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ABSTRACT

Many modern buildings become uncomfortably warm during sunny spells in the summer, and until recently there was no simple, reliable method of assessing at the design stage whether a building would become overheated. This paper describes a method of calculating summertime temperatures which was developed at the Building Research Station, and gives data on parameters required for calculation. These include--(1) solar radiation intensities, (2) solar gain factors for glass, (3) blinds and other sun controls, and (4) 'admittances' of building components which are a measure of the ability of the components to smooth out diurnal temperatures in the building. (TC)

MAY 1968

Summertime temperatures in buildings

A G Loudon

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Paper presented at the IHVE/BRS Symposium 'Thermal environment in modern buildings - aspects affecting the design team', February 29, 1968

Many modern buildings become uncomfortably warm during sunny spells in summer, and until recently there was no simple reliable method of assessing at the design stage whether a building would become overheated. The paper describes a method of calculating summertime temperatures which was developed at the Building Research Station, and gives data on parameters required for the calculation. These include solar radiation intensities, 'solar gain factors' for glass, blinds and other 'sun-controls', and 'admittances' of building components which are a measure of the ability of the components to smooth out diurnal temperature swings in the building. Experimental data are presented which show agreement with predicted temperatures in unoccupied buildings. Predicted peak temperatures in occupied buildings of two types - schools and offices - are compated with user comments on overheating in summer, obtained from social surveys. The results show that predicted temperatures are closely related to user comments - in other words that the procedures advocated are related to the practical experience of users.

Different solutions to the problem of avoiding thermal discomfort can be explored by this technique and a rational decision made on whether air-conditioning provides the best solution, or whether other changes could be made to the building design to provide a comparable degree of thermal satisfaction.

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BUILDING RESEARCH STATION
Ministry of Public Building and Works

SUMMERTIME TEMPERATURES IN BUILDINGS WITHOUT AIR-CONDITIONING

A. G. Loudon

1. INTRODUCTION

Before the war the chief thermal problem in buildings was underheating in winter. Most buildings were 'heavy' - i.e. constructed of dense concrete or brickwork - and windows were fairly small. There was little trouble from overheating in summer in this type of building. A survey conducted in pre-war office buildings in 1948[1] indicated that only about 9% of the occupants were concerned about overheating.

However summer overheating is now a much more widespread problem than winter underheating, at least in non-domestic buildings such as offices, schools, hospitals and factories. This has been stressed in various publications. A House of Commons Estimates Committee on School Buildings[2] referred to excessive use of glass leading to cases of 'heat exhaustion' in school children. Manning[3, 4, 5] reported overheating in factories, offices and schools. He referred to cases where factory employees refused to work because of summer overheating, arising from solar gains through roofs. Langdon[6, 7] showed that as many as 40% of a sample of 2000 workers in modern London offices were sometimes too warm in summer. By contrast the proportion sometimes too cool in winter was only 23%. Stewart and Kibblewhite[8] showed that air temperatures in July-September 1964 in a group of naturally ventilated offices facing south of east-west were above 24°C (75°F) for some 30-35% of the time.

The chief reason for the recent increase in overheating is the change in styles of building and constructional methods. It is common to use large areas of glazing which can admit large solar heat gains, and also to use lightweight constructional materials which warm up quickly under the influence of solar gains. In some areas, windows have to be kept closed to exclude traffic noise, and buildings cannot be freely ventilated. This means that buildings which are warmer than outside cannot be cooled so effectively by ventilation.

Until recently there was no simple reliable means of predicting internal temperatures in hot weather as a function of building construction, glazing and sun-controls. Work at the Building Research Station has now provided a method. It is simple enough to use along with available methods of computing daylighting and other building requirements to achieve integrated building designs.

This paper sets out the method in some detail, shows how computed peak temperatures relate to user response, and applies the work to design. The essential features of the method are outlined in the main body of the paper, and Appendices give a fuller treatment as taught at recent Building Research Station post-graduate courses. The scheme of calculation forms the basis of a book now in preparation.

2. BASIS OF THE DESIGN METHOD

Maximum temperatures are calculated using:

(1) Data on external temperatures, and radiation intensities on vertical and inclined building surfaces, on days of full sunshine. Loads due to occupancy, lighting and other sources must also be determined.

(2) Data on the transmission, absorption and reflection of solar radiation by glass, sun-controls and other building surfaces.

(3) The method of calculating the thermal response of the building to solar heat gains and any other heat inputs, developed by Danter at BRS.[9]

The first two stages have been described elsewhere[10, 11] and are here briefly recapitulated. The calculation of resulting internal temperatures is set out in more detail.

2.1 Solar heat gains to buildings

Maximum internal temperatures in buildings occur during 'heat-waves' with a succession of warm cloudless sunny days. Such days are rare in Britain, averaging only about ten a year, but the intensities on cloudless days are needed for design calculations. Figure 1 shows how the internal temperature builds up on successive sunny days. The example is for a poorly ventilated room in a lightweight building with south-facing windows occupying 80% of the external wall, where temperatures are very high, and illustrates how buildings warm up. The radiation data and outside temperatures apply to sunny August days. The mean internal temperature slowly builds up to an equilibrium value and there is a diurnal swing about the mean. The maximum temperature occurs during 'steady cyclic' conditions when a regular regime of internal temperature has become established.

BRS research on radiation intensities on horizontal and vertical surfaces[10] has shown that it is convenient to include with direct radiation some of the 'circumsolar' diffuse radiation from near the sun, giving 'augmented direct' radiation.[10] The remaining 'background diffuse' radiation can be assumed to be uniform over the sky vault, and its value was determined. For most parts of Britain in the summer months it was found that 'augmented direct' intensities vary with solar altitude as proposed by P. Moon[12] for direct intensities. Data in Table 6.4 of the 1965 IHVE Guide[13] are a little higher than Moon's values, but are accurate enough for practical purposes. Petherbridge[14] has prepared sunpath diagrams and overlays for cloudless skies based on the BRS data; they enable direct and diffuse intensities to be found for surfaces with any orientation and inclination.

Design daily amounts of radiation on horizontal and vertical surfaces, assuming 20% ground reflectance, are plotted in Figure 2. The maximum daily amounts of radiation are seen to be similar on all vertical surfaces oriented south of east-west, viz. about 17 000 kJ/m^2 (1500 Btu/ft^2) of surface, although orientation affects the time of year at which the maximum occurs; it is June on east and west faces, February and October on south faces. In August, when outside air temperatures are highest, all vertical surfaces south of east-west receive fairly large amounts of radiation. Horizontal surfaces receive more - as much as 28 000 kJ/m^2 (2500 Btu/ft^2) in June. Buildings such as factories with large areas of unshaded rooflights, or poorly insulated roofs, are therefore particularly prone to overheating.

Peak intensities, plotted in Figure 3, are also similar in magnitude for all vertical surfaces oriented south of east-west - about 700 W/m^2 (220 Btu/ft^{2}h) of surface. Orientation, however, affects both the time of year and the time of day at which the maximum occurs. The peak occurs in the morning on east-facing surfaces, at noon on south-facing surfaces and in the evening on west-facing surfaces. The times of year when maxima occur are the same as for daily amounts of radiation.

The transmission of radiation depends on the angle of the sun, and data for glass and louver systems were set out in a CIE Conference paper.[11] The sunpath diagrams and overlays assembled by Petherbridge,[14] give the fractions of the incident radiation absorbed or transmitted at different times of year and different times of day. Another BRS paper[15] briefly describes different types of sun-controls and their properties.

3. THERMAL RESPONSE OF BUILDINGS TO SOLAR HEAT GAINS

The simplified method for calculating the thermal response of buildings to solar and other periodic heat gains[9] applies to steady cyclic conditions. Referring back to Figure 1, the problem is to calculate both the mean internal temperature $\bar{t}_i$ and the swing about the mean $(t_i - \bar{t}_i)$, here denoted $\tilde{t}_i$.*

For winter heating calculations, the rise in internal temperature above outside, $(t_i - t_o)$, is normally calculated from the rate of heat input q using the conventional steady-state heat balance equation:

$$q = (\Sigma AU + C_v)(t_i - t_o) \qquad (1)$$

* Symbols are listed in Appendix 5

where A's and U's are areas and thermal transmittances of exposed panels (walls and windows, roofs and rooflights)

C_v is the ventilation heat loss per degree

t_i and t_o are inside and outside air temperatures.

This equation will not serve for calculating summertime temperatures:

(1) Because it is not strictly valid unless internal air and mean radiant temperatures are equal. Heat is transferred to the surfaces of exposed panels by longwave radiation from other room surfaces as well as by convection from air. The mean radiant temperature (MRT) is as important as the air temperature in determining heat losses;

(2) Because solar gains are frequently generated part-way through the structure. This applies, for instance, to the heat absorbed by glass, or by a blind between two sheets of glass. The fraction of the absorbed heat entering the building depends on where the heat is absorbed;

(3) Because solar heat gains are by no means uniform throughout the day. They reach a peak at noon on the south face, early morning on an east face and evening on a west face. Another factor causing internal temperature fluctuations is that in summer the outside air temperature varies diurnally by 6 - 10 deg C (10 - 15 deg F) about the mean. The diurnal variations in internal temperature $\tilde{t}_i$ can be as large as the rise in the mean above outside $(\bar{t}_i - \bar{t}_o)$,(see Figure 1).

These points are now discussed in turn.

3.1 Internal environmental temperature

Equation (1) has to be modified to take account of the effect of the MRT on heat losses. Appendix 1 shows that this can be done by taking the internal temperature t_i, not as the air temperature t_{ai} but as the environmental temperature t_{ei}. This is a weighted mean between MRT and air temperature, given approximately by:

$$t_{ei} = 2/3\ t_{ri} + 1/3\ t_{ai} \qquad (2)$$

where t_{ri} is the mean radiant temperature.

The environmental temperature is a convenient temperature for calculating rates of heat flow, both for the steady state and for diurnal temperature swings. In addition to this, however, it is a better measure of the warmth of the environment than the air temperature since it is approximately equal to the 'equivalent temperature' used as an index of thermal comfort. At an air temperature of, say 21°C, a room with radiant heating and warm walls (or warm blinds heated by solar radiation) feels warmer than a room at 21°C with air heating and cool walls. If the environmental temperature is 21°C, however, both rooms will (to a close approximation) feel equally warm. Whether heated by air or radiation, Appendix I shows that for all internal environments, we can write:

$$\bar{q}_t = (\Sigma\, AU + C_v)\,(\bar{t}_{ei} - \bar{t}_o) \qquad (1a)$$

where $\bar{q}_t$ is the total equivalent heat input to the building arising from solar and other sources. The ventilation conductance has to be adjusted to allow for the fact that ventilation heat transfer depends on inside air temperature, not on inside environmental temperature. This equation holds only where the heat losses through internal room panels (flank and rear walls, floor and ceiling) are zero - for instance, in a room in a multi-storey block surrounded by other rooms at the same temperature. Other terms can be added when necessary to allow for heat transmission through internal panels. When ventilation rates are high, C_v has to be corrected as described in Appendix 3.

