PERFORMANCE OF AN EVAPORATIVE COOLING SYSTEM IN AN ENCLOSURE OVER THE ROOF-TOP OF AN AIR CONDITIONED BUILDING WITH A MICROCONTROLLER BASED CONTROLLER

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ABSTRACT

In this paper, a computer aided design technique is used with an aim to optimize the cooling potential of evaporating water and reducing the roof heat flux in an air conditioned building. As a case study, a room at the top floor of a college building with a narrow enclosed space for water evaporation over the roof is proposed. A microcontroller based controller is designed to meet the specifications of temperature and flow rates of incoming and outgoing air streams. Hourly requirement of water and air flow to achieve the indicated reduction in roof heat flux during summer are computed. The advantage of the same structure in reducing roof heat loss in winter is also presented.

Key Words: Evaporative Cooling, Roof Heat Flux, Thermal Comfort

1. INTRODUCTION

P.O. Fanger [1] in 1977, suggested certain combination of the indoor environmental parameters such as air temperature, mean radiant temperature, air velocity and humidity that should be maintained for human thermal comfort. He also suggested that no discomfort should be created by local heating or cooling of the body or by a vertical air temperature gradient. ASHRAE Handbook of Fundamentals, 2001 [2] also stipulates that temperature difference between the head and ankle should be less than 3K, as the basic thermal comfort requirement.

However, if the roof of a building is directly exposed to solar radiation in summer, the ceiling temperature is much higher than the temperature of the floor and other walls, causing thermal discomfort due to the unsymmetrical temperature fields within the room. Further, if such a room is air conditioned, by providing an ordinary air conditioner, the cool air settles towards the floor, whereas the ceiling is at a much higher temperature, due to the exposed roof. In order to study the effect of unsymmetrical temperature fields, Vladimir Zmrhal [3] has presented experimental measurement results of thermal comfort in a space with radiant cooled ceiling to achieve optimal thermal comfort.

In order to reduce roof heat flux, several methods are employed all over the world. Green Roof Technologies have been developed to keep the roofs cool and provide aesthetic looks to the buildings. Mathew Frith [4], and Erik van Lennep and Sinéad Finn[5] have presented some guidelines for incorporating and developing Green Roofs. Melissa Senatore [6] has also beautifully described the advantages and merits of the Green Roof Technology in urban settings.

However, the Green Roof Technologies involve extensive use of water and strengthening of building structures to take the additional loads. Places such as Delhi, can not afford to use water for green roofs. We also have problems of mosquito breeding, growth of bacteria and fungi and accumulation of dirt. It is necessary to look for other solutions to reduce the roof heat flux and the resulting thermal discomfort.

In the present paper we propose to optimally utilize the cooling potential (latent heat) of water by the process of evaporation within a built up enclosed space over the roof top of the building. During the day time a controlled quantity of liquid water will be evaporated and it will absorb a corresponding amount of thermal energy from the space. During the night a certain amount of water will condense back to liquid phase. Controlled quantities of make up water will be introduced to the space at the required intervals of time. The incoming and outgoing airflows will also be controlled. In the following sections, the processes of heat and mass transfer are studied by simulation and the results are presented.

2. A CASE STUDY

We consider a class room (6m x 6m x3 m high) located at the top floor of the college. It is ((9AM to 5 PM)) assumed to be well air conditioned for room air temperature of 25°C but its roof is exposed to sun (figure 1). As explained above, vertical thermal gradients exist in the room and cause thermal discomfort. It is proposed to cool the ceiling of this room by constructing a narrow (0.15m high) space over the roof for controlled evaporation process. The following specifications of the structure are considered:

Room: 6mx6mx3 m
Roof (0.15m thick RCC):
Thermal Capacity = 330 kJ/m2.K ;
Thermal Conductivity = 1.3/mK
Space: height = 0.15 m
Roofing (0.02 m thick RCC):
Thermal Capacity = 40 kJ/m2.K

With these values, the heat transfer coefficients and thermal capacitances are computed
As follows:
Overall heat transfer coefficient of the thin roofing, U1 = 676 kJ/hr. K
Overall heat transfer coefficient of the space, U2 = 1100 kJ/hr. K
Overall heat transfer coefficient of the main roof, U3 = 371 kJ/hr. K
Lumped thermal capacitance of the space (including roofing), C1 = 1450 kJ/K
Lumped thermal capacitance of the roof, C2 = 11880 kJ/K

