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Temperature Swing A Design Concept for Air Conditioned Buildings

Introduction

In all developing nations including India, the demand for better standards of comfort is increasing along with the improvements in the economic conditions. As a result more and more buildings, especially commercial, office and hotel buildings are being airconditioned in these countries. The fact remains that air-conditioning of buildings is an expensive proposition and may form as high as 25 percent of the total building financial outlay. In tropical countries like India, cooling forms the major function of airconditioning in most parts and it is well known that refrigeration costs several times more than heating. The modern trends in building design which are characterised by light panel walls and large glass areas have also contributed towards the increase of airconditioning costs, both the initial and operating costs. This has brought to the forefront the need for finding practical ways and means of achieving sizeable economics in airconditioning costs of buildings through a better understanding of the interaction of the building and the air-conditioning system. In the last decade this problem has drawn the attention of research scientists, air-conditioning engineers and architects even in affluent countries.

The relevance of continuing the orthodox design procedures and concepts for estimating the air-conditioning loads is constantly questioned. In recent years a good deal of rethinking has taken place in this field and improved mathematical models,[1,2,3] which closely simulate the real physical problem with all its complexities, have been developed. Equally sophisticated digital computational methods[4],[5],[6] for speedy evaluation of a number of alternative designs and systems, to arrive at an optimum solution. New design concepts like permitting a swing[7 8] in indoor air temperatures of the conditioned space, within the acceptable limits, have been put forward as a possible means of achieving substantial savings in air-conditioning costs.

Before accepting such proposals on an universal basis, its implications are to be examined with reference to the building design and climates concerned. This paper presents the results of a computer study, made to illustrate the influence of the type of construction (heavy or light weight) and type of climate (hot day or hot humid) on the temperature swing of the indoor air of a typical conditioned building module and the consequent effects of such a swing on air-conditioning loads.

Temperature swing

When buildings are to be air-conditioned it is a common procedure to estimate the cooling and heating loads, taking it for granted, that the internal air temperature and humidity are held constant through out the usage of the building.[9] Here the implicit assumption is that the rate of extraction or supply of heat from or to the enclosure, is perfectly matched at all times, with the rate of heat gain or loss into or from the

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conditioned space. In practice such a perfect matching of loads is extremely difficult with the usual types of controls.

The thermal storage effect of the internal structural elements and contents of the building comes into play under two situations. Firstly, the instantaneous heat gains of the directly transmitted solar radiation through unshaded glazed areas and from the radiant heat gains from the internal heat sources will be modified considerably, before they are reflected as the actual cooling load to the plant. Secondly the, "thermal inertia" effects of the internal structural parts and the furniture, come into play when the indoor air temperature is variant. This implies that if the indoor air temperature is allowed to vary, say cyclically, by a few degrees, greater advantage of the thermal storage effects of heavy structures can be taken and the plant size and running costs can be substantially reduced. However, it is necessary to ensure that this temperature swing should be within the acceptable comfort range. Extensive studies carried out in recent years on this problem of fixing comfort limits[10, 11] for different degrees of activity and clothing have confirmed the view point that a close temperature control is not necessary for human comfort. On the other hand, it is even suggested that a gradual change of temperature by 2 or 3 deg. C during the course of the day will prove more stimulating than keeping the temperature rigidly constant.

The commonly used procedures of air conditioning load estimation were developed for constant indoor air temperature conditions and as such are not capable of determining the temperature swing and its effects on airconditioning loads. Methods have been developed by the authors[12], [13] and others[14-15] for the determination of indoor air temperature variations of unconditioned buildings. The same procedures can be applied for the determination of temperature swing in conditioned spaces that can occur under a variety of situations. Loudon[16] has extended the steady-cyclic method to quasi steady cyclic conditions. By these methods it is also possible to estimate the reduction in load that can be expected due to programmed temperature swings of different amplitudes and profiles in air conditioned buildings.

Effect of type of construction and climate on temperature swing

The actual reduction of loads and the consequent savings achieved by permitting a temperature swing in conditioned spaces will depend mostly on the type of construction, design features and the characteristics of the climate of a given place. A typical building module (Fig. 1) has been considered for the purpose of illustration of the above effects. Two types of constructions namely heavy weight and light weight with and without internal partitions have been considered in this study. The constructional details and areas of the building components are listed in table 1.

