EVALUATION OF EFFECTIVENESS OF PASSIVE COOLING(ROOF COOL) TECNIQUE IN INDIAN CLIMATE

Dr. Govind Maheshwari [1], Abhay Singh Gehlot[2]

[1] *Associate professor , Dept. of Mechanical Engineering, I.E.T. Davv, M.P., India*
[2] *M.E. scholar , Dept. of Mechanical Engineering, I.E.T. Davv, M.P., India*

ABSTRACT

Energy consumption of the building sector is high , buildings are responsible for about 30-40% of the total energy demand. The impact of air conditioner usage on electricity demand is an important problem as peak electricity load increases continuously, forcing utilities to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning. Passive and hybrid cooling techniques involving microclimate improvements, heat and solar protection, and heat modulation and dissipation methods and systems can greatly contribute to buildings' cooling load reduction and increase thermal comfort during the summer. In this context passive cooling techniques are very helpful to achieve thermal comfort and save power , in passive cooling technique roof cool technologies are very popular in hot countries to achieve thermal comfort.

Keyword: - *Thermal , HVAC , passive cooling technique etc….*

1.INTRODUCTION

In many hot countries, and also in countries with a temperate climate having hot summers, there is increasing interest in utilizing passive and low-energy systems for cooling buildings, both residential and commercial. In developed countries this interest is motivated by the desire to conserve energy and to reduce the summer peak demand for electricity caused by air conditioning. In developing countries, where air conditioning is not applied at present on large scale, the interest in passive cooling motivated by the desire to minimize the heat stress experienced in buildings and its deleterious effect on health and productivity, as well as the desire to minimize the pressure for large-scale installation and use of air-conditioning. Passive cooling building design attempts to integrate principles of physics into the building exterior envelope to slow heat transfer into a building. This involves an understanding of the mechanisms of heat transfer, heat conduction, convective heat transfer, and thermal radiation (primarily from the sun. In mild climates with cool dry nights this can be done with ventilation. In hot humid climates with uncomfortable warm / humid nights, ventilation is counterproductive, and some type of solar air conditioning may be cost effective. The term 'passive' does not exclude the use of a fan or a pump when their application might enhance the performance. This term emphasizes the utilization of natural cooling sources, or heat sinks.

1.1 Main Problems of conventional Air Conditioning

There are different problems associated with the use of conventional air conditioning. Apart from the serious increase of the absolute energy consumption of buildings, other important impacts include:

• The increase of the peak electricity load;

• Environmental problems associated with the ozone depletion and global warming;

• Indoor air quality problems.

The main environmental problems of air conditioning are associated with:

• Emissions from refrigerants used in air conditioning which adversely impact ozone levels and global climate. Refrigeration and air conditioning related emissions represent almost 64% of all CFC's and HCFC's produced (AFEAS, 2001).

• Cooling systems' energy consumption contributes to CO_2 emissions.

Refrigerant gases used in air conditioning are CFC's, HCFC's or HFC's. Chlorofluorocarbons have a very important impact on ozone depletion and they also exert global warming effects. According to the Montreal Protocol, CFC's production and use was banned by 1996 in the developed countries and must be stopped by 2015 in the developing countries. In Europe, "Regulation 2037/2000" totally bans their use for maintenance and servicing of equipment as of January 1, 2001.

1.2 Alternative Techniques to Air Conditioning - Passive Cooling

Passive cooling techniques in buildings have proven to be extremely effective and can greatly contribute in decreasing the cooling load of buildings. Efficient passive systems and techniques have been designed and tested. Passive cooling has also proven to provide excellent thermal comfort and indoor air quality, together with very low energy consumption.

When a building's internal and solar gains are sufficiently reduced, a lean climatization concept can be developed (Reinhart et al., 2001). The term lean signifies that the system is energy efficient so that only the amount of electricity needed to run fans and circulation pumps is required to maintain comfortable indoor temperatures year-round**.**

Following are some passive cooling techniques which are commonly known:-

Nocturnal radiation cooling , Roof spray , Roof Pond , Use of roof insulation over the roof , Green roof , Earth sheltering beaming , Night ventilator etc.

