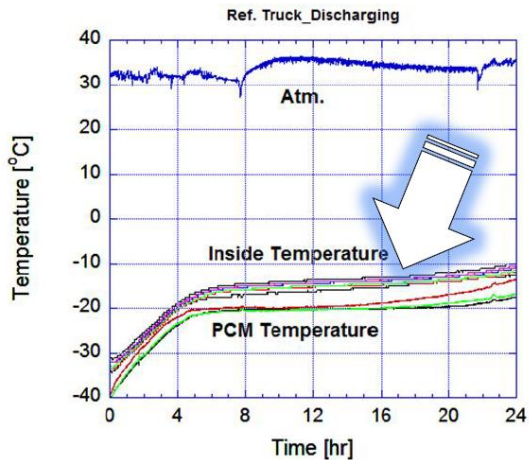
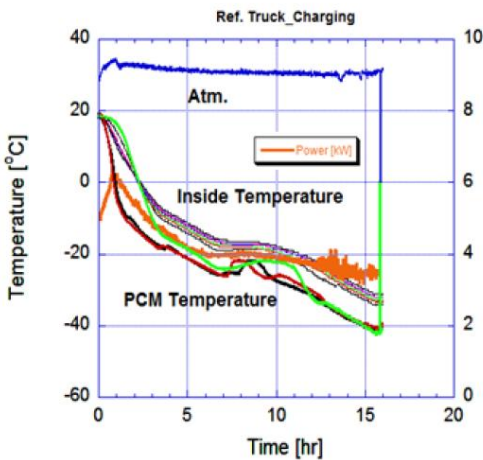
Phase changed Temp.	-21.0 °C
Weight	192 kg
Latent Heat	12,883 kcal



Case Study

Holdover refrigerated truck (Indonesia)

- ◆ Outside temperature in Indonesia : over 30 °C
- ◆ Internal temperature maintained below -10 °C for 24 hours for discharging



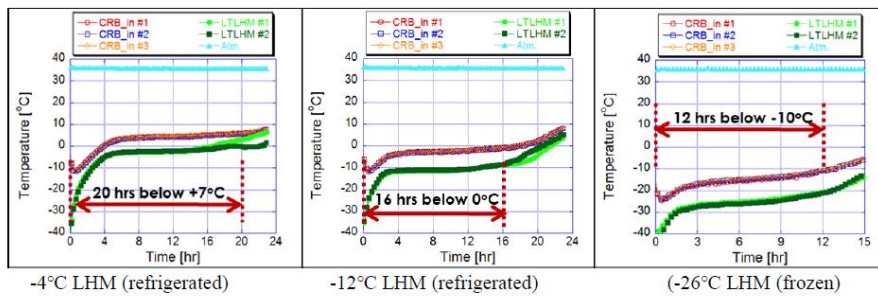
Case Study

Cold roll box (Indonesia)

- ◆ Freezing station to freezing the LHM module for CRB
- ◆ CRB to transport frozen/refrigerated goods with different keeping temperatures



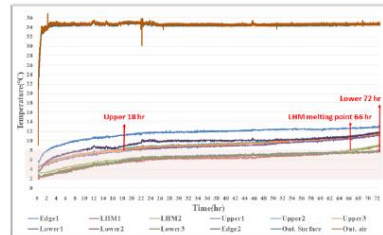
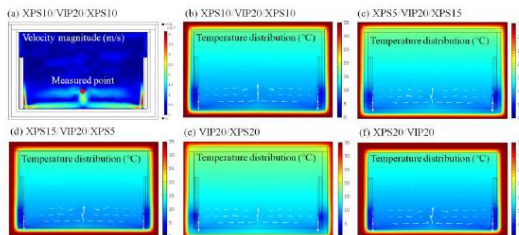
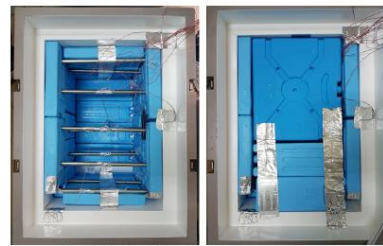
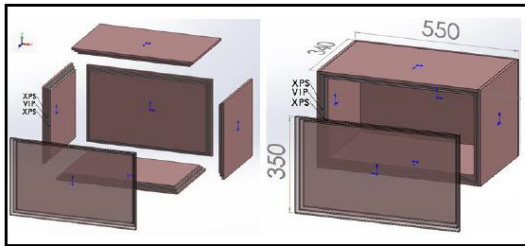
It is possible to distribute 3 kinds of products as different keeping temp.