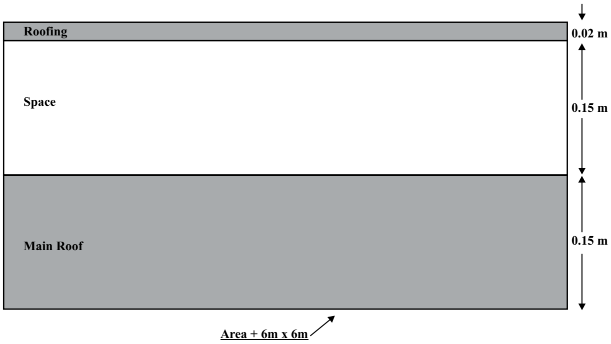

Figure 1 (a) Dimensions (not to scale) of the proposed enclosed space showing the roofing, air space for evaporation of water and the main roof of the room

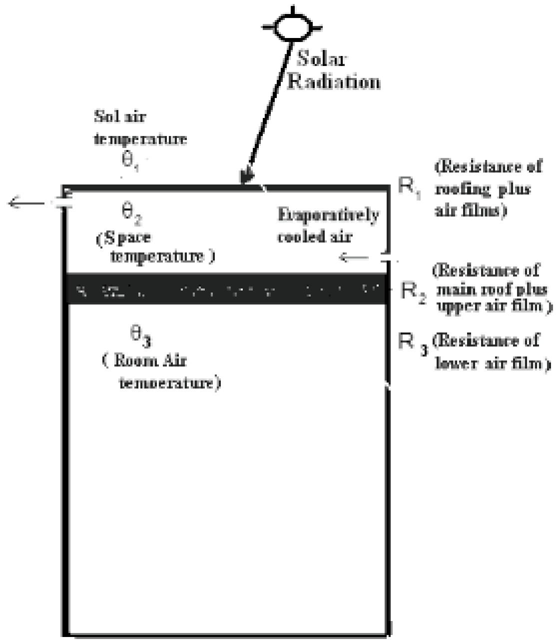

Figure 1(b): An Air Conditioned Room with an Enclosed Space for Evaporatively Cooled Air over its Roof Top. (Temperatures of sol air, enclosed space and room air as well as various thermal resistances are depicted)

The thermal system of Fig.1 can be represented by an equivalent network shown in figure 2. It is based on the simplifying assumptions that the thermal properties of the system may be represented by their lumped equivalent values and it is also assumed that the room is maintained at some constant temperature by its air conditioning equipment (not considered in this paper).

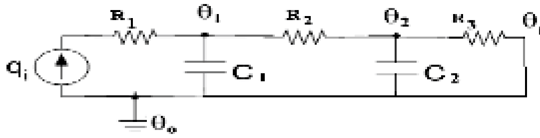

Figure 2: An equivalent network of the thermal system

Under these conditions, heat balance equations for the space and the roof material can be written as follows:

$$\underbrace{q_{in}}_{\text{Heat in}} = \underbrace{\frac{\theta_1-\theta_2}{R_2}}_{\text{Heat Out}} + \underbrace{C_1\frac{d\theta_1}{dt}}_{\text{Heat Stored}} \quad \text{.... (1)}$$

$$\underbrace{\frac{\theta_1-\theta_2}{R_2}}_{\text{Heat In}} = \underbrace{\frac{\theta_2-\theta_3}{R_3}}_{\text{Heat Out}} + \underbrace{C_2\frac{d\theta_2}{dt}}_{\text{Heat Stored}} \quad \text{.... (2)}$$

These differential equations can be solved for θ1 and θ2 in terms of the resistances and capacitances of the above structures using Laplace Transforms or some other method. In our case study, θ3 represents the constant temperature of the air conditioned room, as already stated above. Several Computer Simulation techniques are also available.

Here we have used Trnsys [7] to analyze the model. TYPE 12 model of TRNSYS analyzes a building structure using a single thermal conductance and lumped capacitance. It provides mass fluid rate of the fluid, instantaneous heating/cooling loads and average space temperature etc as outputs of the model.

Figures 3a, 3b and 3c depict the hourly values of roof heat flux during the months of April, May and June respectively. The reduction in roof heat flux for summer in Delhi due to the proposed over roof structure is clearly visible in these diagrams. The hourly quantities of water required to be recharged to the proposed enclosure are shown in diagrams 4a, 4b and 4c for April, May and June respectively. The latent heat of evaporation of this water will neutralize the heat entering the space due to solar radiation, and this will result in decrease in temperature of the space and also reduction in heat flux entering the main room.

