HEAT TRANSFER ANALYSIS OF COLD STORAGE

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ABSTRACT

India is largest producer of fruit and vegetable in world scenario but availability of fruit and vegetable per capita is significantly low because of post-harvest loses which is about 25% to 30% of production so the requirement of refrigeration and air conditioning has been increased. Building or group of buildings with thermal insulation and refrigeration system in which perishable food or products can be stored for various length of time to slow down deterioration with necessary temperature and humidity is called as cold storage. In cold storage refrigeration system brings down the temperature initially during start up but thermal insulation maintains the temperature later on continuously. In this view, the simple methodology is presented to calculate heat transfer by analytical method also attempt has been made to minimize the energy consumption by replacing 150 mm Expanded polystyrene (EPS) by 100 mm Poly Urethane foam (PUF) insulation. The methodology is validated against actual data obtained from Penguin cold storage situated in Pune, India.

KEYWORDS: *Cold storage, Steady state analysis, insulation, EPS, PUF*

I. COLD STORAGE DESCRIPTION

Cold storage has floor plan area of 400 m^2 and sidewall length of 14 m. The overall dimensions of cold storage are 17m x 14m x 12m. The cold storage building is of three floors with each floor having 4 cold chambers of 8m*5m sizes operating at different temperature as per the requirements of commodities. Ground and First floor called as Defrost zone where -20 ^{0}C temperatures is maintained while second floor is called as Cold storage where 0 ^{0}C is maintained. The height of zone wall is taken to be 4 m, leading to a total storage volume of 160 m^3. Entire cold storage building is considered for study of simulation where the actual product is stored (for either long or short term storage periods) and is referred to as the “Defrost Zone” or “Cold Storage Zone”. Defrost zone and Cold Storage zone having area of 8x5 m has with the height floor of 4m with area of 40 m^2 and a volume of 160 m^3.

The “Dock” is available immediate entrance of cold storage building which is a separate zone that serves as the staging area for incoming and outgoing products. The office of a cold storage and ante room for loading and unloading of the commodities is as shown in fig. 1.1. The condensing unit i.e. evaporative cooled condenser with two fans and a pump is located outside the zone in still atmosphere.

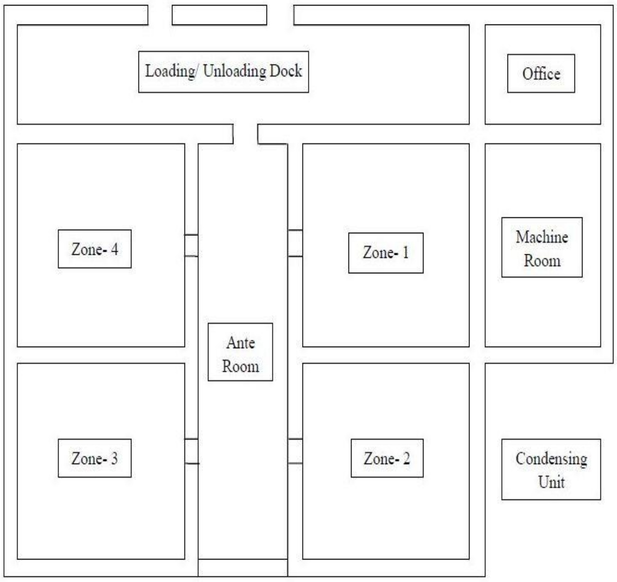

Fig 1.1 Cold storage floor plan

Under normal operating conditions, the Zone is at a lower temperature than the dock. The dock temperature is maintained around 10^0C, while different set-point temperatures have been investigated for the Zone depending on the optimum storage temperature for the various food products considered during the course of study.

An important concept to be understood in the operation of cold storage warehouses is the way the temperature of the products and the zone air is lowered. Since, the refrigeration equipment directly cools the air in the zone; it is the zone air temperature that reduces first. As the stored product has a higher thermal mass than the zone air, there is a time lag between when the air temperature is reduced and when the product temperature is reduced over time as heat is extracted. Alternatively, when the refrigeration equipment is shut-off, the air temperature shows a greater risk than the product temperature in the same time interval. Adequate precaution and care still has to be taken in the design of cold storage to make them energy efficient and to reduce the operational costs as much as possible.