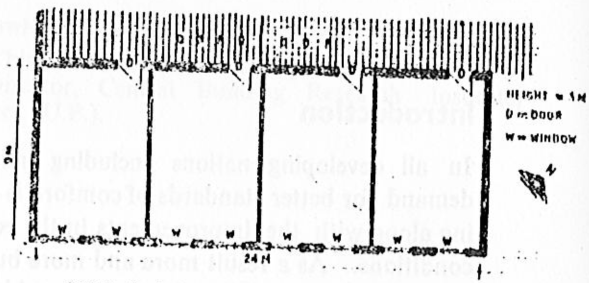

FIG.1-PLAN OF THE BUILDING MODULE OF ILLUSTRATIVE EXAMPLE

Component Loads

Initially the individual component peak loads and their time of occurrence and the actual load presented by each component at time of total peak (sensible) load, of the building module, for both types of constructions, under two types of climate i.e., hot dry (Roorkee) and hot humid (Bombay), on a typical summer day, have been determined. These are presented in tables 2(a) and 2(b) respectively. In these calculations the indoor air temperature is assumed to be kept constant at 25°C. From these tables it can be seen that if the total load is taken as the sum of the individual component peak loads instead of finding out the actual total peak load by summing up the component loads hour by hour, will result in about 20 percent excess. It is also apparent that the percentage load contributed by each component will depend upon many factors such as

Table-1

CONSTRUCTIONAL DETAILS OF BUILDING MODULES

S. No.	Element	Area M²	Construction	
			Heavy weight	Light weight
1.	Roof	216.0	5.0. cm foam conc + 10.0 cm RCC + 1.50 cm plaster	10.0 cm. RCC + 5.0 cm Air space + 5.5 cm Insulation Board*
2.	Walls			
	South East	50.4	1.25 cm plaster + 23.0 cm Brick + 1.25 cm plaster	15.0 cm foam concrete
	South West	27.0	1.25 cm plaster + 23.0 cm Brick + 1.25 cm plaster	15.0 cm foam concrete
	North West	72.0	1.25 cm plaster + 11.5 cm Brick + 1.25 cm plaster	10.0 cm foam concrete
	North East	27.0	1.25 cm plaster + 11.5 cm Brick + 1.25 cm plaster	10.0 cm foam concrete
3.	Floor	216.0	15.0 cm RCC	15.0 cm RCC
4.	Doors (4 nos.)	10.0	2.5 cm Teak wood	2.5 cm Teak Wood
5.	Windows (8 nos.)	21.6	0.125 cm Glass	0.125 cm Glass
6.	Furniture	70.0	2.5 cm Teak Wood	2.5 cm Teak wood
7.	Partition wall (3 nos.)	162.0	1.25 cm plaster + 11.5 cm Brick + 1.25 cm plaster	1.25 cm plaster + 11.5 cm Brick + 1.25 cm plaster

* 1.5 cm Wood Wool Board + 2.5 cm Thermocole + 1.5 cm Wood Wool Board.

type of constructions, ventilation rate and the type of climate. The latent load component due to ventilation and occupants has also been estimated and found to form 17 and 32 per cent of the total (sensible + latent) air conditioning load of the building module, for Roorkee and Bombay respectively.

Hourly Loads and Temperature Swing

The hourly variation of total sensible load with a constant indoor air temperature at 25°C have been determined for heavy and light weight constructions and presented in figures 2 and 3 respectively. The temperature swing that would result, if a constant cooling rate at the mean load level is maintained instead of matching the cooling rate with hourly heat gains, has been determined, for the above four cases and included in the above figures. It can be seen that for a given climate the light weight construction results in larger temperature swing (4.7°C) than that of the heavy weight construction (2.6°C). Similarly for a given construction the temperature swing is higher for hot dry climates than for hot humid climates. The corresponding figures of temperature swing for light weight and heavy weight constructions for Bombay are 2.9°C and 1.6°C respectively. If the temperature swing is much in excess the acceptable limits, as in the case of light weight construction, higher cooling rates than of the mean load level are to be provided. For heavy weight constructions, by accepting a temperature swing of 2° to 2.5°C, as much as 40 per cent reduction in plant capacity can be achieved.

