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# Comparative Heat Conduction Model of a Cold Storage with Puf & Eps Insulation Using Taguchi Methodology

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**ABSTRACT**
In this project work a mathematical heat conduction model of a cold storage (with the help of computer program; and multiple regression analysis) has been proposed which can be used for further development of cold storages in the upcoming future. 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. Insulation thickness of the side walls (TW), area of the wall (AW), and insulation thickness of the roof (TR) have been chosen as predictor variables of the study.
**KEY WORDS:** Cold storage refrigeration plant, cold storage insulation, EPS, PUF.

## I. INTRODUCTION

A cold store is a building or a group of buildings with thermal insulation and a refrigerating system in which perishable food products can be stored for various lengths of times in set conditions of temperature and humidity. Such storage under controlled conditions slows the deterioration and spoilage that would naturally occur in an uncontrolled natural environment. In addition to providing control of temperature and humidity, cold stores can also be designed to deliver controlled atmospheres by maintaining the requisite concentration of various gases that aid in the preservation of food products. Thus, cold storage warehouses play an important role in the storage of food products in the food delivery chain throughout the year under conditions specially suited to prevent their degradation. This function makes seasonal products available all year round. The quality and nutritional value of food products is affected by the time and temperature of the storage. Large temperature fluctuations during storage, transportation, and handling accelerate the deteriorative effects to food products. Proper temperature and humidity levels have to be maintained in the warehouse at all times to maintain high quality, nutritious and safe food products.

A cold storage is a building or a group of buildings with thermal insulation and a refrigerating system in which perishable food products can be stored for various lengths of times in set conditions of temperature and humidity. Such storage under controlled conditions slows the deterioration and spoilage that would naturally occur in an uncontrolled natural environment. Thus, cold storage warehouses play an important role in the storage of food products in the food delivery chain throughout the year under conditions specially suited to prevent their degradation. This function makes seasonal products available all year round. So it is very important to make cold storage energy efficient or in the other words reduce its energy consumption. The energy consumption of the cold storage can be reduced, by minimizing the heat flow from high temperature ambience to low temperature cold room. By setting optimum values of different control parameters the heat gain in the cold room can be reduced. 65% of Indian population is engaged in agriculture and it is a key sector with profound impact on the nation’s economy. The total agriculture output contributes nearly 40% to the national income. The country approximately produces nearly 137 million tones of fruits and vegetables annually. Since most products are perishable they require specialized environment controlled facilities for prolonged storage and transport.

In this present study predictor variables are-insulation thickness of the side walls (TW), area of the side walls(AW), and the insulation thickness of the roof(TR). After graphical analysis critical values of the predictor variables have been identified for minimum heat transfer from the outside ambience to the inside of the cold room.

## II. MODEL DEVELOPMENT

Three control parameters, viz. insulation thickness of the side walls (TW), area of the walls (AW), insulation thickness of the roof (TR) taken as predictor variables and heat flow(Q) from outside to inside of the cold room taken as response variable. The insulating material taken as PUF (Polly urethane foam) Panel for analysis. The available Panel Thicknesses are [7]- 40mm, 50mm, 60mm, 80mm, 100mm, 150mm, 200mm.out of the available insulation thicknesses only three values are taken for analysis. The cold storage building taken for the study is Penguin Cold Storage situated in the region of Khed Shivapur of Pune city. The overall dimensions of cold storage plant are 17m x 22m x 12m [6]. It consist four cold chambers. They are called cold rooms. The dimension of the cold rooms are 8m x 5m. The height of the cold chamber is 4m. Only one chamber is considered for this study. The levels of the AW are obtained by only varying the height of the chamber. TABLE 1 shows the control parameters and their levels.