2.PROBLEM FORMULATION AND OBJECTIVES OF STUDY

After the crisis in 1970s, energy becomes one major topic in agendas of developed and developing countries which offer their energy needs from others [Oluklulu C.(2001)]. Because of significant amounts of energy consumed in heating, ventilating and air-conditioning (HVAC) systems, there have been efforts to study energy use performance and promote well operational practice in building. Studies about minimizing energy consumption and using renewable energy sources speeded up with the reduction of fossil fuels and increasing of various environmental problems. If the lack of technology and materiality are considered the wisest solution is to lower the extravagant consumption with energy-efficient buildings. The term energy efficiency in buildings can be defined as, providing comfort conditions with minimum energy consumption. The necessity of replacing the lost or excessive gains to protect the indoor comfort conditions makes it necessary to use energy in buildings. The energy load of a building is the amounts of heating or cooling energy that must be taken on by heating and cooling systems. In recent years, the use of energy conservation in modern architecture for space heating/cooling has been reported frequently.

Now-a-days the interior of building is made comfortable as required, with the help of electromechanical devices, air conditioners and other cooling devices. Such devices consume substantial power which increases with increase of cooing load of the building In order to reduce power consumption in a building the cooling load is required to be reduced and we need some alternative solution so

The objective is to evaluate the effectiveness of passive cooling methods (with reference to thermal comfort) in Indian climate.

3. EXPERIMENTAL INVESTIGATIONS AND CALCULATION ON ROOF PASSIVE COOLING TECHNIQUES

Two identical prototype rooms each having dimensions 16 ft×16 ft×12 ft were fabricated. All the walls of rooms were constructed using brick work. Both rooms have one door of 6ft×4 ft. and one window of 3.4 ft×2 ft. The roofs were constructed using RCC slab of 100 mm thickness. A major heat load in building is from the roof, so only treatment on the roof was compared. Following five passive techniques were applied on one of the test rooms (room 1) while other test room was kept with bare RCC roof (room 2).

3.1 Method-1 Roof Pond

A roof pond was built over the roof. Roof pond is a unique passive system that can be used for both passive heating during winter and passive cooling of buildings during summer. Water was filled to some depth of to build a roof pond, and net reduction in heat gain from room was calculated by using experimental data. Then similar experiments were performed with recommended water level , to find the optimal water level in roof pond. Experimental observation and % reduction in heat gain in roof using Roof Pond (Water level 150 mm)

Time	Wind velocity (km/h)	Relative humidity (%)	Room 1 with passive cooling		Room 2 without passive cooling		Heat transfer (W) with passive cooling	Heat transfer (W) without passive cooling	% Reduction in heat transfer
			T1= Top surface temp (^{0}c)	T2 = Bottom surface temp (^{0}c)	T3 = Top surface temp (^{0}c)	T4= Bottom surface temp (^{0}c)	Q1	Q2	
10:00	12.4	57	25	23.7	33.4	28	28.05	55.88	57.4%
10:30	12.4	58	25.4	23.5	33.8	28.2	30.50	58.32	55.32%
11:00	12.4	55	27	24	34.3	29.1	35.5	53.44	42.30%
11:30	12.4	55	29.7	25.8	35.1	30.5	35.40	55.12	37%
12:00	12.4	51	30.5	27.1	35.2	31.1	41.48	52.22	33.33%
12:30	12.4	54	31.1	28.5	37.3	32.0	30.50	54.55	52.8%
01:00	12.4	55	33	29.5	38	34.2	41.48	45.35	10.5%
01:30	12.4	48	34	30.7	39.9	35.0	40.25	51	34%
02:00	12.4	45	37.1	32.9	42	35.3	51.24	81.74	38.31%
02:30	12.4	51	38	34	43.1	35	48.80	85.4	42.3%
03:00	12.4	52	38	33.8	42.4	35.5	51.24	71.98	29%
03:30	12.4	49	35	31.7	41	35.9	40.25	57.82	30.35%
04:00	12.4	50	33	30.5	39.3	35.5	30.5	45.14	32.43%
04:30	12.4	52	31.8	30.5	39.2	34.2	15.00	51	75%
05:00	12.4	51	31	29.9	38.1	33	13.42	52.22	78%
							Avg. Reduction		43.20%

