Journal of Applied Horticulture, 27(2): 200-206, 2025
https://doi.org/10.37855/jah.2025.v27i02.37
Journal of Applied Horticulture
ISSN: 0972-1045

# Design of cold storage structure for sixteen tonnes onion

**Robin Kumar Mahato, Jayant Chand, Sapna Soni, Divya Bera, Nikhil H Lakra, Augustin Guria, Md. Irfan Ahmad Ansari* and Pramod Rai**

*Department of Agricultural Engineering, Birsa Agricultural University, Ranchi, Jharkhand – 834006, India.*
**E-mail: irfaniitkgp2000@gmail.com*

## Abstract

Cold storage is an important method for storing onions in fresh and wholesome state for a longer period. Small cold storage for storing sixteen tonnes of onion at 1°C was designed to reduce post-harvest losses of onions and ensure a better return to small and marginal farmers. The polypropylene plastic mesh bags of 50 kg capacity were selected for onion storage with dimensions of 94 cm x 57 cm x 35 cm. The number of bags was found to be 3200 for storage of sixteen tonnes (16 MT) of onions. Considering 8 layers of bags stacked on wooden pallets, the stack height was obtained as 2.8 m. The inside and outside dimension of onion cold storage was was 8.3 m × 5.5 m × 4 m and 9 m × 6.3 m × 4.7 m in length, width and height, respectively with 10 stacks in 8 layers. The volume of cold storage was found to be 1802.6 $m^3$. The construction and insulating materials selected were polyurethane sheet, PUF, polythene sheet, PCC, PVC panels, brick, etc., for floors, walls, door and roof for cooling load calculation. The cooling load was calculated considering all the possible heat sources. The total cooling load was found to be 2052770.6 kJ/day with 85.88% product heat load, 5.61% transmission heat load and 4.02% air infiltration load of total heat load. The cooling load for cooling sixteen tonnes of onions was found to be 9.5 tonnes which would be helpful in the selection of appropriate refrigeration systems by farmers and traders.

**Key words:** Cold storage, onion, pp plastic mesh bag, stacking arrangement insulating materials, cooling load

## Introduction

Onion (*Allium cepa*) is one of the most valuable vegetables cultivated and consumed worldwide. Its dietary use improves digestion and mental health. The red and white varieties of onions have antimicrobial and antioxidant activities (Upadhyay, 2016). It is mainly cultivated in three seasons *i.e.,* during *kharif*, late *kharif*, and *rabi.* India is the second-largest onion-growing country in the world as well as one of the largest producers of onion in the world second only to China (Bhardwaj, 2020). The major onion producing states are Maharashtra, Karnataka, Madhya Pradesh, Gujarat, Bihar, Andhra Pradesh, Rajasthan, Haryana and Telangana. In India, onion is cultivated in an area of 1.54 million hectares with a production of 25.44 million MT. Onion accounts for 67 per cent of total foreign exchange among fresh vegetables. Onion is stored throughout the world to fulfil the daily requirement of consumers (Tripathi and Lawande, 2019). Onion, the 'Queen of kitchen' is one of the important crops of the farmers of Jharkhand state. The production of onion was 322.73 MT in Jharkhand (Agarwal and Kumar, 2018). The storage of onions in Jharkhand state is a big problem. The low-temperature storage facilities for onions are not available in Jharkhand. The losses of onions stored under ambient storage conditions are very high in most of the tropical countries. Improper storage limits its shelf life and a considerable amount of the bulb gets lost during the storage. The storage losses of onion in tropical regions are 30 to 40 % due to improper post-harvest management (Tripathi and Lawande, 2019). The postharvest losses of onions include physiological weight loss, decay loss and sprouting loss. Due to the lack of proper storage facilities, farmers are compelled to sell their produce at a throwaway price during harvesting season. During natural calamities, the losses go beyond 40 % which leads to heavy stress both on demand and supply. The supply volatility creates market distress causing a steep rise in the price of onion that eventually affects the end consumers (Kumar *et al.*, 2023; Ghosh *et al.*, 2024). The post-harvest losses can be minimized by the proper design of cold storage structure and it can help in checking the supply volatility and steep rise in onion prices.

Onions, like other vegetables, are influenced by climatic factors such as temperature, humidity and fungal threats. To address these challenges, cold storage is required for the storage of onions at low temperatures. Cold storage space is cooled by the circulation of cold air produced by the refrigeration system. It reduces biochemical changes, respiration rates, and senescence processes, slows down the growth of microbes, extends the shelf life of fruits & vegetables beyond the harvest season, stabilizes prices and also prevents significant postharvest losses. The cold storage facility also prevents farmers from selling their produce at low prices and ensures the availability of produce throughout the year at reasonable prices. Tripathi and Lawande (2019) stated that the sprouting in stored onions is due to storage at elevated temperatures. The temperature and relative humidity are the prime important factors associated with the storage of onion. It is well established that onions stored in the temperature range of 0 to 2°C at 65 to 70 % relative humidity retain their quality with minimum loss.

