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Cost Effective and Low Energy Cold Storage

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Abstract - - in this paper a design of cost effective and low energy hybrid cold storage which is capable to store post-harvest products of the small farmers on a personal basis. The energy required by hybrid cold storage is supplied by electric supply of local utility and photovoltaic power plant and battery system. Apart from design paper includes analysis of compound insulation system how the use of compound insulation system improves the efficiency of cold storage. Its simple constructions make it different from the conventional cold storages. Also comparison analysis is also done between proposed hybrid cold storage and conventional cold storage in terms of capital and running cost of the system and use of energy. The result shows proposed hybrid cold storage consumes low energy and also its cost effective; running cost is reduced as it consist photovoltaic panel in system : also that makes it suitable for rural area site where electricity isn't available for full time a day. Where compound insulation system also improves its efficiency of running cost

Key Words: hybrid system, cold storage, var and vcr cycle, cold chamber, insulation

1. INTRODUCTION

• Cold storage plays vital role in reducing post-harvest losses; it is an integral component of postharvest management of many fruits, vegetables and processed product cold storage plays vital role in reducing post-harvest losses of edible commodities by enhancing their storability and shelf-life. Timely storage of highly perishable and perishable commodities helps in their regular and continuous supply either for storage or processing purposes.
• As per the report by ASSOCHAM, it is claimed that Indian cold chain industry; which stood at 54 billion in 2019; Will register a compound annual growth rate of 30%
• India is the second largest contributes 11% of global fruits and vegetable production; but situation with to postharvest management of fruits and vegetables has remained extremely discouraging in India. This trend is continuing in spite of the fact that horticultural commodities generate maximum employment and provide qualities and balanced nutrition. As per an estimated by CEPHET, post-harvest losses in India are estimated at 133 billion rupees per year. almost 40% of less cold storage capacity India have ; major reasons behind loss of post-harvest product is unavailability of proper cold-chain in India.
• Enzymes in the vegetables and fruits lens then to increase in the activity of micro-organisms that leads to product deteriation will take place at lower temperature in all food products[1]. the number of cold storages in India is so how to save huge post-harvest product losses ;hybrid cold storage contains lower energy and coming up with lower and affordable prize which improves the efficiency of conventional cold storage; cold storage capacity and cold chain; we can reduce the past harvest losses. Here is detailed hybrid cold storage which is cost effective and consumes lower energy. There are several systems studied on the cold storage [3]-[13] Reflecting the studies in different scenarios.

1.1 Mathematical Model of Cold Storage

• To reduce post-harvest losses and save the harvested products from perishing it is important to store it in cold storage. At particular low temperature and humidity the products kept in store in order to prevent it from degradation and perishing.

• Heat transfer from a hot region to the cold region; where equation of heat transfer from storage capacity will be given as;

$$\Delta Q = C\,\Delta T$$

Where, c is the heat capacity, ΔT is the temperature difference between two objects.

Calculations Regarding the Cooling and Heat Transfer inside the Cold Storage.

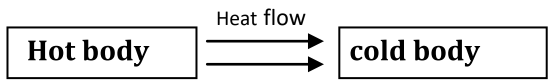
Thermal Conductivity (K) :-

The rate at which heat passes through a specified material expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance[2].

$$K = Q.\,\Delta X / A\,((\Delta T) \quad W/m.°C$$

Where Q is the heat transfer coefficient,

ΔX thickness of heat passes, and a is the area of the object.



Thermal Conductance(C):-

It is the measure of the ability of a material to transfer heat per unit time, given one-unit area of the material and a temperature gradient through the thickness of the material.
C can be calculated by dividing K on the material thickness D; so

C= K/D W/m °

Thermal Resistance (R) :-

It is the opposite of thermal conductance.

Overall Heat Transfer Coefficient or "Thermal Transmittance" (U):-

Thermal transmittance, also known as U-value, is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure.