3.2 Heat generated part-way through the structure

Heat absorbed by a sheet of glass or a blind is partly retransmitted inwards and partly outwards. The 'equivalent heat input' to the room q_e due to solar gain is required for calculation. The mean value of q_e, $\bar{q}_e$, is equal in magnitude to the 'cooling load' due to solar radiation, which is required to keep the mean internal temperature $\bar{t}_{ei}$ equal to the mean outside temperature t_o. Appendix 2 shows that q_e may be obtained by multiplying the heat absorbed by the glass or blind by a fraction f, the retransmission factor, given by:

$$f = \frac{\text{thermal resistance from outside air to sheet}}{\text{total thermal resistance of system}} \quad (4)$$

Values of f for various combinations of glass and blind are listed in Table I.

Table I. Fractions of absorbed heat retransmitted to building

Component	Retransmission factor f
Single glazing, no solar control	0.3
Double sheet	
outer glass	0.15
inner glass, or internal blind separated by an unventilated airspace	0.65
Single glazing, internal venetian blind	
glass	0.3
venetian blind	0.8
Single glazing, external louver system	
glass	0.3
louver system	0.03
Double glazing, blind behind both panes	
outer glass	0.1
inner glass	0.6
internal blind	1.0
Double glazing, blind between panes	
outer glass	0.1
blind	0.4
inner glass	0.7
Double glazing, blind outside both panes	
external blind	0
outer glass	0.2
inner glass	0.7

Figure 4 illustrates the calculation of equivalent heat input due to solar gain for a window system consisting of two sheets, e.g. double glazing or single glazing with an internal blind enclosing an unventilated air space. Taking the incident radiation intensity as I_s, the proportions absorbed at outer and inner sheets as α_o and α_i (allowing for inter-reflections) and the proportion directly transmitted as τ , we have:

$$q_e = Is\ (0.15\alpha_o + 0.65\alpha_i + \tau)$$

since the values of f for outer and inner sheets are 0.15 and 0.65;

and in general:

$$\bar{q}_e = S \times \bar{I}_s \quad (5)$$

Equation (5) defines the 'solar gain factor' S for the window system, or for a wall or roof.

Solar gain factors, like radiation transmittances and absorptances, depend on the angle of the incident radiation. Moreover, allowance has to be made for inter-reflections between different surfaces in the window system. Average values for

August for orientations south of east-west have been calculated for a number of typical window systems, and are listed in Table 2. They can be applied without serious error throughout the summer months.

The term 'solar gain factor' was chosen as appropriate for both glass and blinds; these factors are equivalent to the 'shade factors' in the IHVE Guide.

There is also an effective heat input from solar heat absorbed at the outside surface of walls or roofs. It can be seen by reference to equation (4)that the 'retransmission factor' $f = R_{so} \times U$ since U is the reciprocal of the total thermal resistance. Effective heat inputs from solar gains through different windows, rooflights, walls or roofs, and heat inputs from occupants, lights or other sources have to be added to obtain $\bar{q}_t$. The mean temperature $\bar{t}_{ei}$ is then found from equation (1a).

3.3 Thermal response to periodic variations in heat input

Danter's procedure enables the swings in internal temperature to be calculated from the swings in effective heat input to the room and the properties of the building structure. The method is a very simple one and, although approximate, is sufficiently accurate for most practical purposes. Briefly, the actual heat exchanges in a room by convection between air and surfaces and by radiation between surfaces (Figure 5a) are replaced by exchanges between the point X (Figure 5b) and surfaces. The circuits are equivalent, and the temperature at X is the 'environmental temperature' t_{ei}. Heat exchanges between the X-point and the surroundings are calculated.

For a steady-state heat flow we consider only the heat flow rates by ventilation and by transmission through the exposed wall 1.

For periodic heat flow, however, we also consider the rates of heat flow into and out of the thermal capacity of internal walls, floors and ceilings. The heat flow paths to internal panels (walls, floors, or roofs) are through the surface resistances and resistance-capacity networks representing the half-thickness of the panels. (Only the half-thickness is considered when rooms are surrounded by similar rooms since the heat flow rates at the centres are zero.)

The heat flow rates to the partitions are determined by their areas and 'admittances' per unit area, Y. The 'admittance' of a building component is a measure of its ability to smooth out diurnal temperature swings in the building. Heat flow rates by ventilation and transmission through windows are determined by the 'ventilation conductance' C_v and thermal transmittance U, as with steady-state flow. Admittances per unit area are listed for a number of constructions in Table 3.

TABLE 2. Solar gain factors

System	Solar gain factor S	Alternating solar gain factor S_a	
		heavy building	light building
Single glazing			
Clear sheet glass (24 oz or 32 oz)	0.77	0.43	0.54
Clear plate ($\frac{1}{4}$ in.)	0.74	0.41	0.51
Heat absorbing ($\frac{1}{4}$ in. Antisun)	0.51	0.35	0.41
Heat absorbing ($\frac{1}{4}$ in. Calorex)	0.38	0.34	0.36
*Lacquer coated glass (Grey)	0.55	0.37	0.42
Double glazing (outer + inner panes)			
Clear sheet glass (24 oz + 24 oz or 32 oz + 32 oz)	0.67	0.40	0.49
Clear plate ($\frac{1}{4}$ in. + $\frac{1}{4}$ in.)	0.61	0.39	0.47
Heat absorbing ($\frac{1}{4}$ in. Antisun) + clear (32 oz)		0.30	0.35
Heat absorbing ($\frac{1}{4}$ in. Antisun) + clear ($\frac{1}{4}$ in. plate)	0.37	0.27	0.30
Heat absorbing ($\frac{1}{4}$ in. Calorex) + clear ($\frac{1}{4}$ in. plate)	0.23	0.19	0.20
Heat reflecting ($\frac{1}{4}$ in. Stopray) + clear ($\frac{1}{4}$ in. plate)	0.25	0.14	0.17
Internal sun controls + 32 oz. glass			
*Dark green woven plastics blind	0.64	0.57	0.62
*White venetian blind	0.46	0.43	0.46
*White cotton curtain	0.41	0.25	0.33
*Cream holland linen blind	0.29	0.26	0.29
Blinds between double glazing			
*White venetian blinds between two panes of clear glass (32 oz)	0.28	0.23	0.25
External suncontrols + 32 oz glass			
*Dark green woven plastics blind	0.20	0.13	0.18
*White louvered sun-breakers with blades at 45° (horizontal or vertical blades)	0.12	0.06	0.09
*Canvas roller blind	0.11	0.07	0.09
*Miniature louvered blind	0.10	0.05	0.06

* Typical value.

Data refers to British glass unless otherwise stated

TABLE 3. Admittances of building elements

Building element	Admittance Y W/m^2 deg C	(Btu/ft^2h deg F)	Surface factor F
Walls and windows:			
Glass or blind	same as U-value		same as retransmission factor f
Perfectly lightweight structures, Internal	0	(0)	1.0
External	same as U-value		1 - U x R_{si}
Walls of the following densities, more than 0.075 m thick			
650 Kg/m^3	3.0	(0.5)	0.8
1100	4.0	(0.7)	0,65
1750	5.0	(0.9)	0.5
2250	6.0	(1.1)	0.4
Heavy partition with lining of resistance 0.18 m^2 deg C/W (1.0 ft^2 h deg F/Btu)	3.0	(0.5)	0.7
Two 0.013 m fibreboard sheets separated by airspace	2.0	(0.3)	0.8
Floors:			
Concrete	6.0	(1.1)	0.5
Concrete and carpet or wood blocks, furniture	3.0	(0.5)	0.7
Suspended timber	2.0	(0.35)	0.8
Suspended timber and carpet	1.5	(0.25)	0.85
Ceilings:			
Plastered concrete	6.0	(1.1)	0.4
Cavity-plasterboard	3.0	(0.5)	0.7
Lath and plaster and timber	2.0	(0.3)	0.8

When temperatures and rates of heat input are changing slowly, no great error is introduced by directly adding heat flow rates by ventilation and conduction through windows to the heat flow rates into and out of internal panels, although the latter do in fact lag behind temperature changes by one hour or so. This leads to the simple equation relating the temperature swing $\tilde{t}_{ei}$ to the swing in effective heat input $\tilde{q}_t$:

$$\tilde{q}_t = (\Sigma AY + C_v)\ \tilde{t}_{ei} \qquad (6)$$

Though developed for sinusoidal heat inputs, studies with an electrical analogue have shown that equation (6) can be used without serious error when the heat input is non-sinusoidal; errors are greater when the heat input is 'peaky' (concentrated in a small part of the day) than when it is more nearly sinusoidal.

Effective alternating heat inputs $\tilde{q}_e$ have to be determined separately for the various heat sources, and then added to obtain $\tilde{q}_t$.

These effective heat inputs are equal in magnitude (and opposite in sign) to the rates at which heat would have to be abstracted or put in to hold the internal temperature constant. Alternating heat gains due to solar heat absorbed by glass and blinds have to be multiplied by retransmission factors f just as in steady-state calculations. However, alternating heat inputs due to radiation absorbed at the surfaces of panels (walls or floors) have to be treated differently from mean heat inputs. This is because these panels have a finite impedance to alternating heat inputs, as opposed to an infinite impedance to steady heat inputs. They therefore have to be multiplied by 'surface factors' F to obtain effective alternating heat inputs $\tilde{q}_e$:

$$\text{i.e. } \tilde{q}_e = F\ (q_e - \bar{q}_e)$$

Thus the alternating heat input at the surface of a concrete floor has to be multiplied by the factor F = 0.5 to obtain the effective heat input. Surface factors for some different building elements are listed in Table 3.

The effective alternating heat input due to solar gain can be written:

$$\tilde{q}_e = S_a \times \tilde{I}_s \qquad (7)$$

where S_a is the 'alternating solar gain factor' for the window system or wall or roof. S_a differs between 'heavy' and 'light' buildings because of differences in the surface factor F. In this context 'heavy' buildings have solid internal walls and partitions, and 'light' buildings have lightweight demountable partitioning with suspended ceilings; both are assumed to have concrete floors. Values of F of 0.5 and 0.8 have been assumed in the two cases. Average alternating solar gain factors for orientations south of east-west are listed in Table 2 for 'heavy' and 'light' buildings; these are not found in existing reference manuals. One point revealed by the Table is that internal blinds, particularly dark coloured blinds, are no better than unprotected glass in reducing temperature swings, although they can reduce the mean temperature rise.

3.4 Gains through walls and roofs

Solar heat gains through walls are usually negligible compared with solar gains through windows, but solar gains through poorly insulated roofs can cause overheating in factories and other single-storey buildings. A method developed by Danter[16] allows the resulting heat flow through the wall or roof to be calculated. This method can also be used to calculate the effect of temperature swings in one room on an adjacent room of dissimilar characteristics; in general, however, the diurnal swing due to transmission from an adjacent room is small.