Bhardwaj (2020) designed a storage structure for onion bulbs and maintained conditions that are necessary for significantly reducing physiological weight loss, unwanted sprouting and rotting. Basu and Ganguly (2016) designed a solar thermal photovoltaic powered potato cold storage having dimensions of 20 m x 10 m x 5 m for storage of potatoes. Mishra *et al.* (2020) designed a ten-tonne capacity cold storage (39.64 $m^3$) and used a domestic split air conditioner for storage of okra. They reported that the developed cold storage system can significantly reduce postharvest losses and boost the income of marginal farmers. Bhuvaneshwari *et al.* (2021) designed a coir peat-insulated cold storage system for 1000 kg of onions and they reported a total heat load of 4 tons.

One of the potential energy wastes is the wrong cold storage design and mismatch between the intended cooling load during the actual operation and the selected capacity of the refrigeration equipment during planning. Cooling load is the total heat energy that must be removed from the cold room to lower the temperature to the desired level. All the possible incoming heat load sources are considered in the calculation of cooling load which serves as the basis for the selection of the proper capacity of refrigeration equipment that leads to an efficient refrigeration process in cold storage. The choice of an ideal cooling system requires good calculation of cooling load and all sources of cooling load must be taken into consideration (Akdemir, 2008). The establishment of cold storage at the catchment area is the need of the hour to reduce the wastage of onions as well as for the economic benefits of growers, traders and consumers. The main objectives of the study were to estimate the structural dimension of the cold storage for 16 tonnes of onion and calculate the heat load.

## Materials and methods

The dimension and cooling load of a 16 MT cold storage structure was estimated in order to store onions for extended shelf life. The building and insulating materials used in the calculation are given in Table 1.

**Calculation of dimension of storage structure:** To estimate the dimension of storage structure, a polypropylene mesh bag of 50 kg capacity was selected for the storage of onion. The dimension of the bag chosen was 94 cm x 57 cm x 35 cm in length, width and height respectively (NHB, 2010). Since the required storage capacity is 16 tonnes, hence number of bags needed is computed as 320.

The wooden pallets were selected to place and make the stacks of bags. The dimension of the pallet was taken as 151 cm × 151 cm × 13 cm. The height of the pallet was 13 cm from the floor to avoid direct heat from the floor and for proper air circulation to keep the onions at a uniform storage temperature. An arrangement of four bags in one layer was taken for stacking of onion bags. The number of layers was calculated as 8.

The proper stacking of produce helps in easy handling, movement, loading, unloading and also in uniform cooling of produce. Assuming eight layers in one stack of onion bags, the number of bags per stack was computed as:

Number of bags in one stack = number of bags per layer x number of layers

= 4 × 8 = 32 bags

Mass of onion in one stack = 32 x 50 = 1600 kg

Number of stacks = Total mass of onion/ Mass of onion in one stack

= 16000/1600 = 10

The number of pallets for stacking onion bags was calculated as:

Number of pallets required for stacking = Total number of bags/Number of bags in one stacks = 320/32 = 10

A gap of 20 cm was considered between the walls and stacks in a cold storage structure (NHB, 2010). Also, a gap of 8 cm was considered between each stack to ensure the free circulation of cold air (NHB, 2010), 117 cm gap was considered between the ceiling and the top layer of stacks (Rao, 2015) and a 200 cm space was kept between two rows of stacks for the movement of humans and forklift.

The internal length of the cold storage structure was calculated as:

Internal length = 2 × space between walls and stack + 5 × (length of bag + width of on bag) + 4 × space between two adjacent stacks

= 2 × 20 + 5 × (94 + 57) + 4 × 8 cm

= 827 cm = 8.27 m =8.30 m (Assumed)

Similarly, the internal width was calculated as:

Internal width = 2 × space between walls and stack + 2 × (length of one bag + width of one bag) + space for movement

= 2 × 20 + 2 × (94 + 57) + 200 cm

= 542 cm = 5.42 m = 5.5 m (Assumed)

Similarly, the internal height was calculated as:

Internal height = height of pallet from floor + 8 × height of each layer + distance between the tip of the topmost layer and ceiling

= 13 + 8 × 35 + 117 cm = 400 cm = 4 m

The dimension of door of the cold storage was taken as 1.5 m × 2.5 m (Sakare, 2014).