3.1.2 Method-2 jute cloth (Evaporative cooling)

Second method consists of laying a thin uniform organic material lining (a layer of empty jute cloth) on the roof in close contact. The cloth is soaked with water which evaporates by the heat absorbed by the roof and the air movement. The heat due to Sun's rays incident on the roof are also utilized for evaporation of the water present in the wet matting and, therefore, prevents the heat content of the roof. The higher the incident radiation of the Sun and wind speed on the roof, higher will be the quantity of water evaporated resulting in more cooling effect. Therefore,

this technique is very useful for cooling of buildings in arid areas where high solar radiation and high wind speed are available. By this technique, indoor dry bulb temperatures can be achieved near the outdoor wet bulb temperatures.
Experimental observation and % reduction in heat gain in roof using jute cloth on the roof

Time	Wind velocity (km/h)	Relative humidity (%)	Room 1 with passive cooling		Room 2 without passive cooling		Heat transfer (W) with passive cooling	Heat transfer (W) without passive cooling	% Reduction in heat transfer
			T1= Top surface temp (^{0}c)	T2 = Bottom surface temp (^{0}c)	T3 = Top surface temp (^{0}c)	T4= Bottom surface temp (^{0}c)	Q1	Q2	
10:00	14	57	27	24	34	29	35.5	51	40%
10:30	14	50	27	23.8	34.5	29	39.04	57.1	41.8%
11:00	14	49	28	24.5	35	30	41.48	73.2	43.33%
11:30	14	50	29	25.4	37.4	31.2	44	75.54	41.8%
12:00	14	48	29.7	25.5	37.9	32.2	50.02	73.2	31.55%
12:30	14	47	29.7	25	38.2	33.1	45.14	58.44	34%
01:00	14	45	31.5	27.2	39	33.5	53.58	73.2	35.5%
01:30	14	42	32.7	28.8	40.5	34.3	47.58	80.52	41%
02:00	14	47	33.1	29.3	42	35.8	45.5	85.4	45.5%
02:30	14	43	32.8	29.5	41.5	35.7	39	58.32	42.85%
03:00	14	48	32.5	29	40	35.5	44	51	28%
03:30	14	44	32.5	29.4	40	35.4	38	48.8	22.13%
04:00	14	45	33	31	41	35.8	24.4	39	37.4%
04:30	14	48	33.2	31	41.3	35.4	25.84	44	39%
05:00	14	50	33.5	31.4	39.5	37	25.52	35.5	31.70%
							Avg. Reduction		37.20%

This indicates that the average percentage reduction in heat gain from the roof is 37.20%. The maximum percentage reduction in heat gain from the roof was observed at 2 pm.

3.1.3 Method-3 Insulation over the Roof

In third technique test structure's roof was covered with thermocol sheet, the thickness of insulation was 60 mm science theomocol is a bad conductor of heat than its also resist hat coming towards inside room.
Experimental observation and % reduction in heat gain in roof using spray over the roof

Time	Wind velocity (km/h)	Relative humidity (%)	Room 1 with passive cooling	Room 2 without passive cooling	Heat transfer (W) with passive cooling	Heat transfer (W) without passive coolin	% Reduction in heat transfer