Case Study

Vaccine Transfer Container

- ◆ Target temperature range : 2 °C to 8 °C (Outside temperature 35 °C)
- ◆ Maintaining time : over 72 hours



Case Study

Small logistics transport device

- ◆ Development of small transport device for low-temperature logistics delivery for Southeast Asian market
- ◆ Consisting of a DC refrigerator by battery and LHM
- ◆ Target temperature : below 10 °C for refrigerated goods
- ◆ Target maintaining time : over 3 hours



KITECH's LHM Technology

- KITECH's advanced thermal energy storage group provides R&BD services to help small and medium size companies in any types of industries incorporate LHMs into their existing products or processes.
- KITECH's advanced thermal energy storage group provides various kinds of LHMs that maintain a constant temperature and higher reliability.
- Theses services and turnkey projects include as follows;
 - Technical, commercial assessment and selection of suitable LHMs
 - Development of new LHMs and Modules
 - Thermal performance research of LHMs into your existing and new products
 - Testing of LHMs and prototypes in the fields
 - Consulting for advanced thermal energy storage systems



Thank you for your attention

Calculating the heat load of a low-temperature container using simulation techniques

19 August 2025

UN CTCN Project in Bangladesh
Solar Electric-Based
Cold Warehouse equipped with
Low-temperature Latent Heat Material

Korea Institute of Industrial Technology
(KITECH)
Dr. LEE Daegyul

Contents

- I ----- Necessity for Heat Load Calculation
 - II ----- Key Factors of Heat Load Calculation
 - III ----- Example for Heat Load Calculation
 - IV ----- Example for Simulation
 - V ----- Q&A
-

Necessity for Heat Load Calculation

Why Heat Load Calculation is needed??

- 1. Maintaining Freshness**
Ensures long-term quality by maintaining precise temperature and humidity.
- 2. Saving System Efficiency**
Optimizes refrigeration unit size to reduce energy waste and lower operating costs.
- 3. Reducing Cost-Effective Investment**
Prevents oversizing and minimizes unnecessary capital expenditure.

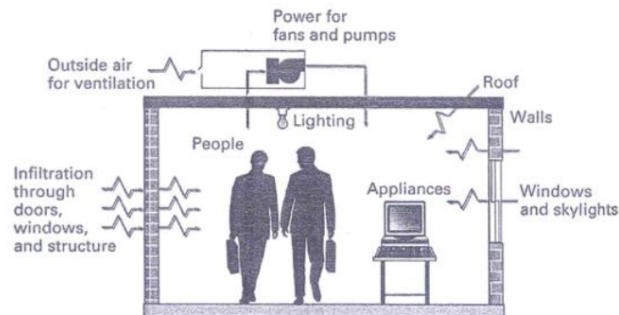


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Key Factors of Heat Load Calculation

Key Factors of Heat Load in Cold Storage Warehouse

- 1. Structural Heat Loss ($Q_{\text{transmission}}$)** → Formula: $U \times A \times \Delta T$
 - Conduction through walls, floor, ceiling, doors
 - Influenced by U-value and ΔT
- 2. Internal Heat Sources (Q_{internal})**
 - Workers (~200W/person)
 - Lighting and equipment during operations
 - Fan motors, defrost heaters, etc.
- 3. Air Exchange ($Q_{\text{air_exchange}}$)**
 - Door opening (warm, humid air inflow)
 - Ventilation fan operation
 - Infiltration through gaps → causes latent heat and frost on coils



Key Factors of Heat Load Calculation

Special Key Factors of Heat Load in Cold Storage Warehouse

1. **Product Sensible Heat** ($Q_{\text{product_sensible}}$) → Formula: $(m \times C_p \times \Delta T) / t$
 - Cooling fresh fruits from harvest temp (~30°C) to storage temp (~2°C)
 - Major load on the first day of storage
2. **Product Latent Heat**
 - Released as fruit moisture condenses during cooling
3. **Respiratory Heat** ($Q_{\text{product_respiration}}$) → Formula: $m \times R$
 - Fruits continue to respire after harvest, generating heat
 - Varies by type, ripeness, and storage temp
 - High in delicate fruits like strawberries