The units of measurement are W/m^{2}K. The better-insulated a structure is, the lower the U-value will be. Workmanship and installation standards can strongly affect the thermal transmittance. If insulation is fitted poorly, with gaps and cold bridges, then the thermal transmittance can be considerably higher than desired. Thermal transmittance takes heat loss due to conduction, convection and radiation into account[14].

U = Q/ΔT W/m^2. °C

Air to air thermal resistance (Ra) :-

It's the summation of thermal resistances "from air to air" and it's the opposite of overall heat transfer coefficient (U)[14].

R = 1/U m^2.°C /W

Inside and Outside Air Film Thermal Resistances (Rsi & Rso) :

Air being a good insulator forms a layer inside and outside of the walls[14][-[26].

Rsi = 1/hi and **Rso = 1/ho** **m^2. °C/ W**

Analysis of refrigeration required :-

The refrigeration required for the product stored inside the facility, is given by below equation[15].

Tref = Hrem/ 3.5

Where, **Tref is the total refrigeration required to safe the products remained**
H is the total heat to be removed that has been calculated from the earlier analysis.

$$R = \frac{1}{c}\ m^2.°C/W$$

Co-Efficient Of Performance (C.O.P) :-

COP of VCR S :-

(heat transfer rate in evaporator)/(power input rate to the compressor)
= (refrigeration effect)/(compressor work)
= (h2-h1)/(h3-h2)

COP of VAR system :-

(heat removed by evaporator)/(heat supply to the generator) = Qe/Qg

2. Hybrid Cold Storage Design with Compound Insulation System

1. Hybrid Cold Storage System:-

• Hybrid cold storage system can be designed inside the ground or it also constructed same as conventional cold storage building style.
• The complete cold storage system is founded with bricks; concrete and rcc.
• The layout of the system; components and materials used as follows
• There are the temperatures sensors were placed over there; which keep the temperature range as required and the product post-harvest keeps well. The humidifiers are also installed in it to control humidity.
• Evaporator and chilling plates are applied for the cooling and to regulate the temperature in desired range of cooling inside the storage area. With the help of proper regulation of temperature and humidity; the post-harvest product will survive the longer duration.

2. Compound Insulation System:-

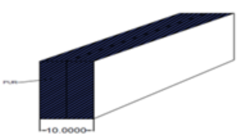
• Insulation is the very important part of the cold storage; the whole system isn't going to give desired or required output.
• Insulation of the wall and pipe and the connecting wires are to be taken under consideration.
• If we use insulation in the spray form it will be efficient for particular time duration , but compound insulation system which is costlier but will be more beneficial for longer duration which also improve the energy saving

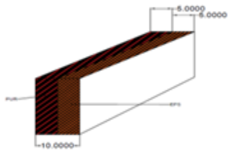
• We are using compound insulation wall in hybrid cold storage system which is totally new for hybrid cold storage system and its became a more helpful for maintaining the cooling effect for as long as possible.
• We are using two different materials for making compound wall which is
1. Glass wool
2. Expanded polystyrene (eps)

Cost and Properties of the Insulations that We Are Using

Sr no	Type of material	Conductivity(k)	Price per m2 (in $)
1.	Glass wool	0.04	3.35
2.	EPS	0.029	85.00

Comparison between Compound and Simple Insulation System:-

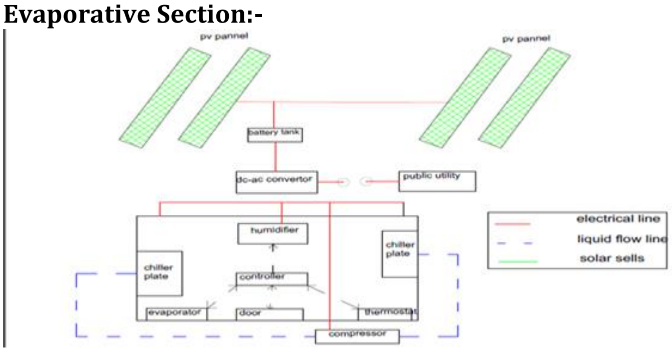




K(PVR) = 0.024 w/m °c
Cost = 280 \$/m2
{unit area = 1 meter}
Thermal resistance R= L/KA
R= 10/0.024
= 0.4166 °c/w