								g	
			T1= Top surface temp (^{0}c)	T2 = Bottom surface temp (^{0}c)	T4 = Top surface temp (^{0}c)	T5= Bottom surface temp (^{0}c)	Q1	Q2	
10:00	13.8	55	30.8	23.3	30.8	25.8	48.8	91.5	45.55
10:30	13.8	55	32.8	24.1	32.8	27.9	50	105.14	43.47
11:00	13.8	55	34.7	25	34.7	28.5	75.54	118.34	35
11:30	13.8	53	35.1	25.5	35.1	29.4	82	128	35
12:00	13.8	53	38	25.9	38	33.5	55	135.42	59.38
12:30	13.8	49	40.3	28.2	40.3	35	54.55	144	55.10
01:00	13.8	47	42	29.1	42	35.4	58.32	152	55.05
01:30	13.8	45	44.4	32	44.4	39	55.88	151	55.37
02:00	13.8	42	44.9	33.3	44.9	40.1	58.55	141	58.45
02:30	13.8	39	43.3	33.3	43.3	39.9	41.48	122	55
03:00	13.8	40	43.1	32.9	43.1	39.5	43.92	120	53.34
03:30	13.8	38	42.4	32.5	42.4	39	41.48	124.44	55.55
04:00	13.8	41	41.2	33	41.2	38.8	29.28	100.04	70
04:30	13.8	42	40.3	33.3	40.3	38.3	24.4	85.4	71
05:00	13.8	44	40	33.5	40	38	24	80.52	59.7
							Avg. Reduction		50.445

3.1.4 Method-4 Reflective cooling

Fourth technique was to use reflective roof in which silver paint was used to reflect solar radiation. Heat load from the roof can be reduced by applying reflecting coating on the roof. Generally white wash is used over the roof. Its reflectance for short wavelength is about 0.7—0.9. This test structure, roof was painted using silver paint.

Experimental observation and % reduction in heat gain in roof for reflective roof

Time	Wind velocity (km/h)	Relative humidity (%)	Room 1 with passive cooling	Room 2 without passive cooling	Heat transfer (W) with passive cooling	Heat transfer (W) without passive cooling	% Reduction in heat transfer

			T1= Top surface temp (^{0}c)	T2 = Bottom surface temp (^{0}c)	T4 = Top surface temp (^{0}c)	T5= Bottom surface temp (^{0}c)	Q1	Q2	
10:00	15	55	25.4	23.3	30.5	25	37.82	55.12	28.10%
10.30	15	54	27.7	24.1	32.1	27.5	44	55.12	21%
11:00	15	54	29.3	25	33.7	28.3	52.45	55.88	20.37%
11:30	15	51	31.3	25.3	37	31	5	73.2	15.57%
12:00	15	51	33.5	28.4	39.2	32.3	52.22	84.18	35%
12:30	15	48	34	29.4	39.5	33.4	55.12	74.42	24.5%
01:00	15	43	35	30.4	40	34.1	55.12	72	22%
01:30	15	42	35.4	32.5	43	35.8	45.35	75	39%
02:00	15	41	37.2	33	44.5	37.2	52.8	89	40%
02:30	15	40	38.3	33.5	45	37.7	58.55	89	34%
03:00	15	41	38.5	33.3	43.8	37	53.44	82.95	23.52%
03:30	15	39	38.9	33.7	43.5	37.2	55.12	78	28%
04:00	15	40	35.3	32.1	43	37.3	52.45	.59.54	24.7%
04:30	15	41	35.7	32	43.2	37	45.14	75.55	24%
05:00	15	43	35.3	31.8	42.7	37.5	42.7	50.32	29%
							Avg. Reduction		24.8%

3.1.5 Method-5 Roof insulation inside the room

Fifth technique was to use insulation inside the room this is most commonly used technique in Indian state like Rajasthan , Madhya Pradesh , Uttar Pradesh , Bihar etc. In this method roof is insulated from inside the room by thermocol foil and insulation sheet which also protect incoming heat and helps to cool room and reduce energy consumption.