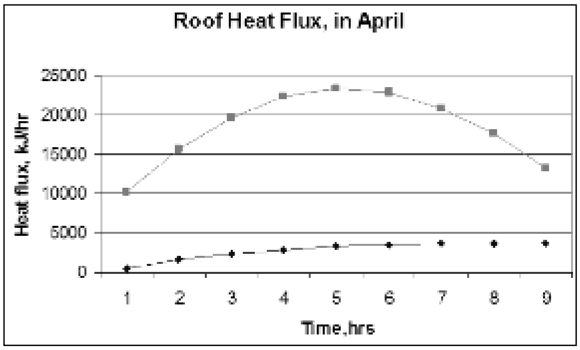

Figure 3a:
Hourly Values of Roof Heat Flux in the Month of April

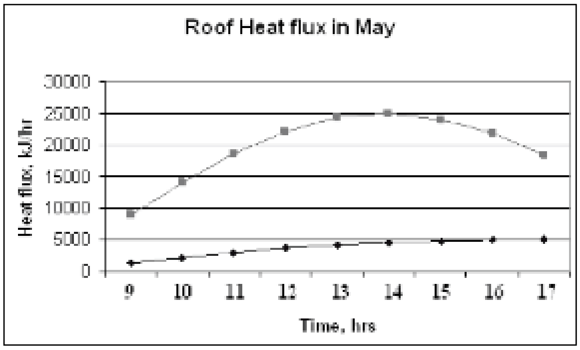

Figure 3b:
Hourly Values of Roof Heat Flux in the Month of May

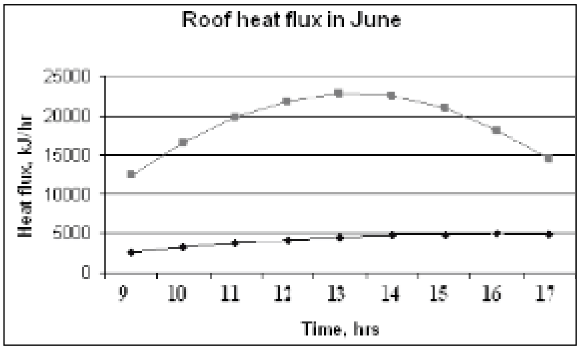

Figure 3c:
Hourly Values of Roof Heat Flux in the Month of June

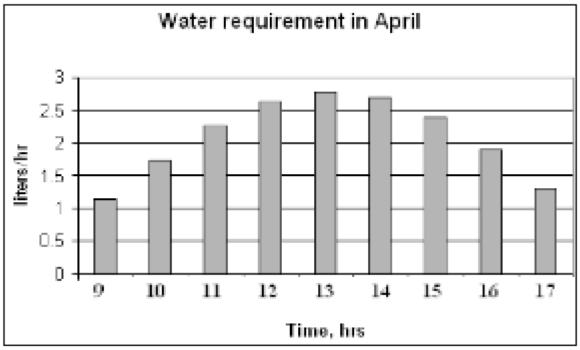

Figure 4a:
Hourly Values of Water Requirement in the Month of April

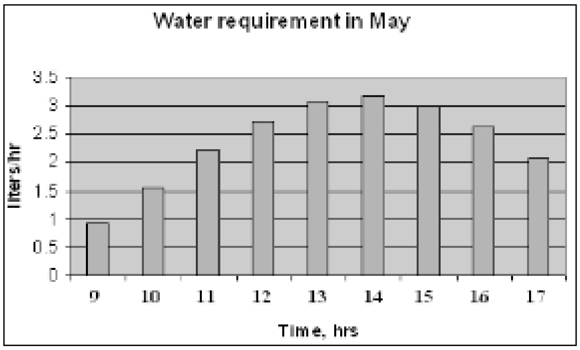

Figure 4b:
Hourly Values of Water Requirement in the Month of May

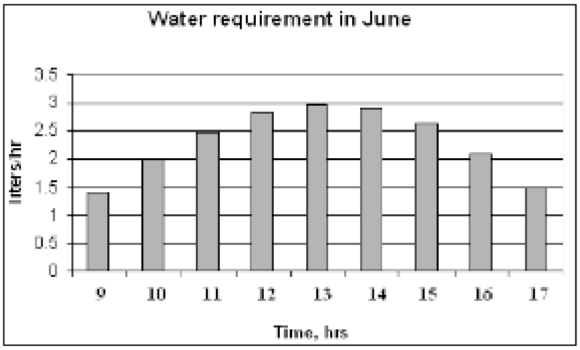

Figure 4c:
Hourly Values of Water Requirement in the Month of June

Table 1 (a): Hourly values of required mass flow rate of moist air in April for different saturation Levels Air saturation, %