Product Load
~55 - 75% of total

- Product exchange
- Cooling/Freezing of products and packaging
- Product respiration heat

Cooling Loads
Transmission (5-15%)
Products (55-75%)

If cooling then calculate sensible heat
If Freezing then calculate sensible + latent heat as phase change occurs

TheEngineeringMindset.com

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Key Factors of Heat Load Calculation

6 Factors in Cold Storage Warehouse Heat Load

$$Q_{\text{total}} = Q_{\text{transmission}} + Q_{\text{internal}} + Q_{\text{air_exchange}} + Q_{\text{product_sensible}} + Q_{\text{product_respiration}} + Q_{\text{safety}}$$

1. $Q_{\text{transmission}}$
 - Heat conduction through walls, roof, floor, doors
 - Formula: $U \times A \times \Delta T$
2. $Q_{\text{air_exchange}}$
 - Heat from air infiltration via door openings, gaps, ventilation
3. Q_{internal}
 - Heat from workers, lighting, and equipment
4. $Q_{\text{product_sensible}}$
 - Cooling load to reduce fruit temperature
 - Formula: $(m \times C_p \times \Delta T) / t$
5. $Q_{\text{product_respiration}}$
 - Heat from fruit respiration after harvest
 - Formula: $m \times R$
6. Q_{safety}
 - Extra margin for uncertainty (e.g. piping, defrost, assumptions)

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Key Factors of Heat Load Calculation

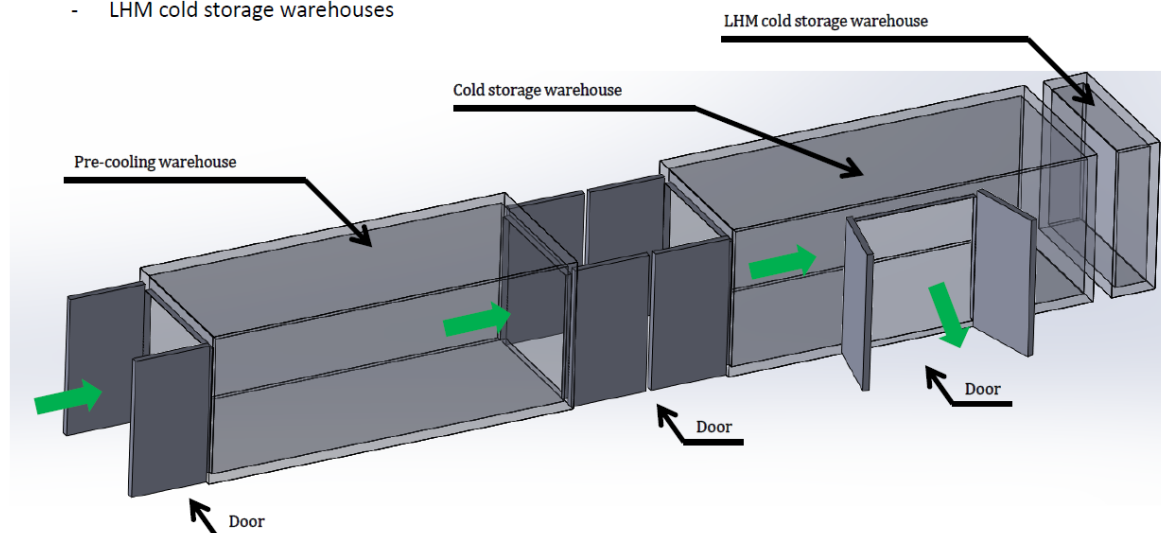
Considerations for Calculating Heat Loads

1. **Peak Load Timing**
 - Occurs when warm fruits are delivered
 - Must size system for initial sensible load spike
2. **Latent Heat Impact**
 - Humid air → frost on coils
 - Use dehumidifiers or control humidity
3. **Safety Margin (10–20%)**
 - Covers unexpected factors:
 - Power fluctuations
 - Equipment aging
 - Estimation errors
 - Defrost cycle heat
4. **Why It Matters**
 - Ensures reliable operation under all conditions

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Example for Heat Load Calculation

- Storage warehouses
 - pre-cooling warehouses,
 - cold storage warehouses
 - LHM cold storage warehouses