K(PUV) > 0.04 , m2 K(EPS) > 0.029
PUV = 280\$/m^2 EPS = 85 \$/m^2
K (PUR) + K (EPS), {Take R = 0.4166 °c/w}
R= x/0.01406 = 0.4166 * 0.1406
R = 5.85 mm

Evaporative Section:-



• Evaporator is placed on the top of the side walls along with liquid cooled plates below the side walls.
• This allows to take away immediate heat away from it which is contains due to surrounding.
• Heat transfer or due to latent heat inside the product that are kept in the storage room humidifier is also mounted to maintain humidity inside the storage area. It plays vital role to maintain product fresh.
• With the water droplets on the product that are stacked inside cold Storage ; they come in contact with the cold air circulated inside the storage ; and with that heat is taken away from the droplets which gets conveyed in them due to process of vegetables.
• This process lead to a long shelf life. The compressor is mounted at the bottom helping the coolant circulate in the evaporator and chilling plates.

Electrical System and Sources Size Estimator:-

• The photovoltaic (PV) power plant is mounted on the roof top of the cold storage as shown left sight figure.
• This storage is also connected with the public utility. During the daytime the PV system supply the electricity to the cold storage .The PV plant power generation is dependent on the weather condition therefore battery is also connected with the PV system.
• The battery bank provides the power balancing during the PV mode by load following and generation following property of the battery. In the PV mode the battery increase the charging to store the surplus PV Power during peak time and while Battery start discharging when the PV generation is not sufficient to fulfill the electricity demand of the cold storage.

The power equation for this mode can be expressed as :-

Pd = Ppv (t) ± Pbb (t)

Where; **Pd (t)** = electricity power demand of the cold storage at the time instant "t"
Pbb (t) = battery power at the time instant "t"
Ppv (t) = power generation of PV plant at time instant "t"

• During the non-sunny hours the SPDT switch connect the cold storage with the public utility and the PV plant and battery bank remains in the isolated mode.
• The required size of the PV plant and battery bank to supply the electricity demand of the cold storage during sunny hours cab be calculated as below.

PV size: the PV plant size depends on the watt hour need per day and average sunny hours per day in the year and can be calculated as[18]-[19];

$$\text{PV plant size} = \frac{\textit{PV watt hours need per day}}{\textit{average sun hours per day in year}}$$

Where PV watt-hours needed per day is the sum of energy demand (Wd) and energy losses in the system and average sun hours per day in year are considered to be 7 hours[20].

The power loss (Wloss) may depend on the following parameters:

1. Energy loss in convertors (i.e. source and load)
2. Energy loss in lines (i.e. cables)
3. Energy loss in the storage unit (i.e. battery)

The PV watt-hours needed per day can be calculated as:

Wpv = Wd + Wloss

• Battery Capacity:-

The battery is responsible for the power balance during sunny hours. Therefore the battery size is the function of peak power exchange and maximum energy exchange with the battery in micro grid system to provide the uninterrupted power system and keep the system stable. The battery nominal capacity depends to balance the maximum power (PBmax) exchange of the battery and can be calculated as[21]-[22];

Battery nominal capacity (µn) = **(pbmax .Cn)/Vn**

Where Vn is the system voltage; Cn is the type of battery

• The number of batteries required in each system can be calculated by dividing the maximum power exchange Between the system and battery bank; with the rated power of one battery.

Basic design calculations:-

• For particular compressor model; a voltage regulator is designed to automatically maintain a constant voltage level.

COP cooling = desired output or cooling capacity(W)/(input power)

Input power (W) = (desired output)/(cop cooling)

• Now let we take desired output required (required output) as 180W and COP for system recommended by the supplier should be 1.2

Input power = 180W/1.2 = 150W

• Total input power required = motor power(W) + cold storage input power (W)
= 850 + 150 = 1000 W

• Let we assume that 1000W input power we used for 12 working hour per day ; then

Work × working hour in a day = work hour per day

1000 × 12 = 12 KW.hr/day

• Let 1 unit cost in Ahmedabad = RS 5.00

One day cost = RS 60.00

One month cost = RS 1800.00

• Minimum hour for sunlight per day = 7 hr./day

Total capacity = (work per day)/(min.hour of sunlight per day)

Total load capacity = (12000 Whr/day)/(2 hr/day)

= 2000 W

We need photo voltaic solar system with capacity 2000 W.

