BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE, INDIA

THERMAL PERFORMANCE RATING AND CLASSIFICATION OF FLAT ROOFS IN HOT DRY CLIMATES

Introduction

A proper selection of roof sections should receive attention in the design stage itself. but in the absence of thermal performance standards a true comparison of the cost of different roofing materials and systems is not possible. A roof should provide adequate protection from the sun and the rain, in addition to satisfying the structural and durability requirements. In tropical climate the thermal problem gets more complicated by the large diurnal swings of temperature and high intensity of solar radiation. Under these conditions the commonly used steady state property namely the U-value alone cannot form a satisfactory basis and the thermal storage effects of thick roof sections cannot be ignored. The periodic heat flow characteristics expressed in terms of decrement factor and time lag have to be considered. The relative importance of the U-value and the periodic characteristics depend upon the type and thickness of the materials employed in the construction.

In an earlier Digest* thermal time constant (Q/U) and damping (D) values for a few sections were given. They were based on empirical relations, and find limited application. The thermal damping and thermal time constant of a section will, of course, give some idea on the thermal capacity effect, but do not provide the actual thermal performance of a section. The thermal behaviour of a building section is also a function of the sol-air temperature wave form, which depends on the climatic factors, surface colour, and orientation. For arriving at a generalised basis of thermal rating of building sections rigorous periodic heat flow theory is to be considered. It is possible to compute hourly inside surface temperature and heat flow through building sections under given climatic conditions, but the procedure involved requires large computations, which may not be easy for practising architects and engineers. What is needed is a single parameter which takes into account the actual thermal behaviour of building sections, under typical climatic conditions. This digest attempts to fulfill this need and provides a guidance to the designers for proper selection of flat roof sections in hot dry climates.

For thermal comfort the roof should ensure lower internal surface temperatures to minimize the radiant heat load to the occupants. Higher ceiling temperatures also contribute indirectly in raising the indoor air temperature. Hence ceiling temperature can be taken as a criterion for thermal performance rating of the roofs. Peak degree hours (P.D.H.) above a base temperature of 30°C, and peak heat gain factor (P.H.G.F.) for a conditioned enclosure at 25°C have been taken as the basis for the evaluation of thermal performance of roof sections of unconditioned and conditioned buildings respectively.

Flat Roof Sections

A typical flat roof may be of three or four layer composite construction (Fig. 1). The basic structural

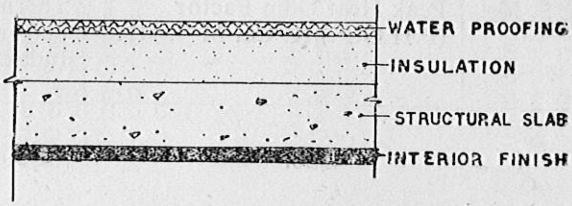

FIG. I. A GENERAL FLAT ROOF CONSTRUCTION

element usually consists of RCC, REC or stone slabs. Precast concrete roofing units of different types and shapes have come into use in recent years. Light weight concrete and aerated concrete are also expected to become popular in the near future.

Exterior treatments fall under two categories -insulative and water proofing. In traditional roof constructions, lime concrete and mud phuska, which are believed to act as thermal insulation, are common.

*Building Digest No. 15—"Thermal Considerations in Building Design ...

A variety of other insulating materials such as foamed concrete, vermuculite, coconut pith concrete; and materials with extremely low density and high thermal resistivity, such as thermocole, fibre glass, mineral wool are also in use to some extent.

The water proofing layer may be either a bitumenous product like tarfelt or simple bricktiles.

Cement sand plaster is the most common interior finish for normal buildings.

