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Design of a 25 Metric Ton Fresh Sweet Maize Cobs Cool Storage Structure

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Abstract
Inadequate storage systems posed significant threat to global food and nutrition security. This study was conducted to design an appropriate cool storage structure for fresh maize cob. The material selection and design were based on the Tropical region of Nigeria, where the temperature and humidity prevail throughout the year. The total internal volume of the cool room was 1566 m^3 and it was designed to accommodate 100,000 sweet corn cobs. Results obtained from the design calculation revealed that the respiration heat load of the corn cobs was 107675 kcal/24h, total heat load of the cool room was 704452.82 kcal/24h, and the refrigeration capacity was 63400.75 kcal/h. The calculations revealed that the cool room can effectively maintain the temperature of the maize cobs at 5°C by employing 12 units of 2-ton capacity air conditioners.

Keywords: Agricultural products, food security, maize cobs, nutritional qualities, refrigeration

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1.0 Introduction

Inadequate storage systems leading to food spoilage stand as a significant contributor to global food insecurity. This is exacerbated by lack of postharvest handling techniques, climate change, and poor investment in food value chains. Postharvest operations are critical phases in supply chain of any fresh agricultural produce, and when poorly managed result in significant losses due to microbial invasion (Yahia *et al*., 2019; Balali et al., 2020; Ekruyota *et al*., 2021). Though food loss occurs at various stages of the food supply chain, approximately 45% of food loss takes place during harvesting and postharvest operations (Aragie *et al.*, 2018; Rajeev *et al*., 2022; Uguru *et al*., 2022). Therefore, reducing food wastage associated with postharvest operations is a major keyway in actualizing food security (Affoghon *et al*., 2015; Shafiee-Jood and Cai, 2016; Uguru *et al*., 2021). Maize (*Zea mays*) belonging to the grass family, is a widely cultivated cereal crop globally. The fresh cob is susceptible to spoilage due to pathogenic microbial activities (Díaz-Valderrama *et al*., 2020; Yewle *et al*., 2023). Poor storage conditions result in the farm products suffering losses that will lead to reduction their quantity and nutritional status. To mitigate these challenges, there is advancement in farm products storage and conservation technologies (Edafeadhe and Uguru, 2020; Sissinto Gbenou *et al*., 2021).

Cool storage system is one of the best techniques used to preserve perishable food items. The agricultural products are stored under controlled low temperatures and controlled humidity conditions, which will retard microbial performance without causing serious alterations to the food nutritional and biochemical qualities (Ali *et al*., 2022). The design of storage structures, including cool rooms, considered these factors – the heat of respiration and other engineering properties of the products being stored. This helps to preserves the quality and freshness of stored products (Eboibi and Uguru, 2017; Elansari *et al*., 2019; Gupta, 2023).

Temperature control is of paramount importance in cool storage system, as very low temperatures can accelerate freezing or chilling injuries (Kader *et al*., 2021). Additionally, some crops produce ethylene, while others are sensitive to ethylene exposure, and hence they cannot be stored together to avoid detrimental effects, including yellowing, softening, browning, increased decay and abscission or loss of leaves (Cantwel, 2001). Through several researches have been done on grain storage (Adégbola, 2011; Abass *et al.*, 2014; Baributsa *et al*., 2020), but related literature search revealed little information on the cool storage of sweet corn (maize) cobs. Therefore, the aim of this study is to design a cool storage structure from sweet maize cobs in Delta State region of Nigeria.

2.0 Design Methodology

2.1 Coolroom plan

The cool room was designed to accommodate 25 tons of fresh sweet corn cobs, and was equipped with adequate ventilation and lighting systems. The internal dimensions of the cool room were: 27 m × 14.5 m × 4 m was (Figure 1).