1.1 Cold storage construction

In this simulation we assume that on an average, 60% of the cold storage floor area is covered with pallets of stored product. The walls of the cold storage zones are modeled as a layer of solid concrete block followed by three layers of EPS and a layer of Aluminum from outside to inside respectively. The insulation thickness is different for the zone and the dock. For the zone walls, three different values of insulation thicknesses were studied for the insulating material of EPS, resulting in different thermal resistance values (R values) for each wall. Then 150 mm EPS insulation is compared with 100 mm insulation of PUF. While Surface Area of wall is shown in Table 1.2

Table-1.1 Surface Area of wall

NAME	AREA(m^2)
Ceiling	40
Wall between DF and Surrounding	32
Wall between DF and Loading Unloading	20
Wall between DF and Dock	32
Wall between DF and DF	20
Floor	40

The wall of cold chamber as shown in fig.1.2 has a layer of solid concrete block on external side with 20 cm of thickness facing towards the external surroundings, and 15 cm of expanded polystyrene with 1 mm layer of aluminum foil facing into the conditioned space or the cooler.

Fig.1.2 Wall of cold chamber

The roof of the dock and the zone is assumed to have the same construction as the zone walls. The floor construction for the warehouse is common for both the dock and the zone space.

Table 1.2 Applied insulation thickness details

Application Area	Thickness of Insulation (mm)	U value (W/m^2K)	R value (m^2K/W)
Exposed walls	150	0.27	3.70
Intermediate walls and Inter-floors	50	0.58	1.72
Exposed roofs	150	0.24	4.17
Floors	150	0.29	3.45

The floor has two layers, from outside to inside: 200 mm of concrete, and 150 mm of EPS insulation, resulting in a floor with a total thickness of 350 mm , and a U-value of 0.686 W/m2-K. The commonly used insulating materials for cold storage walls, floors and roofs and their details are given in Table No. 1.3

1.2 Thermal insulation details

Table 1.4 Cold storage insulation characteristics [1]

Types of Insulation	Material	
	ρ Density(Kg/m^3)	K value (W/m^0C)
EPS	16	0.036
PUF	32	0.023
XPS	30-35	0.025
Phenolic foam	50	0.026
Mineral wool	48	0.033
Bonded fiber glass	32	0.033

II. HEAT TRANSFER CALCULATION

2.1 Average temperature calculation

Average Temperature is taken as 31^0C because on date 12 May 2014

Table 2.1 Average Temperature [2]

Time	Temp
23 to 5	27^0C
5 to 11	24^0C
11 to 17	37^0C
17 to 23	36^0C
Total	**124 ^{0}C**

So average temperature on dated 12 May 2014 is

Total Temp./ 4= $\frac{124}{4}$ = 31^{0}C

Cold storage capacity –1400 MT, Plant Size –17 m (L) x 14 m (W) x 12m (H),Average Outside Temperature –31 ^{0}C, Operating Temperature –-20 ^{0}C
In Defrost and 0 ^{0}C in Cold Storage
Heat transfer is calculated by using Fourier's law
Q=A (T1-T3) / (L1/k1)
Q=Heat transfer in Watt, A=Area (m2),(T1-T3)= Temperature difference (^{0}C or K),
L1=Thickness of insulation (m), K1=Thermal Conductivity (W/mk)

$$Q=\frac{A(T1-T3)}{\frac{l1}{k1}} = \frac{32(31-(-20))}{\frac{0.15}{1.14}} = 9302.4W$$

While similar calculations are carried out by using above formula [3]