Overall internal dimension = 8.30 m x 5.5 m x 4 m

**External dimensions of cold storage:** Assuming wall thickness, floor thickness, and roof thickness of 38.29 cm, 25.92 cm and 45.29 cm respectively, the external dimensions of cold storage were estimated as:

External length = 2 × wall thickness + total internal length

= 2 × 38.29 cm + 830 cm

= 0.7658 m + 8.3 m = 9.0658 m = 9 m (assumed)

External breadth = 2 × wall thickness + total internal breadth

= 2 × 38.29 cm + 550 cm

= 0.7658 m + 5.5 m = 6.2658 m = 6.3 m (assumed)

External height = floor thickness + ceiling thickness + total internal height

= 25.92 cm + 45.29 cm + 400 cm = 4.7121 m = 4.7 m

The overall external dimension in cold storage = 9 m x 6.3 m x 4.7 m.

**Estimation of cooling load:** It is necessary to estimate the cooling load while designing a cold storage to determine the capacity of the refrigeration plant that needs to be set up to achieve the desired cooling effect. The selection of proper insulating materials is very important to reduce the operating cost of the refrigeration plant by reducing heat gain through the structure of cold storage. The thermal conductivity of building and insulating materials is given in Table 1. The required refrigeration capacity should match the determined cooling load and thus, enabling a proper selection of refrigeration equipment.

The optimal storage temperature must be continuously maintained to obtain the full benefit of cold storage. The design consideration for the cold storage is only temperature controlled. The calculation of the cooling load is carried out using the most severe conditions expected during operation in Jharkhand state. These conditions include the mean maximum outside temperature; the maximum amount of produce to be cooled, the entry temperature of the

Table 1. Thermal conductivity of building and insulating materials (NHB, 2010: Mishra *et al.*, 2020)

| Building and insulating Materials | Thermal conductivity (W/m °C) |
|---|---|
| Polyurethane (internal finish) | 0.0229 |
| Concrete screed | 1.7398 |
| Insulation (PUF) | 0.024 |
| polythene sheet (Vapour-barrier) | 0.329 |
| Tar felt | 0.4792 |
| PCC | 1.9887 |
| PVC panels (internal finish) | 0.12 |
| Brick | 0.9769 |
| Cement plaster | 0.9257 |
| Coir peat (insulation) | 0.0479 |
| RCC | 1.5794 |
| Plywood | 0.174 |

produce and the temperature of produce to be stored in the cold storage.

The total amount of heat that the refrigeration system must remove from the cooling room is called the heat load. The heat load for cold storage consists of transmission heat load through walls, roof, floor and door, air infiltration load, heat load due to lights, heat load due to fans, heat load due to onion, heat load due to PP mesh bags, heat load due to respiration of onions, heat load due to wooden pallets and human occupancy load. Based on the technical standards and protocol for the cold chain in India (NHM, 2010), the materials were chosen for the design of a cold storage structure for sixteen tonnes of onion. It is assumed that the total amount of heat is removed in 24 h. (Saravacos and Kostaropoulos, 2006).

**Transmission heat load:** The transmission heat is thermal energy that flows through the warmer sides of walls, roof, floor and door into the cold room. By considering steady-state flow, the heat transmission load was calculated using the following formula:

$Q = U \times A \times (T_o - T_i)$…………… (1)

Were,

Q = Heat transmission rate, W

U = Overall heat transfer coefficient, W/m² °C

A = Heat transfer area, m²

$T_i$ = Inside temperature of cold storage air, °C

$T_o$ = Outside Temperature of atmosphere air, °C

The average extreme outside temperature was considered as 45ºC which prevails in Jharkhand state while the onion storage temperature was taken as 1ºC.

**Heat transmission load through walls:** The walls of the cold storage structure comprised 0.0127 m PVC, 0.1 m PUF, 0.25 x $10^{-3}$ m polythene sheet, 0.01m plaster, 0.23 m brick, and 0.03 m plaster from inner to outer surfaces respectively. Thus, the total wall thickness was 0.383 m. The overall heat transmission coefficient is calculated by the following equation:

$$U_{wall} = \frac{1}{\frac{1}{h_i}+\frac{x_{pvc}}{k_{pvc}}+\frac{x_{puf}}{k_{puf}}+\frac{x_p}{k_p}+\frac{x_p}{k_p}+\frac{x_b}{k_b}+\frac{x_p}{k_p}+\frac{1}{h_o}} \quad (2)$$

