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Role of Roof Treatment in Thermal Design of Buildings

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The paper describes the treatment of roof sections used by the construction agencies in different parts of India for low income group and economically weaker sections of the society. The thermal performance of roofs should be improved for alleviating indoor thermal conditions and minimising the effect of solar heat in buildings. The evaluation of various roof sections reveals that the low cost materials like mudphuska and lime concrete with thickness varying from 12cm to 15cm can be used with advantage to improve the thermal behaviour of buildings. Alternative roof sections using foam concrete and thermocole insulation and effect of white wash on roof have also been compared.

Introduction

It is common to find that walls and windows are carefully planned in relation to the sun but that little is done to minimise the effect of the sun on the roof, which is directly exposed to solar heat for most of the day. Uncontrolled heat gains and losses through roofs have a pronounced influence on indoor thermal conditions. There is little doubt that these problems can be overcome by careful design by providing thermal insulation in some form or the other.

Steady heat flow depends only on thermal conductivity of the materials but unsteady state heat flow which occurs in variable conditions depends on diffusity of the material used in the building construction. In view of the very significant influence of mass on thermal performance of any building element under conditions of large daily variations in outdoor air temperature and solar radiation, distinction would be made between light weight, medium weight and heavy weight roofs. The use of insulating materials which are resistive, resistive-capactive or reflective in nature can prevent flow of heat to a great extent. Depending upon thermophysical properties and economics of the construction, such materials can be suitably utilised for the roof.

Thermal performance of roof sections commonly used by Housing Boards and various other Construction Agencies in India along with alternative treatments have been presented in this paper.

Roof Classification

The heat storing capacity of the roof also plays a vital role and there is a marked difference between the thermal performance of light weight roof, medium weight roof, and heavy weight roof. Since the insulation minimises the temperature range and mass increases the delay in the heat flow, the judicious use of these two phenomena can be made with advantage in thermal design of roof.

The light weight roofs are mainly asbestos cement sheet, galvanised iron sheet and thin concrete shells. These roofings have low thermal resistance and heat capacity and need high insulative treatment to minimise excess heat gains in summer and heat losses in winter. A layer of insulating material like fibre glass, mineral wool, thermocole and/or reflective treatment may be used for this category.

The brick panel, concrete slab of moderate thickness, core unit and D.C. tile roofings may be termed as medium weight roofs. These roofs have medium thermal resistance and fairly high heat capacity. In this case though the peak heat gain is high but the incoming heat flow is delayed considerably. These roofs can be treated with insulative — capacitive materials like foam concrete, mud phuska and lime concrete.

The heavy weight roofs consist of thick brick panels and thick concrete slabs. For these roofs, treatments such as thin layer of mud phuska and brick tiles is sufficient from thermal consideration.

Proposed Roof Sections

The UN conference on Human Settlement [1] in June 1976, amongst its various other recommendations had suggested that efficient utilisation of energy should be given special consideration in the choice of designs and technologies for human settlements. However, the options in design for energy consideration will vary, depending upon the economics of construction. This study deals with determination of thermal performance of roof sections used in dwellings, for low income group and economically weaker sections of the society, by the following agencies.

1. Delhi Development Authority, City planning units, (DDAP), New Delhi
2. Central Public Works Department (CPWD), Madras
3. Tamil Nadu Housing Board (TN HB), Madras
4. Delhi Development Authority Housing Wing (DDAH), New Delhi
5. National Building Construction Corporation (NBCC), New Delhi
6. Shellcons, Madras
7. Matinee Building Organisation, (NBO), New Delhi
8. Central Building Research Institute (CBRI), Roorkee
9. Hindustan Housing Factory, (HHF), New Delhi
10. Rajasthan Housing Board (RHB), Jaipur

The various roof sections, used by these agencies are shown in Table 1, and are marked by an asterisk. The basic elements in these sections are channel unit, double curved precast shells, foam concrete slab, precast RCC slab; reinforced celcon panels, reinforced brick slab, hollow clay blocks and stone slab. The various treatments to achieve the standard thermal conditions as defined by Indian Code of Practice *I.S.:3792 - 1978 [2]* have been worked out with the help of a computer program "THP" in Fortran Language on SN-73 computer.