Rating and Classification

The basis adopted for rating and broad classification (A,B,C,D and E) for unconditioned and conditioned situations are given in Table 1 (a) and 1 (b) respectively. The thermal performance index (T.P.I.) and broad classifications for a number of roof sections with different combinations of structural and insulative layers have been worked out for both unconditioned and conditioned situations and are given in Table 2. It can be seen from the Table 2 that the traditional

TABLE—1 **Basis for Thermal Performance Rating of Roofs**
(a) **Unconditioned Buildings**

S. No.	Peak Degree Hours (P.D.H.) Deg. C. above 30°C	Thermal Performance Index (T.P.I.)	CLASS	Quality of Performance.	Remarks
1.	⩽6°C	⩽75	A	Good	Preferable where better standards are aimed at.
2.	>6°⩽10°C	>75⩽125	B	Fair	Acceptable though not adequate.
3.	>10°⩽14°C	>125⩽175	C	Poor	Unsatisfactory. Requires moderate treatment to upgrade to B.
4.	>14°⩽18°C	>175⩽225	D	Very poor	Very unsatisfactory
5.	>18°C	>225	E	Extremely poor	Requires high degree of insulation to upgrade to B.

N B: P.D.H. 8°C corresponds to 100 in T.P.I.

(b) **Conditioned Buildings**

S. No.	Peak Heat Gain Factor (P.H.G.F.) K. Cal M^{-2}. HR^{-1}	Thermal Performance Index (T.P.I.)	CLASS	Qnality of Performance	Remarks.
1.	⩽20.	⩽50	A	Good	Pereferable and economically justified.
2.	>20⩽40	>50⩽100	B	Fair	Acceptable but not fully adequate.
3.	>40⩽60	>100⩽150	C	Poor	Unsatisfactory. With moderated treatment can be upgraded to B.
4.	>60⩽80	>150⩽200	D	Very poor	Very unsatisfactory. Requires high degree of insulation to upgrade to B.
5.	>80	>200	E	Extremely poor	

N. B.- P.H.G.F. 40.0K. cal. M^{-2}. HR^{-1} Corresponds to 100 in T.P.I.

TABLE 2—Thermal Performance Index (T.P.I.) and Classification of Flat Roofs (Hot Dry Climate)

S. No.	Basic Structural Element	ROOF SECTION: Exterior Treatment: Insulative	ROOF SECTION: Exterior Treatment: Water Proofing	ROOF SECTION: Interior Finish	UNCONDITIONED: TPI	UNCONDITIONED: Class	CONDITIONED: TPI	CONDITIONED: Class
I	**Reinforced Cement Concrete (R.C.C.)**							
1.	10.0 cm R.C.C. Slab	—	Tarfelt	1.5 cm Plaster	225	E	274	E
2.	,,	—	9 cm Lime Conc.	,,	134	C	143	C
3.	,,	5.0 cm Mud Phuska	5.0 cm Bricktile	,,	122	B	125	C
4.	,,	7.5 Mud Phuska	,,	,,	110	B	106	C
5.	,,	5.0 cm Vermuculite Conc.	Tarfelt	,,	90	B	70	B
6.	,,	5.0 cm Foam Conc.	,,	,,	81	B	55	B
7.	,,	2.5 cm Thermocole.	,,	,,	76	B	46	A
8.	,,	2.5 cm Coconut Pith Conc.	5.0 cm Bricktile	,,	71	A	39	A
9.	,,	10.0 cm Vermuculite Conc.	Tarfelt	,,	72	A	39	A
10.	,,	10.0 cm Foam Conc.	,,	,,	66	A	30	A
11.	,,	5.0 cm Thermocole	,,	,,	64	A	26	A
II	**Reinforced Brick Concrete (R.B.C.)**							
1.	11.5 cm R.B.C.	—	Tarfelt	1.5 cm Plaster	203	D	235	E
2.	,,	—	9 cm Lime Conc.	,,	126	C	128	C
3.	,,	5.0 cm Mud Phuska	5.0 cm Bricktile	,,	116	B	114	C
4.	,,	7.5 cm Mud Phuska	,,	,,	105	B	97	B
5.	,,	5.0 cm Vermuculite Conc.	Tarfelt	,,	89	B	65	B
6.	,,	5.0 cm Foam Conc.	,,	,,	81	B	53	B
7.	,,	2.5 cm Thermocole	,,	,,	76	B	44	A
8.	,,	5.0 cm Coconut Pith Conc.	5.0 cm Bricktile	,,	71	A	38	A
9.	,,	10.0 cm Vermuculite Conc.	Tarfelt	,,	72	A	38	A
10.	,,	10.0 cm Foam Conc.	,,	,,	66	A	28	A
III	**Stone**							
1.	5.0 cm Sand–Stone	—	Tarfelt	—	306	E	384	E
2.	,,	—	9.0 cm Lime Conc.	—	182	D	205	E
3.	,,	7.5 cm Mud Phuska	5.0 Bricktile	—	143	C	147	C
4.	,,	5.0 cm Foam Conc.	Tarfelt	—	108	B	83	B
5.	,,	2.5 cm Thermocole	,,	—	99	B	70	B
6.	,,	10.0 cm Foam Conc.	,,	—	86	B	42	A
IV	**Cored Unit**							
1.	13.0 cm Cored Unit	—	Tarfelt	1.5 cm Plaster	184	D	210	E
2,	,,	—	9.0 cm Lime Conc	,,	119	B	117	C
3.	,,	5.0 cm Mud Phuska	5.0 cm Bricktile	,,	110	B	105	C
4.	,,	7.5 cm ,,	,,	,,	99	B	90	B
5.	,,	5.0 cm Vermuculite Conc.	Tarfelt	,,	85	B	61	B