• The available size of panel with the standard 500 W output.

• Number of panels = (total required capacity)/(capacity of single panel)

= (2000 W)/500W = 4 PANELS

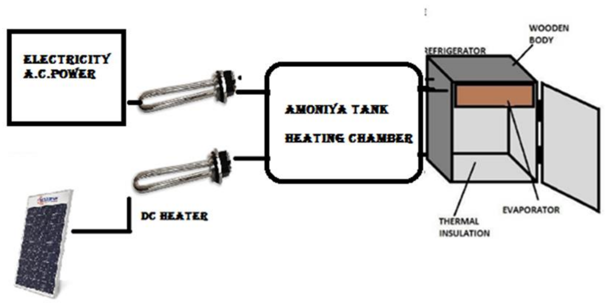
We required 4 PV panels for required cooling effect.

(Above calculations are done by taking assumption of required output)

3. Hybrid Cold Storage Working On VARS System:-

• For smaller capacity of cold storage; vapor absorption refrigeration system provides better efficiency as it doesn't requires high grade mechanical energy; it gives comparatively smoother operations then VCRS.

There will be lesser dangerous for VARS system in evaporator to have liquid traces as it gives more simple operations; beneficial for smaller capacity cold storage to have VARS system.



• Absorption Cycle System :-

The function of the compressor in the vapor compression refrigeration system is to continuously withdraw the refrigerant vapor from the evaporator and to raise its pressure and hence temperature; so that the heat absorbed in the evaporator, along with the work of compression, may be rejected in the condenser to the surrounding.

In the vapor absorption system the function of the compressor is accomplished in 3 step processes by use of **absorber, pump & generator.**

1. Absorber

• It is used for absorption of the refrigerant vapor by its weak or poor solution in a suitable absorbent forming a strong or rich solution of the refrigerant in the absorbent.

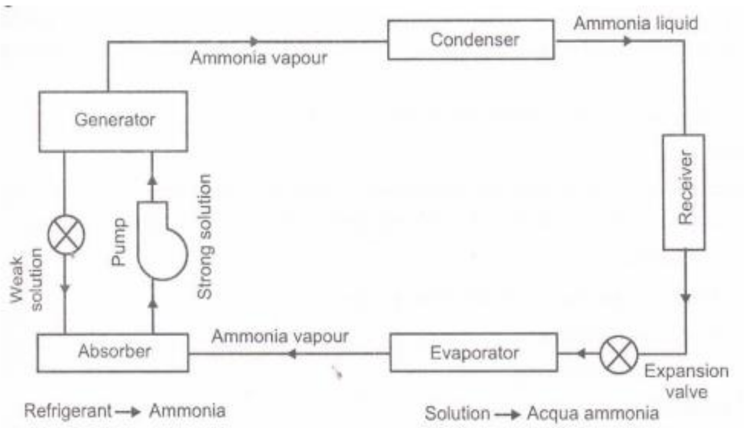
2. Pump

• It is used for pumping of the rich solution raising its pressure to the condenser pressure.

3. Generator

• It is used for distillation of the vapor from the rich solution leaving the poor solution for recycling.

• For hybrid cold storage the required in generator coil will be provided by dc heater ; which will be worked with both photovoltaic panel generated solar energy and grid power.



Result and Discussion:-

• During the design of hybrid cold storage; our main aim to make it cost effective and energy efficient as both of them are equally important to increase the number of cold storages in India to improve the cold chain.

• The main components that consumes most of the cost in cold storage are evaporator; PV solar power panel with batteries and cold plates.

• For agricultural purpose proposed hybrid cold storage will be most efficient as it is cost effective and also energy efficient.