Where, $x_{pvc}$ = thickness of PVC panels, m

$x_{puf}$ = thickness of PUF insulation, m

$x_{ps}$ = thickness of polythene sheet, m

$x_{cP}$ = thickness of cement plaster, m

$x_b$= thickness of brick, m

k = thermal conductivity of respective above materials W/m ºC

$h_i$ = convective heat transfer coefficient on the inner surface = 15 W/m$^2$ ºC (Mishra *et al.*, 2020)

$h_o$ = convective heat transfer coefficient on the outer surface = 4 W/m$^2$ ºC (Mishra *et al.*, 2020)

$$U_{wall} = \frac{1}{\frac{1}{15}+\frac{0.0127}{0.12}+\frac{0.1}{0.024}+\frac{0.00025}{0.329}+\frac{0.01}{0.9257}+\frac{0.23}{0.9765}+\frac{0.03}{0.9257}+\frac{1}{4}}$$

= 0.205 W/m$^2$ K

**Heat exchange areas**: The heat transfer area for walls is given as:

Total area of 4 walls = (2 x internal length x internal height) + (2 x internal breadth x internal height) - Area of the door

= (2 x 8.3 x 4) + (2 x 5.5 x 4) – 2.5 x 1.5
= 106.65 m$^2$

Assuming 45℃ as ambient temperature and 1℃ as cold storage temperature, the heat transmission load through walls under steady state conditions is estimated as:

$Q_{wall}$ = $U_{wall}$ x $A_{walls}$ x ($T_o$ – $T_i$) x 24 x 3600 J/day …………… (3)
= 106.65 x 0.205 x (45 - 1) x 24 x 3600
= 83115.33 kJ/day

**Heat transmission load through the roof:** The thickness of the roof included 0.0127 m PVC, 0.16 m coir peat, 0.1 m PUF, 0.25 x $10^{-3}$ m polythene sheet, 0.15 m reinforced cement concrete and 0.03 m plaster from inner to outer surface respectively. So, the total thickness of the roof was 0.452 m. The overall heat transmission coefficient was calculated as:

$$U_{roof} = \frac{1}{\frac{1}{h_i}+\frac{x_{pvc}}{k_{pvc}}+\frac{x_{coir}}{k_{coir}}+\frac{x_{puf}}{k_{puf}}+\frac{x_p}{k_p}+\frac{x_{rcc}}{k_{rcc}}+\frac{x_p}{k_p}+\frac{1}{h_o}} \quad \ldots\ldots\ldots (4)$$

Where, $x_{coir}$= thickness of coir peat insulation, m. $x_{rcc}$ = thickness of RCC, m. $x_{cP}$ = thickness of cement (outside), m

$$U_{roof} = \frac{1}{\frac{1}{15}+\frac{0.0127}{0.12}+\frac{0.16}{0.0479}+\frac{0.1}{0.024}+\frac{0.00025}{0.329}+\frac{0.15}{1.5794}+\frac{0.03}{0.9257}+\frac{1}{4}}$$

= 0.124 W/m$^2$ K

Area of floor and roof = internal length x internal breadth = 45.65 m$^2$

So, the heat transfer through the roof is given by the following equation:

$Q_{roof}$ = $U_{roof}$ x $A_{roof}$ x ($T_o$ – $T_i$) x 24 x 3600 J/day …………… (5)
= 0.124 x 45.65 x (45 – 1) x 24 x 3600 J/day
= 21519.34 kJ/day

**Heat transmission load through floor:** The thickness of the floor included 0.006 polyurethane sheet, 0.05 m concrete creed, 0.1 m PUF, 0.25 x $10^{-3}$ m polythene sheet, 0.003 m tar felt and 0.1 m PCC from inner to outer surface, respectively. So, the total thickness of the floor was 0.259 m. The overall heat transmission coefficient was calculated as:

$$U_{floor} = \frac{1}{\frac{1}{h_i}+\frac{x_{pu}}{k_{pu}}+\frac{x_{puf}}{k_{puf}}+\frac{x_{cs}}{k_{cs}}+\frac{x_{ps}}{k_{ps}}+\frac{x_{tar}}{k_{tar}}+\frac{x_{pcc}}{k_{pcc}}+\frac{1}{h_o}} \quad \ldots\ldots\ldots(6)$$

Where, $x_{pu}$ = thickness of polyurethane as an internal finish, m.

$x_{cs}$ = thickness of concrete screed, m.

$x_{tar}$ = thickness of tar felt, m.