Time	100%	80%	60%	40%
9:00	8.73E+01	1.09E+02	1.46E+02	2.18E+02
10:00	1.03E+02	1.29E+02	1.72E+02	2.58E+02
11:00	1.11E+02	1.39E+02	1.85E+02	2.78E+02
12:00	1.12E+02	1.39E+02	1.86E+02	2.79E+02
13:00	1.06E+02	1.32E+02	1.76E+02	2.64E+02
14:00	9.54E+01	1.19E+02	1.59E+02	2.38E+02
15:00	8.06E+01	1.01E+02	1.34E+02	2.01E+02
16:00	6.34E+01	7.92E+01	1.06E+02	1.58E+02
17:00	4.34E+01	5.42E+01	7.23E+01	1.09E+02

Table 1 (b): Hourly values of required mass flow rate of moist air in May for different saturation levels Air saturation, %

Time	100%	80%	60%	40%
9:00	6.18E+01	7.72E+01	1.03E+02	1.54E+02
10:00	8.48E+01	1.06E+02	1.41E+02	2.12E+02
11:00	9.85E+01	1.23E+02	1.64E+02	2.46E+02
12:00	1.04E+02	1.31E+02	1.74E+02	2.61E+02
13:00	1.04E+02	1.29E+02	1.73E+02	2.59E+02
14:00	9.77E+01	1.22E+02	1.63E+02	2.44E+02
15:00	8.72E+01	1.09E+02	1.45E+02	2.18E+02
16:00	7.31E+01	9.13E+01	1.22E+02	1.83E+02
17:00	5.67E+01	7.08E+01	9.45E+01	1.42E+02

Table 1 (c): Hourly values of required mass flow rate of moist air in June for different saturation Levels Air saturation, %

Time	100%	80%	60%	40%
9:00	1.39E+00	8.66E+01	2.78E+03	1.24E+04
10:00	2.00E+00	1.04E+02	3.40E+03	1.66E+04
11:00	2.49E+00	1.14E+02	3.82E+03	1.97E+04
12:00	2.83E+00	1.14E+02	4.21E+03	2.18E+04
13:00	2.98E+00	1.08E+02	4.55E+03	2.28E+04
14:00	2.92E+00	9.77E+01	4.82E+03	2.25E+04
15:00	2.62E+00	8.37E+01	4.97E+03	2.09E+04
16:00	2.11E+00	6.62E+01	4.99E+03	1.80E+04
17:00	1.49E+00	4.70E+01	4.93E+03	1.45E+04