2.2 When existing model with EPS Insulation

Table 2.2 Heat transfer through existing Model

FLOOR	SR.NO	ZONE	NAME	EPS 0.15m Q	EPS 0.05m Q
GROUND FLOOR	1	DF1	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING	375.855	
	3		WALL BETWEEN DF AND L.U	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	418.776	
	1	DF2	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING1	375.855	
	3		WALL BETWEEN DF AND SURROUNDING2	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	418.776	
	1	DF3	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING1	375.855	
	3		WALL BETWEEN DF AND SURROUNDING2	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	418.776	
	1	DF4	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING	375.855	
	3		WALL BETWEEN DF AND L.U	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	418.776	

FIRST FLOOR	1	DF5	CEILING	94.5078	
	2		WALL BETWEEN DF AND SURROUNDING	375.855	
	3		WALL BETWEEN DF AND L.U	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	0
	1	DF6	CEILING	94.5078	
	2		WALL BETWEEN DF AND SURROUNDING1	375.855	
	3		WALL BETWEEN DF AND SURROUNDING2	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	0
	1	DF7	CEILING	94.5078	
	2		WALL BETWEEN DF AND SURROUNDING1	375.855	
	3		WALL BETWEEN DF AND SURROUNDING2	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	0
	1	DF8	CEILING	94.5078	
	2		WALL BETWEEN DF AND SURROUNDING	375.855	
	3		WALL BETWEEN DF AND L.U	234.909	
	4		WALL BETWEEN DF AND DOCK		613.682
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	0

SECOND FLOOR	1	CS1	CEILING	288.49	
	2		WALL BETWEEN DF AND SURROUNDING	228.461	
	3		WALL BETWEEN DF AND L.U	142.788	
	4		WALL BETWEEN CS AND DOCK		204.561
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-94.5078	
	1	CS2	CEILING	288.49	
	2		WALL BETWEEN DF AND SURROUNDING1	228.461	
	3		WALL BETWEEN DF AND SURROUNDING2	142.788	
	4		WALL BETWEEN CS AND DOCK		204.561
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-94.5078	
	1	CS3	CEILING	288.49	
	2		WALL BETWEEN DF AND SURROUNDING1	228.461	
	3		WALL BETWEEN DF AND SURROUNDING2	142.788	
	4		WALL BETWEEN CS AND DOCK		204.561
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-94.5078	
	1	CS4	CEILING	288.49	
	2		WALL BETWEEN CS AND SURROUNDING	228.461	
	3		WALL BETWEEN CS AND L.U	142.788	
	4		WALL BETWEEN CS AND DOCK		204.561
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-94.5078	

	INSULATING MATERIAL	EPS	
TOTAL HEAT TRANSFER	Q TOTAL	9200.16	5727.7
	TOTAL	14927.9	

2.3 Recommended model

Table 2.3 Heat transfer through recommended Model

FLOOR	SR.NO	ZONE	NAME	PUF 0.1m Q	PUF 0.05m Q
GROUND FLOOR	1	DF1	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING	360.801	
	3		WALL BETWEEN DF AND L.U	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	401.839	
	1	DF2	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING1	360.801	
	3		WALL BETWEEN DF AND SURROUNDING2	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	401.839	
	1	DF3	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING1	360.801	
	3		WALL BETWEEN DF AND SURROUNDING2	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	401.839	
	1	DF4	CEILING	0	0
	2		WALL BETWEEN DF AND SURROUNDING	360.801	
	3		WALL BETWEEN DF AND L.U	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	401.839	
FIRST FLOOR	1	DF5	CEILING	90.6286	
	2		WALL BETWEEN DF AND SURROUNDING	360.801	
	3		WALL BETWEEN DF AND L.U	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	
	1	DF6	CEILING	90.6286	
	2		WALL BETWEEN DF AND SURROUNDING1	360.801	
	3		WALL BETWEEN DF AND SURROUNDING2	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	0
	1	DF7	CEILING	90.6286	
	2		WALL BETWEEN DF AND SURROUNDING1	360.801	
	3		WALL BETWEEN DF AND SURROUNDING2	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	
	1	DF8	CEILING	90.6286	
	2		WALL BETWEEN DF AND SURROUNDING	360.801	
	3		WALL BETWEEN DF AND L.U	225.501	
	4		WALL BETWEEN DF AND DOCK		408.623
	5		WALL BETWEEN 2 DF		0
	6		FLOOR	0	