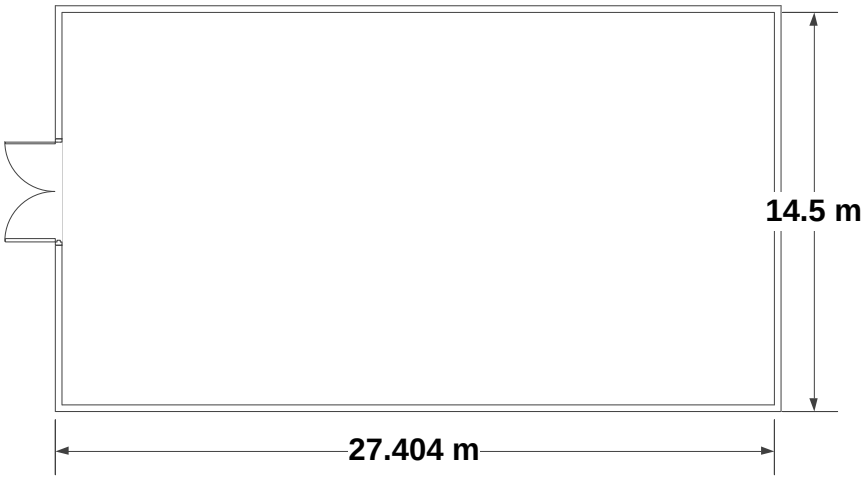


Figure 1: Floor plan of the cool room

Internal dimensions of the cool room
Length = 27 m
Breadth = 14.5 m
Height = 4.0 m
Total internal volume = 27 m x 14.5 m x 4.0 m.
= 1566 m^3

The construction of the cool room walls will involve the use of 6-inch solid sandcrete blocks. Following that, the beams, columns, and foundation will be strengthened using 12 mm and 8 mm mild steel rods. River bed sand and 20 mm crushed granite were utilized as the fine and coarse aggregates, respectively, for the concrete production. Pests' resistance light-weight wood was used for the roofing and shelves construction; while air conditioning units will be used for temperature control and ventilation within the cool room.

2.2 Design for the cool room structure
To design a cool room efficiently, it is essential to have an understanding of various factors. These include the heat of respiration of agricultural products, the heat conduction characteristics of the storage structure (including walls, floor, and roofing), and the heat generated by both human activity and materials present within the structure.

Some parameters needed for the designing of the 25 tons cool room for fresh corn storage are:

i. Ideal storage temperature of fresh corn: 5°C
ii. Ideal relative humidity (RH) of fresh corn during cool storage: 90% RH
iii. Mass of fresh corn to be stored: 25 tons
iv. Ambient outside environmental conditions: 35°C and 70% RH
v. Heat of respiration: 4307 Kcal/ton/24h
vi. Specific heat (5% M.C): 0.2388 Kcal/Kg°C (Fasina and Fleming, 2001).

Assumed parameters of the sweet corn cob
i. Mass of each sweet corn cob 0.25 kg
ii. Mean volume of each corn cob 0.00047 m^3

2.2.2 Design of the cool room capacity

Total number of sweet corn cobs to be stored in the cool room was calculated through Equation 1.

$$number\ fruits = \frac{total\ capacity\ of\ the\ ware\ house}{mass\ of\ one\ sweet\ corn\ cob} \quad 1$$

$$= \frac{25{,}000}{0.250}$$

= 100,000 sweet corn cobs

The total volume occupied by these 100,000 cobs is calculated by using Equation 2.

$$\sum Volume = volume\ per\ cob \times number\ of\ cobs \quad 2$$

Σ volume = 0.00047 m^3 x 100000 **= 47 m^3**

Total number of cartons required for packaging the 100,000 maize cobs is expressed in Equation 3.

$$\text{Number of cartons} = \frac{total\ number\ of\ maize\ cob}{number\ per\ carton} \quad 3$$

$$= \frac{100000}{1000}$$

= 1,000 paper cartons

2.2.3 Design of containers used for the corn cobs storage

The sweet corn cob will be packaged (stored) in paper carton boxes, which will be placed in wooden shelves inside the cool room. Each carton box will have the following dimensions = length (0.6 m) by width (0.5 m) by height (0.4 m).
Therefore volume of each box = 0.5 m x 0.5 m x 0.4 m = **0.1 m^3**.

Consequently, the total volume occupied by the 1000 carton boxes = 0.1 x 1000
= 100 m^3

Engineering properties of the paper carton

Mass of each paper carton = 2 kg
Specific heat of paper carton = 0.33 Kcal/Kg°C (Engineering ToolBox, 2003)
Net mass of each carton box = mass of each carton box + mass of the content (40 100 cobs)
= 2 kg + 25 kg **= 37 kg**

2.2.4 External dimensions of the cool room

The wall of the cool room will be constructed with the following materials:
Six inches (0.152 m) sandcrete blocks,
Concrete floor having thickness of 0.152 m,
Rendering made from cement mortar and thickness of 0.05 m, and
Insolating ceiling material with thickness of 0.01 m.

Therefore:
External length of the cool room = 27 m + 0.304 m (two walls at 0.152 m each) + 0.1 m (2 faces rendering) = **27.404 m**
External breadth of the cool room = 14.5 m + 0.304 m (walls) + 0.1 m (2 faces rendering) = **14.904 m**
Height = 4 m (to the roofing level) + 0.152 m of floor thickness + 0.152 m concrete decking + 0.01m ceiling + 0.05 m (1 face rendering) = **4.364 m**

Total external volume = 27.404 x 14.904 x 4.364**= 1782.385 m^3**

Total volume of materials (concrete, mortar and sandcrete blocks) used for the cool room construction

Total volume of materials used for the building walls and floor construction is calculated through Equation 4.

