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Effect of Waterproof Insulation on Thermal Design of Residential Building—A Case Study

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Paper presents cooling load comparison of building with waterproof insulated roof section and the building with moist and conventional sections. Influence of moisture on overall thermal performance, heat gain factors and indoor air temperature of the envelop have also been dealt with. The study is based on the work done at Central Building Research Institute (CBRI), Roorkee, which gives a simple alternate method to compute indoor air temperature of the envelop. It requires to compute total heat gain through all its components of the building. Net heat gain averaged over the entire surface of a building is correlated with indoor air temperature. A single storied residential building comprising two rooms and a kitchen are taken into consideration. In high humidity prevailing condition the absorbed moisture in building sections increases and as a result there is a change in thermophysical properties of the material. Therefore, thermal transfer functions and indoor environment change accordingly.

Introduction

Studies on energy planning and modelling have become a very active area of research because energy supply has become scarce, expensive and unreliable. In India, energy consumption is given as 52 per cent (of energy) in the industrial sector, 23 per cent of it in transportation and 11 per cent in domestic sector. Out of 11 per cent energy consumption in domestic sector, most of it is consumed for achieving comfort in buildings. In terms of energy savings in the residential sector, cooling load plays an important role for both conditioned and unconditioned buildings. If cooling load of an enclosure increases the energy consumption also increases and by utilizing water proof insulation, cooling load may be reduced which will help to reduce energy consumption in buildings. Thermal design of residential buildings is important, for providing suitable thermal conditions without artificial means of cooling, both for day and night occupancy, due to common practice of sleeping indoors for unconditioned residents. A suitable method[1] has been evolved to evaluate the indoor thermal conditions of a building by which building design can be evaluated with respect to thermal comfort in given conditions. The method deals with the net heat gain averaged over the entire surface area. The ratio of the net heat gain to the building surface area is termed as Building Index (BI). The BI has been correlated with actual indoor air temperature of a room. From this indoor air temperature, air velocity and relative humidity of the place the indoor thermal comfort condition can be determined at a given place.

The research work lacks in comparison to moisture influence on thermal comfort in an envelop and other area of thermal design of buildings. The objective of building design is to make indoor comfort at minimum energy consumption. For hot-dry and hot-humid regions, heat flow into the building is important. Heat flow depends upon the extent of the variation of outdoor environment and thermophysical properties, k, and C of the materials which are used in the structure. Thermal conductivity (k) is a characteristic property of a material which depends on density () and on the amount of moisture present in the sample at the time of computation of cooling load. Thus, total thermal transmittance of a building section is to be determined by the k-values of the materials at an appropriate moisture content. The moisture levels in masonry walls are likely to vary considerably depending on factors like indoor and outdoor climate the type of masonry and construction. Since it is not feasible to take all such factors into consideration while calculating the thermal

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transmittance, it is convenient to assign a so-called standard moisture content. In hilly and hot-humid areas moisture contents vary from 3 to 5 per cent by volume. Similar views were expressed by Cammerer[2] stating that the magnitude of the moisture content depends on many factors such as climate, season, location, and height of the building as well as quality of the building material. He assumed that the moisture content was greater for a material facing outside than for one facing inside and explained that the moisture in organic materials, owing to their hygroscopic qualities, is entirely or partly absorbed by the fibres where insulating properties are thereby reduced. The air space, on the other hand, which takes the most active parts, remains intact. In one of the study[3], changes in specific heat and density of porous material take place along with an increase in moisture content. On the basis of these changes in basic thermophysical properties the variation in response factor of phase lag, decrement factor, etc. has been studied.

Theoretical Background

The energy balance equation in a thin layer of moist material may be expressed as Eq. (1).

$$\frac{dQ}{dx}+\rho C\frac{dT}{dt}+\frac{dW_m}{dt}.h_m=0, \qquad \ldots (1)$$

and heat flow caused by moisture content may be added to the conduction heat transfer described by Fourrier's law giving total heat flow as Eq. (2).

$$\frac{dT}{dt}=\frac{k}{\rho .C}.\frac{d^2T}{dx^2}+g_m.h_m\,. \qquad \ldots (2)$$

Now by assuming the moisture to be distributed uniformly in the medium, i.e. by taking moisture gradient as zero, we have the resultant heat flow equation as given by:

$$\frac{dT}{dt}=\frac{k_m}{\rho_m .C_m}.\frac{d^2T}{dx^2}\,. \qquad \ldots (3)$$

where, k_m, ρ_m and C_m are the weighted values of k, ρ and C, respectively caused by uniformly distributed moisture.