Experimental observation and % reduction in heat gain in roof for insulator inside the room

Time	Wind velocity (km/h)	Relative humidity (%)	Room 1 with passive cooling		Room 2 without passive cooling		Heat transfer (W) with passive cooling	Heat transfer (W) without passive cooling	% Reduction in heat transfer
			T1= Top surface temp (^{0}c)	T2 = Bottom surface temp	T3 = Top surface temp (^{0}c)	T4= Bottom surface temp	Q1	Q2	
10:00	15	57	25	23.3	30.8	25.5	33	51.24	35%
10:30	15	57	28	24.8	32.8	27	51.24	82.95	38.23%
11:00	15	55	30	25	34.7	27.4	51	90.28	32.07%
11:30	15	52	31.3	25	37	28.9	34.55	98.82	34.55%
12:00	15	51	33.5	28	39.1	30.4	57.1	105	35.8%

12:30	15	49	34	29.3	39.8	33.8	57.34	73.2	21.55%
01:00	15	43	35	30	42	34.9	51	85.52	29.5%
01:30	15	41	35	30.8	42.7	35	53.44	81.74	22.5%
02:00	15	41	37.2	32.8	43.5	35.4	53.58	87.84	34%
02:30	15	40	38.2	34.2	44.8	37.5	48.8	87.84	44%
03:00	15	40	35.9	32.5	42.9	35.7	48.8	75.54	35.48%
03:30	15	39	35	32.5	42.3	35.5	41.48	70.75	41.37%
04:00	15	41	35.5	31.2	41.8	35.7	52.45	74.42	29.50%
04:30	15	41	35.35	31.4	40.2	34.8	48.05	57.1	28.50%
05:00	15	42	34	30.4	39.4	34.5	43.92	58.55	25%
							Avg. Reduction		32.51%

4. RESULT AND DISCUSSION

4.1 Using roof pond

It was seen that the measured room air temperature under passive cooling to be lower than those of without passive cooling conditions during the one day measurement. In order to further evaluate the cooling potential of passive cooling with roof pond compared to the without passive cooling conditions; table 5.1 shows sample data for the variation of room temperature of room 1 (roof pond with water level 150 mm) and room 2 (with Bare RCC roof). It also indicates that the temperature below the RCC slab in room 2 was between 28 ^{0}C to 36.9 ^{0}C while it was 23.6 ^{0}C to 33.8^{0}C in room 1. This roof cooling system gives stable indoor temperature and reduce heat flux through the roof than bare RCC roof. Even in the afternoon, when the air temperature is relatively higher and solar radiation is intense, there is still a lower amount of heat flux flows through roofs into the room. Figure 6.1 indicates that the averag percentage reduction in heat gain from the roof is 43.20%.

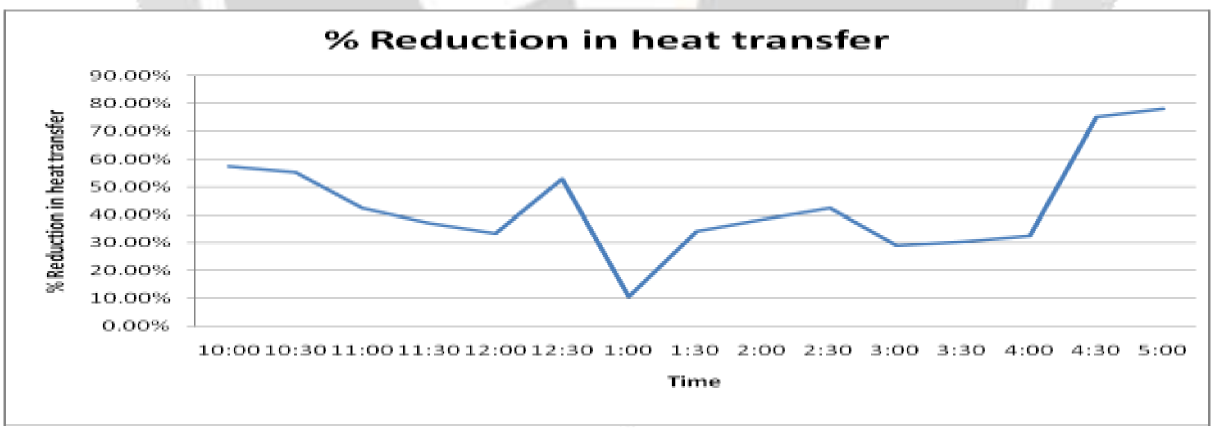

Figure 4.1: % reduction in heat gain through roof pond

4.2 Using wet jute cloth on the roof

It was seen that the measured room air temperature under passive cooling to be lower than those of without passive cooling conditions during the one day measurement. In order to further evaluate the cooling potential of passive cooling with wet jute cloth compared to the without passive cooling conditions Table 5.2 shows experimental observations with wet jute cloth. It shows the variation of room temperature of room 1 (Jute cloth over the roof) is from 23.8^{0}C to 31.4^{0}C and room 2 (with bare RCC roof) is from 29^{0}C to 37^{0}C.