$x_{pcc}$ = thickness of PCC (outside), m

$$U_{floor} = \frac{1}{\frac{1}{15}+\frac{0.006}{0.023}+\frac{0.1}{0.024}+\frac{0.05}{1.7398}+\frac{0.00025}{0.329}+\frac{0.003}{0.4792}+\frac{0.1}{1.9887}+\frac{1}{4}}$$

= 0.207 W/m$^2$ K

Assuming a ground temperature of 10°C, heat transfer through the floor is given by the following equation:

$Q_{foor}$ = $U_{floor}$ x $A_{floor}$ x ($T_o$ – $T_i$) x 24 x 3600 J/day .............. (7)

= 0.207 x 45.65 x (10 – 1) x 24 x 3600 J/day

= 7347.97 kJ/day

**Heat transmission load through door:** The thickness of the door included 0.01 m PUF, 0.01 m plywood, 0.003 m air space, 0.01 m plywood and 0.1 m PUF respectively. Thus, the total thickness of the door was 0.123 m. The overall heat transmission coefficient for the door was calculated as:

$$U_{door} = \frac{1}{\frac{1}{h_i}+\frac{x_{puf}}{k_{puf}}+\frac{x_{ply}}{k_{ply}}+\frac{x_{air}}{k_{air}}+\frac{x_{ply}}{k_{ply}}+\frac{x_{puf}}{k_{puf}}+\frac{1}{h_o}} \text{ .............. (8)}$$

Where,

$x_{ply}$ = thickness of plywood, m

$x_{air}$ = thickness for air space, m

$$U_{door} = \frac{1}{\frac{1}{4}+\frac{0.05}{0.024}+\frac{0.01}{0.174}+\frac{0.003}{0.002}+\frac{0.01}{0.174}+\frac{0.05}{0.024}+\frac{1}{15}}$$

= 0.211 W/m$^2$ K

Heat transfer area of door = 1.5 m x 2.5 m =3.75 m$^2$

Hence, heat transfer through the door is given by the following equation:

$Q_{door}$ = $U_{door}$ x $A_{door}$ x ($T_o$ – $T_i$) x 24 x 3600 J/day .............. (9)

= 0.211 x 3.75 x (45 – 1) x 24 x 3600 J/day

= 3008.02 kJ/day

**Air infiltration load:** Infiltration is the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through the use of doors for passage. Assume that the outside air temperature is 45°C and 60 % relative humidity and the number of air changes per day was 2.7 (Basu and Ganguly, 2016). The heat load due to air infiltration was calculated using the following equation (Dincer, 2017):

$Q_a$ = VHC.............. (10)

Where,

V= Volume of cold store

H = Heat gain per unit volume of store

C = Number of air changes per day

The value of heat gain at 45°C and 60% relative humidity was taken as 40 kcal/m$^3$ from the psychrometric chart.

Volume of cold storage = 5.5 x 8.3 x 4 = 182.6 m$^3$

Hence, air infiltration load = 2.7 x 182.6 x 40 kcal/day = 82511.83 kJ/day

**Heat load due to onion:** The heat load added by the produce to be stored is the most important component to be considered in the design of cold storage. It represents the amount of heat load that is required to reduce the temperature of the onion from the initial temperature to the storage temperature. A temperature of 1ºC is considered for storage of onion (Buhamadi and Aldaijani, 2021). It is assumed that the onion was loaded at 30ºC and cooled to 1ºC in 24 h. The product load was calculated using the following equation:

Qp = mp × Cp × ($T_p$– $T_s$).............. (11)

Mass of onion = 16 MT

Average specific heat of onion = 3.8 kJ/kg ºC

Tp = entering temperature of onion = 30ºC and Ts = 1ºC.

Qp = 16,000 x 3.8 × (30 - 1)

= 1763200 kJ/day

**Heat load due to polypropylene (PP) mesh bags:** The PP plastic mesh bags are used for the storage of onions since plastic mesh bags are cheaper in comparison to jute bags.

Average specific heat capacity of PP mesh bag = 1920 J/kg ºC

Mass of one PP bag = 38 g

Mass of total bags = 320 bags × 38 g = 12160 g = 12.16 kg

$T_P$ = 30ºC, $T_s$ = 2ºC

The heat load due to the PP mesh bag is calculated as:

$Q_{pp\ mesh\ bag}$ = $m_{pp\ mesh\ bag}$ x $c_{pp\ mesh\ bag}$ x ($T_p$ – $T_s$).............. (12)

= 12.16 x 1920 x (30 – 1)

= 677.07 kJ/day

**Heat load due to respiration of onion:** Respiration is a metabolic process by which fruits and vegetables take in oxygen and release carbon dioxide and produce energy for growth and maintenance. This process takes place even after harvest and heat generates heat due to respiration.

The heat of respiration for onion is 750 kJ/tonne per day (Rao, 2015).

