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# Studies Conducted on A Unique Roof Pond Layout for Cooling Buildings

**P Sudheer Rao[1], B. Bhavsingh[2], PVR Girish Kumar[3]Dr. R. Sudarshan[4]**

*[1,4]Associate Professor, Geethanjali College of Engineering and Technology, Hyderabad, T.S, India.*

*[2]Assistant Professor, Geethanjali College of Engineering and Technology, Hyderabad, T.S, India.*

*[3]Senior Assistant Professor, Geethanjali College of Engineering and Technology, Hyderabad, T.S, India.*

***Abstract:*** -Over the past two decades, developing countries have experienced a severe energy crisis, particularly during summer, due to high building cooling load requirements. This crisis is expected to continue due to improved living standards and an increasing global population. Passive techniques, such as evaporative cooling, can help reduce energy consumption in hot climatic conditions. A study using ANSYS (CFD) tool was conducted to determine the temperature distribution and average temperature of the room, with the average temperature obtained being 313.15K without a roof pond and 302.15K with a roof pond.

***Keywords****: Creo, Ansys, Temperature.*

## I. Introduction

Evaporative cooling uses evaporation as a natural heat sink, absorbing sensible heat from the air to evaporate water. The amount of sensible heat absorbed depends on the amount of water evaporated. Evaporative cooling can reduce room temperature to wet bulb temperature, reducing refrigeration load. Passive cooling techniques, like a roof pond, can also be used to decrease heat entering the roof. Building cooling load components include direct solar radiation, transmission load, ventilation/infiltration load, and internal load. Calculating these loads individually and adding them up gives the total cooling load, which is the sensible load. Latent load is added based on the building type. The calculation procedure is scientific but time-consuming. The total cooling load consists of heat transferred through the building envelope and heat generated by occupants, equipment, and lights. The percentage of external versus internal load varies with building type, site climate, and design. Passive solar design uses natural processes for heating and cooling to achieve balanced interior conditions. This approach reduces heat gains and encourages the removal of excess heat from buildings. Passive cooling relies on the availability of a lower-temperature heat sink and promotion of heat transfer towards it. Environmental heat sinks include outdoor air, water, the night sky, and ground. Passive cooling techniques can reduce peak cooling loads, reducing air conditioning equipment size and duration. The rapid depletion of non-renewable energy sources and the environmental impacts of fossil fuels have led to the adoption of passive cooling techniques for buildings. In a building the heat is entered into the room by various components like wall, windows, fenestration and internal load which comprises occupancy inside the room, various electrical appliances, heat though lighting. Out of all the components that add heat to the room the maximum heat is added through the roof of the building. Roof is a part of the building which is always exposed to the sun in a day. So, if we could decrease the heat entering into the room through the roof a lot of cooling load necessity can be decreased. Various roofing techniques will be discussed below. To cool the envelope of a building by using evaporative cooling. A test building was modified in Baghdad, Iraq to test the system. The roof was cooled using a pool in a tunnel-like compartment. The latter was ventilated by a small fan. The walls enclosed a 10 cm cavity. Cooled air from a small evaporative cooler was pumped into it. The test results showed a drop in interior temperature of more than 10 ◦C to an average of 31.76 ◦C. This system allows a compressor air conditioner to be used to further cool the interior. Calculations revealed that after using it to reduce temperatures to comfortable levels, the cooling load was less by up to 88% compared to untreated rooms. Performance of different passive techniques for cooling of buildings in arid regions. Different techniques were used to cool the building like covering the roof with white cement that a lot of incident solar rays get reflected back. Insulating the roof with an earthen pot and installing a water tank on the roof etc. For each technique the temperature difference is calculated. Concrete slabs are one of the most important roofing methods. There are different structures, but the majority has high thermal conductivity. They absorb external heat in summer while thermal losses may occur in winter, which makes occupancy under these roofs thermally unstable and unbearable. Researchers have been trying to improve the concrete slabs by applying different treatments to these structures. Adding plastic waste and tires in the concrete mixture can reduce concrete heat gain by 10–19% without affecting its performance [2]. Rubberized concrete which can reduce the dead-load of roofs is also important. Hollow concrete roofs can reduce thermal conductivity by 13.65– 40.42%. In addition, adding reflective coating and insulation layers to these slabs can reduce their thermal conductivity significantly. Some researchers have introduced the use of phase change. This can absorb heating by a melting process before reaching internal spaces, thus reducing heat up to 40%. From figure 1, research conducted upon different climates and specifications of PCM have produced different outcomes [3] for instance, estimated that it reduced heat flux by 15.9–17.3%, and in Alexander and Gaurav's study and it could be reduced up to 100% in a Mediterranean climate. By applying a reflective layer/coating over a roof slab, solar radiation can be reflected. Usually, this layer is white. When colors become darker, the reflectance decreases, and the superficial temperature becomes higher. However, researchers have discussed the fact that dark colours can still be effective if they have a high reflectivity performance. This treatment is usually used for passive cooling, and it works well in hot climates such as arid and tropical climates. On the other hand, this method has an energy penalty in cold days or the winter season, because it blocks passive heating at the building's roof and is not able to block heat loss from internal spaces though the roof slab, unless it is combined with thermal insulation. [12] This method can reduce heat flux up to 33%. The cool roof payback period is short compared with other methods which can be in two months. In other climates, as mentioned before, it has an energy penalty towards heating loads, which was recorded in a Mediterranean climate, of about 12%, and 30% reduction in cooling [4]. Cool roofs, compared with photovoltaic panel roofs and roof gardens, maintain a lower surface temperature, [5] which can improve the passive cooling during night time. Careful selection of this method is needed when heating is highly required in a building, in order to evaluate its efficiency before applying it on the roofs of a building, and avoiding its negative impact on heating loads. Diagram representation is shown in figure 2.