This indicates that the average percentage reduction in heat gain from the roof is 37.20%. The maximum percentage reduction in heat gain from the roof was observed at 2 pm.

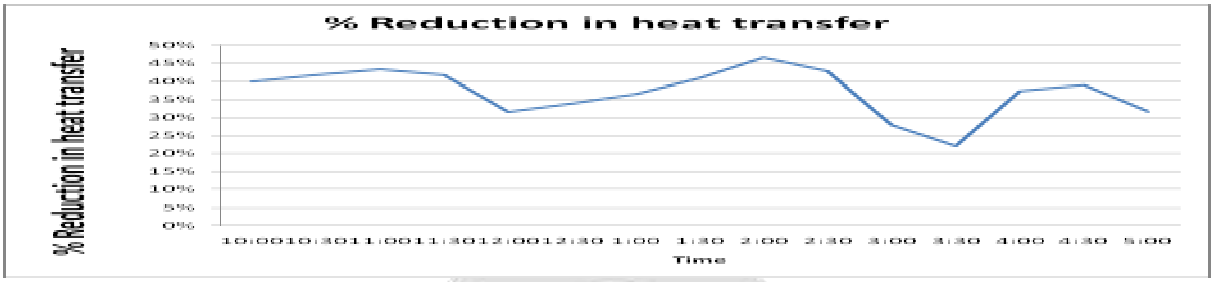

Figure 4.2 % reduction in roof heat gain using jute cloth

4.3 Roof insulation

4.3 shows sample data for the variation of room temperature of room 1 (evaporative cooled roof using spray water) and room 2 (with Bare RCC roof). It shows that the temperature below the RCC slab in room 2(bare RCC roof) was between 26 ^{0}C to 36.8 ^{0}C while 24 ^{0}C to 36.2^{0}C in room 1 during 10 AM to 5.00 PM. Room 1 has lower indoor temperatures at all hours of the day. Less heat was transferred though the roof of room 1. Evidently room 1 has a better cooling effect than room 2; therefore better thermal satisfaction can be achieved in spray cooled roof.
This indicates that the average percentage reduction in heat gain from the roof is 50.45. The maximum percentage reduction in heat gain from the roof was observed at 4.30 pm.