3.5 Effect of outside air temperature variations

The effect of outside air temperature variations on internal temperature variations is allowed for as in other cases by calculating the heat which would have to be put into or extracted from the X-point to hold the internal temperature constant. This heat input is:

$$\tilde{q}_e = (\Sigma\ AU + C_v)\ \tilde{t}_o \qquad (8)$$

The heat gain from occupants, lighting and other internal sources can as an approximation be regarded as being generated at the X-point, i.e. the factor F for these heat inputs can be taken as unity.

The various components $\tilde{q}_e$ have to be added to find the total heat input swing $\tilde{q}_t$, and the swing in internal temperature $\tilde{t}_{ei}$ is found from equation (6).

The method can be extended to conditions which are not steady-cyclic ones by combining the 'Q/U' method of calculating the response of a room to changes in heat input or external temperature with the admittance procedure for calculating temperature swings. The diurnal swing $\tilde{t}_{ei}$ is then calculated in relation to a slowly varying quasi-mean temperature $\bar{t}_{ei}$. Temperatures have been successfully predicted during variable weather conditions using this technique.[19]

4 COMPARISONS WITH FIELD MEASUREMENTS

The procedure described has been used to calculate temperatures in a variety of buildings in which measurements have been made. As an example, Figure 6 gives comparisons of calculated and measured temperatures in a number of unoccupied and nominally unventilated offices during a Whitsun holiday period. Agreement is fairly good; it is difficult to get very close agreement in field studies because basic data, particularly on air infiltration rates, are not known accurately. It has not been possible to make such comparisons in occupied and naturally ventilated offices, because of the irregular use of blinds and ventilation openings.

Buildings in use have been investigated in a different way. Because of the difficulty of obtaining temperatures and ventilation records in occupied buildings during the rare periods when heat-waves occur, calculated peak temperatures have been compared directly with complaints of overheating obtained in user surveys. Data from the office survey mentioned in the Introduction[6, 7] were divided into sub-samples with different window aspects and window sizes, and offices in noisy and quiet areas were considered separately. This latter distinction was made because it was expected that there would be more overheating complaints in noisy than in quiet areas; this is because people could not open windows to ventilate buildings freely. Overheating complaints were related to calculated peak temperatures in offices of the type illustrated in Figure 7, where room dimensions are averages for the offices in the survey. These results have been reported elsewhere.[17, 18]

Calculated inside temperatures are based on the radiation intensities on sunny days, and on the corresponding daily-mean outside temperatures and temperature swings in Table 4. They are a few degrees higher than monthly-mean values. Of course there are occasions on which outside temperatures on sunny days are higher than those in Table 4, but it is very unusual to have a spell of sunny days during which both radiation intensities and outside air temperatures are simultaneously maintained at their highest values. Preliminary results suggest that the design data in Table 4 yield internal 'peak' temperatures which are exceeded on only about 10% of occupied hours.

TABLE 4 Daily-mean outside temperatures for sunny days (Garston, Herts)

Month	Temperature			
	Daily-mean on sunny days *		Mean diurnal swing on sunny days *	
	°C	°F	deg C	deg F
March	7 (6)	44 (43)	12 (9)	22 (16)
April	8 (8)	47 (47)	12 (10)	22 (18)
May	12 (12)	54 (53)	13 (11)	24 (19)
June	16 (15)	60 (59)	15 (11)	27 (19)
July	19 (17)	66 (62)	14 (9)	25 (17)
August	18 (16)	64 (61)	13 (10)	23 (18)
September	14 (14)	58 (57)	12 (9)	21 (16)

* Mean values for all days are given in brackets
Data are fairly typical for most of the populous areas in Britain

Figure 8 shows how calculated peak temperatures vary with window size in 'heavy' and 'light' buildings with low and high ventilation rates, (2 and 10 air changes/h). (As before, 'heavy' buildings have solid partitions, 'light' buildings have demountable partitions and suspended ceilings; both have concrete floors.) Figure 9 shows how peak temperatures calculated from outside temperature on sunny days relate to complaints of overheating in different categories of office. (A similar graph in earlier papers[17, 18] was based on 'sunny day' outside temperatures during the year preceding the survey.) Those 'sometimes too warm' and those 'definitely uncomfortable' are shown separately on the graph. A ventilation rate of 2 ach was assumed in noisy areas, and 10 ach in quiet areas. There is a clear relationship between user comments and calculated peak temperatures.

This technique has been repeated in a survey of school buildings, and this will be reported later. Although the data have not yet been fully analysed, the preliminary results are interesting. As with offices, a considerable proportion of the occupants (teachers) were sometimes too hot in summer. Again, more discomfort was experienced in noisy than in quiet areas. Moreover, other things being equal, there was more discomfort when classrooms could be ventilated from only one side than when they had openings on more than one wall and could have cross-ventilation. Within each of these categories, discomfort was related to window size and orientation in the manner suggested by calculations of maximum temperature.

Figure 10 gives a preliminary comparison of overheating complaints and calculated temperatures, based on the outside temperatures in Table 4 and the assumed ventilation rates set out in Table 5. These rates were selected to bring the data on to the same curve.

TABLE 5 Assumed ventilation rates for heat-wave conditions

	Position of opening windows	Whether quiet or noisy area	Ventilation rate air changes/h
Offices	one side only	quiet	10
		noisy	2
Schools	one side only	quiet	10
		noisy	5
	more the one side	quiet	30
		noisy	10

In the earlier survey, the office workers were simply asked whether they were 'slightly' or 'definitely' uncomfortable because of overheating, and were not offered the choice of 'occasionally' or 'often' in their response. In the schools study a wider range of alternatives were offered. For the purposes of this paper, the scale, which ranged from comfort to definite discomfort, has been divided to produce two plots which represent these extremes. The upper points (filled symbols in Figure 10) show the proportions reporting any degree of discomfort except 'occasionally slightly uncomfortable'. The lower points (open symbols) show the proportions 'definitely uncomfortable' except those 'occasionally definitely uncomfortable'.

The proportions reporting thermal discomfort shown in Figure 10, like those in Figure 9, are clearly related to the calculated peak temperatures. Moreover, although there were differences in the assumptions made in the calculations and in the forms of the questions relating to offices and schools, the amounts of thermal discomfort at different calculated peak temperatures were similar.

The important point is that, if temperatures are calculated on the assumptions which have been set out, criteria can be set which enable one to decide in advance whether a given design of office or school is likely to be thermally comfortable. The setting of a criterion involves a value judgement on what is acceptable, but the graphs provide an essential link between such a judgement and computed temperatures. For instance, adopting the criterion that not more than 10% of the occupants would be definitely uncomfortable would lead to a design requirement of about 27°C (80°F) for both offices and schools.

5 DESIGN IMPLICATIONS

As a first point, heavy buildings screened from solar radiation do not rise more than a few degrees above the mean outside temperature unless there are appreciable heat gains from lighting, occupants or other heat sources. It is primarily the daily-mean temperature that has to be considered, rather than the maximum; diurnal temperature variations can be smoothed by the thermal capacity of the building. In heavy buildings, the outside temperature variations of 10 - 15 deg C that occur during the day cause internal variations of only 1 - 2 degrees. In this connection, Table 6 shows how frequently daily-mean temperatures of 20°C to 24°C are exceeded at Garston, Herts and in London.

TABLE 6 Frequency with which given daily-mean temperatures are exceeded

Location	Average number of days per annum exceeding: 20°C	21°C	22°C	23°C	24°C
Garston	3.2	1.6	0.8	0.4	0.2
London Weather Centre	8.4	4.4	2.2	0.9	0.7

These data show that even in central London, which is warmer than the surrounding country, daily-mean external temperatures seldom exceed 22°C. Very few parts of Britain are much warmer than central London. Internal temperatures in heavy buildings need not therefore exceed 24°C on more than 1 or 2 days per annum unless solar gains are admitted or there are other appreciable internal heat gains.

It is clear, therefore, that the British climate does not in itself make air-conditioning essential, if buildings are heavy, screened from solar radiation and do not have appreciable internal heat gains. As an illustration of this point, Figure 11a shows that the measured temperature in an east-facing office of massive construction, shaded by trees, remained at 20.5°C (69°F) throughout a sunny spell when the outside temperature varied from 10 - 27°C (50 - 80°F). By contrast, the temperature in a neighbouring room with large south-facing windows reached 26°C (78°F) during the same period, and the occupants complained of overheating (Figure 11b). This room had a smaller admittance than the first, as it was carpeted and had a lightweight roof structure.

On the basis of this work, recommendations have been made(18) about maximum areas of unshaded clear glass that can be used in naturally ventilated offices without exceeding a calculated peak temperature of 24°C(75°F). The corresponding maximum window sizes were calculated for 'heavy' and 'light' buildings, defined as above, and for noisy and quiet areas, assuming ventilation rates of 2 and 10 ach. It would be reasonable to use the same criteria of discomfort when making similar calculations for different office types, and for buildings shaded by sun-controls. Appendix 4 sets out the recommended procedure for calculating peak temperatures in more detail, and gives an illustrative example.

Mean temperatures during the summer months vary by a few degrees over Britain, and local data could be used when additional accuracy is sought. As the variations are only a few degrees, however, the data in Table 4 may be adequate for design calculations in most of Britain.

Air-conditioning may provide the preferred solution for lightweight buildings, or deep buildings with large internal heat gains. It may be worth while in some cases to compare the cost of a heavy, shallow building which is naturally ventilated, with the cost of a lightweight or deep building with air-conditioning.

6. CONCLUSIONS

A technique for calculating peak internal temperatures is presented which agrees with experimental measurements and is related to user complaints of overheating in offices and schools. The method can be applied generally to different types of building, but it is difficult to make accurate estimates of ventilation rates in naturally ventilated buildings, and further cross-checks with user experience may be needed. Data are given on properties of building components (e.g. surface factors and admittances) to use in calculations.

It is shown that a single 'shading factor' is not sufficient to specify the effect of a sun-control on internal temperatures, and both 'solar gain factors' and 'alternating solar gain factors' are listed for different types of sun-control. These can be applied directly to calculate the rise in the mean internal temperature and the swing about the mean.

This technique of calculation should be helpful in designing comfortable buildings. Peak temperatures can be calculated and if excessive, the designer has the choice of reducing the window size, increasing the mass of structure, fitting sun-controls or installing air-conditioning. The final choice will depend on cost, amenity and other considerations, but the methods outlined should provide useful guidance on alternative methods of controlling peak temperatures. Application of this work to air-conditioning design is also being studied, and preliminary results are reported in another contribution to this symposium.