Programmed Swing

For a given construction and climate, by maintaining a constant cooling rate at the mean load level, as was the case discussed above, there will be no control over the temperature swing that would

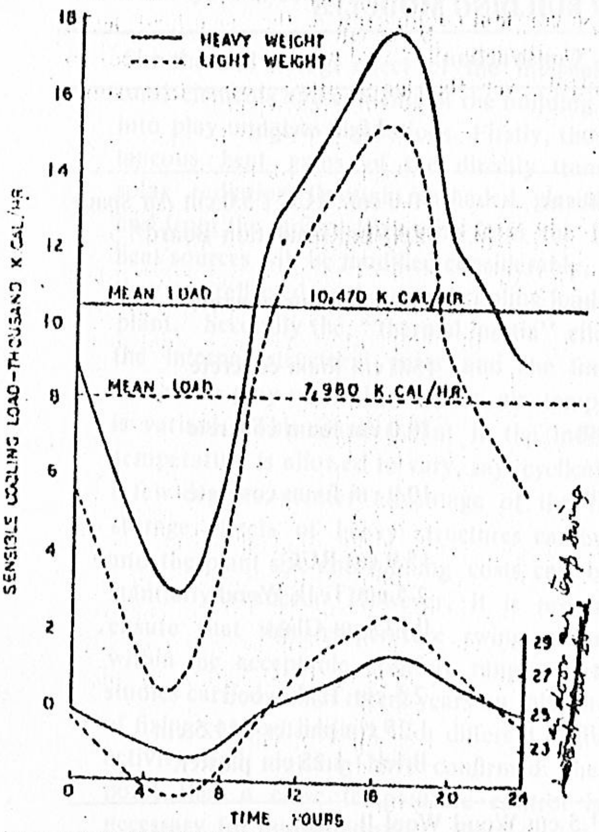

FIG. 2 EFFECT OF TYPE OF CONSTRUCTION ON COOLING LOAD AND TEMPERATURE SWING – HOT DRY CLIMATE (ROORKEE)

result due to the unbalanced heat gains. However, it is also possible to obtain a programmed temperature swing of any desired amplitude and profile with a suitably motorised thermostatic control arrangement. The hourly reductions of the loads due to such a programmed sinusoidal temperature swing of 2°C amplitude and the modified total load profiles have been determined for heavy and light weight constructions for Roorkee and are shown in Figures 4 and 5 respectively. It can be seen that a reduction in peak loads of the order of 30 percent for heavy weight construction and 20 percent for the light weight construction can be expected by a 2°C programmed temperature swing. This brings out the advantages of heavy weight constructions when a temperature swing is permitted.

Under Capacity Plant

Temperature swing occurs also under extreme conditions such as heat wave periods and when under capacity plant is employed. In these situations it is assumed that as long as heat gains are below the capacity of the plant, indoor air temperature is maintained constant at the pre-set temperature by the thermostat controls and a rise in temperature occurs only for the period when the heat gains exceed the plant capacity.