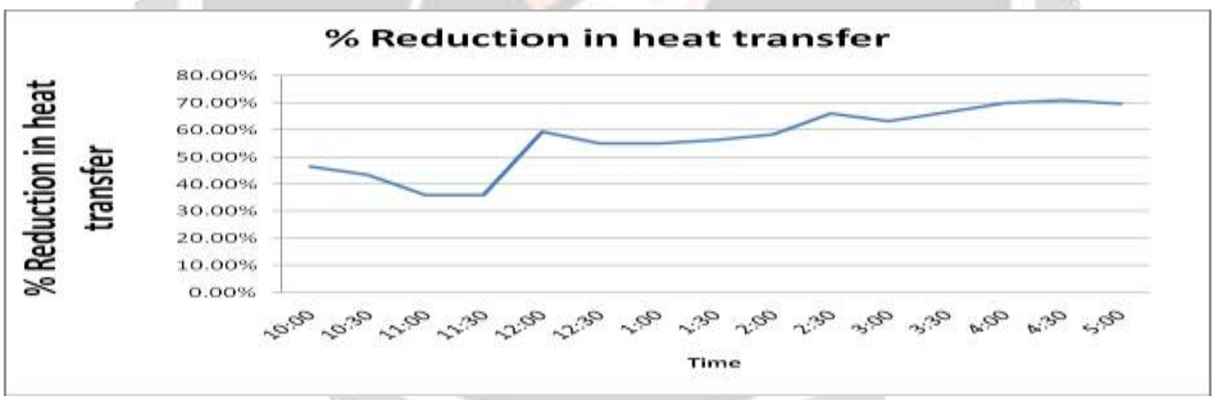

Figure 4.3:- % reduction in heat gain through roof insulation

4.4 Use of insulation on the roof

Figure 4.4 indicates the cooling effect of insulated roof by thermocol sheet. It shows the sample one day data for the variation of room temperature of room 1 (insulated RCC roof with thickness of insulation 60 mm) and room 2 (with bare RCC roof). It also indicates that the temperature below the RCC slab in room 2 was between 26.6 ^{0}C to 37.6 ^{0}C while 23.3 ^{0}C to 34.2^{0}C in room 1. This roof cooling system has stable indoor temperature and lower heat transfer from roof than bare RCC roof, so better cooling effect was achieved.
This indicates that the average percentage reduction in heat gain from the roof is 32.61%. The maximum percentage reduction in heat gain from the roof was observed at 3.15 pm. More cooling can be achieved by increasing the insulation

thickness.

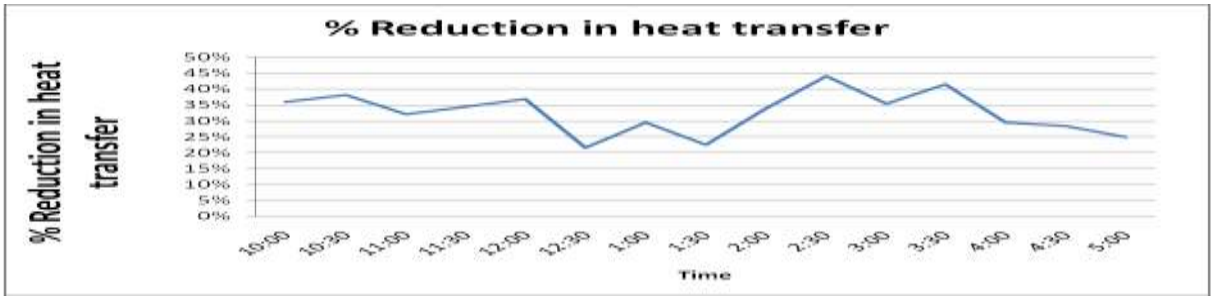

Figure 4.4:- % reduction in heat gain through insulation on the roof

4.5 Use of reflective Roof

Figure 4.5 shows the effect of reflective cooling (use of silver paint) on room temperature. It shows the sample data for variation of room temperature of room 1 (use of silver paint) and room 2 (with bare RCC roof). It also indicates that the temperature below RCC slab in room 2 was between 26^0C to 37.7 ^{0}C while 23.3 ^{0}C to 33.7 ^{0}C in room 1. This roof cooling system provides stable and lower indoor temperature than bare RCC roof. . Evidently room 1 has a better cooling effect than room 2.

The reason for this seems to be the thermal stratification inside the reflective roof during day hours. Figure 2.6 indicates that the average percentage reduction in heat gain from the roof is 24.8%. The maximum percentage reduction in heat gain from the roof was observed at 2.00 pm. reduction in heat gain from the roof was never constant it always changes with time.