Table 1 control parameters and their levels

| **Notation** | **Factors** | **Unit** | **Levels** | | |
|---|---|---|---|---|---|
| | | | **1** | **2** | **3** |
| TW | Insulation thickness of the side wall | m | 0.100 | 0.150 | 0.200 |
| AW | Area of the side wall | $m^2$ | 78 | 104 | 130 |
| TR | Insulation thickness of the roof | m | 0.080 | 0.100 | 0.150 |

The following equation is used for calculating the values Q:

$$\mathbf{Q = \frac{K A \Delta T}{x}}$$

Where, Q – Rate of heat flow (W)

K – Thermal conductivity of insulating material ($W/m^2K$)

A – Cross sectional area of wall ($m^2$)

ΔT– Temperature difference between outside and zone conditions ($^0C$)

x – Thickness of insulation (m)

As there is no temperature difference between the inside temperature of the room and the side walls of the room so there will be no convection current setup inside the room after steady state condition reached. Similar situation exist between the outside face of the side walls and ambient. So that outside convection current can also be neglected. As the temperature difference is not of a very big amount radiation effect can also be neglected. So the only mode of heat transfer from the ambient to the cold room is the conduction mode. Hence we consider only conduction. Now the dimension of the cold room is 8m*5m*4m. We only vary the height of the cold room. The heights are – 3m, 4m, and 5m.

Therefore the values of the side walls area are-

$(AW)_1$=2*(8*3) +2*(5*3) =78 $m^2$

$(AW)_2$=2*(8*4) +2*(5*4) =104 $m^2$

$(AW)_3$ = 2*(8*5) +2*(5*5) =130 $m^2$

Now the area of the roof of the cold room is constant whose value is-

Area of the roof (AR) = (8*5) =40 $m^2$.

Now the conduction loss is composed of two components – conduction through the side walls and conduction through the roof. Then the Q becomes-

$Q=Q_{\text{side walls}} + Q_{\text{roof}}$

Now here insulating material used as PUF & EPS. The thermal conductivity of PUF is, K=.023W/$m^2$k and thermal conductivity of EPS is, K=.036 W/$m^2$k.The cold room inside temperature is 2℃ and average ambient temperature taken as 26℃. So the temperature difference becomes ΔT= (26-2) =24℃. Now the values of Q for the side walls can be computed as-

$Q_{\text{side walls}}=\frac{K\times Aw\times\Delta T}{TW}$

Where, K= thermal conductivity of insulation =.023 W/$m^2$k for PUF and .036 W/$m^2$k for EPS

AW= area of the side walls= 78 $m^2$, 104 $m^2$, 130 $m^2$

ΔT= temperature difference=24℃

Insulation thickness of the side walls =.100m, .150m, .200m

Similarly the Q values for the roof for different set of runs can be computed by the following equation-

$Q_{\text{roof}}=\frac{K\times AR\times\Delta T}{TR}$

Where, K= thermal conductivity of insulation material = .023 W/$m^2$k for PUF and .036 W/$m^2$k for EPS

AR= area of the roof= 40 $m^2$.

ΔT= temperature difference= 24℃

Insulation thickness of the roof= .080m, .100m, .150m

Therefore the total heat gain will be-

$Q=Q_{\text{sidewalls}} + Q_{\text{roof}}$

Sample calculation-

For the first test run we will take the values of control factors, those are present in the first row of the observation table. The values are-

TW= $(TW)_1$=.100m, $(TW)_1$= thickness value for the first row.

AW= $(AW)_1$=78$m^2$, $(AW)_1$=area of the side walls for the first row.

TR= $(TR)_1$ =.080m, $(TR)_1$=thickness value for the first row.

Therefore, $Q=Q_1= \frac{K\times(AW)1\times\Delta T}{(TW)1} + \frac{K\times AR\times\Delta T}{(TR)1}$

$= \frac{.023\times78\times24}{.100} + \frac{.023\times40\times24}{.080}$

= 706.56watt. for PUF

Again Q=$Q_2$= $= \frac{K\times(AW)1\times\Delta T}{(TW)1} + \frac{K\times AR\times\Delta T}{(TR)1}$