So, respiration load can be calculated as:

$Q_{res}$ = 16 x 750 = 12000 kJ/day

**Heat load due to pallets:** The wooden pallets are taken for keeping the onion bags.

Mass of one pallet = 10 kg, Number of pallets=10

Specific heat of wooden pallets = 1.67 kJ/kg ºC (Rao, 2015)

The heat load due to pallets is calculated as:

$Q_p$ = $m_{pallets}$ x $c_{pallets}$ x ($T_p$ – $T_s$).............. (13)

= 16 x 10 x 1.67 x (30 – 1)

= 7748.8 kJ/day

**Human occupancy load:** Assuming two persons work in the cold store for 4 hours per day, the heat produced by human working in the cold store is calculated from the equation given below:

$Q_{hu}$ = number of person x working time in cold storage (h/day) x heat released per person per hour

One person gives off around 170 kcal/h of heat energy (Sahay and Singh, 1994) which is equivalent to 711.28 kJ/h.

Thus, the heat load due to human occupancy: $Q_{hu}$ = 2 x 4 x 711.28 = 5690.24 kJ/day

**Heat load due to air cooling fans:** It is important to maintain adequate circulation of air using fans around all sides of stacks to avoid the risk of spoilage by moulds. The four air cooling fans each of 250 watts were taken for cold storage and are assumed to be fitted to work inside cold storage which runs for 18 hours per day. The motors of air-cooling fans produce heat which depends on the power rating, number of fans and duration of operation of fans.

The heat generated by the fans is calculated from the following equation:

$Q_{fan}$ = No. of fans x operating time x wattage ……………..... (14)

= (4 x 250 × 18 x 3600) /1000

= 64800 kJ/day

**Heat load due to lights:** Four LED tube lights each of 20 watts (Mishra *et al.,* 2020) were assumed to be fitted to work inside cold storage for four hours per day.

The heat generated by the lights was calculated from the following equation:

$Q_{light}$ = No. of lights x operating time x wattage …………… (15)

= 4 x 4 x 20 Wh/day

= 320 Wh/day

= (320 x 3600) /1000 kJ/day = 1152 kJ/day

**Total heat load:** The total heat load was calculated as the summation of all the heat load components.

Total heat load = $Q_{onion} + Q_{res} + Q_{bag} + Q_{pallet} + Q_{fan} + Q_{human} + Q_{light} + Q_{air} + Q_{floor} + Q_{walls} + Q_{roof} + Q_{door}$

= 1763200 + 12000 + 677.07 + 7748.8 + 64800 + 5690.24 + 1152 + 82511.83 + 7347.97 + 83115.33 + 21519.34 + 3008.02 kJ/day

= 2052770.6 kJ/day

Taking the 5% factor of safety to take care of unforeseen heat load (Basu and Ganguly, 2016), the gross heat load was determined as:

Gross heat load = Total heat load + 5 % of total heat load

= 2052770.6 + 2052770.6 x 0.05

= 2155409.13 kJ/day

Based on this, the refrigeration plant capacity was calculated considering the operation of refrigeration equipment for eighteen hours per day (Ramaswamy, 2015).

Plant capacity = 2155409.13 kJ/day/ (12660.67 kJ/h x 18)

= 9.45 ~ 9.5 tonnes of refrigeration

Hence, a refrigeration system of 9.5 tonnes capable of producing a cooling effect can be selected for storage of 16 MT onions at the desired temperature in Jharkhand and other locations with similar climatic conditions.

## Results and discussion

**Dimension of cold storage structure:** A cold storage structure of 16 MT capacity was designed for the storage of onion at 1°C. The construction materials selected for the design of onion cold storage included polyurethane (internal finish), concrete screed, PUF (insulation), polythene sheet (vapour-barrier), Tar felt, PCC, PVC panels (internal finish), brick, cement plaster, coir peat (insulation), RCC and plywood. A vapour barrier material is used in cold storage to prevent moisture migration as well as provide insulation from moisture condensation. The materials used depended on the product and temperature standards. Similar insulating/construction materials were used by Mishra *et al.* (2020). The thickness of the wall, roof, floor and door was selected as 0.383 m, 0.452 m, 0.259 m and 0.123 m respectively. A polypropylene plastic mesh bag of 50 kg storage capacity was used for storage of onions. The number of bags required for storage of 16 MT onions was found to be 3200 which were stacked in 8 layers arrangement on each wooden pallet with a stack height of 2.8 m with 10 stacks. The length, breadth and height of the stack were found to be 1.51 m, 1.51 m and 2.8 m, respectively. The dimensions of the onion cold storage were estimated based on the storage capacity of the onion. The stacking arrangement, working space, space for air circulation, *etc.*were considered to decide the dimensions of the cold storage. The internal length, internal breadth and internal height of the cold storage structure were found to be 8.3 m, 5.5 m and 4 m in length, width and height, respectively while the external length, external breadth and external height of cold storage were found to be 9 m, 6.3 m and 4.7 m, respectively. The total area of the 4 walls was estimated to be 106.65 $m^2$. The area of floor and roof was found to be 45.65 $m^2$. The size of the door was chosen for the ease of handling the produce. The selected door was 2.5 m long, 1.5 m wide and 0.1 m thick. The sectional view of the designed cold storage structure is shown in Fig. 1.