• This will reduce the wastage of time of farmers who visits the cold storage which is located far from agriculture farm.

• The cost reduced almost 65% of conventional cold storage cost.

• More ever it is compact in size so it can be installed in multiple locations which make it easy to access as compared to conventional one.

Comparison of Capital Cost Between Hybrid And Conventional Cold Storages:-

PERIPHERALS	CONVENTIONAL COLD STORAGES	COST OF CONVENTIONAL COLD STORAGE (IN INR)	HYBRID COLD STORAGE	COST OF HYBRID COLD STORAGE(IN INR)
Storage area dimensions	10*10*10(meter)	120000/-	5*5*5(meter)	60500/-
Storage area temperature	4°C(±2°C)		5°C(±3°C)	
Humidity	85% RH		85-86 % RH	
Products to store	Vegetables , fruits		Vegetables , fruits	
Storage area	8.5 mega ton		3.00 mega ton	
Floor	Rcc or brick layer		Rcc or brick layer with insulation	
Door	35 inch * 80 inch	20000	35 inch * 80 inch	20000
Refrigerant	R-22 or r-404a	380/kg	R404a	380/kg
Compressor	830 watt	7500	360 watt	5000
Humidifier	600 watt	18000	300 watt	8000
Batteries	-		No.6,150 ah, 12 V	60000
PV panels	-		1.5 KWP	80000
Invertor	-		2 KWA	8000
Refrigerant & power supply	8 KW	400000	650 W	20000
Evaporator	-	-	100 W	6000
Insulation	60 mm puf layer sheet	125000	Compound insulation system with 30 mm glass wool + 30 mm EPS	132500
Cost of other machinery	Extra pump and etc.	520000	Pumps and etc.	50000
Total cost(INR)		1210000/-		409000/-

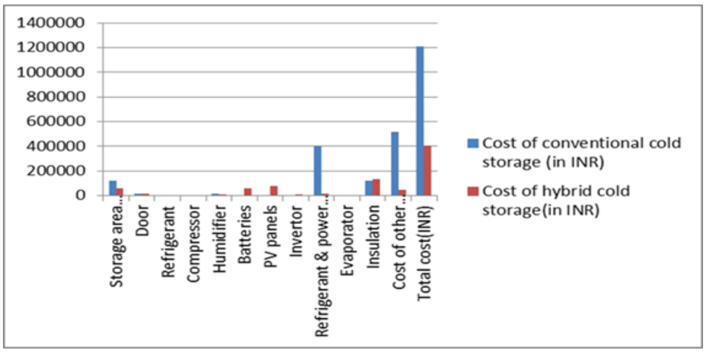
• Hybrid cold storage which consist of PV power plant and battery bank. Which also connected with public utility.

• If we consider a storage capacity 2.5 mega ton is approximately 15.5 KWH.

• While average peak of demand is approximately 0.65 KW; considering efficiency of battery bank and convertors are 90 %(assumed). Therefore 0.8 KWP (kilo watt peak) output PV plant need to install top supply the cold storage.

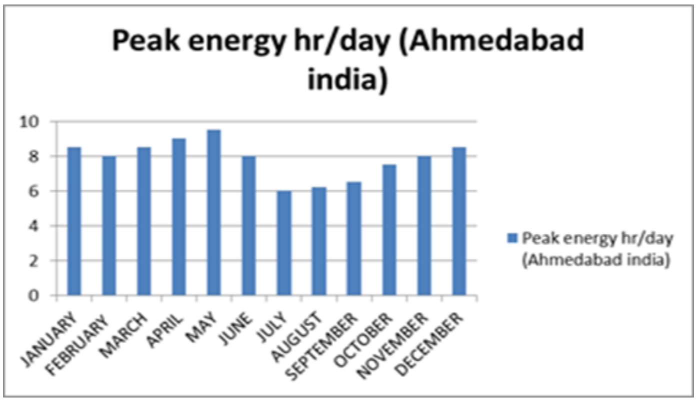
• Let us take a domestic price in India rupees 5 per KWH (unit)

