Heat loss in buildings as a result of infiltration

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Synopsis

The thermal load imposed by the passage of cold outside air into the interior of a building is a function of the external climate, specifically the wind speed and outdoor air temperature.

Meteorological data relating to Birmingham Airport was obtained and analysed to determine suitable design conditions applicable to the accurate assessment of infiltration heat losses. The multiple of wind speed and indoor to outdoor air temperature difference was termed the 'wind-temp number' and was used as a measure of the infiltration heat loss caused by wind. The wind-temp numbers which were exceeded for only 1 per cent of the time were plotted for a range of outdoor air temperatures and wind directions. Differences were found between the maximum wind-temp number at each wind direction and the temperatures at which these maxima occurred.

Further analysis revealed that the peak values of the summation of fabric heat loss and both wind and stack induced infiltration heat loss generally occurred at the temperatures which corresponded to the strongest wind effect. It is these peak values which should be used for design purposes.

The design criteria developed from this study may be incorporated into the methods of deriving infiltration heat losses given in the IHVE *Guide* (1970). However, further studies are required to determine criteria which are applicable to other areas in the UK.

1 INTRODUCTION

One important aspect of heat loss calculation is the determination of the thermal load imposed by the passage of cold outside air into the interior of a building. This thermal load (or heat loss) is a function of the rate at which the air enters the building and the difference between the indoor and outdoor air temperatures. The latent component of the thermal load is small and can thus be neglected.

The flow of air into a building may be generated either by the effect of the difference between the indoor and outdoor temperatures (stack effect) or under the influence of wind. However, the accurate calculation of the rate of infiltration is a complex and difficult procedure so that it is generally necessary to adopt a method based on some broad assumptions.

The 1970 IHVE *Guide*[1] presents three methods of determining rates of infiltration or natural ventilation, and each of these may be considered useful depending on the particular application. The main concern of this paper is not so much the method of determining infiltration rates, but the design values of, for instance, wind speed and outdoor air temperature, used in the calculation of not only infiltration rates but also the heat loss resulting from the infiltration. To determine suitable design values of the overall heat loss it is also necessary to consider the relationship between the infiltration and the fabric heat losses.

Meteorological data covering a 10-year period for a single site (Birmingham Airport) was analysed. The analysis was directed at the assessment of suitable infiltration heat loss design conditions by considering the frequency of occurrence of various simultaneous combinations of wind speed, wind direction and outdoor air temperature.

It is envisaged that the method of analysis described may be applied to the data recorded from many meteorological stations throughout the United Kingdom so that any regional differences may be incorporated in comprehensive tables of design values

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for use in the assessment of the thermal load imposed in buildings by infiltration.

2 METEOROLOGICAL DATA

The rate of infiltration caused by wind on a given building is a function of wind speed. The thermal load imposed by this infiltration is additionally a function of the difference between indoor and outdoor air temperatures (Δt). Thus the thermal load with a light wind and a low outside temperature may be the same as with a strong wind and a moderate outside temperature.

The thermal load imposed by infiltration resulting from stack effect is a function of $(\Delta t)^{1 \cdot 5}$, so that the lower the outdoor air temperature the greater will be the heat loss. The details and derivations of these relationships are given in Appendix 1.

The meteorological data that needed to be considered was thus confined to wind speed and outdoor air temperature. In addition, however, the direction of the wind was also taken into account to determine the significance of variations in building orientation.

Tabulated information[2] was obtained from the Meteorological Office giving, for a 10 year period, the number of hours in which the recorded data were in various combinations of wind speed, wind direction and temperature. The information was based on mean hourly measurements made at Birmingham Airport for the 08.00 to 18.00 period of each day. The wind speed range was from 'calm' to 23 m/s (45 knots) in 2·57 m/s (5 knots) intervals; 12 equally spaced wind directions through 360° were included, and the range of outdoor temperatures was from −12°C to 28°C in 2°C intervals.

3 INFILTRATION HEAT LOSS RESULTING FROM WIND EFFECTS

As the infiltration heat loss caused by wind effects is a function of the multiple of wind speed and indoor-outdoor air temperature difference, the meteorological information was analysed to determine the frequency of occurrence of this multiple at the 12 wind directions. For this purpose the indoor air temperature was assumed to be 20°C.