Contd.

Table 2 Contd.

S. No.	Basic Structural Element	ROOF SECTION: Exterior Treatment: Insulative	Water Proofing	Interior Finish	UNCONDITIONED TPI	UNCONDITIONED Class	CONDITIONED TPI	CONDITIONED Class
6.	13.0 cm Cored Unit	5.0 cm Foam conc.	Tarfelt	1.5 cm Plaster	78	B	49	A
7.	,,	2.5 cm Thermocole	,,	,,	74	A	41	A
8.	,,	5.0 cm Coconut Pith Conc.	5.0 cm Bricktile	,,	69	A	35	A
9.	,,	10.0 cm Foam Conc.	Tarfelt	,,	70	A	34	A
10.	,,	10.0 cm Vermuculite Conc.	,,	,,	65	A	27	A
V.	**Cellular Unit**							
1.	7.5 cm Cellular Unit	—	Tarfelt	1.5 cm Plaster	216	D	250	E
2.	,,	—	9.0 cm Lime conc.	,,	140	C	140	C
3.	,,	5.0 cm Mud Phuska	5.0 cm Bricktile	,,	129	C	124	C
4.	,,	7.5 cm ,,	,,	,,	116	B	105	C
5.	,,	5.0 cm Vermuculite Conc.	Tarfelt	,,	99	B	75	B
6.	,,	5.0 cm Foam Conc.	,,	,,	90	B	60	B
7.	,,	2.5 cm Thermocole	,,	,,	84	B	51	B
8.	,,	5.0 Coconut Pith Conc.	5.0 cm Bricktile	,,	79	B	42	A
9.	,,	10.0 cm Foam Conc.	Tarfelt	,,	79	B	42	A
10.	,,	10.0 cm Vermuculite Conc.	,,	,,	72	A	32	A
VI	**Sintered Fly Ash Aggregate Concrete**							
1.	15.0 cm C.F. Ash Conc.	—	Tarfelt	1.5 cm Plaster	156	C	160	D
2.	,,	—	9.0 cm Lime conc.	,,	110	B	97	B
3.	,,	5.0 cm Mud Phuska	5.0 cm Bricktile	,,	102	B	88	B
4.	,,	7.5 ,,	,,	,,	92	B	76	B
5.	,,	5.0 cm Vermuculite Conc.	Tarfelt	,,	85	B	55	B
6.	15.0 cm C.F. Ash Conc.	5.3 cm Foam conc.	,,	,,	79	B	45	A
7.	,,	2.5 cm Thermocole	,,	,,	75	A	38	A
8.	,,	5.0 Coconut Pith Conc.	5.0 cm Bricktile	,,	70	A	32	A
9.	,,	10.0 cm Vermuculite	Tarfelt	,,	71	A	32	A
10.	,,	10.0 cm Foam Conc.	,,	,,	66	A	25	A
VII	**Siporex Slab**							
1.	12.5 cm Siporex Slab (A)	—	Tarfelt	1.5 cm Plaster	100	B	54	B
2.	,,	3.0 cm Cement conc.	,,	,,	99	B	52	B
3.	15.0 cm Siporex Slab (A)	—	,,	,,	92	B	42	A
4.	,,	3.0 cm Cement conc.	,,	,,	90	B	40	A
5.	12.5 cm Siporex Slab (B)	—	,,	,,	102	B	59	B
6.	,,	3.0 Cement conc.	,,	,,	99	B	55	B
7.	15.0 cm Siporex Slab (B)	—	,,	,,	91	B	45	A
8.	,,	3 0 cm Cement conc.	,,	,,	89	B	43	A