$T_M = \sum E_m - \sum E_i$ 4

Where ΣE_m = total external volume, ΣE_i = total internal volume, T_M = total materials used

Total volume of materials used = 1782.385 m^3 – 1566 m^3

= 216.385 m^3.

2.2.5 Arrangement of the cartons inside the cool room

The cartons will be arranged on shelves within the cool room, as illustrated in Figure 2, to facilitate convenient access and ensure proper ventilation for the cooling space.

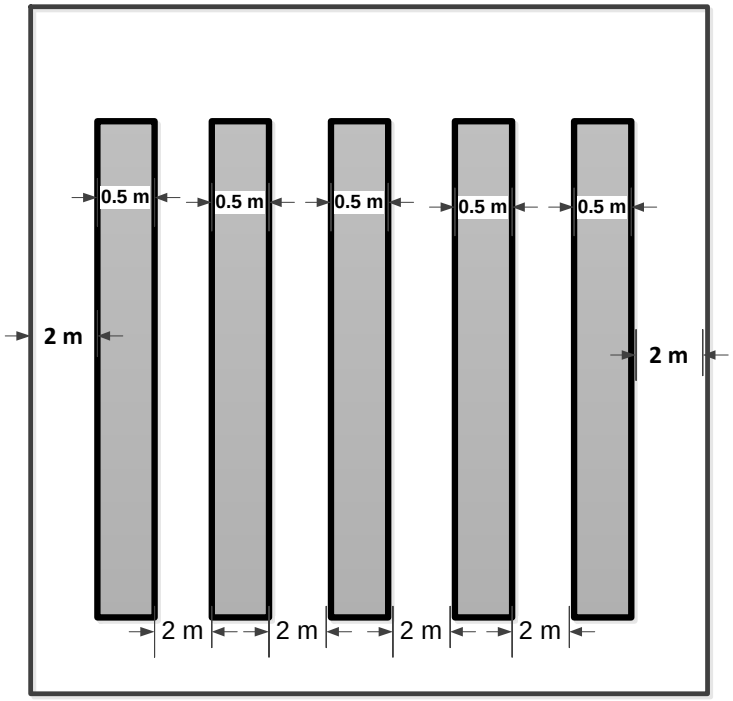


Figure 2: Arrangement of the wooden shelves

2.2.6 Free space (volume) inside the cool room

Total free space inside the cool room = total internal volume – (cartons volume + wooden shelves volume).

Volume of the wooden shelves used in storing the cucumber fruits = **45.211 m^3**.

Therefore free volume = 1566 m^3 – (100 m^3 + 45.211m^3)

= **1420.79 m^3**.

2.3 Calculating Cooling Loads

2.3.1 Heat transfer through the wall materials

Some essential parameters required to calculate the heat transfer through the walls:

i. Thermal conductivity of the sandcrete block = 0.7 kcal/m/h^{o}C

ii. A thermal conductivity of cement mortar = 1.122 kcal/m/h^{o}C (Bamogo *et al*., 2023).

iii. R-values used here are R1.5, R2.5 and R2.5 for the walls, ceilings, and floors respectively as stated by Aldawi and Alam (2016). From relevant documents the outside (ambient) temperature (To) of the region is 35^{o}C, and ideal storage temperature of sweet corn cob is 5^{o}C.

Total internal surface area of the cool room is calculated through Equation 5.
Total surface area = effective length + effective breadth 5
Effective length = (2 x 27) x height of the building
= 54 x 4
= 216 m^2
Effective breath = (2 x 14.5) x height of the building
= 19 m x 4 m
= 116 m^2

Therefore internal total surface area of the cool room = 216 m^2+ 116 m^2
= 332 m^3

Overall heat transfer coefficient of the wall component of the cool room was calculated through equation 6.

$$U = \frac{T_1}{TC_1} + \frac{T_2}{TC_2} \quad 6$$

Where:
T_1 is the thickness of the wall, T_{C1} is the thermal conductivity of the sandcrete block, T_2 is the thickness of the rendering, and T_{C2} is the thermal conductivity of the cement mortar used for the rendering.

$$U = \frac{0.152}{0.7} + \frac{0.05}{1.122} + \frac{0.05}{1.122}$$

U = 0.217 + 0.045 + 0.045
= 0.307 kcal/m^2/h^{o}C

Likewise the total heat transfer through walling and rendering materials was calculated through Equation 7.