Example for Heat Load Calculation

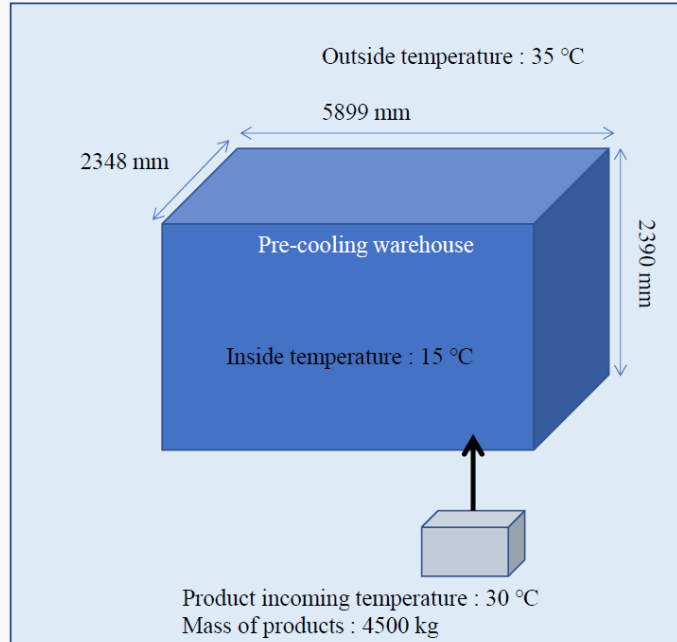
Calculation of heat load for pre-cooling warehouse

Conditions

- Geometry for pre-cooling warehouse
 - Length : 5899 mm
 - Width : 2348 mm
 - Height : 2390 mm
- Insulation thickness and thermal conductivity
 - Insulation thickness : 100 mm
 - Thermal conductivity : 0.03 W/m·K
- Outside temperature : 35 °C
- Inside temperature : 15 °C
- **Product incoming temperature : 30 °C**
- **Product outgoing temperature : 15 °C**
- **Mass of products : 4500 kg**
- **Cooling time : 4 hour**

Loads

- ✓ Transmission loads : 406.2 kcal/h
- ✓ Air exchange loads : 160.9 kcal/h
- ✓ Internal heat loads : 922.4 kcal/h
- ✓ **Cooling loads : 14,563.1 kcal/h**
- ✓ Respiration loads : 427.7 kcal/h
- ✓ Safety factor 110%
- ✓ Total heat loads : 18,128.2 kcal/h = 21.08 kW



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Example for Heat Load Calculation

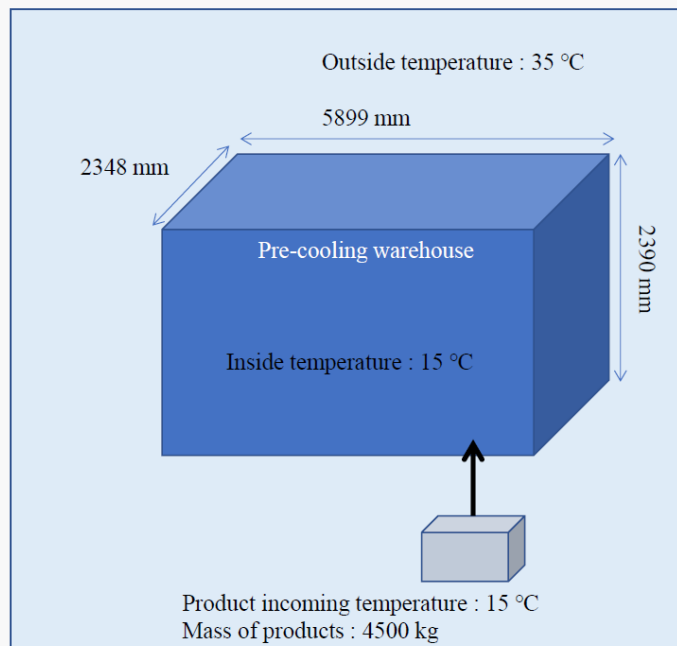
Calculation of heat load for cold storage warehouse

Conditions

- Geometry for pre-cooling warehouse
 - Length : 5899 mm
 - Width : 2348 mm
 - Height : 2390 mm
- Insulation thickness and thermal conductivity
 - Insulation thickness : 100 mm
 - Thermal conductivity : 0.03 W/m·K
- Outside temperature : 35 °C
- Inside temperature : 15 °C
- **Product incoming temperature : 15 °C**
- **Product outgoing temperature : 15 °C**
- **Mass of products : 4500 kg**
- **Cooling time : 4 hour**