Siporex (A)—density 496 Kg. M^{-3}
Siporex (B)—density 688 Kg. M^{-3}

roofing constructions without additional thermal protected treatment (I.1, II.1, III.1), mostly fall under the class D and E which are poor in thermal performance. Lime Concrete and mud phuska type of treatments (I.2, I.3, I.4, II.2, II.3, II.4, III.2, III.3), which provide capacitive type of insulation, can hardly push them to class C or to the border line level in class B. Sections with insulative concrete (I.5, I.6, I.8 II.5, II.6, II.8, III.4) treatment of 5.0 cm thickness, mostly come under class B. In order to bring into class A atleast 10.0 cm thickness of insulating concretes (I.9, I.10, II.9, II.10, III.6) or 5.0 cm thickness of thermal insulating materials (I.11) are to be used.

Higher standards (class A) are justifiable for conditioned buildings as the additional cost involved would pay for itself in terms of reduced initial and running cost of air conditioning. For unconditioned buildings also, classA may be preferred as it would practically eleminate radiant heat load from the ceiling to the occupants. But taking into consideration the prevailing economic conditions of the country, class B, the next lower performance standard may be recommended.

Within a class, further grading of the sections can be made on the relative merit as indicated by the T.P.I values.

Effect of Different Treatments on T.P.I.

The thermal performance of a roof section can be improved in several ways viz, white washing, shading, and insulation treatments. The effectiveness of the treatment also depends on the type and thickness of the basic structural element. The relative improvement in the performance, by the above mentioned treatments for three basic roof slabs namely 5.0 cm stone, 10.0 cm R.C.C. and 20.0 cm R.C.C. is illustrated in Fig. 2 (a)