$= \frac{.036\times78\times24}{.100} + \frac{.036\times40\times24}{.080}$

= 1105.92 watt. for EPS

Similarly the values of $Q_2$, $Q_3$, $Q_4$, $Q_5$, $Q_6$, $Q_7$, $Q_8$, and $Q_9$ can be computed by using the values of different factors that appeared in successive rows in the table no (1). All the parameters values are same except the factors TW, AW, TR while computing the values of the total heat (Q) gain in the cold room. The following table (2) shows the different values of Q for the nine test runs-

Table 2: Observation table

| Test Runs | TW | AW | TR | Q(PUF) | Q(EPS) |
|---|---|---|---|---|---|
| 1 | 0.100 | 78 | 0.080 | 706.56 | 1105.92 |
| 2 | 0.100 | 104 | 0.100 | 794.88 | 1244.16 |
| 3 | 0.100 | 130 | 0.150 | 864.80 | 1353.6 |
| 4 | 0.150 | 78 | 0.100 | 507.84 | 794.88 |
| 5 | 0.150 | 104 | 0.150 | 529.92 | 829.44 |
| 6 | 0.150 | 130 | 0.080 | 754.40 | 1180.80 |
| 7 | 0.200 | 78 | 0.150 | 362.48 | 567.36 |
| 8 | 0.200 | 104 | 0.080 | 563.04 | 881.28 |
| 9 | 0.200 | 130 | 0.100 | 579.60 | 907.2 |

Now we get our full observation table. It shows different combination of control factors and their outcome i.e. the different values of output variable.

## III. Result and Discussion

Table 3: Data set for the variation of TW with Q

| TW | Q(PUF) | Q(EPS) |
|---|---|---|
| 0.100 | 794.88 | 1244.16 |
| 0.105 | 767.54 | 1201.37 |
| 0.110 | 742.69 | 1162.47 |
| 0.115 | 720.00 | 1126.95 |
| 0.120 | 699.20 | 1094.40 |
| 0.125 | 680.06 | 1064.44 |
| 0.130 | 662.40 | 1036.80 |
| 0.135 | 646.04 | 1011.20 |
| 0.140 | 630.85 | 987.42 |
| 0.145 | 616.71 | 965.29 |
| 0.150 | 603.52 | 944.64 |
| 0.155 | 591.17 | 925.31 |
| 0.160 | 579.60 | 907.20 |
| 0.165 | 568.72 | 890.18 |
| 0.170 | 558.49 | 874.16 |
| 0.175 | 548.84 | 859.06 |
| 0.180 | 539.73 | 844.80 |
| 0.185 | 531.11 | 831.30 |
| 0.190 | 522.94 | 818.52 |
| 0.195 | 515.20 | 806.40 |
| 0.200 | 507.84 | 794.88 |

While varying the TW with Q the constant values of AW and TR were-

AW-104 $m^2$,

TR-.100m.