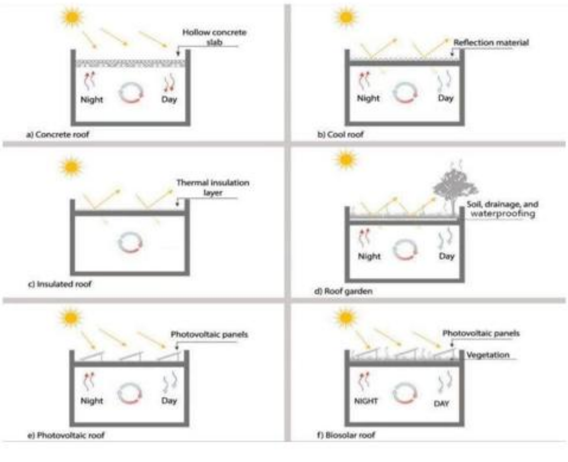


**Fig 1 Different Roofing Methods**

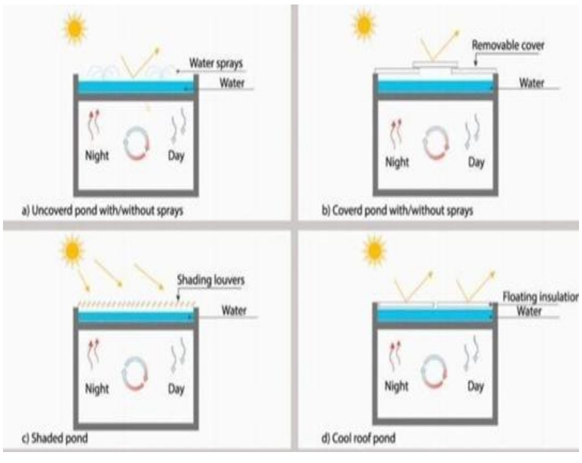


**Fig 2 Load Impacts on Roof**

[6] introduced a system that can achieve a closer result by using the half thickness of insulation layer; in their system they used a 2.5 cm thickness of insulation layer over a slab, and then they placed a screed layer over the insulation with discontinuous concrete strips to support the system and to insure its stability. This insulation system can reach a heat reduction of up to 75% in a tropical climate. [7] In Mediterranean climates another three materials were tested, which were polystyrene, rock wool, and fine white sand, and their results in heat reduction were 58.5%, 38.01% and 62% respectively. They were tested during hot days, which mean that they have similar effects in hot climates. [8] We can see in figure 3, if insulation is integrated with other techniques