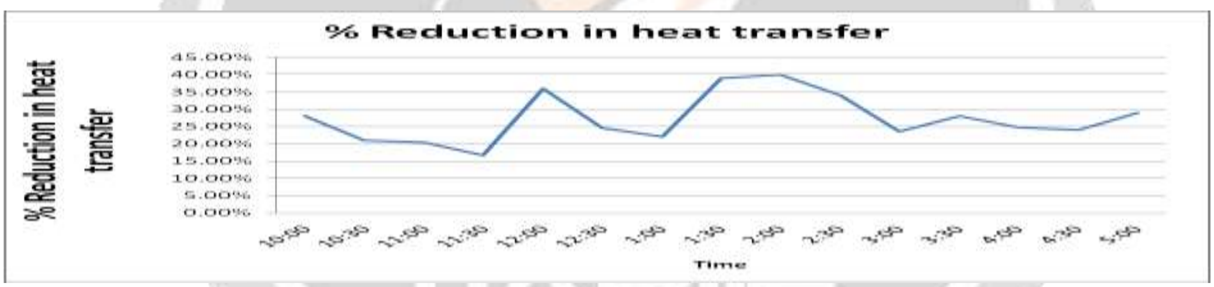

Figure 6.5:- % reduction in heat gain through Reflective roof

5. CONCLUSION

An extensive review of the experiments results has exposed the following key factors

1.Observations in the City of Ujjain, all five methods (roof pond, evaporative cooling using Jute cloth over the roof and spraying water over the roof, using insulation (thermocol), and reflective roof) were effective in reducing heat flow through the roof, thus lowering the energy demand for space conditioning in the building.

2. Net reduction in roof cooling load has been computed and compared for five roof cooling methods e.g., roof pond, use of wet jute cloth over the roof, use of spay water over the roof, insulation over the roof, and use of reflective roof as shown in Fig 7.1. The results show that the average % reduction of heat gain was found to be, 43.20%, 37.20%, 50.45%, 32.51%,25% using roof pond , wet jute cloth , roof insulation , insulation on the roof , reflective roof respectively.

3. In order to study optimum depth of water in roof pond, experiments were conducted using water depth of 50 mm, 100 mm and 150 mm. The net % reduction in heat gain from roof was found to be 37%, 48 % and 42% for water depth of 50 mm. 100 mm and 150 mm respectively. The 50 mm water depth was found to optimum for practical use. This may be due to too much water increasing the heat storage of the pond, and in turn causing less heat transfer by water evaporation due to lower water temperature. Thus, the optimal water depth is about 100 mm in this case.

4. All five methods were thermally effective in the summer. All methods installed on a conventional roofing system reduced the heat flow through the roofing system and all the time gives better performance than conventional RCC roof because the temperature in room with RCC slab was always grater then room with passive cooling concept.

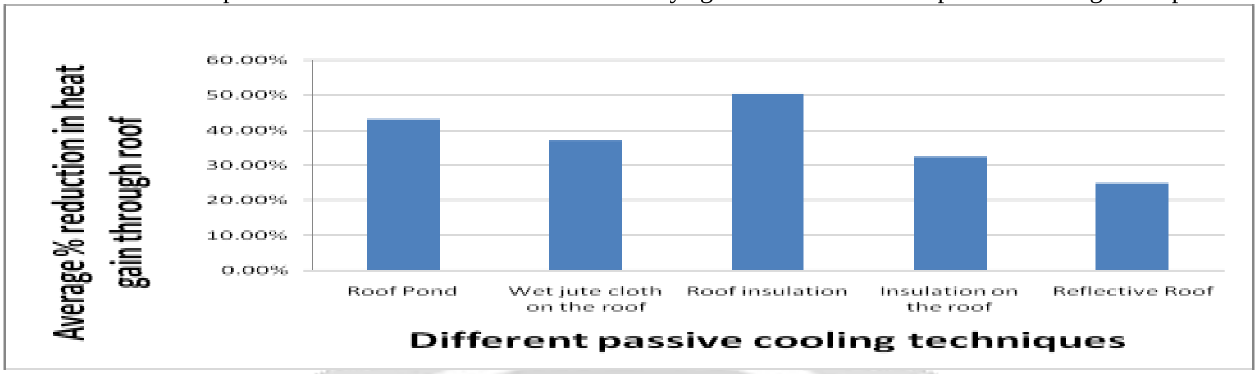

Figure 5.1 Average % cooling load reduction in heat gain though roof by different passive cooling techniques

5. Thermal comfort cannot be archived only by applying any of these passive cooling techniques because maximum number of time room temperature was above comfort level, but we can reduce the load on air conditioner.
6. All six methods were effective in reducing high temperature and diurnal temperature fluctuations experienced by the roof membrane in conventional roofing system in the summer.

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