Using the data from table no-3 the following graph can be generated-

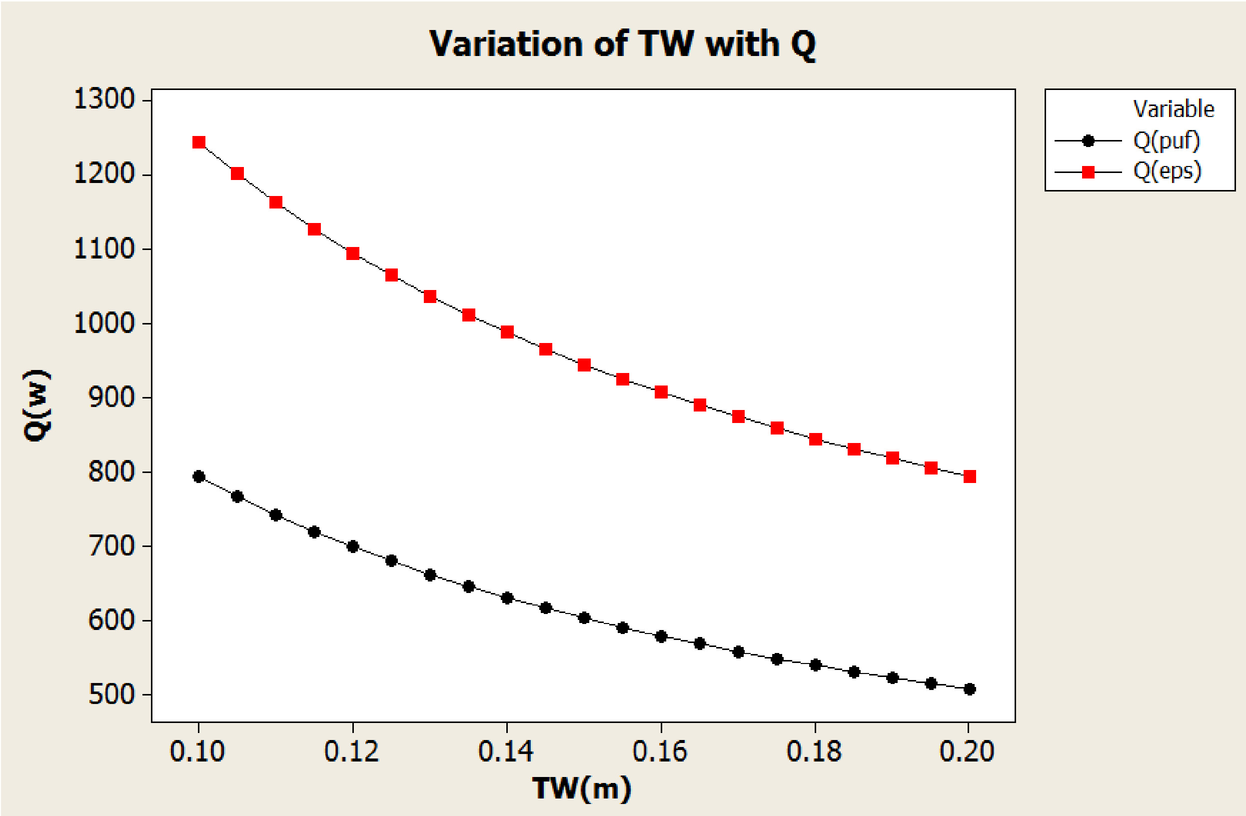


Fig 1 variation of insulation thickness of the side walls (TW) with heat gain (Q) in the cold room

From the above graph it can be seen that as insulation thickness of the side wall increases the heat gain Q decreases, it can be seen that for TW=.200m the heat gain in the cold room (Q) becomes minimum.