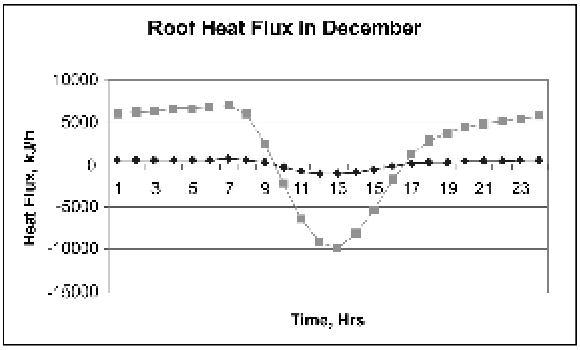

Figure 5a:
Hourly Values of Roof Heat Flux in the Month of December

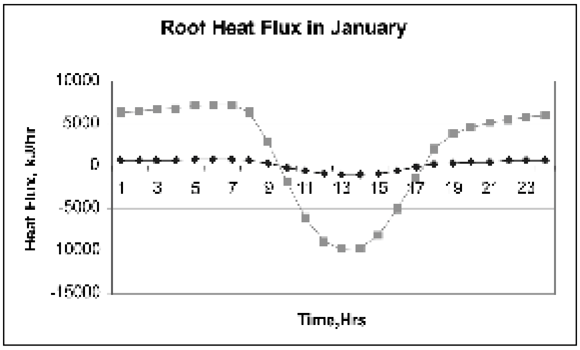

Figure 5b:
Hourly Values of Roof Heat Flux in the Month of January

3. DESIGNING THE CONTROLLER

Some manufacturers such as MICROCHIP [9] offer dc motor controllers based on microcontrollers. The objective of the present study is to design a control system to optimize the consumption of electrical energy and also control the flow rates of air and water effectively. The motor will start & run for 5 minutes at 9 AM and remain off during the next 55 minutes up 10A.M if the dry bulb temperature is higher than the wet bulb temperature and the requirement of water as shown in Figs. 4-6. The dutycycle will vary according to the water requirement in the subsequent hours of the day. The motor will shut down at 5 P.M. The following program is proposed to run the microcontroller:

```
int dbt                 // dry bulb temperature
int wbt         //  wet bulb temperature
int wbd         // wet bulb depression
int i           //number of days in the month
int j           // number of months
int dbtPin = 3;
int wbtPin = 4;
void setup(){
pinMode(2,OUTPUT);
pinMode(3,INPUT);
pinMode(4,INPUT);

void loop(){
dbt == analogRead(3)
wbt == analogRead(4)
wbd = dbt- wbt
}

for(j=0;j<3;j++) {

for(i=0;i<30;i++){
if(wbd>1){
digitalWrite(2,HIGH);
delay(300000)           //motor runs for 5 minutes
digitalWrite(2,LOW);
delay (3300000)         // motor does not run for 55 minutes
}
else
digitalWrite(2,LOW);
}

if(wbd>1){
digitalWrite(2,HIGH);
delay(450000)
digitalWrite(2,LOW);
delay(3150000)
}
else
digitalWrite(2,LOW);
}
if(wbd>1){
digitalWrite(2,HIGH);
delay(600000)
digitalWrite(2,LOW);
delay(3000000)
}
else
digitalWrite(2,LOW);
}
if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(750000)
digitalWrite(2,LOW);
delay(2850000)
}
else
digitalWrite(2,LOW);
}

if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(900000)
digitalWrite(2,LOW);
delay(2700000)
}
else
digitalWrite(2,LOW);
}

if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(750000)
digitalWrite(2,LOW);
delay(2850000)
}
else
digitalWrite(2,LOW);
}

if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(600000)
digitalWrite(2,LOW);
delay(3000000)
}
else
digitalWrite(2,LOW);
}
```

```
if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(450000)
digitalWrite(2,LOW);
delay(31500000)
}
else
digitalWrite(2,LOW);
}
if(dbt1>wbt){
digitalWrite(2,HIGH);
delay(300000)
digitalWrite(2,LOW);
delay(3300000)
}
else
digitalWrite(2,LOW);
}
Delay(5400000)        // motor does not run for
15 hours
}                     //  during night
}                     //  loop for 30 days
}                     // loop for 3 months
```

CONCLUSION

A microcontroller based control system has been designed with an objective of optimizing consumption of water in the evaporative cooling of an over the roof enclosure. The reduction of downward roof heat flux in summer and the upward roof heat loss during the winter in Delhi has been demonstrated by simulation.

References

[1] P.O. Fanger, 1977 "local discomfort to the human body caused by non-uniform thermal environments", Annals of Occupational Hygiene, (1977) 20 (3): 285-291

[2] ASHRAE Handbook 2001 Fundamentals. Atlanta, 2001

[3] Vladimir Zmrhal, 1999, "Thermal Comfort and Temperature Distribution in a Room with Radiant Cooled Ceiling" Czech Technical University, Prague, 1999.

[4] Mathew Frith, 2004, "Green Roofs - Benefits and Cost Implications" Draft guidelines for DCC to develop planning directives for the incorporation of Green Roofs in new development. - enquiries@ecologyconsultancy.co.uk

[5] Erik van Lennep and Sinéad Finn, 2008, "A green roof policy guidance paper for dublin"

[6] Melissa Senatore, 2009, "Green Roof Technology in Urban Settings", msenatore@kentlaw.edu

[7] Klein et al, " Transient System Simulation "1971

[8] S.Mani, " Handbook of Solar Radiation in India", 1981

[9] Microchip, 2010 " Motor Control Design Solutions", www.microchip.com