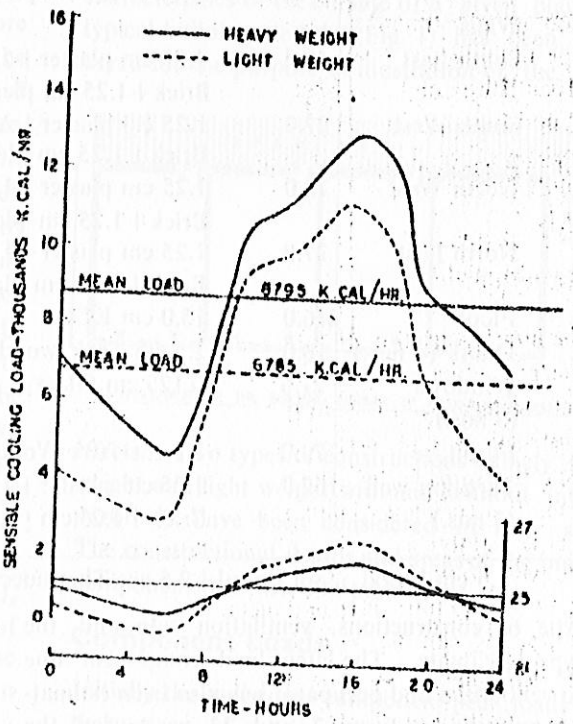

FIG. 3 EFFECT OF TYPE OF CONSTRUCTION ON COOLING LOAD AND TEMP. SWING – HOT HUMID CLIMATE (BOMBAY)

The temperature swing profile that would result due to a 25 percent under capacity plant has been determined for heavy and light weight building modules, for Roorkee and shown in Fig. 6. This again brings out the advantages of a heavy construction in preventing large swings of temperature when the load exceeds the capacity of the plant. As 2° to 2.5°C rise above 25°C is considered to be the acceptable limit for comfort, the possible reduction in plant capacity in the case of light weight construction will be much less than 25 per cent.

Roof Insulation and Partition

In the above cases the building module is taken as a single room without partitions and the roof is insulated and exposed (top floor). The type of

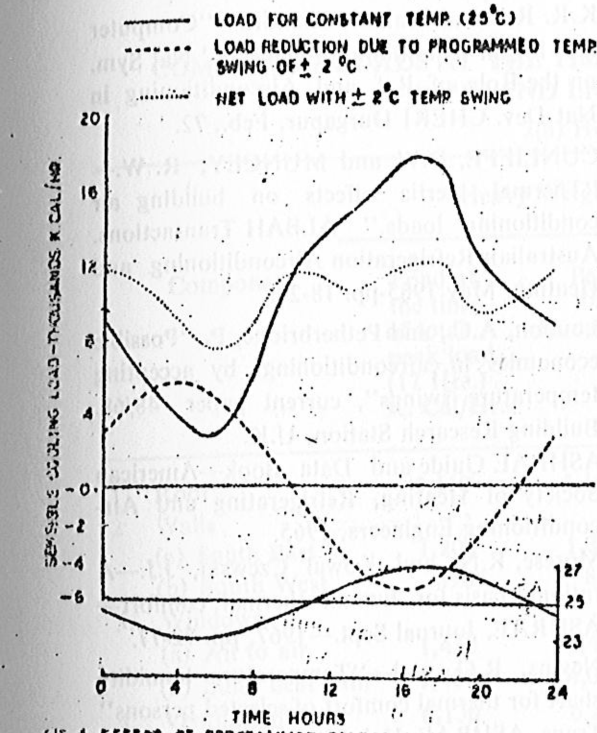

FIG. 4 EFFECT OF PROGRAMMED TEMPERATURE SWING ON COOLING LOAD FOR HEAVY WEIGHT CONSTRUCTION (ROORKEE)

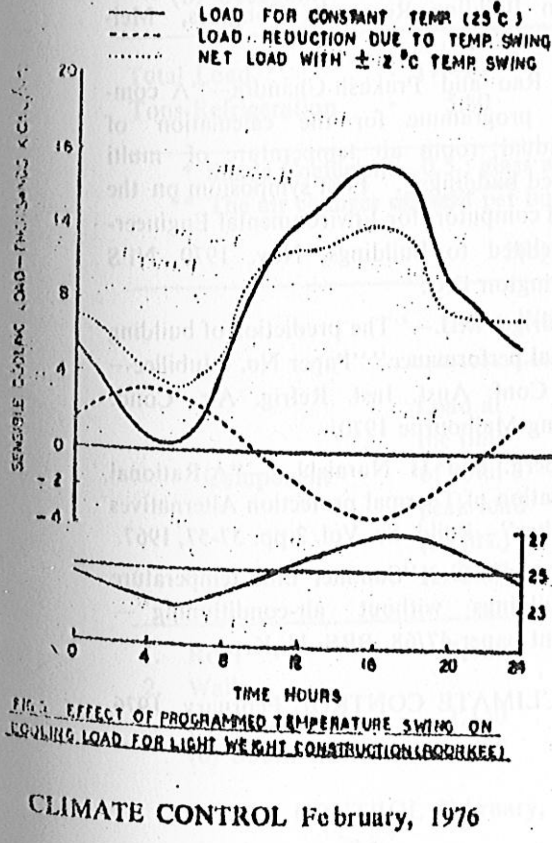

FIG. EFFECT OF PROGRAMMED TEMPERATURE SWING ON COOLING LOAD FOR LIGHT WEIGHT CONSTRUCTION (ROORKEE)