$$Q = U \times A \times \Delta T \times t \quad 7$$

Where "t" is the time = 2h hrs.
Q = 0.307 x 332 x 30 x 24
Q = **73385.28 Kcal/24h**
But R value adopted was 1.5
Therefore effective Q value = $\frac{73385.28}{1.5}$
= 48932.52Kcal/24h

2.3.2 Heat transfer through the floor

The heat transfer (Q) through the floor of the cool room was calculated through Equation 8.

$$Q = \frac{A \times \Delta T \times t}{R} \quad 8$$

Where A is the area of the floor = 27 x 14.5 = **391.5 m^2**
R value adopted = 2.5
t = time (24 hrs.)
ΔT = change in temperature
Q = $\frac{391.5 \times 30 \times 24}{2.5}$

= 112752 kcal/24h

2.3.3 Heat transfer through the concrete decking (roofing) and ceiling

Equation 9 was used to design for the overall heat transfer coefficient of the decking (roofing) and rendering components.

$$U = \frac{T_1}{TC_1} + \frac{T_2}{TC_2} \quad (9)$$

Where:

T_1 is the concrete thickness = 0.152 m,

TC_1 is the concrete thermal conductivity = 1.49 kcal/m/h^{o}C,

T_2 is the thickness of the rendering = 0.05 m,

TC_2 = thermal conductivity of the cement mortar used for the rendering (1.122 kcal/m/h^{o}C),

$U = \frac{0.152}{1.49} + \frac{0.05}{1.122}$

U = 0.102 + 0.045

= 0.147 kcal/m^2/h^{o}C

The heat transfer through the roofing materials (concrete and rendering materials) is calculated through Equation 10.

$$Q = U \times A \times \Delta T \times t \quad (10)$$

Where "t" is the time = 2h hrs.

Q = 0.147 x 391.5 x 30 x 24

Q = 41436.36Kcal/24h

Heat transfer (Q) through the ceiling (insulating) material was calculated through Equation 11, using an R value of 2.5.

$$Q = \frac{A \times \Delta T \times t}{R} \quad (11)$$

Where A is the area of the roof = 27 x 14.5 = **391.5 m^2**

$Q = \frac{391.5 \times 30 \times 24}{2.5}$

Q = 112752 Kcal/24 h

Total heats transfer through the roofing and insulation materials = 41436.36 + 112752

Q = 154188.36 Kcal/24h

Summation of the total heat load through the wall, floor, roofing and insulation materials

= 48932.52 + 112752 + 154188.36

= 315872.88 **Kcal/24h**

2.3.4 Products load

(a) Corn cobs

The product cooling is calculated through Equation 12.

$$\text{Product cooling} = W \times sp \times \Delta T \quad (12)$$

Where: W = sweet corn cob mass, sp = sweet corn specific heat, and Δt = temperature difference

Product cooling = 25000 x 0.2388 x 30

= 179100 kcal/24h

(b) Paper carton box

Equation 13 was used to calculate the paper carton boxes heat load

$$\text{Paper carton box heat load} = W_B \times sp \times \Delta t \quad (13)$$

Where W_B = mass of the box, and sp = specific heat of boxes
Paper carton box heat load = (1000 x 2) x 0.33 x 30
= 19,800 kcal/24h

Total products load = load of the corn cobs + load of the paper carton box.
Therefore the total products load = 179100 + 19800
= **198,900 kcal/24h**

2.3.5 Respiration load during cool storage

The respiration heat load of the corn cobs is calculated through Equation 14.

$$R_H = W \times h_r \quad (14)$$

Where R_H = respiration heat load, W = weight of the sweet corn cob, and h_r is the heat of respiration.
R_H = 25 x 4307
= **107675 kcal/24h**

2.3.6 Internal heat load

Lighting load

The cool room will be lighting with eight (8) 0.2 KW energy saving bulbs. The bulbs will be on for an average of 8 hours per day. The heat load was calculated by using Equation 15.

Q = p x t (15.)