Acknowledgment

This work was made possible by research on the thermal response of buildings by Mr. E. Danter, who kindly made his results available. The author is also indebted to other colleagues, particularly Mr. P. Petherbridge and Miss P. J. Arnold, who made important contributions to other aspects of the work.

REFERENCES

1. Gray, P.G. and Corlett, T. 'A survey of lighting in offices' (Appendix 1). Post-war Building Studies 30, HMSO, 1952.

2. Eighth Report of Select Committee on Estimates, HMSO, 1961.

3. Manning, P. 'The design of roofs for single-storey general-purpose factories'. Department of Building Science, University of Liverpool, 1962.

4. Manning, P. 'Office design: a study of environment'. Pilkington Research Unit, Department of Building Science, University of Liverpool, 1965.

5. Manning, P. 'An environment for education'. Pilkington Research Unit, Department of Building Science, University of Liverpool, 1967.

6. Langdon, F.J. 'Thermal conditions in modern offices'. RIBA Journal, Vol. 72(1), January 1965.

7. Langdon, F.J. 'Modern offices: a user survey'. National Building Studies Research Paper 41, HMSO, 1966.

8. Stewart, L.J. and Kibblewhite, D. 'A survey of the thermal environment in naturally ventilated offices'. JIHVE, 35, July 1967, pp. 121-6.

9. Loudon, A.G. and Danter, E. 'Investigations of summer overheating'. Building Science 1965, Vol. 1(1), pp. 89-94, and BRS Current Papers Research Series 37.

10. Loudon, A.G. 'The interpretation of solar radiation measurements for building problems'. Proc CIE Conference - Sunlight in Buildings, 1965, pp. 111-8, Bouwcentrum International, Rotterdam 1967, and BRS Current Papers Research Series 73.

11. Petherbridge, P. 'Transmission characteristics of window glasses and sun-controls'. Proc CIE Conference - Sunlight in Buildings, 1965, p. 183-98, Bouwcentrum International, Rotterdam 1967, and BRS Current Papers Research Series 72.

12. Moon, P. 'Proposed standard solar radiation curves for engineering use'. J. Franklin Institute, 1940, Vol. 230 (5), pp. 583-617.

13. IHVE 'Guide to Current Practice'. IHVE, 1965, London.

14. Petherbridge, P. 'Sunpath diagrams and overlays for solar gain calculations'. BRS Current Papers Research Series 39.

15. Petherbridge, P. and Loudon, A.G. 'Principles of sun control'. AJ, 1966, January 12, pp. 143-9, and BRS Current Papers Design Series 41.

16. Danter, E. 'Periodic heat flow characteristics of simple walls and roofs'. JIHVE, 1960, 28, pp. 136-46.

17. Loudon, A.G. 'Window design criteria to avoid overheating by excessive solar heat gains'. Proc CIE Conference - Sunlight in Buildings, 1965, pp. 95-102, Bouwcentrum International, Rotterdam, 1967, and BRS Current Papers Design Series 66.

18. BRS Digest 68 II. 'Window design and solar heat gain'.

19. Loudon, A.G. and Petherbridge, P. 'Possible economies in air-conditioning by accepting temperature swings'. IHVE/BRS Symposium, February 1968.

Appendix 1. Inside environmental temperature

The conventional steady-state heat balance equation giving the average rate of heat flow q through an exposed building element of area A and thermal transmittance U is:

$$q/A = U(t_i - t_o) \quad \text{(A1)}$$

with $$U = 1/(R_{si} + R_1 + R_2 + \ldots + R_{so}) \quad \text{(A2)}$$

and $$R_{si} = 1/(Eh_r + h_c) \quad \text{(A3)}$$

where the R's are thermal resistances of the components of the structure, R_{si} and R_{so} inside and outside surface resistances, E the longwave emissivity factor for the surface, and h_r and h_c the radiation and convection coefficients.

The temperatures t_i and t_o are normally taken as inside and outside air temperatures. However, a difficulty arises when the internal air and mean radiant temperatures differ, because heat is transferred to the surface of the exposed panel (wall, window, roof or rooflight) by longwave radiation from other surfaces, as well as by convection from room air. Equation (1) is not therefore universally valid if t_i is taken to represent the inside air temperature. However, a valid equation can be developed as follows.

The equation for the rate of heat flow to the inside surface is:

$$q/A = Eh_r\,(t'_{ri} - t_{si}) + h_c(t_{ai} - t_{si}) \quad \text{(A4)}$$

where t'_{ri} is the mean surface te nperature seen by the inside surface of the exposed panel, whose temperature is t_{si}. At the inside surface of a wall, typical values of Eh_r and h_c are 5.1 and 2.8 W/m^2 deg C.

This equation involves t'_{ri}, the mean radiant temperature seen by the exposed wall. However, it is more convenient to express heat losses in terms of the area-weighted mean temperature of all room surfaces, including that of the exposed panel, t_{ri}. This is the mean radiant temperature at the centre of a cubical room; it can be imagined as the temperature of a small sphere at the centre of an air-free room. The temperature t'_{ri} is the area-weighted mean temperature of surfaces other than that of the exposed panel, at least for a cubical room. This is because for a cubical room the form factor (i.e. the fraction of the radiation from one surface which falls on another) is 0.2 for each surface. t_{ri} could thus be calculated by adding contributions of the temperatures of the surfaces, 1/5 for each. The area-weighted mean temperature is:

$$t_{ri} = 5/6\ t'_{ri} + 1/6\ t_{si} \quad \text{(A5)}$$

Hence $t'_{ri} = 6/5\ t_{ri} - 1/5\ t_{si}$. Substituting in equation (A4)

we have:

$$q/A = 6/5\ Eh_r(t_{ri} - t_{si}) + h_c(t_{ai} - t_{si})$$

To obtain the conventional form of equation (A1), we write:

$$q/A = (6/5\ Eh_r + h_c)\,(t_{ei} - t_{si}) \quad \text{(A6)}$$

where $$t_{ei} = (6/5\ Eh_r t_{ri} + h_c t_{ai})/(6/5\ Eh_r + h_c) \quad \text{(A7)}$$

The temperature t_{ei} is here called the inside environmental temperature and is an appropriate inside temperature for calculating heat losses. An an approximation, it is 2/3 MRT + 1/3 Air temp. Equation (A6) can be written:

$$q/A = (1/R_{si})\,(t_{ei} - t_{si}) \quad \text{(A6a)}$$

with $$R_{si} = 1/(6/5\ Eh_r + h_c) \quad \text{(A8)}$$

$$R_{si} = 0.11 \text{ if } Eh_r = 5.1, h_c = 2.8$$

Danter has shown that heat losses can be calculated within an accuracy of ± 5% for a wide range of buildings using this environmental temperature t_{ei}, but that errors of up to 40% are obtained if heat losses are calculated in terms of the air temperature t_{ai}. Moreover, t_{ei} is a convenient temperature when considering the effect of a periodically varying heat input, as discussed in Appendix 3. The conventional values for inside surface resistance (0.13 for walls, 0.11 for ceilings with upward heat flow, 0.14 for floors with downward heat flow) can be retained without serious loss of accuracy, in spite of the difference between equation (A3) and equation (A8).

Appendix 2. Effect of heat inputs generated part-way through the structure

Equations (A1) to (A3) apply when no heat is generated within the structure, e.g. by absorption of solar radiation, taking t_i as the inside environmental temperature t_{ei}, and R_{si} as defined by equation (A8). Equation (A7) can be combined with other equations representing heat flow through thermal resistances. The mean rate of heat flow through a wall or roof of thermal resistance R is given by:

$$q/A = (t_{si} - t_{so}) / R \qquad \text{(A9)}$$

The thermal resistance of the material is of course negligible for single glazing, but for double glazing R = 0.18 m^2 deg C/W, the resistance of the airspace.

If the outside air temperature and the external surroundings are at the same temperature t_o, and no solar radiation falls on the surface:

$$q/A = (t_{so} - t_o) / R_{so} \qquad \text{(A10)}$$

where $$R_{so} = 1/(Eh_r + h_c)$$

Combining equations (A6a), (A9) and (A10), we have the conventional steady-state equation (A1).

When considering double glazing, or glass in combination with a blind, however, it is necessary to take account of solar radiation absorbed at the inner face. If solar radiation of intensity I_s is transmitted through an outer sheet and absorbed by an inner sheet, equation (A9) becomes:

$$q/A + \alpha_i I_s = (t_{si} - t_{so})/R \qquad \text{(A9a)}$$

where α_i is the fraction of the incident radiation absorbed by the inner sheet. If solar radiation of intensity I_s falls on the outside surface of a wall, window, roof or rooflight of solar absorptivity α_o, the rate of heat input to the surface from this source is $\alpha_o I_s$. There is heat loss by convection equal to $h_c(t_{so} - t_{ao})$, where t_{so} is the outside surface temperature, t_{ao} the outside air temperature.

There is also heat transfer by longwave ratiation to the external surroundings, sky and ground. On cloudless days the sky temperature seen by a horizontal surface is some 20 deg C below air temperature. The mean of sky and ground temperatures seen by a vertical surface is, however, roughly equal to air temperature. This is because the ground is warmer than air during sunny spells and thus compensates for the cool sky.

The equation for the rate of heat flow at the outside surface is:

$$q/A = Eh_r(t_{so} - t_{ro}) - \alpha_o I_s + h_c(t_{so} - t_{ao}) \qquad \text{(A10a)}$$

where t_{ro} is the mean radiant temperature of the external surroundings. At the outside surface of a wall, a typical value of Eh_r is 4.1 W/m^2 deg C for an outside air temperature of 5°C (0.7 Btu/ft^2h deg F at 40°F), and for normal exposure to wind a typical value of h_c is 15.2 W/m^2 deg C (2.6 Btu/ft^2h deg F).

If we write:

$$EI_L = Eh_r(t_{ao} - t_{ro}) \qquad \text{(A11)}$$

equation (A10a) becomes:

$$q/A \quad + \quad (\alpha_o I_s - EI_L) = (Eh_r + h_c)(t_{so} - t_{ao})$$

$$= (1/R_{so})(t_{so} - t_{so}) \qquad \text{(A10b)}$$

EI_L is the longwave radiation loss from unit area of a surface at air temperature to surroundings. For a horizontal surface, I_L may be taken as 95 W/m^2 (30 Btu/ft^2h) for a cloudless sky, 15 (5) for an overcast sky, and intermediate values proportional to the cloud amount for partially clouded skies. The outside surface resistance R_{so} (= $1/(Eh_r + h_c)$) is about 0.05 for walls and 0.04 m^2 deg C/W for roofs (0.3 and 0.25 ft^2h deg F/Btu) for normal exposure to wind. If heat is absorbed at the inner layer we have:

$$q/A \quad + \quad (\alpha_o I_s - EI_L) + \alpha_i I_s = 1/R_{so} \times (t_{so} - t_{ao}) \qquad \text{(A14)}$$

By combining equations (A6a), (A9) and (A10b) we obtain:

$$q/A = \frac{t_{ei} - t_{si}}{R_{si}} = \frac{t_{si} - t_{so}}{R} = \frac{t_{so} - t_{ao}}{R_{so}} - (\alpha_o I_s - EI_L)$$

i.e.

$$q/A = \frac{t_{ei} - t_{ao}}{R_{si} + R + R_{so}} - (\alpha_o I_s - EI_L) \times \frac{R_{so}}{R_{si} + R + R_{so}}$$

or $$q/A + f(\alpha_o I_s - EI_L) = U(t_{ei} - t_{ao}) \qquad \text{(A12)}$$

where $$f = R_{so}/(R_{si} + R + R_{so}) \qquad \text{(A13)}$$

$$= R_{so} \times U \qquad \text{(A13a)}$$

is the 'retransmission factor' giving the fraction of absorbed heat retransmitted inwards.