roof (insulated or uninsulated) and its exposure conditions (top or intermediate floor) would influence considerably the magnitude of the temperature swing in an enclosure. Addition of internal partition walls increase the internal mass and hence reduce the amplitude of the temperature swing to some extent. The effect of insulation and the exposed aspects of the roof on the peak and mean loads for heavy and light weight constructions under Roorkee (hot dry) and Bombay (hot humid) summer conditions have been determined and given in table 3. The corresponding temperature swings that would result if a constant cooling rate at mean load level, with and without partitions have also been determined and included in the same table. It can be seen that by insulating the exposed roof a reduction of 40 to 45 percent in load can be expected. In the case of an intermediate floor as compared to the exposed insulated roof the reduction in the load will be of the order of 20-25 per cent. The addition of partition walls will have a moderating effect on the temperature swing and this effect is more prominent in the case of light weight constructions. It can be seen from the table that the reduction, in magnitude of

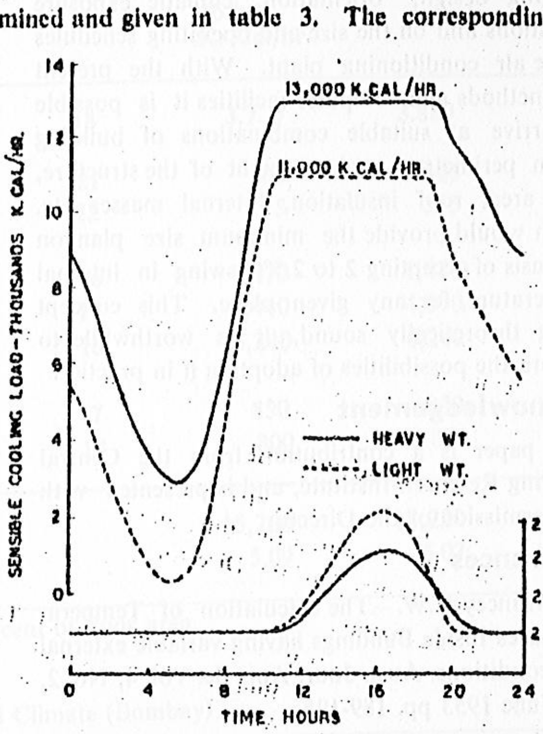

FIG.6 TEMPERATURE SWING DUE TO UNDER CAPCITY PLANT FOR HEAVY AND LIGHT WEIGHT CONSTRUCTION (ROORKEE)

the temperature swing obtained due to the partition walls, is of the order of 0.5°C in the case of heavy weight construction and 1.5°C in the case of light weight construction.

Conclusions

This computer study, on temperature swing as a design concept for air conditioned buildings, brings out clearly that as much as 40 percent reduction in air conditioning loads is possible by accepting a swing of 2 to 2.5°C above the design temperature of the indoor air temperature. The nature and magnitude of the temperature swing in a building will depend on many factors such as building design, orientation, climatic exposure conditions and on the size and operating schedules of the air conditioning plant. With the present day methods and computer facilities it is possible to arrive at suitable combinations of building design perimetres such as weight of the structure, glass area, roof insulation, internal masses etc. which would provide the minimum size plan on the basis of accepting 2 to 2.5°C swing in internal temperature, for any given place. This concept being theoretically sound, it is worthwhile to explore the possibilities of adopting it in practice.