The multiple of wind speed and indoor-outdoor air temperature difference has been termed the 'wind-temp number'. For any given room, the higher the wind-temp number, the greater will be the infiltration heat loss

The percentage of time that the wind-temp number was above a series of values was determined for each 2°C interval in outdoor temperature and for each wind direction. The percentages for adjacent wind angles forming quadrants were added together. This was done on the assumption that the wind is effective in producing infiltration over a 90° angle centred on the perpendicular to the building face in question. Variations depending on the orientation of the building face can thus be assessed.

Figs. 1 and 2 show the values of wind-temp number, for the quadrants centred on the directions indicated, which were exceeded during only 1 per cent of the time. These figures indicate that, for this particular site, the peak wind-temp number occurred at about 5°C with the exception of the north-eastern and eastern quadrants. The peaks at these two directions occurred at lower temperatures, 3°C and 1°C respectively, reflecting the higher frequency of cold winds from that sector. Of the other wind-directions, the variation in the level of the peak wind-temp numbers shows that the lowest wind-speeds (and infiltration heat losses) were associated with the south-eastern and southern quadrants whereas the highest levels correspond with the western and north-western quadrants. The following table presents the peak wind-temp numbers and the outdoor air temperature at which they occurred for the various wind directions.

Wind direction	Peak wind-temp number (m°C/s)	Outdoor air temperatures (°C)	Corresponding meteorological wind speed (m/s)
N	116	5	7·7
NE	94	3	5·5
E	85	1	4·5
SE	66	5	4·4
S	77	5	5·1
SW	101	5	6·7
W	118	5	7·9
NW	119	5	7·9

Table 1. Peak wind-temp numbers and the temperatures at which they occurred.

These wind-temp numbers may be used to assess the infiltration heat loss (resulting from wind effects) at the outdoor air temperatures indicated, which will be exceeded for no more than 1 per cent of the time. The basic method of calculation is as indicated in equation 4 of Appendix 1. However, an alternative method may be used when infiltration rates at a particular wind speed (e.g. 9 m/s) are given as design data. For the infiltration rates so determined, the corresponding heat loss should be calculated using an indoor-outdoor temperature difference equal to

$$\frac{\text{wind-temp number}}{\text{standard wind speed}}$$

For example, in considering a room facing north, a wind-temp number of 116 would be selected from Table 1. If the infiltration rate for this room was calculated on the basis of a 9 m/s meteorological wind speed (e.g. infiltration chart in IHVE *Guide*, Section A4), the temperature difference used to assess the heat loss would be $116/9 = 12{\cdot}9$°C. The heat loss so calculated would only be exceeded for 1 per cent of the time at an outdoor temperature of 5°C (Table 1). At other outdoor temperatures the infiltration heat loss would virtually always be lower than this calculated value.