Thus the heat input ($\alpha_o I_s - EI_L$) generated at the outside surface of a structure is equivalent in its effect on internal temperature to a heat input $f(\alpha_o I_s - EI_L)$ generated within the structure. As an example, a heat input $\alpha_o I_s$ absorbed by vertical single glazing with I_L = 0, and f = 0.3, is equivalent to a heat input to the building of $0.3\,\alpha_o I_s$ per unit area of glass. The value of f = 0.3 applies when R_{so} = 0.05, U = 5.7 (0.3, 1.0 in British units).

Similarly one can see that the heat absorbed at the inner layer of double glazing has to be multiplied by the retransmission factor f = $(R_{so} + R) / (R_{so} + R + R_{si})$ to obtain the equivalent heat input within the structure. If R_{so} = 0.05, R = 0.18, R_{si} = 0.13, f = 0.65; the equivalent heat input within the building is $0.65\alpha_i I_s$.

In general, therefore, heat inputs generated part-way through a structure have to be multiplied by a retransmission factor f, given by:

$$f = \frac{\text{thermal resistance from outside to point where heat is generated}}{\text{total thermal resistance of structure}}$$

Appendix 3. Comments on treatment of periodic variations

The heat interchanges in a room by longwave radiation between surfaces and by convection with the air are illustrated diagrammatically in Figure 5a which represents a cross-section through a room with one exposed surface (surface 1). Since rates of heat transfer by longwave radiation and convection are roughly proportional to temperature difference, we can regard the surfaces and air as being connected by thermal resistances. The 'delta network' of Figure 5a can this be replaced by the 'star network' of Figure 5b.

Analysis shows that for a cubical room the 'star point' X is at the 'environmental temperature'' t_{ei} given by equation (A7), and the inside surface resistances R_{si} are given by equation (A8). Although this analysis is strictly valid only for a cubical room, experiments with an electrical analogue have shown that these equations are reasonably accurate for a wide range of room sizes and shapes.

The effect of heat put in or abstracted (e.g. by ventilation) at the air temperature t_{ai} (see Figure 5a) can be allowed for by introducing a hypothetical conductance h_a between the air-point and the star-point X (Figure 5d). The heat transfer to the walls of area A is given by:

$$q_a = h_a A(t_{ei} - t_{ai}) \quad (A15)$$

and also

$$q_a = h_c A(t_{ri} - t_{ai}) \quad (A16)$$

Substituting $t_{ei} = 2/3\, t_{ri} + 1/3\, t_{ai}$ in equation (A15) we have

$$q_a = 2/3\, Ah_a(t_{ri} - t_{ai})$$

Hence from equation (A16) $h_a = 3/2\, h_c$.

In SI units with $h_c = 2.8$, $h_a = 4.2$ W/m^{2}deg C, (*in* British units $h_c = 0.5$, $h_a = 0.75$.)

The ventilation conductance C_v can be found by combining in series the conductances Ah_a and sV (ventilation heat loss per degree); it is given by:

$$\frac{1}{C_v} = \frac{1}{Ah_a} + \frac{1}{sV} \quad (A17)$$

When the ventilation rate is low, C_v is approximately equal to sV. For a room of 30 - 60 m^3 (1000 - 2000 cu ft) C_v is only about 5 or 10% less than sV when the ventilation rate is 2 air changes/h, but it can be as low as 50% of sV when the ventilation rate is 20 - 30 air changes/h.

Appendix 4. Procedure for calculating m[...]n temperatures

On the basis of this work, the following p[...]dure may be used for calculating maximum internal temperatures. It is illustrated by an example in Figure 12 which is for a south-facing school classroom of heavy construction with 50% of the external wall glazed, occupied by 30 children for 4 hours. For simplicity, it is assumed that there is no heat exchange with adjoining rooms. Calculations are made for July, the hottest month during term-time.

(1) Select an appropriate temperature $\bar{t}_o$ for design calculations. It is suggested that the mean temperature for sunny days should be used; the highest external temperatures (Table 6) are very seldom obtained during a succession of days of full sunshine. Monthly mean temperatures are published for different areas; those for sunny days are about 2 deg C higher during July and August. Data for Garston, Herts, are shown in Table 4. In the example $\bar{t}_o$ was taken as 19°C, the mean for sunny days in July.

The highest internal temperatures generally occur in August, but there are exceptions - e.g. schools which are on holiday in August, and rooms with south-facing windows protected by projecting screens. Such rooms may be reasonably cool in August, but too warm in October when the sun enters the building below the projecting screen.

(2) Find daily-mean solar gains through windows by multiplying the daily-mean radiation intensity (160 W/m^2 for the south-facing surface in the example in Figure 12) by the appropriate solar gain factors and window areas. Some data are given in Table 2; where values are not given, they can be calculated by the methods set out in the text. Find mean heat gains from lighting from known wattage of lighting fittings, mean heat gains from occupants (data are given in IHVE Guide), mean solar gains through walls or roofs exposed to radiation, and any other heat inputs. Add the various heat inputs to find the resultant daily-mean heat input to the room $\bar{q}_t$. In Figure 12 the mean heat inputs are shown on the lefthand side of the diagram. It is often convenient to relate the heat input to unit area of external wall, or, as in Figure 12, to unit area of floor.

(3) Determine the U-values and areas of exposed panels, and ventilation heat loss per degree (C_v). If the ventilation rate is low, C_v can be taken as equal to sV, i.e. the product of the volumetric specific heat of a[i]r s (1.2 x 10^3 J/m^3 deg C) and the ventilation rate V (m^3/sec). If the ventilation rate is high, C_v should be corrected as discussed in Appendix 3.

When buildings are naturally ventilated it is difficult to obtain a realistic estimate of the ventilation rate. This is determined by the occupants' use of window and door openings as well as by wind and stack pressures. Comparisons of computed temperatures with survey findings indicate that the average values in Table 5 may be appropriate for design calculations. Where buildings are mechanically ventilated, the ventilation rate can be established with much greater certainty. If heat inputs are related to unit area of exposed wall or floor, it is of course necessary to do the same for heat losses.

(4) Calculate the daily-mean internal temperature $\bar{t}_{ei}$ from the steady-state heat balance equation:

$$\bar{q}_t = (\Sigma AU + C_v)(\bar{t}_{ei} - \bar{t}_o) \qquad \text{(A18)}$$

This equation applies where there is no heat exchange with adjoining rooms i.e. where each room is surrounded by similar rooms at the same temperature. Additional terms have to be added when necessary to allow for heat transfer to adjacent rooms; if rooms on opposite sides of a building are considered, it is necessary to put in a term for heat transfer between rooms and calculate the mean temperature on both sides of the building by solving two simultaneous equations.

(5) Where the entire curve of daily variation of internal temperature is required, plot out hourly values of the various effective heat inputs, relating to the basic area considered. Daily swings of radiation intensities should first be calculated relative to the daily-mean value. In a detailed calculation, swings about the mean should be calculated separately for absorbed and transmitted components, and multiplied by appropriate retransmission or surface factors. For a more approximate calculation as in the illustrative example (Figure 12), swings in radiation intensity may be multiplied by the alternating solar gain factor (S_a) in Table 2. This will give a good estimate of peak temperatures, but temperatures at say 9 a.m. may be overestimated. The swings in effective heat inputs should be added and the total swing $\tilde{q}_t$ found.

If only the maximum value of t_{ei} is required, it is only necessary to determine the various effective heat inputs for a few hours near the time when the maximum temperature is expected.

(6) Determine the areas and admittances of both external and internal room panels (Table 3), relate to basic area, and calculate the temperature swing from the e equation:

$$\tilde{q}_t = (\Sigma AY + C_v)\,\tilde{t}_{ei} \qquad \text{(A19)}$$

The temperature swing $\tilde{t}_{ei}$ should then be added to $\bar{t}_{ei}$ to obtain the computed internal temperature. The illustrative example shows a maximum temperature of 28°C; this room would be expected to be excessively warm in summer, and some form of external shading would be needed to provide comfortable conditions.

Appendix 5. Symbols

A	area
C_v	ventilation conductance (ventilation heat loss per degree)
E	longwave emissivity factor
f	retransmission factor for components of solar control
F	surface factor for building element
h_a	hypothetical conductance between the air point in a delta network and the X-point in a star network of thermal resistances
h_c	convection transfer coefficient
h_r	radiation transfer coefficient
I_L	longwave radiation loss of surface at air temperature to surroundings
I_s	incident total solar radiation intensity
q	rate of heat input; q_e equivalent heat input;
q_t	total equivalent heat input; q_a rate of heat transfer from air to surfaces
Q	total thermal capacity of the structure
R	thermal resistance; R_{si} inside surface resistance;
R_{so}	outside surface resistance; R_1, R_2 thermal resistance of components of structure
R_v	thermal resistance of ventilating air
s	volumetric specific heat of air
S	solar gain factor of window system or building element; S_a alternating solar gain factor
t_o	outside temperature; t_{ao} outside air;
t_{ro}	mean of external surroundings; t_{so} of outside of building element;
t_i	internal temperature; t_{ai} inside air;
t_{ei}	inside 'environmental' temperature;
t_{ri}	area weighted mean temperature of all room surfaces;
t'_{ri}	mean radiant temperature seen by inside surface of exposed panel;
t_{si}	temperature of inside of exposed building element
U	thermal transmittance
V	ventilation rate
Y	admittance per unit area
α	absorptivity to solar radiation; α_o outer sheet of window system
α_i	inner sheet of window system
τ	transmittance of solar radiation by window system

Note: The symbols $\bar{}$ and $\sim$ indicate the mean, and the deviation from the mean.