Acknowledgement

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Table-2

COMPONENT LOADS AT THE TIME OF TOTAL PEAK LOAD AND PEAK LOADS FOR HEAVY AND LIGHT WEIGHT CONSTRUCTIONS

2(a) Hot Dry Climate (Roorkee)

Component	Heavy Weight Construction			Light Weight Construction		
	Load at the time of total peak load (17 Hrs.) K. Cal/Hr.	Peak load K. cal/hr.	Time of occurrance Hr.	Load at the time of total peak load 16 hrs. K. Cal/hr.	Peak load K. cal/hr.	Time of occurrence Hr.
1. Roof	5,110	5,120	18	3,7.0	3.880	17
2. Walls						
(a) South East	1,200	1,300	21	505	525	19
(b) South West	490	860	22	175	385	20
3. Windows						
(a) Air to air	1,430	1,470	16	1,470	1,470	16
(b) Solar heat gain*	1,400	4,070	10	1,440	4,070	10
4. Ventilation**	6,130	6,240	16	6,240	6,240	16
5. Internal Heat Sources						
(a) Lights	850	850	17	850	850	16
(b) Occupants	800	800	17	800	800	16
Total Load	17,410	20,710		15,260	18,220	
Tons-Refrigeration	5.80	6.90		5.09	6.07	

* Shade Coefficient—0,5 ; glass area—10 percent of floor area.

** The air changes ~~of fresh~~ air per hour.

2(b) Hot Humid Climate (Bombay)

Component	Heavy Weight Construction			Light Weight Construction		
	Load at the time of total peak load (16 hrs.) K. Cal/hr.	Peak load K. cal/hr.	Time of occurrence Hr.	Load at the time of total peak load (15 hrs.) K. cal/hr.	Peak load K. cal/hr.	Time of occurrence Hr.
1. Roof	4,820	5,190	18	3,400	3,850	17
2. Walls						
(a) South East	1,150	1,215	18	600	500	15
(b) South West	460	680	20	180	300	20

3. Windows						
(a) Air to air	520	580	15	580	980	15
(b) Solar heat gain*	1,410	3,320	10	1,580	3,320	10
4. Ventilation**	3,140	3,410	15	3,410	3,410	15
5. Internal Heat Sources						
(a) Light	850	850	16	850	850	15
(b) Occupants	800	800	16	800	800	15
Total	13,150	16,040		11,300	13,610	
Tons-Refrigeration	4.38	5.33		3.78	4.53	

* Shade Coefficient—0.5. Glass area—10 percent of floor area.

** The air changes of fresh air per hour.

Table-3

EFFECT OF TYPE OF CONSTRUCTION AND CLIMATE ON TEMPERATURE SWING WITH CONSTANT COOLING AT MEAN LOAD

	Hot Dry Climate (Roorkee)				Hot Humid Climate (Bombay)			
Design Variable	Mean Load K. Cal/hr.	Peak Load K. Cal/hr.	Maximum Temperature Swing deg. C.		Mean Load K. Cal/hr.	Peak Load K. Cal/hr.	Maximum Temperature Swing deg. C.	
			W.O.P.	W.P.			W.O.P.	W.P.
A. HEAVY WEIGHT CONSTRUCTION								
(a) Exposed Roof¹	16,080	31,770	5.6	4.5	15,350	27,590	4.3	3.2
(b) Exposed Roof²	10,470	17,410	2.6	2.1	8,795	13,150	1.6	1.1
(c) Unexposed Roof³	7,390	12,600	2.1	1.7	5,720	9,200	1.3	0.9
B. LIGHT WEIGHT CONSTRUCTION								
(a) Exposed Roof⁴	7,980	15,260	4.7	3.4	6,785	14,300	2.9	1.7
(b) Unexposed Roof⁵	6,170	11,420	4.1	2.6	4,840	7,870	2.3	1.0

W.O.P. without partition walls.
W.P. with partition walls

1. Uninsulated roof—15 cm. RCC slab.
2. Insulated roof—5 cm. foamed concrete + 10 cm. RCC Slab + 1.5 cm Plaster.
3. Intermediate floor—15 cm. RCC slab.
4. Insulated—10 cm. RC slab + 5 cm air space + 5.5 cm Insulation Board.