Thermal Performance Index

Temperature of the out-door air in contact with the exposed surface of a building which would give the same rate of heat transfer and the same temperature distribution through that material as exists with the actually outdoor air temperature and incident solar radiation upon the sunlit surface is termed as sol-air temperature. The radiation resulting into high sol-air temperature of the components, like wall and roof, contributes significantly to discomfort. It is, therefore, obvious that the criteria based on inside surface temperature of building components would be helpful in evaluating the thermal performance of these components. However, in case of conditioned buildings heat flow is important, since it determines the cooling or heating loads. An index [3] called thermal performance index (TPI) was defined based on peak inside surface temperature for unconditioned buildings such that the rating 100 corresponds to 8°C excess of peak inside surface temperature (θ_m) above 30°C i.e. TPI = (θ_m - 30) x 12.5

Here, TPI of composite roof sections, has been determined by considering the equivalent homogeneous roof construction [4] which give the same contribution to the heating and cooling load at the same time as does the composite construction. For a multilayer composite construction decrement factor (d_n) and phase lag $\varnothing_n$ of the equivalent homogeneous construction are given by

$$d_n = \exp - [(n\pi/24)A^2B]^{1/2} \quad (1)$$

$$\varnothing_n = 1/2\,[(n\pi/24)A2B]^{1/2} \quad (2)$$

Where, $A = \sum (L/K)_1$ (3)

$1 = i, m1, m2..o$

$$B = \frac{1}{A}\left[\Sigma\left(\frac{L}{K}\right)_j (KPC)_j - \left(\frac{L}{K}\right)_o (KPC)_o\right] + \frac{(KPC)_o}{A}\left[\left(\frac{L}{K}\right)_o - 0.1\left(\frac{L}{K}\right)_i - 0.1\left(\frac{L}{M}\right)_{m1} \ldots\right] \quad (4)$$

Where, o is the outer most layer, I is inner most layer, ml, m2 are medium layers. When second term is negative, it is taken as zero. To determine indoor surface temperature the following relation has been employed.

To simulate the outdoor climatic conditions, the average dry bulb temperatures for the hottest period of ten days, in a year over a period of ten years, and sol-air temperatures for absorption coefficient for light and dark exposed surface as 0.7 and 0.3 respectively have been taken.

$$TS = TE + U/h_i\,(SOLTAM - TE) + [\Sigma d_n \cdot A_n \cos(nwt - Y_n - \varnothing_n)] \quad n = 1,2,3 \quad (5)$$

Where,

TE	=	Temperature of enclosure
TS	=	Inside surface temperature
SOLTM	=	Mean sol-air temperature
U	=	Overall thermal transmittance value
A_n	=	$(a_n^2 + b_n^2)^{1/2}$
a_n	=	$\frac{1}{\pi}\left[\int_0^{2\pi} f(t) \cos nwt\, dt\right]$
b_n	=	$\frac{1}{\pi}\left[\int_0^{2\pi} f(t) \sin nwt\, dt\right]$
f(t)	=	function of temperature
Y_n	=	$\tan^{-1}(b_n/a_n)$

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Thermal Performance of Roof Sections

Several ways such as insulations, surface colour and shading can be adopted [5] to reduce solar heat gain through roof sections. In residential buildings the various construction agencies have mostly used medium weight roof for which materials like mud phuska, lime concrete, foam concrete or themocole depending upon the economics can be used to mitigate the flow of heat. The Indian Code suggests maximum TPI value of 100 for roof sections in hot-dry climate. The thickness of layers to achieve recommended thermal standards have been worked out for all the four materials listed above. It may be seen that where a large thickness of mud phuska or lime concrete is needed to satisfy the required standards, a coat of white wash on the roof top may be applied to reduce the solar absorptivity of the surface form 0.7 to 0.3, whereby it minimises the heat flow. It may be seen that, in general, a 38 percent reduction in TPI value is obtained in case where surface is white washed. Further since the dark surfaces absorb more heat, the resulting inside surface temperatures are high as is clear form higher TPI values for section 1.a[3] and 1.b[3] in Table 1. It is seen that colour of exposed surface can play an important role in determination of thermal performance of roof sections which can be improved by providing a light shade finish. The absorption co-efficient for solar radiation for surfaces of different colours are given in Table 2.