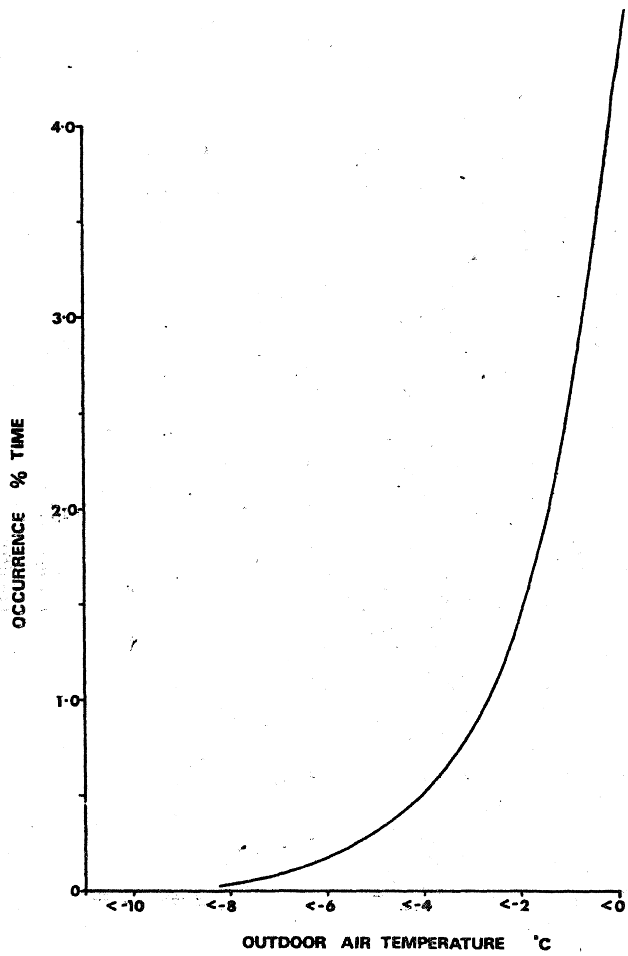

Fig. 3. Occurrence of low outdoor air temperature.

heat loss. Therefore in most instances, the design heat loss may be determined with sufficient accuracy by adding the infiltration heat loss calculated from the peak wind-temp number in Table 1 to the fabric heat loss calculated at the outdoor air temperature, also given in Table 1. Thus for the east facing room in the above example, instead of plotting the curves (as shown in Fig. 4) the design heat loss may be determined by calculating the infiltration heat loss corresponding to a wind-temp number of 66 and adding it to the fabric heat loss calculated for an outdoor temperature of 1°C.

For north facing rooms, however, this simplified calculation procedure may not result in an appropriate design heat loss value because the slope of this wind-temp curve is not as steep as the others. Calculations for an outdoor temperature of 1°C should also be made for this direction to check at which temperature the maximum combined heat loss occurs.

5 STACK EFFECT

In a multi-storey building, even where each floor is identical, the infiltration caused by stack effect varies significantly from floor to floor. In winter, the maximum infiltration caused by stack effect occurs at the ground floor. A reduced level of infiltration occurs at each of the higher floors until at some level, normally near mid-height, the infiltration falls to zero. At all floors above that level air passes out of the building (see Fig. 5). Considering the simultaneous action of wind and stack effects, it is clear that in some parts of the building the two forces will be in opposition while in others they will act in the same direction. Fig. 5 illustrates that in the windward rooms at low level the combined effect will generate the highest infiltration rates.

As noted in reference 3, although the infiltration in some parts of a building is increased when wind and stack effects are acting together, corresponding reductions in other parts result in the total infiltration rate remaining approximately the same—a point worth remembering in connection with the sizing of central boiler plant and in the calculation of running costs.

With regard to the sizing of individual room appliances, however, it is necessary to take into account the variation of infiltration heat loss resulting from stack effect. As has already been noted, the thermal load imposed by stack effect is a function of $(\Delta t)^{1 \cdot 5}$, so that the lower the outdoor air temperature the greater will be the heat loss. In general, the stack effect even in a tall building is restricted by corridor-stairwell (or lift shaft) doors which are required in accordance with fire regulations. Nevertheless, it will affect the peak heat loss in the rooms at low level to some extent and this may be best illustrated by referring again to the example described previously.

Appendix 3 outlines the method and parameters used in calculating the infiltration heat loss caused by stack effect in the ground floor rooms of the same 60 m building. Fig. 6 shows the results plotted against outdoor air temperature. Fig. 6 also shows the curves derived from a summation of the wind and stack heat loss and the fabric heat loss at the various outdoor air temperatures. These curves apply to N, E, S and W facing offices at ground floor level. The resulting peak heat losses, which would be taken as design values, are summarized in Table II, together with the values derived previously which

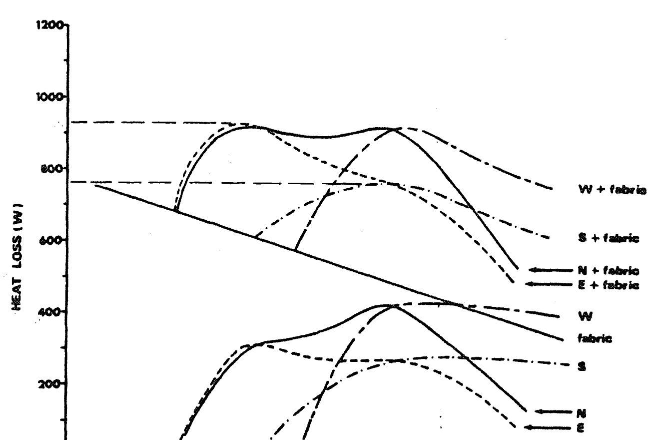

Fig. 4. Example of combined infiltration (wind effect) and wind fabric heat loss.