The weighted values of thermophysical[4] properties ρ_m and C_m are computed as given in Eq. (4).

$$\rho_m = \rho\ (1 + 0.01{*}p)\ \text{kg/m}^3, \qquad \ldots (4)$$

and

$$C = (\rho_d{*}C/\rho_b) + 1000 + V/\rho_b)\ J/\text{kg}^{o}C, \qquad \ldots (5)$$

where p is percentage of moisture present in the material and overall thermal transmittance value (U) is computed as shown in Eq. (6).

$$U=\frac{1}{h_0}+\sum\frac{L}{K}+\frac{1}{h_i}\,. \qquad \ldots (6)$$

From Eq. (6), if k is changed to k_m for different moisture content of the building component, the U-value changes to U_m and is given by Eq. (7).

$$U_m=\frac{1}{\dfrac{1}{h_o}+\sum\dfrac{L}{k_m}+\dfrac{1}{h_i}}\,. \qquad \ldots (7)$$

Computational Procedure

To determine indoor air temperature the correlation has been established between building index BI and indoor air temperature of envelopes. The correlation has been verified for several residential buildings for hot-dry and hot-humid climate of Indian condition.

BI can be computed by the expression derived in Eq. (8).

$$BI = 2.15{*}\left[\frac{\sum_{i=1}^{n} U_i A_i (T_{SOL} - T_{ia})}{\sum_{i=1}^{n} A_i}\right], \qquad \ldots (8)$$

where, n is the number of building components, walls, roof, windows, doors and intermediate walls (wherever available), T_{SOL} is sol air temperature and is given by Eq. (9).

$$T_{SOL} = T_{OA} + \frac{\alpha I}{h_o} - \frac{I}{h_o}\,. \qquad \ldots (9)$$

Here, T_{ia} = Indoor base temperature = 26.7 °C for a given climatic zone in Indian condition has been taken,

A_i = Surface area of i^{th} component, and

U_i = Overall transmittance value of i^{th} component.

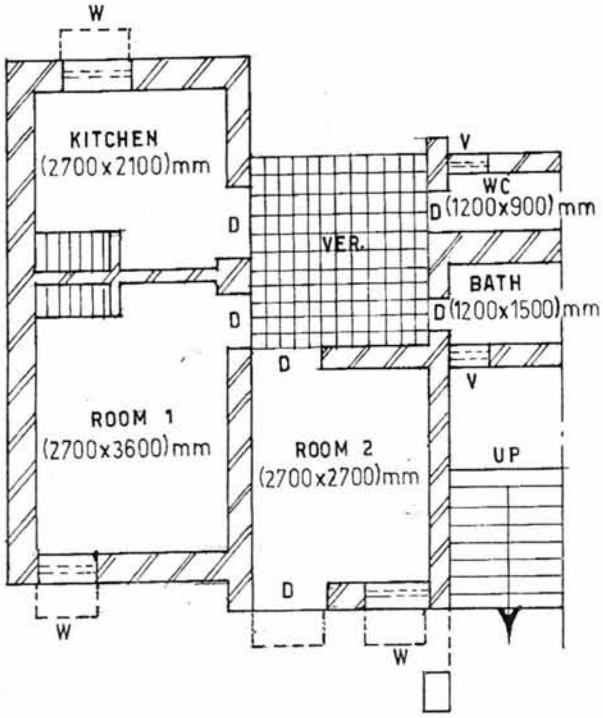

Figure 1—Block diagram of a LIG house

From Eq. (8), BI for 24 h can be computed for an envelop but only maximum, minimum and mean values of BI are sufficient to elaborate the comfort inside a building. Corresponding maximum, minimum and mean values of indoor air temperature can be determined by the BI values which indicates the indoor comfort condition. The correlation between BI and indoor air temperature T_{ia} is given by Chandra *et al.*[4]