such as ventilation or a reflective layer, it could increase its efficiency up to 84% and 88% respectively. [10] Researchers have introduced vacuum panels as insulation layers, but experiments have concluded that they are less effective than traditional insulation and the payback period is about 17 years. [11] The environmental payback period is shorter than its economic payback period for insulation. In addition, the economic payback varied regarding insulation material and its thickness, which can be 3.11–5.55 years. The maximum amount of heat is added to the room through the roof, using a passive technique the heat entering into the room has to be decreased. [13] Cooling load calculations are calculated for a room without using any passive technique and with using a passive technique.

## II. Design & Calculations

Using the ANSYS tool the temperature distribution at different locations in the room and average temperatures are to be studied design and mesh shown in Fig 4 A room of size length = 7.65 m width = 4.2 m and height = 3.23 m is considered in this study. The room consist of one door of length = 2.1 m and height = m and two windows of length = 1m and height = 1.5 m. The door is at the north side of the room and the roof wall is elevated at a height of 1m to hold water. The room of dimensions 7.65m*4.2m*3.23m is considered and the atmospheric temperature is 308K and heat transfer through each wall is calculated and it is observed that maximum heat transfer is through the top roof. For the similar structure of a room a passive cooling technique is used in order to decrease the heat transfer through the roof. A roof pond is added and the cooling load is calculated for the same room shown in Fig 3 & 4.

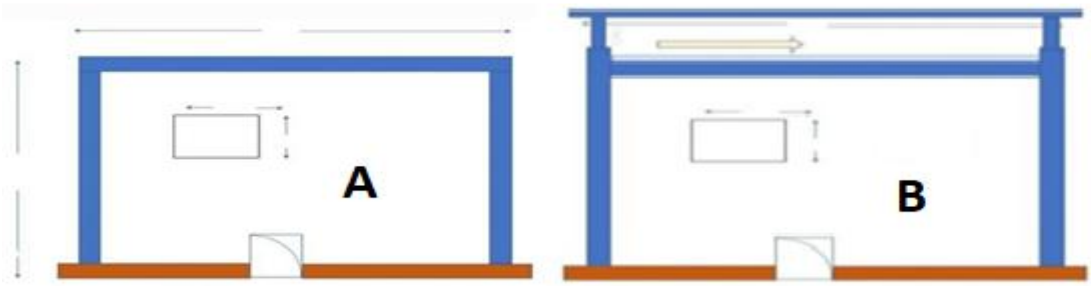


**Fig 3 A) Room without pond B) Room with pond**

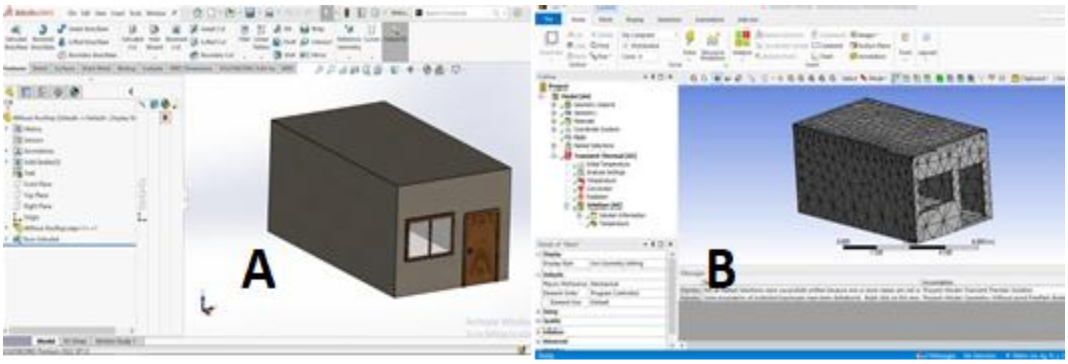


**Fig 4 A) Room Design & B) Meshing**

## III. Cooling Load Calculations:

This is a sensible heat transfer process. The heat transfer rate through opaque surfaces such as walls, roof, floor, doors etc. is given by

Opaque = U.A. CLTDU is the overall heat transfer coefficient and A is the heat transfer area of the surface on the side of the conditioned space.