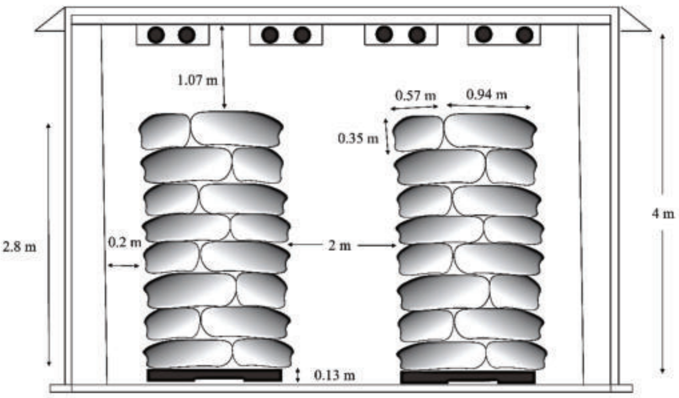


Fig. 1. Sectional view of 16 MT cold storage structure

**Cooling load calculation:** The cooling load was calculated based on the assumption that onions are loaded at 30°C and cooled to 1°C. Twelve heat load components were taken into consideration to compute the cooling load for 16 metric tonnes of onion cold storage structure. Based on the calculation, the summary of different load sources is presented in Table 2. The total heat transfer area for walls was obtained as 106.65 $m^2$. Similarly, the heat transfer area for roof and floor was found to be 45.65 $m^2$ while that of the door was 3.75 $m^2$. Heat load due to walls was calculated as 83115.33 kJ/day while heat load due to roof, floor and door were found to be 21519.34 kJ/day, 7347.97 kJ/day and

Table 2. Summary of different heat load sources

| Component of heat load | kJ/day | Percentage (%) |
|---|---|---|
| Heat gain through wall | 83115.33 | 4.05 |
| Heat gain through roof | 21519.34 | 1.05 |
| Heat gain through floor | 7347.97 | 0.36 |
| Heat gain through door | 3008.02 | 0.15 |
| Air infiltration load | 82511.83 | 4.02 |
| Heat load due to onion | 1763200 | 85.88 |
| Respiration load of onion | 12000 | 0.58 |
| Heat load due to PP mesh bag | 677.07 | 0.03 |
| Heat load due to pallets | 7748.8 | 0.38 |
| Heat load due to human | 5690.24 | 0.28 |
| Heat load due to fans | 64800 | 3.16 |
| Heat load due to light | 1152 | 0.06 |
| Total heat load | 2052770.6 | 100.00 |

3008.02 kJ/day respectively. The product cooling load is the load from the product placed in the cold room. The cooling load for the onion was found to be 1763200 kJ/day while the respiration load was obtained as 12000 kJ/day. From Table 2, it is clear that among structural heat load, the maximum heat load was contributed by heat transmitted through walls and minimum through floors. The heat load due to PP mesh bag was the least.

Also, from Table 2, it is evident that product cooling load constituted 85.88% of the total heat load while transmission heat load constituted 5.61% of the total heat load. The heat transmission load was found to be 114990.66 kJ/day. The air infiltration load, heat load due to humans, fans and lights were found to be 82511.83 kJ/day, 5690.24 kJ/day, 64800 kJ/day and 1152 kJ/day respectively. Overall, the maximum heat load was obtained for the product. Similar results have been reported by Yuzainee *et al.* (2019), Mishra *et al.* (2020), and Bhuvaneshwari *et al.* (2021).

The total heat load calculated was 2052770.6 kJ/day. Considering 5% factor of safety, the gross heat load calculated was 2155409.13 kJ/day. The total refrigeration capacity for storage of 16 MT onion at $1^{o}$C was found to be 9.5 tonnes. Based on this information, the farmers and traders can construct the cold storage and select the refrigeration equipment for proper storage of onions in their catchment area.