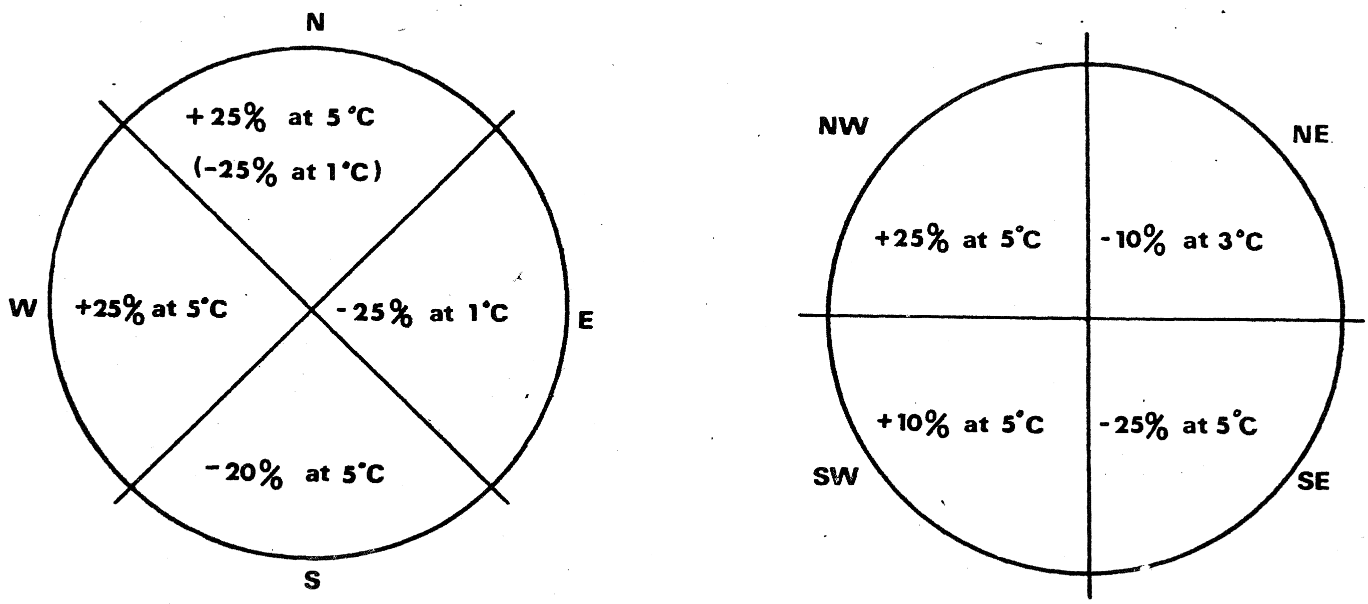

Fig. 7. Variation of infiltration rates (wind effect) with directon.