CLTD is the cooling load temperature difference.

Without Roof Pond (From Fig 3 A)

Room Dimensions (7.6m*4.2m*3.2m)

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Inside conditions: 22 ◦C dry bulb, 50 percent RH

Door (2m*1.5m)

Wall – 250mm brick

Two windows (1.3m*1.9m)

K brick = 2.76kJ /hr - m − K

K cement = 1.56kJ /hr − m −k

K glass = 3kJ /h − m − K

K wood = 1.3kJ /h − m – K

K concrete =5.57kJ /h − m − K

ho = 75×3.6 = 270 kJ /m2 − h− K; hi = 75×2 = 150 kJ /m2 − h – K

The above thermal conductivity values (K) are taken from the heat transfer data book.

U Wall = 1/ (1 h + $t_0$ /$k_{brick}$ + $t_{brick}$ cement / k cement + 1/h i)

= 1/ (1/270 + 0.15/2.76 + 0.01/1.56 + 1/150) =14.059 kJ/h- m2 –K

U Door = 1/ (1/270 + 0.035/1.3 + 1/150) = 26.814 kJ/h- m2 − K

U Glass = 1(1/270 + 0.006/3 + 1/150) =80.838 kJ/h- m2 - K

U Ceiling = 1(1/270 + 0.15/5.57 + 1/150) = 26.81 kJ/h- m2 – K

Q=UA (ΔT)

Surrounding temperature =40˚c =313.15 K  Inner temperature (ROOM) =29˚c =302.15 K

Q North = [(3.23*4.2-2.1*1.9-1.31*1.9)14.059+ (2.1*1.9)1.3+ (1.31*1.9)80.838] (313.15- 302.15)

= 3366.31 kJ/h

Q South = [(3.2384.2-1.37*1.8)14.059+1.37*1.8.80.838] (313.15-302.15)

= 3909.4 kJ/h

Q East−West = 2 [(7.65*3.23)14.059] (313.15-302.15)

= 7672.59 kJ/h

Q Ceiling  = (7.65*4.2)26.81 (313.15-302.15) = 9475.45 kJ/h

Therefore

Q (Total)  = Structure load = 3366.31+3909.4+7642.59+9475.45= 24393.76 kJ/h

Q1 = Structure load including solar radiation = Q (Total) (1.36) = 33175.51kJ/h

If 10% extra load is considered, the tonnage for continuous operation of the air conditioning system is found to be:

Tonnage = (33175.51* 1.1)/12,600 = 2.63 TR.

The cooling load on the room is 2.63 TR, this is reduced by using a passive cooling technique which uses evaporative cooling.

With Roof Pond (From Figure 3 B)

Room Dimensions (7.6m*4.2m*3.2m)

Inside conditions: 22 ◦C dry bulb, 50 percent RH

Door (2m*1.5m)

Wall – 250mm brick,

Two windows (1.3m*1.9m),

A pond of water which is of 3 feet height.

With the same atmospheric conditions again cooling load calculations are calculated with a passive cooling technique.

Atmosphere temperature DBT = 350C; WBT = 270C

Due to evaporation the minimum temperature the roof beneath the water pond can attain is 270C (i.e., WBT)

Difference in Final Temperature with Change in Efficiency

| S. NO | Efficiency of the system | Final temperature |
|---|---|---|
| 1. | Efficiency = 100% | 27 0 C |
| 2. | Efficiency = 90% | 26.7 0 C |
| 3. | Efficiency = 60% | 29.6 0 C |

Calculation of Q: Q=U*A*Δt

Where U (ceiling) = 26.81 kJ/h-m2- k; A = 50 m2

WHEN EFFICIENCY = 100%

Q= (7.65*4.2)26.81(308.15-300.15) = 6891.24 kJ/hr.