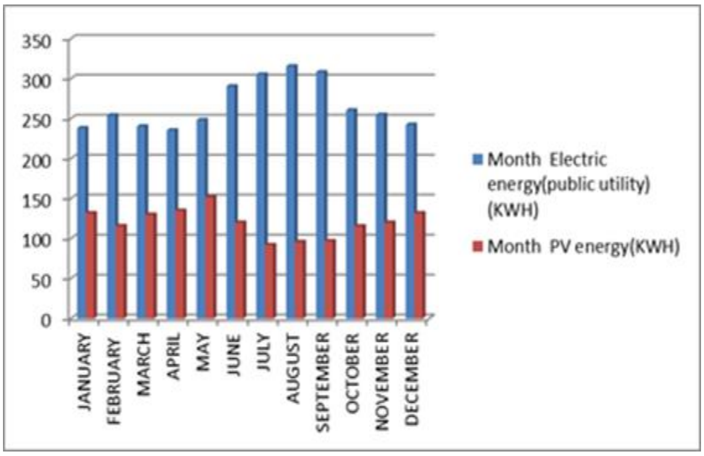
• The energy saving and electricity bill saving by installing 0.8 KWP PV plant can be found in table.

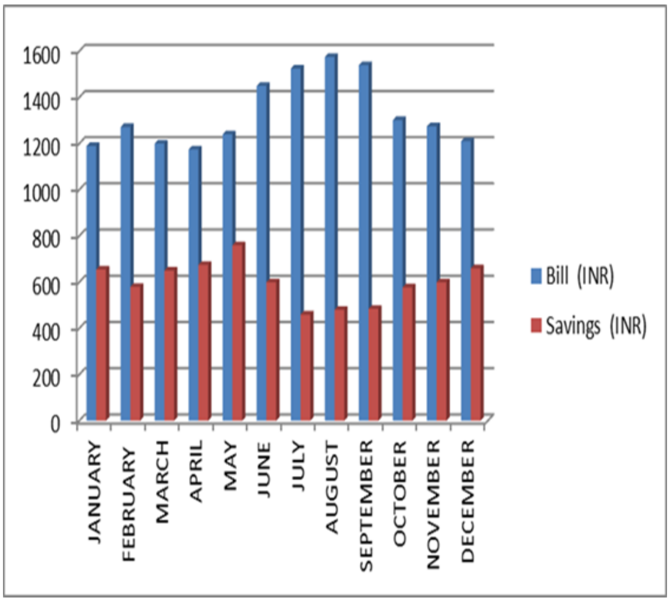


- **Energy Consumption And Cost Saving :-**

Month	Peak energy hr./day (Ahmedabad India)	PV energy(KWH)	Electric energy(public utility) (KWH)	Bill (INR)	Savings (INR)
JANUARY	8.5	131.75	238.25	1190	655
FEBRUARY	8	115.69	254.3	1272	580
MARCH	8.5	130	240.45	1200	650
APRIL	9	135	235.58	1175	675
MAY	9.5	152	248.6	1240	760
JUNE	8	120	290.58	1450	600
JULY	6	92	305.5	1525	460
AUGUST	6.2	96	315.65	1575	480
SEPTEMBER	6.5	97	308.25	1540	485
OCTOBER	7.5	115.5	260.5	1302	577.5
NOVEMBER	8	120	255	1275	600
DECEMBER	8.5	132	242.5	1210	660







3. CONCLUSIONS

• The proposed hybrid cold storage is simple in design easy to construct and needs small number of peripherals which makes it cost effective and energy efficient.

• The automatic controlling of the cooling system makes it more users friendly.

• The low capital and running cost of the cold storage may attract farmers to install it.

• The photovoltaic power plant is mounted on the rooftop which decreases the electricity bill, carbon emission and increases efficiency by covering its ruff from sunlight.

• It also operates with grid energy too, as well as isolated mode.

• The photovoltaic and battery system makes it suitable to the each site or area, which are not connected with the grid or have grid availability for the limited hours.

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