SECOND FLOOR	1	CS1	CEILING	276.822	
	2		WALL BETWEEN DF AND SURROUNDING	219.311	
	3		WALL BETWEEN DF AND L.U	137.069	
	4		WALL BETWEEN CS AND DOCK		136.208
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-90.6286	
	1	CS2	CEILING	276.822	
	2		WALL BETWEEN DF AND SURROUNDING1	219.311	
	3		WALL BETWEEN DF AND SURROUNDING2	137.069	
	4		WALL BETWEEN CS AND DOCK		136.208
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-90.6286	
	1	CS3	CEILING	276.822	
	2		WALL BETWEEN DF AND SURROUNDING1	219.311	
	3		WALL BETWEEN DF AND SURROUNDING2	137.069	
	4		WALL BETWEEN CS AND DOCK		136.208
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-90.6286	
	1	CS4	CEILING	276.822	
	2		WALL BETWEEN CS AND SURROUNDING	219.311	
	3		WALL BETWEEN CS AND L.U	137.069	
	4		WALL BETWEEN CS AND DOCK		136.208
	5		WALL BETWEEN 2 CS		0
	6		FLOOR	-90.6286	

TOTAL HEAT TRANSFER	Q TOTAL	8830.58	3813.82
	TOTAL	12644.4	

INSULATING MATERIAL		EPS		PUF	
TOTAL HEAT TRANSFER	Q TOTAL	9200.16	5727.7	8830.58	3813.82
	TOTAL	14927.9		12644.4	
	DIFFRENCE BETWEEN Q EPS AND Q PUF	2283.464182			

Total amount of heat transfer from existing model when EPS insulation of 150mm Q_{EPS} = 14928 Watt
Total amount of heat transfer from Recommended model when PUF insulation is of 100 mm Q_{PUF}=12644 Watt
If we use PUF as Insulation then 14928-12644= 2283 Watt of heat transfer is restricted (i.e. 2.283 kW).
If plant runs for 24 hours, units saved will be 2.283 x 24 = 54.792 Units.
If cost of a unit of electricity is Rs 9.00, then saving per day =54.792 x 9 = Rs 493.128. Saving in month = 493.128 x 30 = Rs 14,794
Saving in a year = Rs 14,794 x 12 = Rs 1,77,526.08

Table 2.4 Cost for EPS and PUF

NAME	AREA IN SQ.M	EPS	COST	TOTAL	PUF	COST	TOTAL
CEILING	480	0.15	801	384480	0.1	1272	610560
WALL BETWEEN CS AND SURROUNDING	384	0.15	801	307584	0.1	1272	488448
WALL BETWEEN CS AND L.U	240	0.15	801	192240	0.1	1272	305280
WALL BETWEEN CS AND DOCK	384	0.05	267	102528	0.05	636	244224
WALL BETWEEN 2 ROOM	240	0.05	267	64080	0.05	636	152640
FLOOR	480	0.15	801	384480	0.1	1272	610560
TOTAL				1435392			2411712
COST DIFFRENCE BETWEEN EPS & PUF							976320

(Cost values are given in Ref.4)

Pay Back Period = 9, 76,320 / 1, 77,526.08 = 5.49 years

Thus to recover the additional cost invested for PUF insulation, the plant has to operate 5.49 years, without any extra profit but with the replacement of EPS by PUF insulation the cold storage plant can saves Rs 1,77,526.08.

III. CONCLUSION

In existing system of cold storage for external wall, insulation is 150 mm,for wall between two zone and zone and dock Insulation thickness is 50 mm while in between zone and loading and unloading thickness of insulation is 150 mm so the total amount of heat transfer is 14927.9W, but for 100 mm PUF 12644.4W of heat transfer which is 2283.46W lesser than EPS. So saving in RS is 1,77,526.08 and payback period is Extra Investment/Saving=9,76,320/1,77,526.08=5.49years.
Hence it is concluded that the PUF is best suitable insulation material for a Cold storage.

(Cost values are given in Ref.4)

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