Where p is the collect powering rating of the bulbs, and t is the effective time of operation.
Q = (0.2 x 8) x 8
= 12.8 kWh/24h

But 1 KWh/24h = 860 Kcal/24h
Therefore 12.8 kWh/24h = **11008 kcal/24h**

Human load

It was assumed that 5 people be working inside the cool room at a rate of 6 hours per day. The human load was calculated with the modified formula shown in Equation 16, as described by Evans (2017).

$$Q = n \times t \times h \quad (16)$$

Where:
n = number of human workers (5),
t = time (6)
h = heat loss per worker (0.5 kW)

Q = 5 x 6 x 0.5
= 15 kWh/24h
= 12900kcal/24h

Air infiltration load

The air infiltration load was calculated through the modified formula shown in Equation 17 (Evans (2017).

$$Q = N \times v \times e \times \Delta T \quad (17)$$

Where:
N = air changes that occurred inside the storage room due to opening of the cool room doors in a day (8),

v = free volume of the cool room (759.989 m^3),
e = energy per m3 off the incoming fresh air (0.478 kCal/24h), and
ΔT = outside temperature – inside temperature (20^oC)

Q = 8 x 759.989 x 0.478 x 20
= 58096.94kcal/24h

Summation of internal heat load
The total internal heat load was calculated through the summation of lighting load, human load and air infiltration load.

Effective internal heat load (IHL) = 11008.00 + 12900.00 + 58096.94
= 82004.94 **kcal/24h**

2.3.7 Total heat load

Total heat load of the cool room is calculated through equation 18.

$$THL = H_s + P_C + R_H + IHL \quad (18)$$

Where:
R_H = 107675 kcal/24h
Pc = 198,900 kcal/24h
IHL = 82004.94 kcal/24h
H_s = 315872.88 kcal/24h

THL = 107675 + 198,900 + 82004.94 + 315872.88
= 704452.82 **kcal/24h**

2.2.8 Design for miscellaneous load

This is loading that occur through human and mechanical activities within the cool room during loading, unloading, products inspection, and others basic operations. To design for the miscellaneous load, 20% of the THL was taken as the miscellaneous load.

Therefore effective heat load = $704452.82 + \left(\frac{20}{100} \times 704452.82\right)$
= 704452.82 + 140890.56
= 845343.38 **kcal/24 h**

2.3.9 Factor of safety

To design for the factor of safety, 5% of the effective heat load was adopted as factor of safety.

Therefore the net heat load = $845343.38 + \left(\frac{5}{100} \times 845343.38\right)$
= 845343.38 + 42267.17
= 887610.55 kcal/24h

2.4 Refrigeration load calculation

Basic assumption:
The cool room will be powered on 14 hours daily (6 am – 8 pm)
Therefore the refrigeration capacity requirement = $\frac{net\ heat\ load}{time\ of\ operation}$

$= \frac{887610.55}{14}$

Refrigeration capacity **= 63400.75kcal/h**

2.4.1 Design for the refrigeration load

To design for the refrigeration load, we need to convert the kcal values to kJ/h.
From the conversion table 1 kcal/h = 4.1868 kJ/h
Therefore 63400.75kcal/h = 265396 kJ/h

Similarly, the conversion table revealed that one (1) ton of refrigeration = 12660 kJ/h
Therefore 265396 kJ/h = $\frac{1265396}{12660}$
= 20.96 tons of refrigeration

Based on this information, the refrigeration unit capacity can be calculated.
One (1) ton of refrigeration is equivalent to 3.52 kW of cooling.
Therefore, 20.96 tons of refrigeration will require 73.78 kW air conditioning capacity machines.

Remarkably, the cool room will required **12 units of air** conditioning machine each having capacity of 2 tons (7.04 kW) of refrigeration.

3.0 Cost Estimation of cool room construction

The bill of quantity of materials used for cool room construction is presented in Table 1.

Table 1: Bill of quantity of materials

Item	**Size**	**Quantity**	**Unit price**	**Total cost (₦)**
Sandcrete block	6-inch	3248	500	1624000
Cement		420	5,500	2310000
Iron rods	12 mm	63	12,000	756000
Iron rods	8 mm	30	8,000	240000
Fine aggregates	Tripper loads	12	25,000	300000
Coarse aggregates	Tripper loads	4	120,000	480000
Ply board		30	12,000	360000
Nails	4”	10 kg	950	9500
Nails	3”	15 kg	950	14250
Cupper nail	1’’	5 kg	1,000	5000
Hinges	3”	6	1200	7200
Wooden door	2.4 m x 1.2 m	2	25,000	50000
Air condition unit	2 tons	12	450,000	5400000
Electric wire	2.5 mm	3 bundle	6,000	18000
Electric wire	1.5 mm	2 bundle	4,500	9000
Energy saving bulbs	200 W	8	2,000	16000
Paint		6 buckets	4,000	24000
Keys		2	3,000	6000
Labour				1,500,000
TOTAL				**13,128,950**

4.0 Conclusion

This study looked into the design of a cool room of 25 ton sweet corn cobs capacity. It was noted from the calculations that the cool room can contain 100,000 sweet corn cobs, and 12 units of 2 tons capacity air conditioners will be used to adequately keep the maize cobs at a temperature of 5^0C.

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