Application to Residential Building

Thermal performance of a single storied house for low income group has been illustrated. BI for dry and different moisture content have been computed. Later indoor air temperatures have been determined and comparison for different ranges of moisture content in building components have been made with dry building section and with waterproof insulated roof for the same building. The plan and specification of the building are shown in Figure 1.The house consists of two rooms and a kitchen. The various dimensions are also shown in Figure 1 and detail specifications are given in Table 1. All components except window and unexposed surface may not contain moisture and there may have not been an influence of moisture. But other components have different U-value with different moisture content. These values are given in Table 2. It is found that BI value less

Table 1— Rooms specificatio n of a LIG house

	Room 1	Room 2	Kitchen
Wall	22.5 cm brick with cement plaster on both sides		
East and West North and South	2.7 x 3.0 m	2.7 x 3.0 m	2.7 x 3.0 m
	3.6 x 3.0 m	2.7 x 3.0 m	2.1 x 3.0 m
Roof (i) 11.25 cm RCC + 7.5 cm MP + 5.0 cm BT with light surface finish (ii) 11.25 cm RCC + 5.0 cm thermocole + 6 cm BT + waterproofing treatment with bitumen			
Dimension	3.6 cm x 2.7 m	2.7 cm x 2.7 m	2.7 x 2.1 m
Window	3.0 cm glass pan		
Door	5.0 cm wooden		
Height	3 m	3 m	3 m

Table 2—*U*-value of building components for different moisture contents

Moisture content Per cent	Roof				Wall	
	(i) Section ordinary roof	Per cent Increase in *U*-value	(ii) Section roof with waterproof insulation	Per cent increase in *U*-value	*U*-value	Per cent increase
Dry	2.35	0	0.54	Nil	2.12	0
1	2.72	16	0.54	Nil	2.49	17
2	2.93	9	0.54	Nil	2.74	12
5	3.13	8	0.54	Nil	2.87	6

Table 3— Step by step computation of heat gain for kitchen of the house

Elements with orienta-tion	Shading of surface	Surface area (m^2)	Exposed area (m^2)	Computed HGF		Total HGF		HGF. Avg. (KW)
				Max.	Min.	Max.	Min	
Wall N	Unshaded	6.3	6.3	37.6	23.9	236.9	150.6	191.5
S(i)	Unshaded	4.5	2.25	35.5	22.3	88.7	55.7	72.2
S(ii)	Shaded	—	2.25	37.2	22.4	93.0	56.0	74.7
E	Unshaded	8.1	5.94	41.0	24.4	243.5	144.9	201.9
W	-	8.1	NIL	—	—	—	—	—
Door	Shaded-	—	1.8	26.7	26.7	—	—	—
Window	Unshaded	—	2.16	179.1	179.1	386.7	386.7	386.7
Roof	Unshaded	5.67	5.67	41.2	15.4	233.6	87.3	154,.2

Table 4— Building Index value with different moisture content in building sections

Moisture content per cent	Room 1			Room 2			Kitchen		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
0	66.1	43.0	53.6	73.8	50.4	61.5	78.7	55.0	66.9
1	74.3	47.3	59.7	82.8	55.6	68.5	88.2	60.5	74.3
2	79.6	50.2	63.7	88.8	59.0	73.1	94.4	63.6	79.2
5	83.4	52.3	66.6	93.2	61.9	76.6	98.6	66.6	82.6

than 50 gives comfortable temperature. The waterproof insulation on roof has been treated with bitumen and 2.5 cm polyurethane foam which gives minimum BI value.

The detailed procedure calculation of thermal performance for kitchen of the house is illustrated which will be helpful to the users to compute and compare the performance of houses. When building components are exposed and wet, the moisture is absorbed and influence the heat flow through it. The illustration contains the heat flow and BI value due to different ranges of moisture content by the components. These values of heat gain factor, heat flow and BI for different moisture content are given in Table 3 and 4, respectively.

The cooling load for dry and with moisture content of 1, 2, 3 and 10 per cent has been computed and shown as histogram in Figure 2. Similarly heat gain per square meter has been shown for different moisture contents by building components in Figure 3. There is an evident increase in cooling load and heat gain/sqm of the building surface.