Table 1

Thermal Performance Index of Various Roof Sections

Sl No.	Recommended Basic Element	External Elements							
		Mudphuska^{B}		Lime concrete		Foam concrete		Thermocole	
		Th	TPI	Th	TPI	Th	TPI	Th	TPI
1	2	3		4		5		6	
Delhi Development Authority, (City Planning) and National Building Organisation, New Delhi									
1(a)	13 cm channel unit	5*	150	-	-	7.5	102	5.0	99
1(b)	-do-	5^{w}	84	-	-	-	-	-	-
1(c)	-do-	17.5	108	-	-	-	-	-	-
Hindustan Housing Factory, New Delhi									
2(a)	13 cm channel unit and 4cm cement conc.	0*	198	-	-	7.5	104	5.0	98
2(b)	-do-	12.5	112	-	-	-	-	-	-
3(a)	7.5 cm Lime fly ash cellular slab	0*	185	10	149	7.5	112	5	112
3(b)	-do-	15.0	108	10^{w}	83	-	-	-	-
4(a)	Foam concrete	-	-	-	-	20	101	-	-
Hindustan Housing Facctory, New Delhi and Central Building Research Institute, Roorkee									
5(a)	5 cm precast RCC slab	5*	152	-	-	7.5	98	5	102
5(b)	-do-	5^{w}	87	-	-	-	-	-	-
5(c)	-do-	17.5	108	-	-	-	-	-	-
Central Public Works Department, New Delhi									
6(a)	3 cm D.C. tiles	2.5*	195	15	195	-	-	7.5	110
6(b)	-do-	10	143	17.5^{w}	108	-	-	-	-
6(c)	-do-	10^{w}	80	-	-	-	-	-	-
7(a)	7.5 cm RCC	5*	138	7.5^{w}	88	10	105	5.0	105
7(b)	-do-	5^{w}	72	-	-	-	-	-	-
7(c)	-do-	15	114	-	-	-	-	-	-
Tamil Nadu Housing Board, Madras									
8(a)	8 cm celcon panel	4*	140	7.5	143	-	-	5.0	110
8(b)	-do-	4^{w}	74	7.5^{w}	86	-	-	-	-
8(c)	-do-	15	113	-	-	-	-	-	-
National Building Construction Corporation, New Delhi									
9(a)	4 cm D.C. Tiles	0*	257	15^{w}	106	10	100	7.5	103
9(b)	-do-	7.5^{w}	87	-	-	-	-	-	-
9(c)	-do-	17.5	121	-	-	-	-	-	-
Delhi Development Authority (Housing Wing), New Delhi									
10(a)	7.5 R.B. slab	5^{w}	139	-	-	7.5	114	5.0	111
10(b)	-do-	15	101	-	-	-	-	-	-
Shellcon, Madras									
11(a)	13 cm H.cl block	5*	119	10	123	7.5	105	5	108
11(b)	-do-	10	111	5^{w}	76	-	-	-	-
Rajasthan Housing Board, Jaipur									
12(a)	7.5 cm stone slab	5	137	-	-	-	-	-	-
12(b)	-do-	5^{w}	72	9*	151	10	109	5.0	109
12(c)	-do-	15	113	9^{w}	83	-	-	-	-

B - 5 cm brick tiles over mud phuska is layed as water-proofing course
w - Roof top is white washed
* - Original specifications used by the agency
D.C. - Doubly curved
H.cl - Hollow clay
Th - Thickness in cm

Table 2
Absorption Coefficient of Surfaces Due to Colour

Surface colour	Absorption coefficient (for solar radiation)
Black	0.90
Red	0.74
Grey	0.70
Aluminium paint	0.40
Green	0.40
White	0.30

It can be seen from Table 1 that sections used by various construction agencies, mostly need some thermal insulation for providing acceptable thermal conditions. However, in order to bring them to acceptable range a layer of capacitive insulation such as lime concrete and mud phuska in 12 to 15cm thickness may be used.

In the case of insulating materials like foam concrete and thermocole a minimum thickness of 5cm and 2.5cm respectively may be used. It can also be seen that effectiveness of the treatments depends on the type and thickness of the basic structural element and the nature of the surface e.g., in the case of channel unit and D.C . tiles (Table 1, Sections 1.c[3] and 6.c[3] a thickness of 17.5cm and 10cm of mud phuska, respectively, is required to achieve the desired TPI values, with surface as white washed in later case. The data given in this paper has been worked out for hot-dry climate, but it can be extended to other climatic regions of the country.

Conclusion

The classification of data based on thermal performance index enables the designers to make a quick assessment of relative performance of these roof section.

The sections used by the various construction agencies, in general, do not satisfy the thermal performance standards. However, they can be improved by addition of capacitive and insulative layers. The thickness of insulative layer depend on the basic structural element.

Mud phuska and lime concrete with thickness of 12cm to 15cm can be used to improve the thermal performance of roof sections. Further, by white washing the roof top, the thickness of the materials may be reduced. It also provides an average reduction of 38 per cent in TPI value for the same section.

In order to improve the thermal performance, light finish may be applied on exposed surface. If cost permits foam concrete (5cm) or thermocole (2.5cm) can also be used to improve the thermal performance.

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Appendix

- d_e - Decrement factor of equivalent homogeneous construction
- ϕ_e - Phase lag of equivalent homogeneous construction
- L - Thickness of the material
- k - Thermal conductivity of the material
- P - Density of the material
- c - Specific heat of the material
- θ_m - Inside peak surface temperature
- w - Angular frequency ($2\pi/T$ is time period)
- n - Number of Harmonics
- h_i - Inside film heat transfer coefficient