Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

The Variation of Heat Loss Through Suspended Floors with Ventilation Rate

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Synopsis

Increases in the levels of thermal insulation required in the walls and roofs of houses in the U.K. in recent years have meant that heat losses through floors now assume greater significance, as a proportion of the total heat loss from a dwelling. To effect further reductions in the energy consumption of houses, the thermal performance of floors needs to be examined to assess the most cost effective insulation strategy. Suspended floors present a more difficult problem than solid floors because they require under-floor ventilation to prevent build-up of moisture, and variations in wind speed lead to changes in the ventilation rate and consequent heat loss. To assess the thermal performance of a suspended floor, a full-size experimental room was built and tested in an environmental chamber. The magnitude and direction of the airflow under the floor were found to vary substantially over its area, and there were corresponding variations in the effective U-value of the floor, related to the overall ventilation rate and the relative position of the air inlet and outlet vents.

Introduction

The ground floors of new houses are often constructed of solid concrete, but where ground conditions are unfavourable or the site slopes heavily, a suspended floor may be required. The floor itself and the beams on which it rests may be timber or concrete, and although the minimum height of the under-floor space in new houses is fixed by regulations [1], in older houses it may vary from a few centimetres to over half a metre. Suspended timber floors are typical of a large number of local authority houses built in the twenties and thirties, many of which are in need of refurbishment and require improved floor insulation to meet the standards currently expected by householders. Ventilation is required under such floors to prevent mould growth and rotting caused by condensation, and is normally provided by natural means, using air bricks. The regulations require a minimum size of ventilation opening (ie. the number of air bricks per metre run of wall), but do not specify their position. Since a high rate of under-floor ventilation leads to large heat losses, it is important to ensure that it is sufficient to prevent rot, but is not so high as to give rise to large energy bills. In this paper, the way in which the heat losses vary with ventilation rate is investigated.

Theoretical Background

For many years the basis of the CIBSE [2] method for the assessment of U-values of solid floors has been the work of Macey [3] and Billington [4] who assumed that the greater part of the heat loss from a floor takes place through the perimeter. Thus, it was supposed that insulating the perimeter alone would be more cost effective than insulating the whole floor.

However, doubts were cast on this theory when measurements by Spooner [5] showed that vertical perimeter insulation to a depth of 500mm produced no measurable reduction in heat loss from the floor. The CIBSE method enables a steady-state U-value to be calculated, based on the indoor-outdoor air temperature difference. This is not altogether realistic, since the ambient and ground temperatures are constantly changing, but a steady-state U-value at least gives an indication of the long-term thermal behaviour. In addition, timber suspended floors may be assumed to have little inherent heat storage capacity. Since that early work, many analytical studies have been carried out on heat flows through solid ground floors, using such methods as Fourier transforms, [6] finite-difference methods [7] and others, but little additional measured data is available. Anderson [8] developed the CIBSE formula to give a simplified graphical method of estimating the U-value, based on perimeter/area values. The performance of suspended floors has received considerably less attention than solid floors. Anderson extended his calculations to include suspended floors, but of necessity a fixed ventilation rate had to be assumed. The main causes of uncertainty in these predictions are:

i) Uncertainties concerning the thermal conductivity of the ground and the below-ground temperature, both of which vary with soil constitution and moisture content. Some data are available [9], but they are specific to soil type and location. Spooner [4] deduced that in general, variations in the below-ground temperature lagged behind those of the air temperature by about 30 days, but with a much smaller amplitude.

ii) Random variations in the wind speed and direction.

iii) Doubts concerning the relationship between the wind speed and the ventilation rate.

The principal heat loss routes from such a floor are those shown in figure 1. They comprise:

i) Heat losses from the edge of the floor through the walls by conduction, which may be 1,2 or 3 dimensional and which is mainly horizontal.

ii) Heat losses from the underside of the floor to the air in the cavity by convection and radiation.

iii) Ventilation heat loss, dependent on the rate of air change in the cavity, and the difference between the ambient and the cavity temperature.

iv) Conduction through the ground as for solid floors. The relative contribution of each mechanism to the overall heat loss has not been estimated.

Experimental Work

A test room was built and is shown in figure 2. The inside dimensions of the floor were 3.14m by 2.91m, the room was 2.8m high and the under-floor space was 0.5m from floor to bottom of joists. The floor itself was of 18mm chipboard laid on 150mm by 50mm joists at 600mm centres, and between the joists and floor was a layer of damp-proofing membrane to prevent leakage of air from the underfloor space to the room above. The walls and ceiling were constructed of plywood panels on timber frames with 100mm rockwool insulation, and had an average U-value of 0.44 W/m^2K. Between the timber and the internal plywood panel was a plastic damp-proofing membrane which acted as a seal to prevent leakage of air from the room. No thermal insulation was applied under the floor itself.