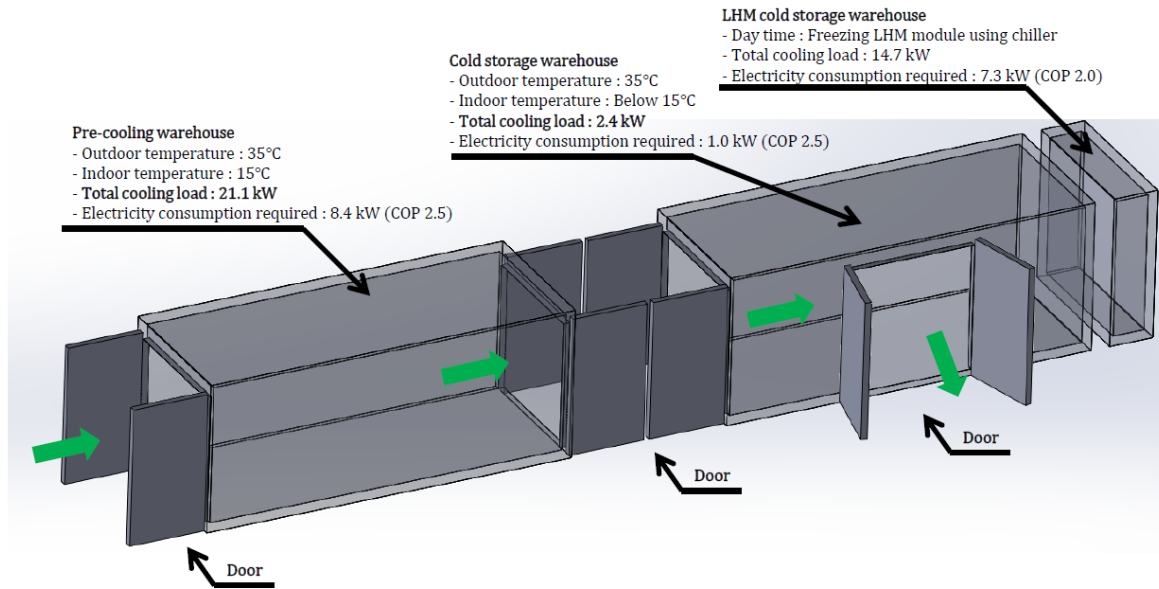
Loads

- ✓ Transmission loads : 406.2 kcal/h
- ✓ Air exchange loads : 111.4 kcal/h
- ✓ Internal heat loads : 922.4 kcal/h
- ✓ **Cooling loads : 0 kcal/h**
- ✓ Respiration loads : 427.7 kcal/h
- ✓ Safety factor 110%
- ✓ Total heat loads : 2,106.6 kcal/h = 2.45 kW



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Example for Heat Load Calculation



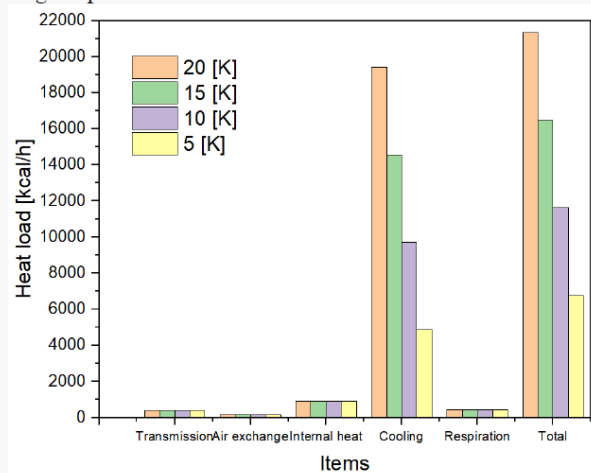
Example for Heat Load Calculation

Case study - heat load variation according to product incoming temperature

➤ Cooling load formula = $(m \times C_p \times \Delta T) / t$

Conditions

- Geometry for pre-cooling warehouse
 - Length : 5899 mm
 - Width : 2348 mm
 - Height : 2390 mm
- Insulation thickness and thermal conductivity
 - Insulation thickness : 100 mm
 - Thermal conductivity : 0.03 W/m·K
- Outside temperature : 35 °C
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- Mass of products : 4500 kg
- Cooling time : 4 hour