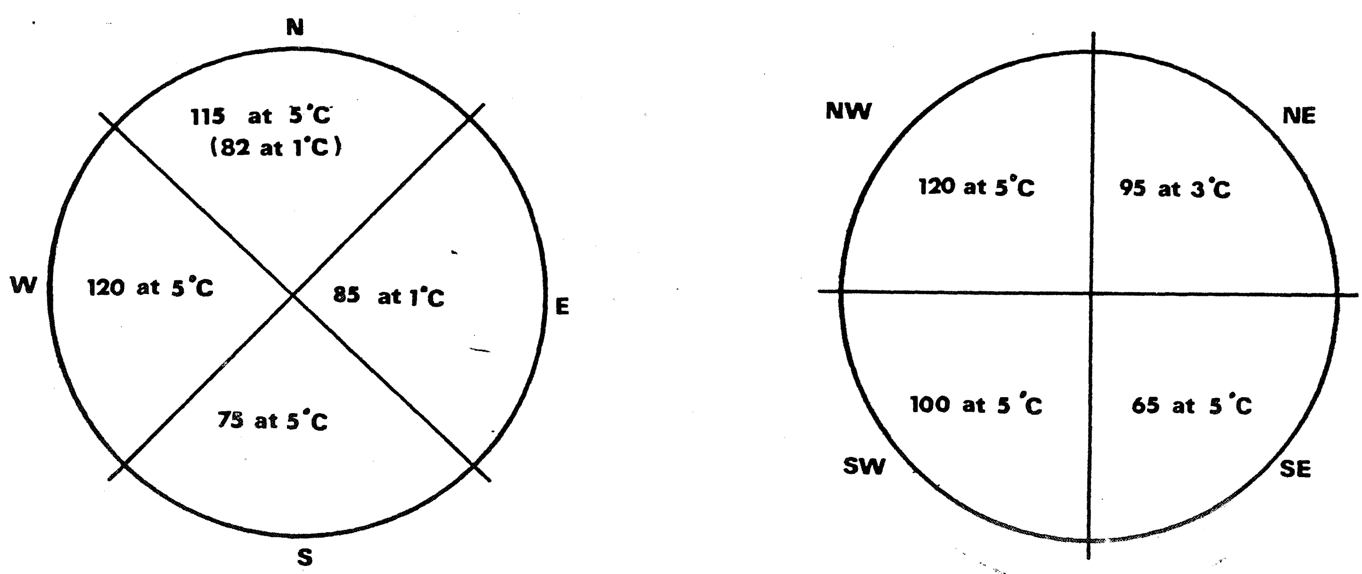

Fig. 8. Peak wind-temp numbers for various wind directions.

To illustrate this modified method of determining design heat losses the following procedure and numerical example may be considered.

Requirement: to calculate design heat losses for offices in a 20-storey (60 m) building located in a surburban area.

(a) Select appropriate infiltration rate from Table A4.8 (IHVE *Guide*).
For offices 1—air change/hour (0·33 W/m³ °C).

(b) Correct the above infiltration rate to allow for degree of exposure, etc.
+50 per cent for tall building in suburban site=1·5 air changes/hour (0·5 W/m³ °C).

(c) Adjust the infiltration rate in accordance with (for a Birmingham site) Fig. 7 and calculate the infiltration heat losses at the given temperatures for each orientation.
For a N-S orientated building—

N	5°C	+25%	563 W
	1°C	−25%	428 W
E	1°C	−25%	428 W
S	5°C	−20%	360 W
W	5°C	+25%	563 W

(d) Calculate the fabric heat loss per degree difference in indoor and outdoor temperature.
25 W/°C (say)

(e) Calculate the fabric heat loss at the temperatures used in stage (c) and at the normal design outdoor temperature (say −3°C).

5°C	375 W
1°C	475 W
−3°C	575 W

References

1. Institution of Heating and Ventilating Engineers, *IHVE Guide*, 1970, Section A4.
2. Private communication from the Meteorological Office, Bracknell, Berkshire.
3. P. J. Jackman: A Study of the Natural Ventilation of Tall Office Buildings, HVRA Laboratory Report No. 53 (1969); also published in *JIHVE*, *38* (August 1970), pp. 103-118.

APPENDIX 1
Parameters of the external climate which affect infiltration heat losses

Infiltration resulting from wind effects

The rate of infiltration through a given building caused by wind is given approximately by

$$m_w = K_1 \ (\Delta p_w)^{0.5} \quad \ldots . \ (1)$$

where m_w = mass flow rate of infiltration caused by wind (kg/s)
K_1 is a coefficient (depending on leakage characteristic of components).
Δp_w = pressure difference across the component or building generated by wind (Pa).