The study successfully designed a cold storage system for 16 metric tonnes of onions and calculated the cooling load requirements. The storage structure was designed to keep the temperature stable from 30°C when the items were put in to 1°C when they were taken out. The inside dimensions were 8.3 × 5.5 × 4 m and the outside dimensions were 9 × 6.2 × 4.7 m. The total cooling load was found to be 2,052,770.6 kJ/day, with 85.88% coming from product heat load, 5.61% from transmission heat load, and 4.02% from air infiltration load. It was determined that the total refrigeration need was 9.5 tonnes, which is a good number to use when choosing the right refrigeration systems. The suggested design, which uses 50 kg polypropylene mesh bags on 10 pallets, makes sure that stacking and airflow work well. Small-scale farmers and traders can use this cold storage model to keep onions fresh longer, reduce losses after harvest, and make more money.Acknowledgement

The authors express their sincere gratitude to the Indian Council of Agricultural Research, New Delhi for providing financial facilities through the AICRP on PHET, BAU, Ranchi to carry out the research work.

## References

Akdemir, S., 2008. Designing of cold stores and choosing of cooling system elements. *J. Appl. Sci.*, 8: 788-794.

Agarwal, P.K. and M. Kumar, 2018. An economic analysis of onion cultivation in Giridih district of Jharkhand. *Eco. Affa.*, 63: 703-707.

Basu, D.N. and A. Ganguly, 2016. Solar thermal–photovoltaic powered potato cold storage – conceptual design and performance analyses. *Appl. Ener.*, 165: 308-317.

Bhardwaj, S. 2020. Onion Storage. *Intl. J.Curr. Adv. Res.,* 9: 22882-22884.

Bhuvaneshwari, B., K. Punitharani and R. Jayachitra, 2021. Design of coir peat insulated cold storage system for 1000kg of onions.*Intl. J. Mech. Eng*.,6: 2165-2169.

Buhamadi M.H. and A.F. Aldaijani, 2021. Effect of refrigerant types in cooling loads calculations and refrigeration cycle performance used in a cold room building located in Kuwait. *Intl. J. Eng. Res. Appl.,* 11: 59-70.

Dincer, I. 2017. *Refrigeration Systems and Applications*. p.750.Third Edition, John Wiley & Sons Ltd, UK.

Ghosh, S., R.K. Tiwari, R.K. Verma, A. Biswal and N.K. Mishra, 2024. Impact of frontline demonstration on the knowledge and adoption level of farmers during kharif onion production in North Alluvial plains of Bihar. *J. Appl. Hortic*., 26(2): 248-251.

Kumar, K. Sathees, T. Ilakiya and T. Gowthaman, 2023. Price instability, seasonal index and modelling for major vegetables in India. *J. Appl. Hortic*., 25(2): 219-223.

Mishra R., S.K. Chaulya, G.M. Prasad, S.K. Mandal and G.Banerjee, 2020. Design of a low cost, smart and stand-alone PV cold storage system using a domestic split air conditioner. *J. Std. Prod. Res*., 89: 17-20.

National Horticulture Board, 2010. *Technical Standards and Protocol for the Cold Chain in India.* p.61.

Ramaswamy, H.S., Jr. 2015. *Post-Harvest Technologies of Fruits & Vegetables.* DEStech Publications, USA. p.326.

Rao, C.G. 2015. *Engineering for Storage of Fruits and Vegetables, Cold Storage, Controlled Atmosphere Storage, Modified Atmosphere Storage*. BSP Pvt. Ltd., Elsevier Inc. p. 890.

Sahay, K.M. and K.K. Singh,1994. *Unit Operations of Agricultural Processing*. p.340. First Edition, Vikas Publishing House Pvt Ltd.

Sakare, P., 2014. Design of cold storage structure for thousand tonne potatoes. *Intl. J. Agr. Fd. Sci. Technol*., 5: 171-178.

Saravacos, G.D. and A.E. Kostaropoulos. 2006. Handbook of Food Processing Equipment. Springer (India) Private Limited, New Delhi, p. 698.

Tripathi, P.C. and K.E. Lawande, 2019. Onion storage in tropical region: Areview. *Curr. Hortic.,* 7: 15-27.

Upadhyay, R., 2016. Nutraceutical, pharmaceutical and therapeutic uses of *Allium Cepa*: A review. *Intl. J. Green. Pharm.,*10: 46-64.

Yuzainee, M.Y., N.H.N. Zafira and J. Nurulnadiah 2019. Cooling load calculation for efficient cold storage of fresh-cut yam bean. *Intl. J. Recent Technol. Eng*., 8: 6506-6513.

Received: December, 2024; Revised: February, 2025; Accepted: February, 2025