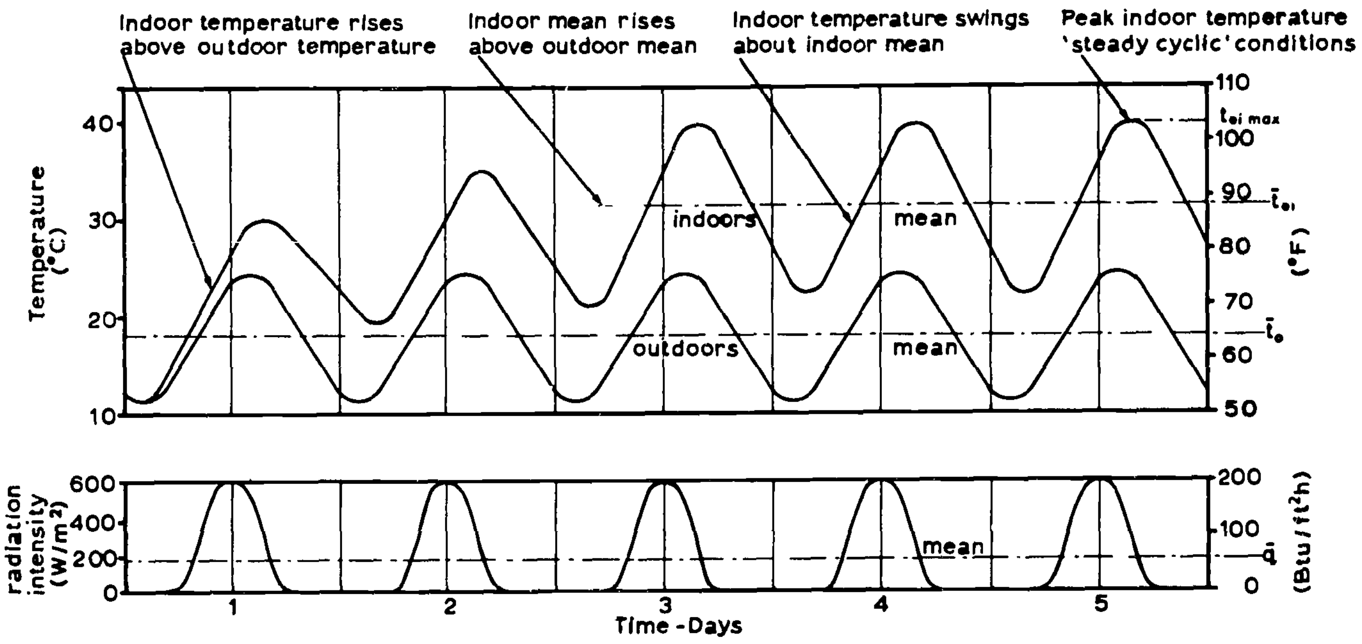

FIG 1 BUILD-UP OF INTERNAL TEMPERATURES DURING A HEAT-WAVE

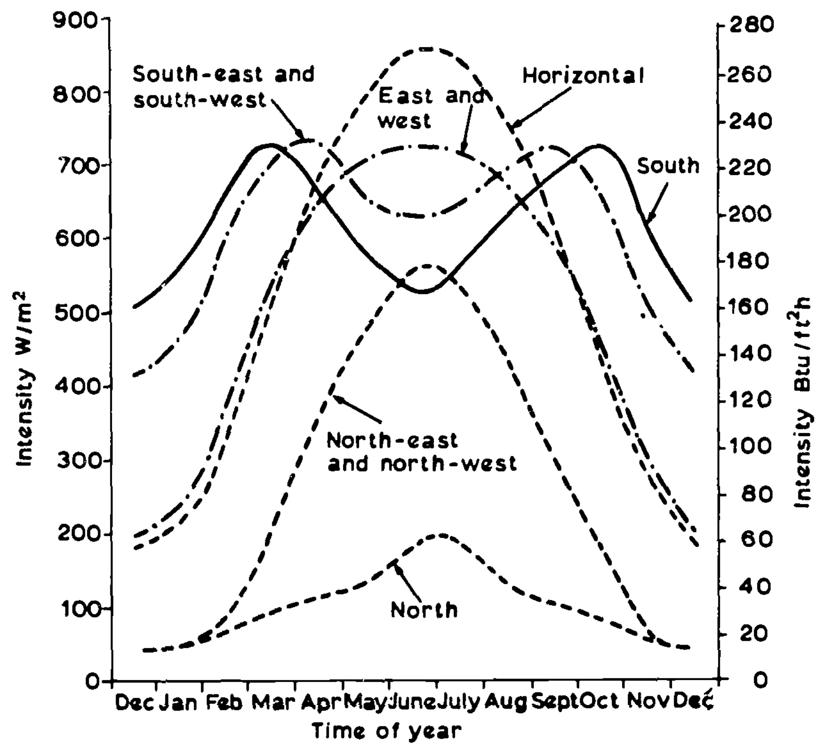

FIG 2 DESIGN PEAK SOLAR RADIATION INTENSITIES (DIRECT + SKY DIFFUSE + GROUND-REFLECTED)
LAT 51,7° N

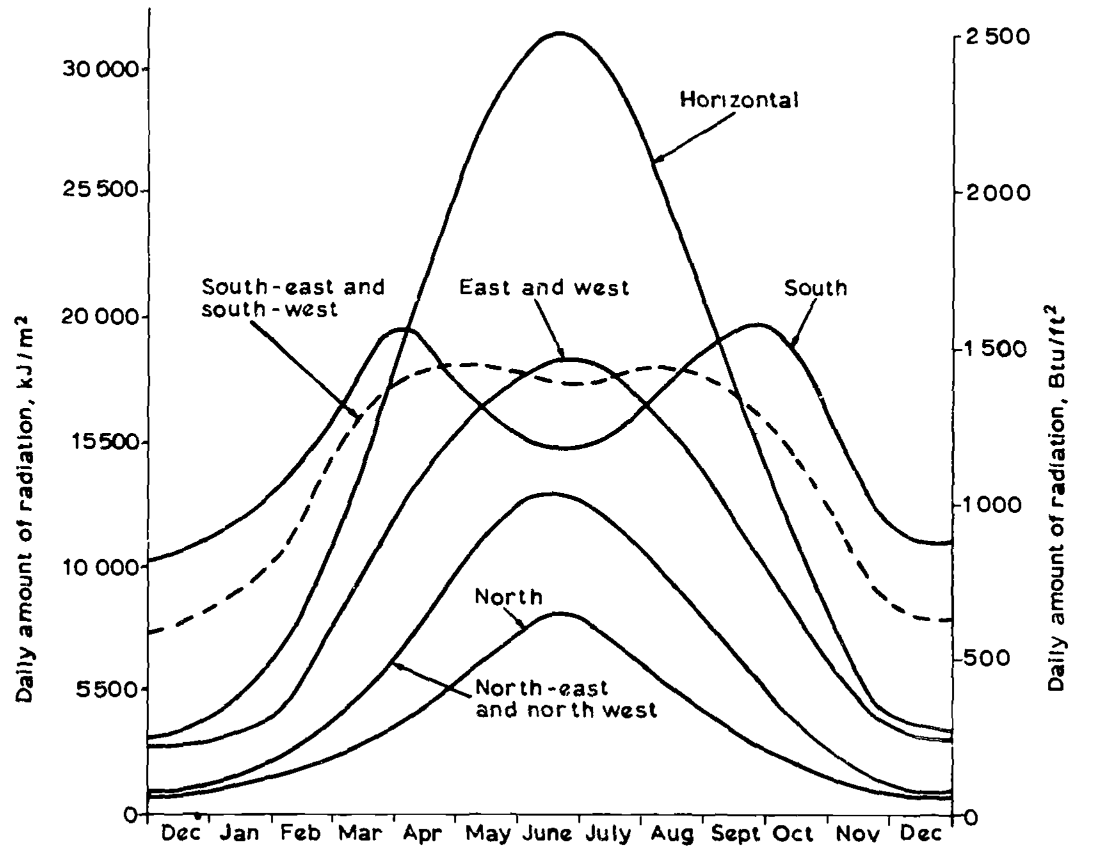

FIG 3 DESIGN DAILY AMOUNTS OF SOLAR RADIATION (DIRECT + SKY DIFFUSE + GROUND - REFLECTED RADIATION) LAT 51°7°N

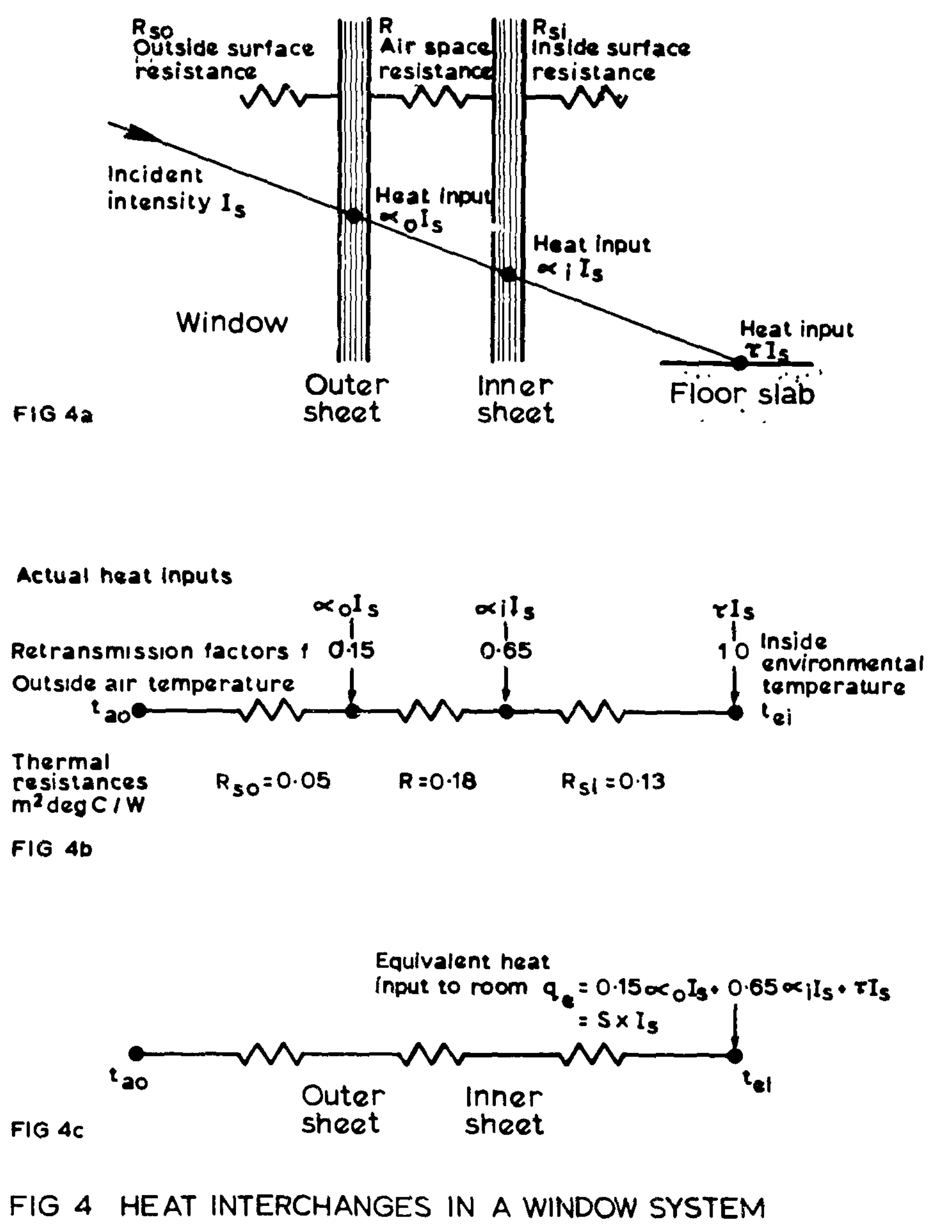

FIG 4 HEAT INTERCHANGES IN A WINDOW SYSTEM

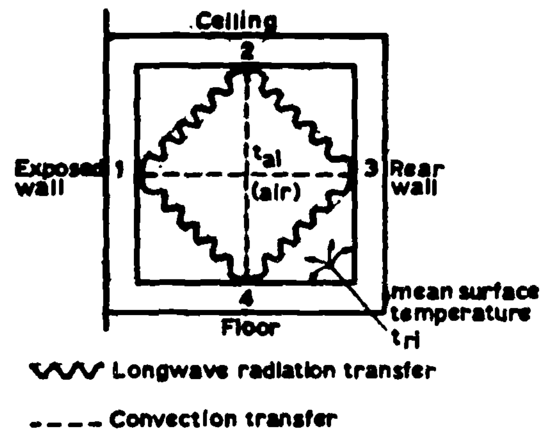

FIG 5a ACTUAL INTERCHANGES WITHIN A ROOM

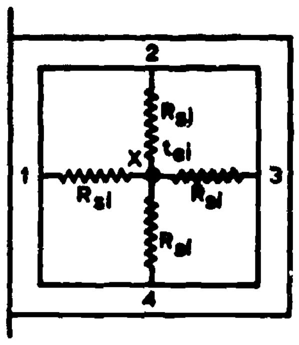