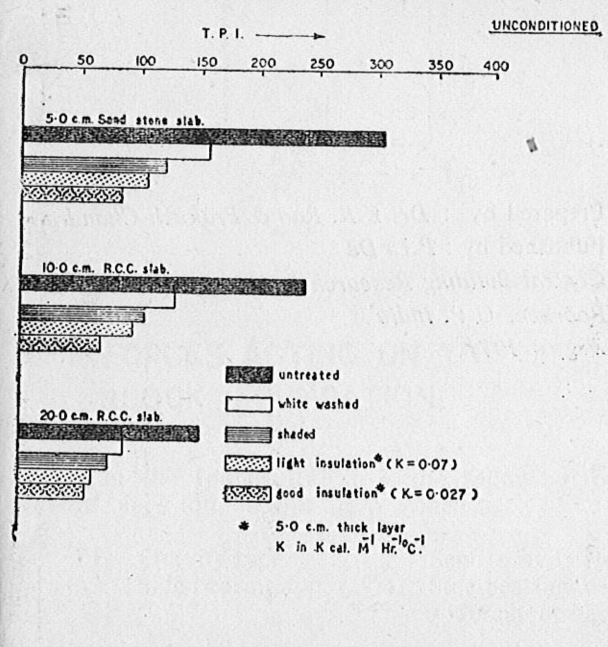

FIG. 2. (a). EFFECT OF DIFFERENT TREATMENTS ON THERMAL PERFORMANCE INDEX

and 2 (b) for unconditioned and conditioned buildings. It can be seen that the insulation is more effective for conditioned buildings. Though fresh white wash brings. the T.P.I. to practically half of its untreated value, its effect should not be expected to last long due to dust collection and algae growth. It is however inexpensive and can be repeated before each summer season. Shading can be expensive and has to be incorporated in the design of the roof system itself. If economics permit a moderate insulation (5.0 cm of foam concrete or 2.5 cm of thermocole, or fibre glass, or mineral wool) is advisable.

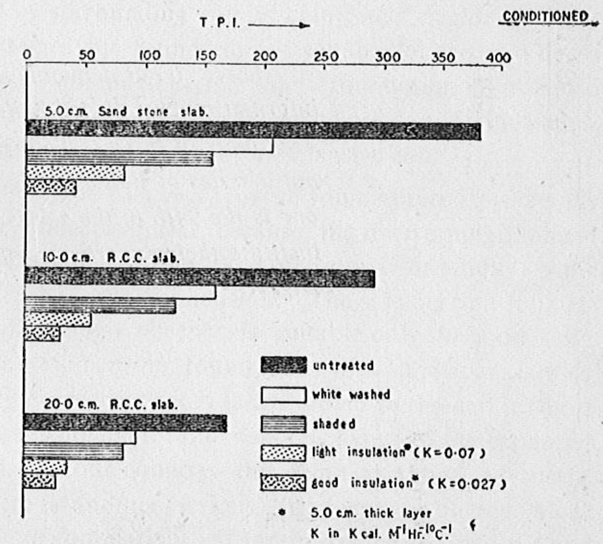

FIG. 2. (b). EFFECT OF DIFFERENT TREATMENTS ON THERMAL PERFORMANCE INDEX

This method of rating can also provide an idea of the absolute values of peak inside surface temperatures and peak heat gain factors for any given section. For example, for the roof section I. 2 in Table 2. the T.P.I. value for unconditioned case is given as 134. The P.D.H. value of the inside surface will then be

$$\text{P.D.H.} = \frac{8}{100} \times 134 = 10.7°\text{C}$$

Thus the peak inside surface temperature will be, t_{is} (peak) = Base temperature + P.D.H. i.e 30°C+10.7°C = 40.7°C.

For conditioned case the corresponding T.P.I. is 143. The peak heat gain factor (P.H.G.F.) will then be

$$\text{P.H.G.F.} = \frac{40}{100} \times 143 = 57.2 \text{ Kcal } M^{-2} HR^{-1}.$$ Similar values can easily be worked out for any other section.

Concluding Remarks

The thermal performance index and classification flow theory and may be used for a proper selection of flat roofs in hot dry climates. As the T.P.I. is evolved on a comparative basis, this rating should hold good for slightly different sol-air temperature and indoor air temperature variations that are likely to occur within a climatic region.

The list presented in the digest covers most of the roofs sections of the existing practice. One may however come across some other combinations of roof sections. The thermal performance index and classification of such roof sections can easily be worked out and supplied to the interested party within a week. Such enquiries are most welcome.

There is a demand for short notes summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need, this Institute is bringing out a series of Building Digests from time to time and the present one is the 94th in the series. Readers are requested to send to the Institute their experience of adopting the suggestion given in this Digest.

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