WHEN EFFICIENCY = 90%

Q= (7.65*4.2)26.81(308.15-299.85) = 7149.66 kJ/h

WHEN EFFICIENCY = 60%

Q= (7.65*4.2)26.81(309.15-299.75) = 8097.2 kJ/h

Q (ceiling) without roof pond =17,427 kJ/h

(ceiling) with roof pond= 6891.24 kJ/h – 100% efficiency

= 7149.66 kJ/h – 90% efficiency

= 8097.2 kJ/h – 60% efficiency

Calculation of cooling load using 90% efficient system:

Q North = [(3.23*4.2-2.1*1.9 1.31*1.9)14.059+ (2.1*1.9)1.3+ (1.31*1.9)80.838(308.15- 300.15)]

= 2448.23 kJ/h

Q South = [(3.23*4.2-1.37*1.8)14.059+ (1.37*1.8)80.838] (308.15-300.15)

= 2843.21 kJ/h

Q East−West = 2 (7.65*3.23)14.059 (308.15-300.15) = 5558.25 kJ/h

Q Ceiling = (7.65*4.2) 26.81(308.15-300.15) = 6891.24 kJ/h

Therefore

Q (Total) = Structure load == 2448.23 +2843.21+5558.25+6891.24 = 17740.93kJ/h

Q1 = Structure load including solar radiation:

Q (Total) (1.36) = 24127.66 kJ/h

If 10% extra load is considered, the tonnage for continuous operation of the air conditioning system is found to be:

Tonnage = 24127.66* 1.1/12600 = 1.91 TR

The calculated values as follows.

Without Roof Pond

Q North = 3366.31kJ/h

Q South = 3909.4kJ/h

Q East−West = 7642.59kJ/h

Q Ceiling = 9475.45kJ/h

Q1 = Structure load including solar radiation = 24393.76 kJ/h

Tonnage = (24393.76* 1.1)/12,600 = 2.63 TR.

The cooling load on the room is 2.63 TR, for the same room dimensions the cooling load is calculated while using a passive cooling technique.

The maximum amount of heat entering into the room is through the roof, in order to decrease this roof pond is added to the room. The temperature of the roof without roof pond is 308K while using the roof pond technique it is decreased to 299.9K. For the same room dimensions and atmospheric temperature, the cooling load is calculated. The results are as follows

Q North = 2448.23kJ/h

Q South = 2843.21 kJ/h

Q East−West = 5558.25 kJ/h

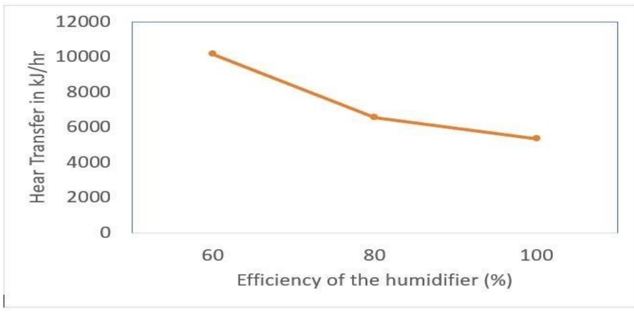
Q Ceiling = 6891.24 kJ/h

As the roof pond is added to the room the temperature of the roof changes accordingly with efficiency. The change in temperature with the change in efficiency is shown in the graph below.

Q1 = Structure load including solar radiation = 24127.66 kJ/h

Tonnage = 24127.66 * 1.1/12600 = 1.91 TR

The cooling load of the room without passive technique was 2.63 TR. And with passive cooling technique is 1.91 TR. This reduce in cooling load is cause by the decrease in the temperature of the Graph between Q and Efficiency roof. The heat transfer through the roof without roof pond technique was 9475.45 kJ/h and the heat transfer through the roof with roof pond technique shown in below graph.