FIG 5b EQUIVALENT INTERCHANGES WITH ENVIRONMENTAL TEMPERATURE

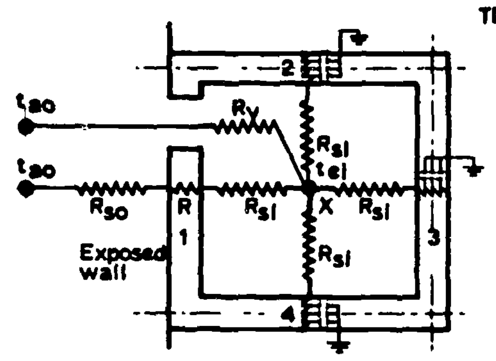

FIG 5c THERMAL RESISANCES AND CAPACITIES

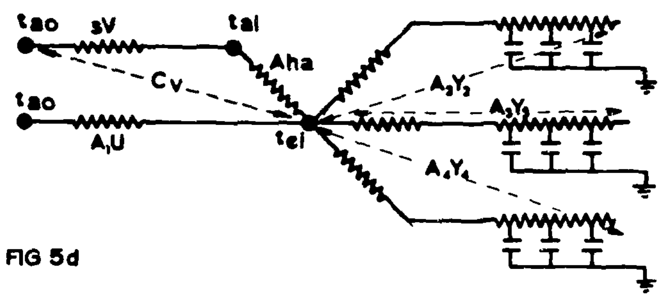

FIG 5d

FIG 5 HEAT INTERCHANGES WITHIN A ROOM

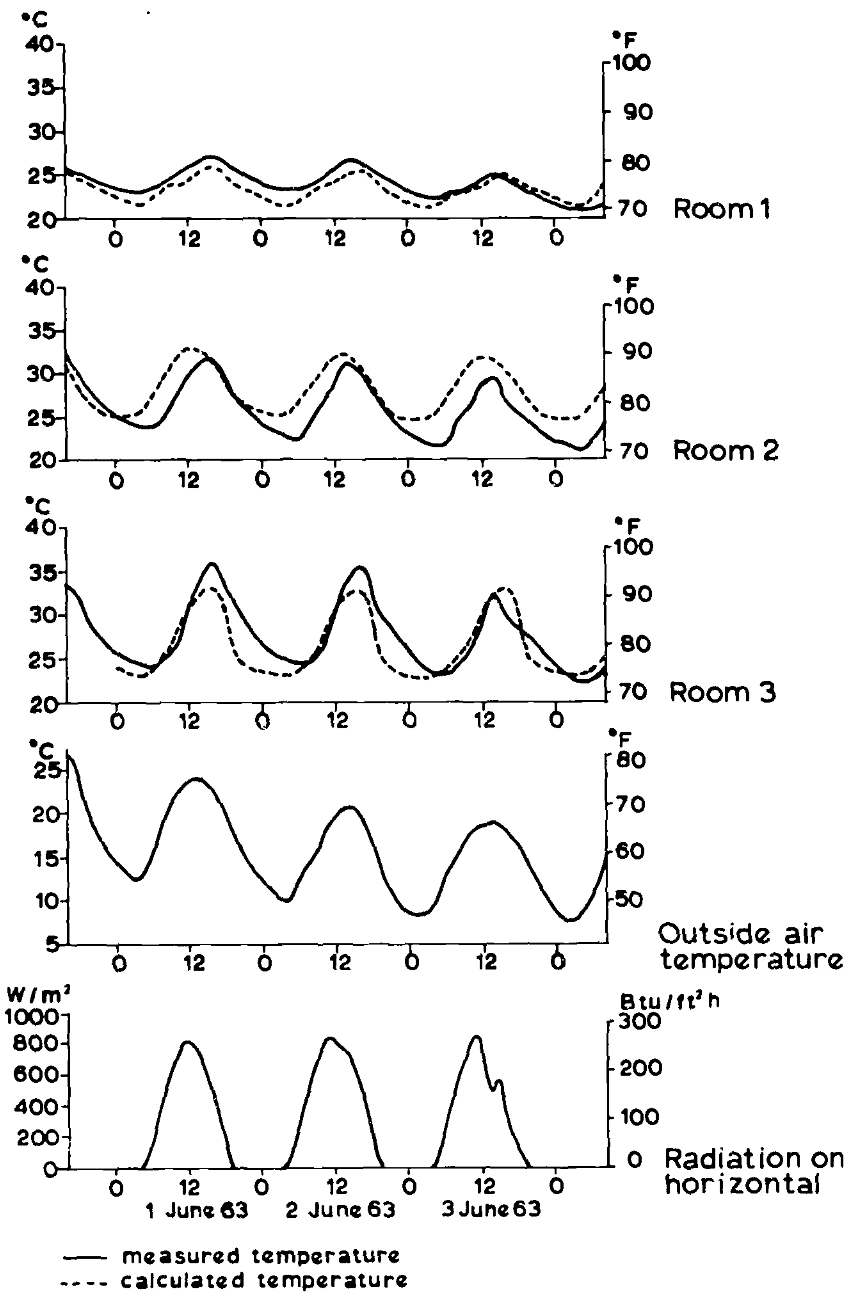

FIG 6 COMPARISON OF MEASURED AND CALCULATED TEMPERATURES IN OFFICES

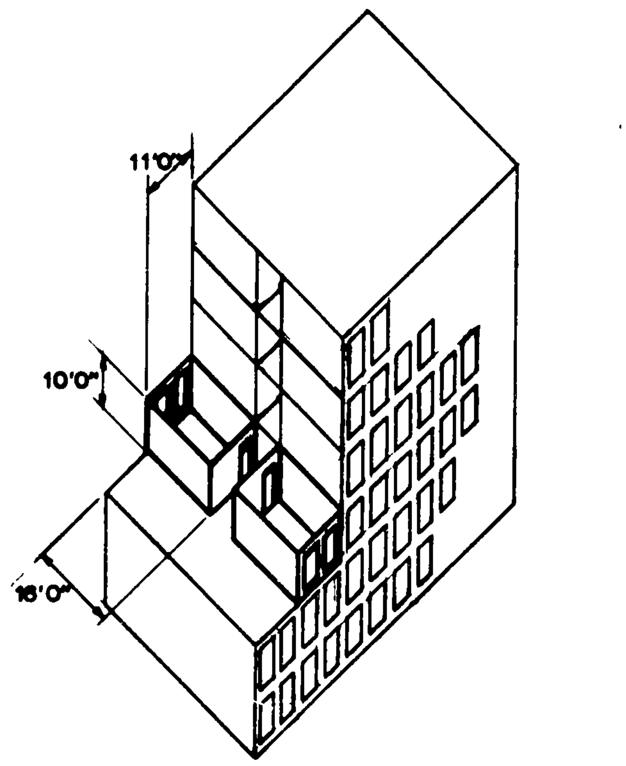

FIG 7 TYPE OF MULTISTORY BLOCK ASSUMED FOR DESIGN CALCULATIONS.

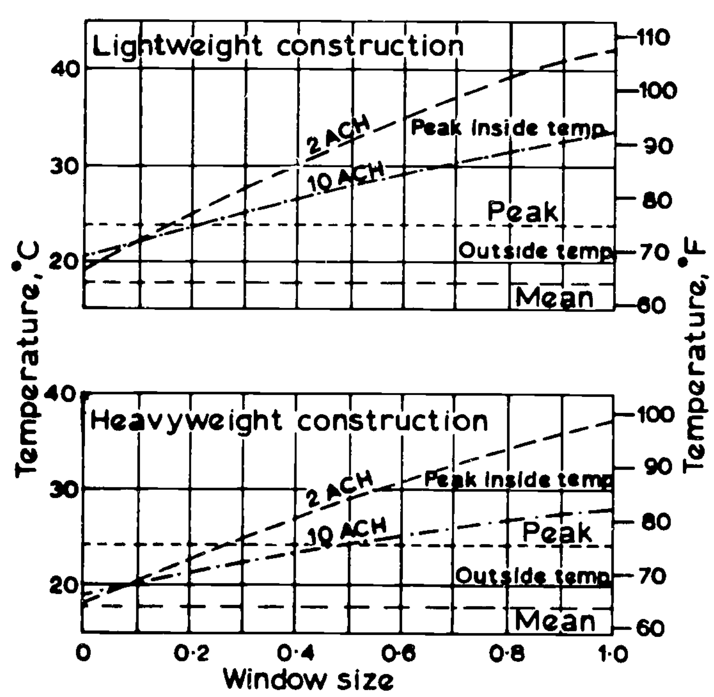

FIG 8 CALCULATED PEAK TEMPERATURE IN OFFICES VERSUS WINDOW SIZE.
(WINDOW SIZE IS GIVEN AS A FRACTION OF THE EXTERNAL WALL AREA)