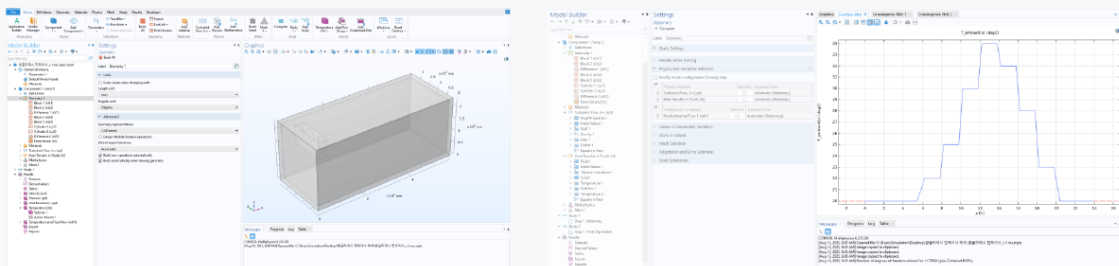
	Transmission	Air exchange	Internal heat	Cooling	Respiration	Total
20	406.2	160.9	922.4	19417.5	427.7	21334.7
15	406.2	160.9	922.4	14563.1	427.7	16480.3
10	406.2	160.9	922.4	9708.8	427.7	11626.0
5	406.2	160.9	922.4	4854.4	427.7	6771.6

✓ Total heat loads [kcal/h] = (Transmission + Air exchange + Internal heat + Cooling + Respiration) × 1.1 (Safety factor)

Example for Simulation

Simulation

- Heat transfer **analysis through simulation**
 - Tools Used: COMSOL Multiphysics
- The conditions **used to calculate the heat load** are used in the simulation
 - geometry, thermal conductivity, temperature, product mass, etc.
- Simulations can be performed under **various conditions**
 - evaporator location, product placement, and changes in outside temperature, etc.

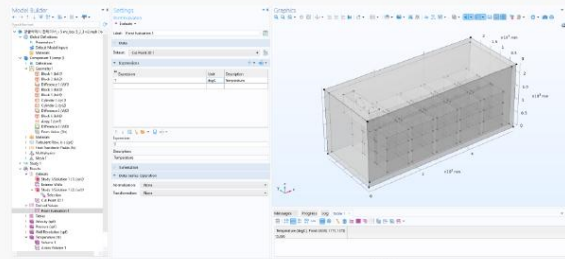


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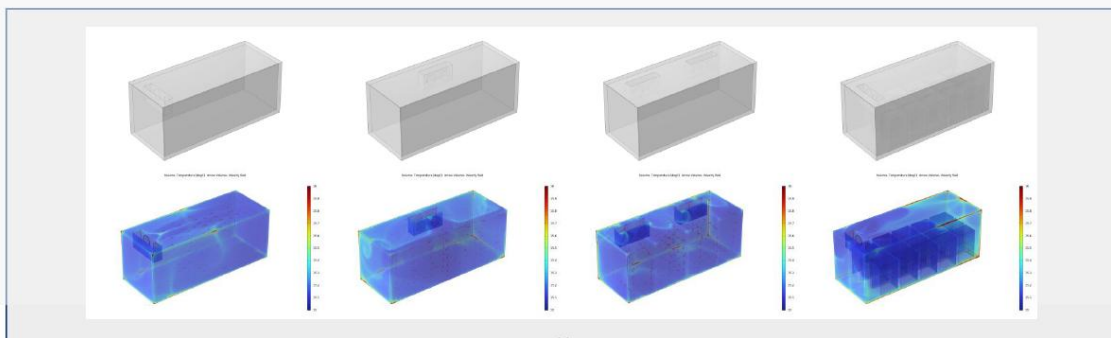
Example for Simulation

Simulation

- Verifiable items
 - Changes in internal air temperature over time
 - Changes in surface and core temperatures of goods over time
 - Temperature uniformity
- Usability
 - Optimization of placement
 - Optimization of item placement
- Support available
 - Simulation training for heat load calculation



- Evaporator location and product placement geometry and simulation calculation results





Thank you for your attention