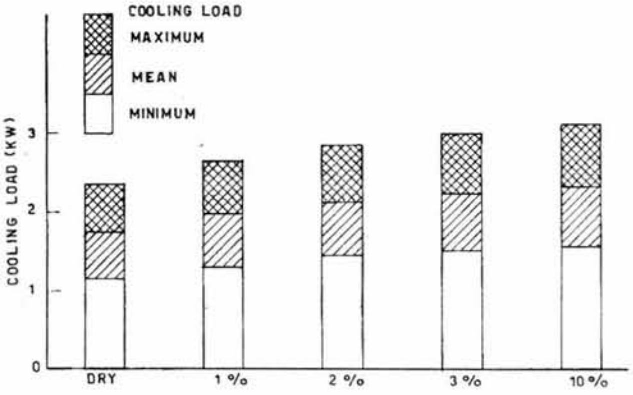

Figure 2—Cooling load for different moisture content of components of room No. 2

Table 5— Effect of waterproof insulation on indoor air temperature, °C

S. no.	Per cent Moisture by Volume			
	0	1	2	5
Room No.1				
Mean	32.4	33.2	33.4	3.7
Maximum	33.6	34.2	34.7	34.9
Minimum	31.0	31.6	32.0	32.4
Room No.2				
Mean	33.2	33.3	34.1	34.3
Maximum	33.7	34.6	34.9	35.4
Minimum	32.0	33.1	33.5	33.6
Kitchen				
Mean	33.7	34.3	34.5	34.9
Maximum	34.3	35.2	35.5	35.8
Minimum	33.0	33.5	33.8	34.0

Moisture Influence on Indoor Air Temperature

The method for finding the BI has been described above. With this BI value, a correlation has been developed between indoor air temperature and BI value. This correlation was developed on the basis of actual measurement of indoor air temperature and BI value for many houses at different temperatures. In the present study, indoor air temperatures are computed by this method for different moisture contents for the material used in building components. Comparisons are made of waterproofing insulation with these values (Table 5). Such types of moist building sections may be treated with moist proof insulation from outside. By using this type of moist proof insulation as 2.5 cm PUF + Bitumen + Aluminum foil, building performance has been predicted in terms of indoor air temperature. The simple way to mitigate heat incoming into the building is white washing on top most surface of roof and outer surface of walls. But for moist building section, its impact is marginal. In both the methods discussed here, indoor temperatures for treated with moist proof insulation have been predicted and comparisons are shown in Figure 4.

One of the studies[5] reveals that insulation can be placed at any side of the building section without any change of comfort level. Sometimes it is observed, for short duration that there is hot air wave flowing which affects comfort environment inside the building. By moisture proof insulation this effect can be minimised. These results are shown in Table 5 and Figure 4 together.

Table 5 shows the mean, maximum, and minimum indoor air temperatures of rooms of the building.

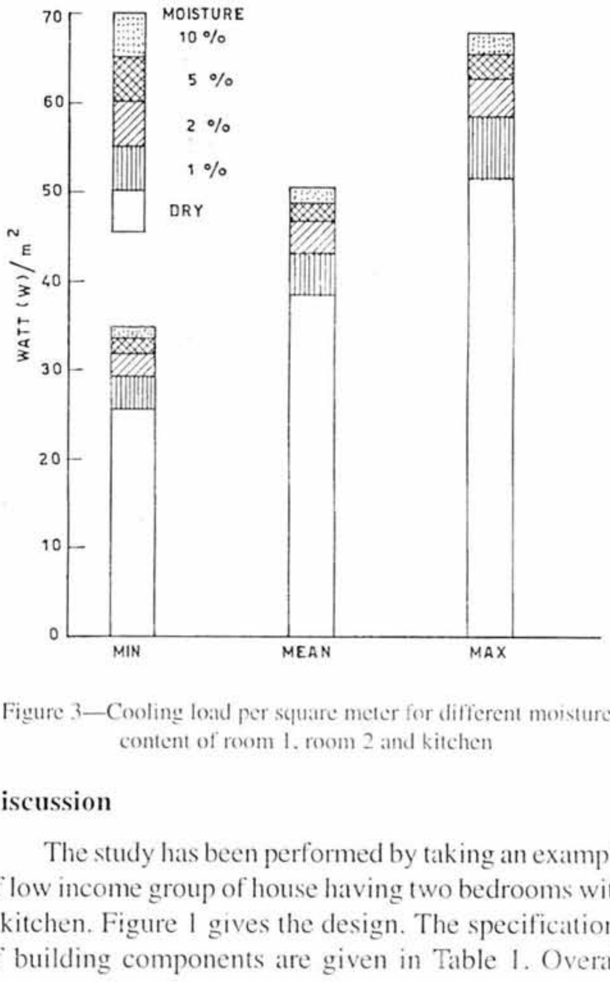

Figure 3—Cooling load per square meter for different moisture content of room 1, room 2 and kitchen