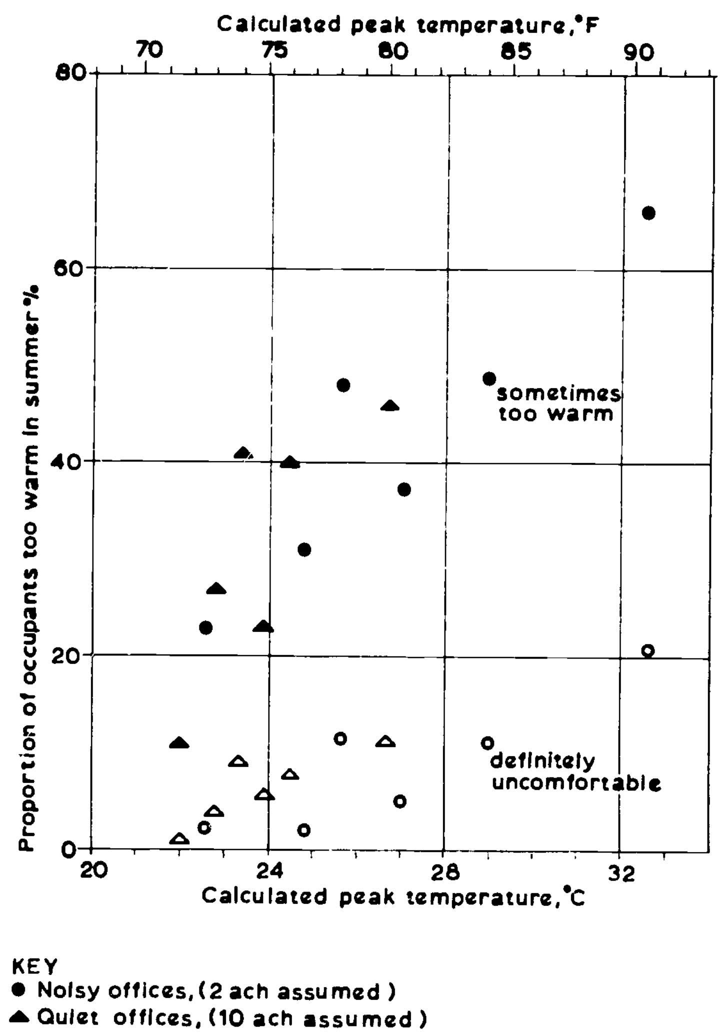

FIG 9 RELATIONSHIP BETWEEN OVERHEATING COMPLAINTS AND CALCULATED PEAK TEMPERATURES IN OFFICES.

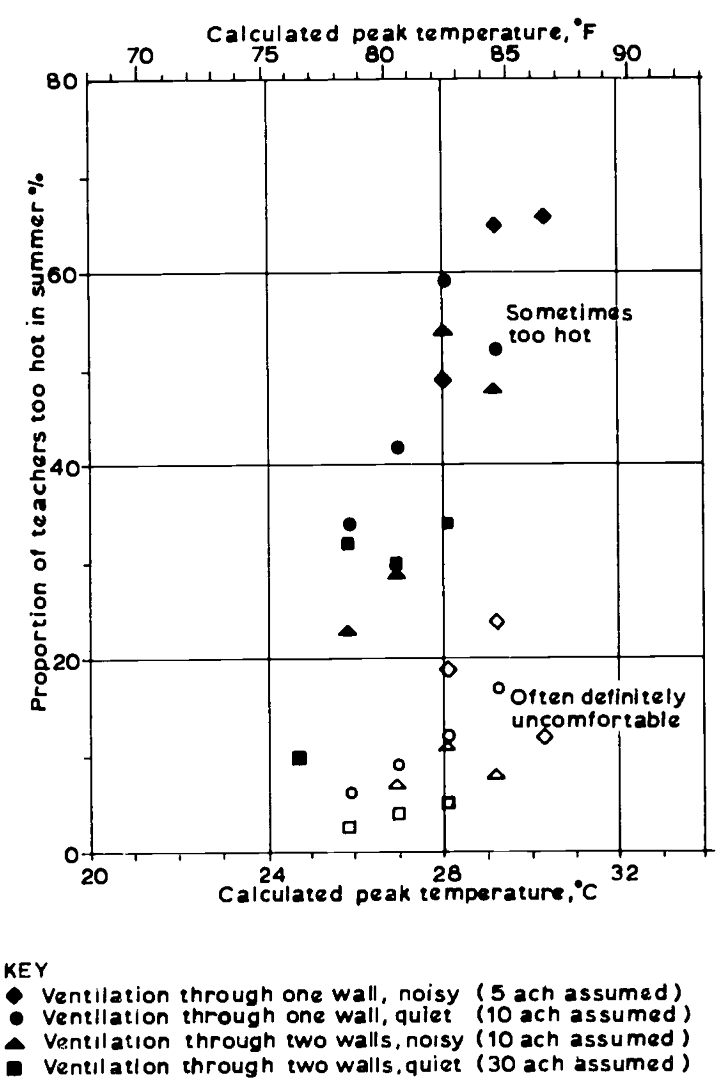

FIG 10 RELATIONSHIP BETWEEN OVERHEATING COMPLAINTS AND CALCULATED PEAK TEMPERATURES IN SCHOOL CLASSROOMS.

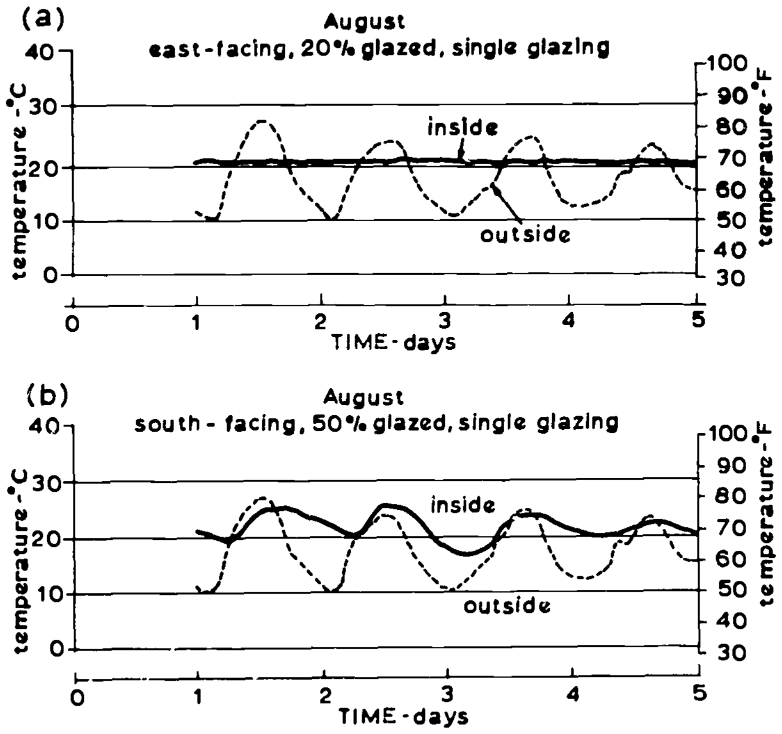

FIG 11 TEMPERATURE RECORDS DURING SUNNY SPELLS

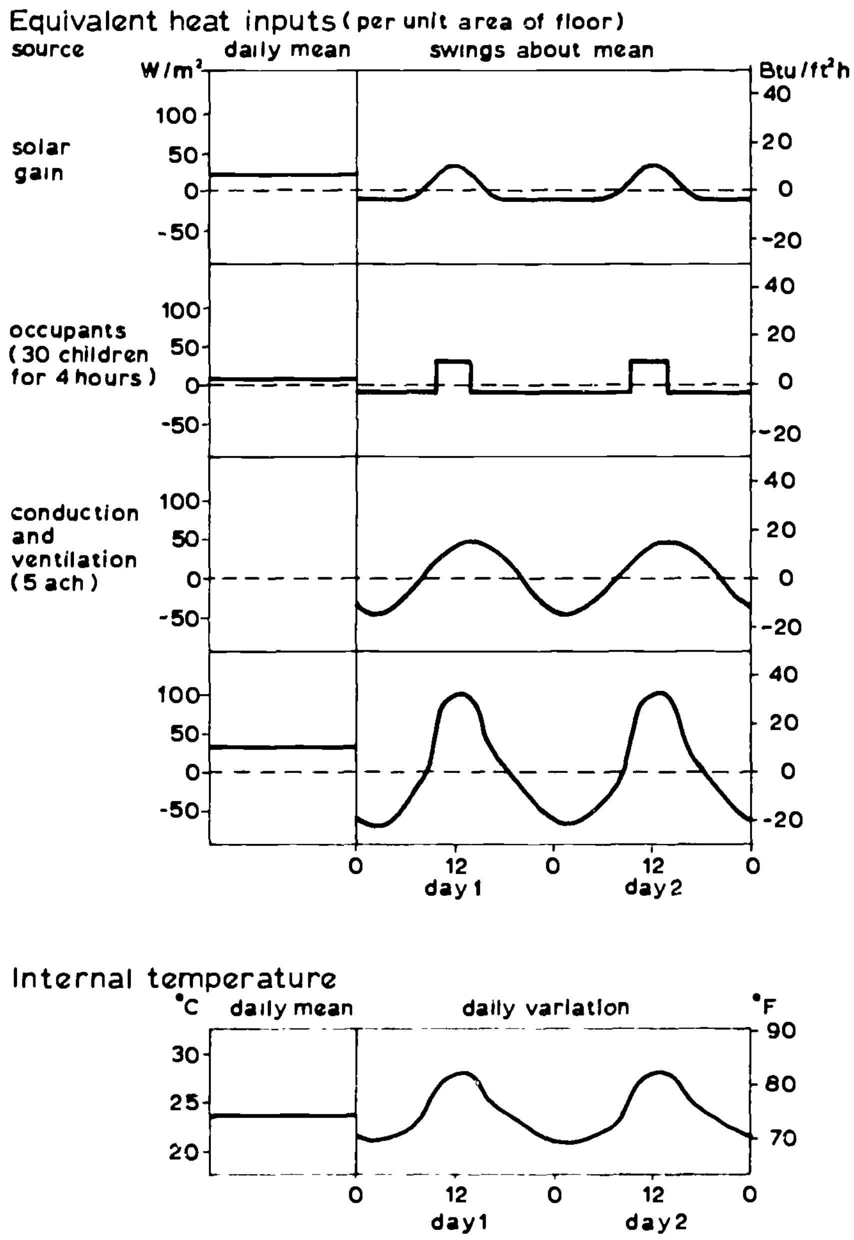

FIG 12 ILLUSTRATION OF PROCEDURE FOR CALCULATING PEAK TEMPERATURE

SCHOOL CLASSROOM 24' x 24' x 9' (7·3m x 7·3m x 2·7m)
HEAVY CONSTRUCTION 50% GLASS ON SOUTH FACE. JULY 15

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