Similarly the variation of AW with Q can be represented as-

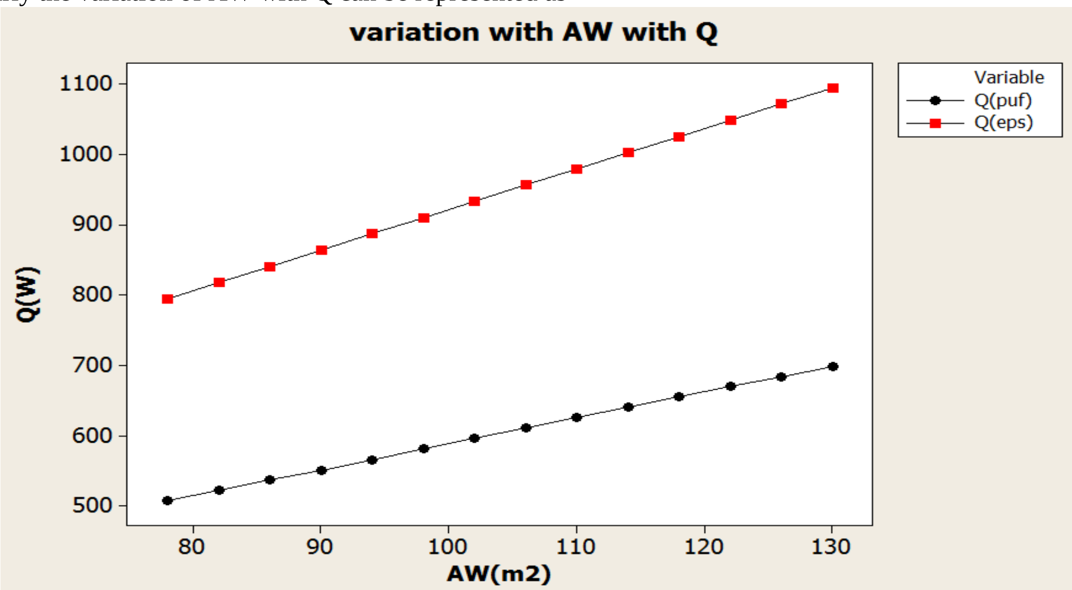


Fig 2 variation of area of the side walls (AW) with heat gain (Q) in the cold room

From Fig 2 it can be seen that for AW=78m2 the heat in the cold room (Q) will be minimum. And the variation of TR with Q can be represented as-

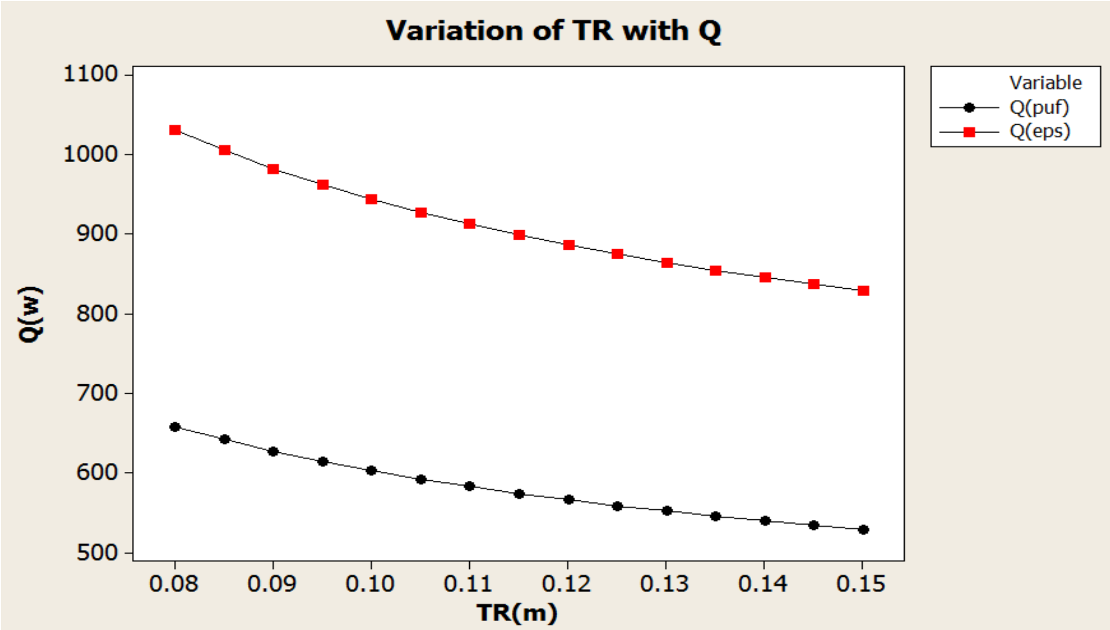


Fig 3 variation of insulation thickness of the roof (TR) with heat gain (Q) in the cold room

From Fig 3 it can be seen that for the value of TR=.150m the heat transfer will be minimum.

## IV. Conclusion

The superior long term performance of metal faced insulated panels with rigid urethane cores is now widely recognized by cold storage investors and designers when compared with site assembled, multi-part, built-up cladding systems. This has resulted in significant growth for this type of construction system. The thermal Conductivity (K) of material decides the insulation property of the material. Lower the K value better is the insulation property. In this study the comparison is made between most commonly used insulating materials for cold storage application i.e. EPS and PUF. The Value for EPS is 0.036 $W/m^2k$ whereas for PUF it is 0.023 $W/m^2k$.

## REFERENCE

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