Now Δp_w is a function of V_{w2}, where V_w = wind speed (m/s).

$$\text{so } m_w = K_2 \ V_w \quad \ldots . \ (2)$$

where K_2 is a coefficient (incorporating K_1 and the factor relating Δp_w and V_w which depends on building height, location, etc.).

The heat loss imposed by this infiltration is given by

$$q_w = m_w \ C_p \ (\Delta t) \quad \ldots . \ (3)$$

where q_w = thermal load or heat loss caused by wind (kw)
C_p = specific heat of air (kJ/kg°C).
Δt = indoor air temperature—outdoor air temperature (°C)

Combining equations (2) and (3)

$$q_w = K_w \ V_w \ (\Delta t) \quad \ldots . \ (4)$$

where K_w is a coefficient (incorporating K_2 and C_p). The multiple V_w (Δt) has been termed the 'wind-temp' number.

Infiltration resulting from stack effect

The rate of infiltration, through a given building, caused by stack effect is given approximately by

$$m_s = K_3 \ (\Delta p_s)^{0.5} \quad \ldots . \ (5)$$

where m_s = mass flow rate of infiltration caused by stack effect (kg/s).
K_3 is a coefficient (depending on leakage characteristic of components).
Δp_s = pressure difference across the component or building generated by stack effect (Pa).

Now for normal temperature ranges Δp_s may be said to be a function of Δt where Δt = indoor air temperature minus outdoor air temperature (°C)

$$\text{so } m_s = K_4 \ (\Delta t)^{0.5} \quad \ldots . \ (6)$$

where K_4 is a coefficient (incorporating K_3 and the factor relating Δp_s and Δt which depends on building height).

The heat loss imposed by this infiltration (q_s) is given by an equation similar to (3), thus

$$q_s = K_s \ (\Delta t)^{1.5} \quad \ldots . \ (7)$$

where K_s is a coefficient (incorporating K_4 and C_p).

APPENDIX 2
Sample calculation of fabric and infiltration (wind effect) heat losses

Consider typical offices on the four sides of a 60 m building located on a N-S axis in a suburban area. Details of the office construction are shown in Fig. A2.1.

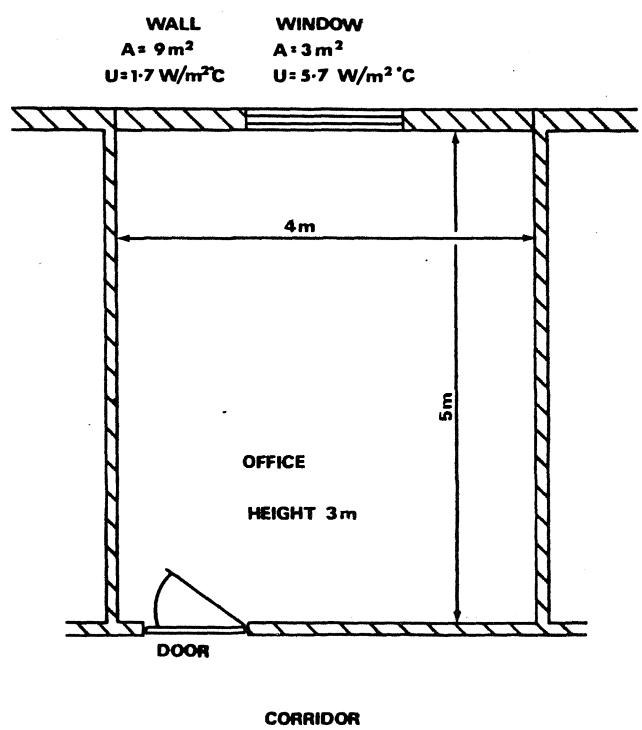

Fig. A2.1. Details of office construction used in example.

Fabric heat loss (q_f)

q_f/°C=UA

where U = thermal transmittance (W/m²°C)
A = area of component (m²)

Windows	3 × 5·7	17·1 W/°C
External wall	9 × 1·7	15·3 W/°C
Total		32·4 W/°C

$$\text{so } q_f/^\circ\text{C} = 32{\cdot}4 \ (\text{W}/^\circ\text{C}) \quad \ldots . \ (8)$$