Discussion

The study has been performed by taking an example of low income group of house having two bedrooms with a kitchen. Figure 1 gives the design. The specifications of building components are given in Table 1. Overall thermal performance value of building section changes and these values of the section are given in Table 2. From Table 2, it is evident that as moisture content increases, *U*-value also increases, but this rate of increase is minimum for higher percentage of moisture content. The

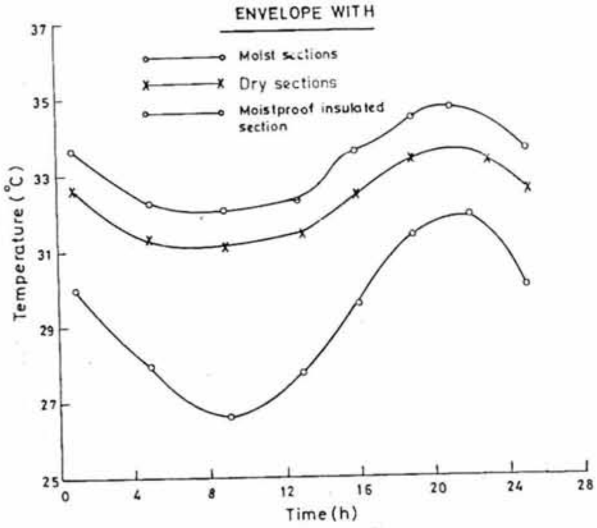

Figure 4—Computed indoor air temperature for room No. 2

performance of building is studied here in terms of BI which is based on total heat gain of the room. The procedure to compute heat gain per unit area of the kitchen, is detailed in Table 3. The value of BI for different percentage of moisture contents are given in Table 4. The values of indoor air temperature for different percentages of moisture content are given in Table 5. The increasing trend of BI with moisture contents is similar to *U*-values. The performance of these bed rooms and kitchen is discussed in terms of room air temperature, cooling load, and heat gain per unit surface area. There are three values of heat gain/m^2 and cooling load of the room is given as mean, maximum, and minimum value. From Figure 2 and 3, it is observed that once moisture is absorbed by building sections, heat flow increases fast. This happens because thermal conductivity value[6,7] for lower percentage of moisture increases rapidly, after that this increase becomes slow, as observed in the case of cooling load and heat gain factors shown in Figure 2 and 3, respectively.

To avoid this trend and mitigate the heat flow, moisture proof insulation is required. By treating with moist proof insulation, building sections became dry with lower *U*-value. Hence, indoor air temperature of building with dry sections during 24 h is also lower than a building with moist sections. Now, if a building is treated with moist proof insulation and coated with white paint then its performance further improves. Effect of coating has been studied[5] and it is found to give about 30 per cent reduction in incoming heat flow. From Figure 4, it is found that reduction in indoor air temperature is higher during morning hours which goes on reducing afterwards. But according to this exercise, it is found that the difference between moist and dry building is of the order of 3°C. By reducing 3°C of peak indoor air temperature, the large amount of cooling load of the room reduces. If the building is moist and treated with moist proof insulation, the reduction of cooling load is observed as 0.45 kW, which is quite encouraging.

Conclusion

The study reveals the importance of moist proof insulation. From the results, it is concluded that more than one-fourth cooling load can be reduced by treatment of building sections. Similarly, indoor air temperature may be reduced by 2°C, on an average. Initially, from zero to 1 or 2 per cent moisture content the rate of increase in heat flow form outside to inside of a building is high. Later this increasing trend of incoming heat is lowered for higher percentage of moisture content in building section.

We already know that comfort inside building depends upon humidity, air temperature and air motion. Comfort condition become uncomfortable although there is minimum rise in room air temperature and humidity because of higher moisture content in building sections. To overcome this type of problem, proper thermal designing of building is required. The required treatment could be carried out, based on the present study. The method to predict indoor air temperature and effect of moisture, and its mitigation is suggested here and is simplified.

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