**Graph 1 Efficiency vs Heat Transfer**

was 6891.24 kJ/h. There is a 62.3% decrease in the heat transfer through the roof. This passive cooling technique reduces the effort of using electrical energy to cool the room.For the same room dimensions and the atmospheric temperature, a simulation is done using ANSYS R19 and the temperature distribution is obtained from the simulation results. The simulation is carried out for two rooms with and without passive cooling technique. Case 1 deals with the result of without passive cooling technique shown in fig 5 and Case 2 deals with the result of with passive cooling technique In this case simulation analysis of a room is done without passive technique (i.e., Roof Pond) shown fig 6. The room operating conditions are, top roof temperature is considered as 313.15 K. The inlet of the room is through the door so temperature at inlet is 313.15 K and inlet velocity is 1 m/s. In this case simulation analysis of a room is done with passive technique (i.e., Roof Pond). The room operating conditions are, top roof temperature is considered as 300.15 K. The inlet of the room is through the door so temperature at inlet is 313.15 K and inlet velocity is 1 m/s. The temperature distributions are taken at various cross sections like through the inlet, through the window and at the wall. In the temperature distribution it is observed that the maximum temperature is at the walls of the room and the room where there is no roof pond the maximum heat entering into the room is through the roof. The heat entering into the room through the roof is resisted by the roof pond, it can be observed from the temperature distribution results of the room with roof pond the heat entering into the room through roof is very low. The average temperature of the room shown in table 1

**Table 1 Average Temperatures of a Room**

| S.No | Type of Room | Average Temperature |
|---|---|---|
| 1 | Without Roof Pond | 313.15° K |
| 2 | With Roof Pond | 308.15° K |

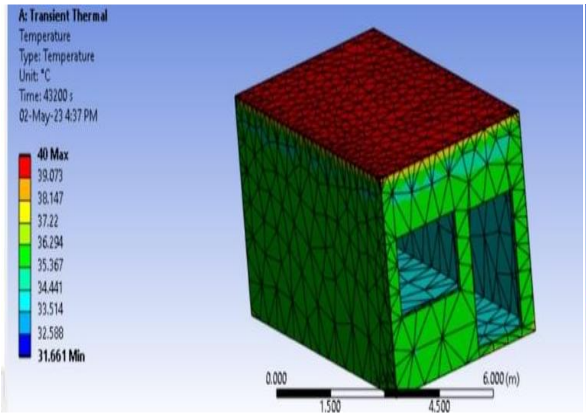



**Figure 5 Temperature variant in the room**

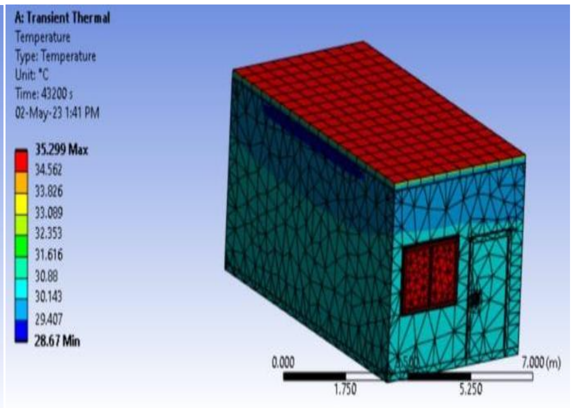



**Figure 6 Temperature variant in the room**

The average temperature of the room without roof pond is 313.15K and with roof pond is 308.15K. These results show that there is decrease in the average temperature of the room by using the passive cooling technique.

## III. Conclusion

The cooling load calculation in a room indicates the refrigeration required to cool or decrease the temperature. The maximum heat entering the room is through the roof, with a 62.3% decrease in cooling load. Passive cooling techniques can control heat entering the room without using electrical appliances. Natural evaporative cooling in the atmosphere can maintain ambient temperatures. ANSYS analysis shows temperature distributions across the room, with constant temperature changes across surrounding walls and top roof temperature. The roof pond technique can significantly decrease room temperature, with average temperatures of 313.15K without a roof pond and 308.15K with a roof pond.

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