Heating in the room was provided by an oil-filled, electrically-heated radiator. The air temperature inside the room was controlled at approximately 20^oC using a proportional controller, and the electrical energy input to the heater was measured using a current clamp. The room was situated inside an environmental chamber, controlled at a temperature of 10^oC +/-0.5^oC, and recordings were made when the system was in a steady-state. This took some eight hours to achieve, and readings were taken over a 24-hour period beyond this. Temperature differences of at least 10^oC between the internal and external environments were maintained.

The rate of air leakage from the room was measured using a blower door pressurisation test, and was found to be too low to register on the scale. Hence it could be assumed that all the heat losses from the room were accounted for by conduction through the fabric.

Ventilation holes, simulating air bricks, were drilled in two opposite walls of the underfloor space, giving an orifice size equivalent to 4500mm^2 in each wall, and a variable-speed fan forced air into the space, simulating the effect of a constant velocity wind perpendicular to the wall. Instrumentation was provided in the form of platinum resistance thermometers, heat flow mats and air flow meters. (vane and hot-wire anemometers) and a data logger. A motorised trolley was devised, on which the hot-wire anemometer probes were mounted, and it was programmed to move to predetermined positions under the floor to take readings of the local air flow rate.

Thus, maps of the pattern of air flow beneath the floor were obtained for a range of ventilation conditions. The direction of the airflow was visualised using a smoke generator. A "nominal" airflow measurement was made using a vane anemometer placed inside the space, 10cm from the inlet holes and directly opposite a ventilation hole. The overall airflow under the floor was calculated by averaging the local airflow measurements taken over the whole floor area.

The ventilation rate was measured in three ways.

i) The "nominal " airflow was measured using a vane anemometer placed under the floor close to the inlet vent.

ii) The local airflow was measured using hot-wire anemometers, which traversed the floor on a trolley and measured the airflow in 56 locations under the floor.

iii) A tracer gas technique was used, employing carbon dioxide, and measuring the rate of decay of concentration. The probe could be positioned in a number of locations, but as this method was very time-consuming, fewer measurements were taken than with the anemometers.

A simple linear relationship existed between the "nominal" and mean airflow rates, with excellent correlation.

Results

The results of the heat flow measurements for straight-through cross-ventilation are shown in Table 1. As shown in figure 3, the effective U-value of the floor increases sharply as the airflow increases from zero, then becomes asymptotic with increasing airflow. From zero airflow to a nominal rate of 4m/s the effective U-value increased from 0.62 to 0.84 W/m^{2}k, an increase of 35%. This increased heat loss, in an average dwelling of 50m^2 ground floor area would amount to some 550 kWh per year in the U.K. climate, which represents a cost of about £27 if gas heating is used. This would result in a reduction in CO_2 emissions of 115kg per year.

In this configuration, the readings from the anemometers and tracer gas measurements indicate that the majority of the air flows straight through the centre, and little is distributed to the corners of the room. (fig 4a). This may have serious implications where there is a risk of condensation or problems of mould growth, as there appears to be little disturbance of the air in the corners of the underfloor space where problems are likely to occur. However, there are differences between the measurement methods, since the tracer gas measures the air change rate in the locality around the probe whilst the anemometer probes measure the velocity of the air. Since some of the air recirculates around inside the space, these results are not directly comparable. The results also imply that the effective U-value of the floor varies depending on position, and therefore it is difficult to estimate the most cost-effective insulation thickness with any accuracy. Measurements taken with the heat flow sensors positioned in different parts of the floor confirm that the U-value is not constant over the floor area.

The system was reconfigured with the outlet vents repositioned, maintaining the same overall inlet and outlet vent area. The corresponding ventilation and airflow rates are shown in figure 4b and 4c.

Under the conditions of this experiment, changes in the effective U-value arise from increases in the heat transfer coefficient in the space beneath the floor, resulting from increased air speeds. This will result in increased heat losses from the floor itself, and from the vertical walls beneath the floor, which will also experience an increase in heat transfer coefficient. The airflows measured close to the vertical walls are small, and the presence of the joists (perpendicular to the main airflow direction) means that the airflow pattern close to them fairly complex.

Changes in heat flow rates from the room to the space beneath are solely the result of increases in airflow beneath the floor. Since the upper surface thermal resistance and the thermal resistance of the solid floor remain the same, these changes must therefore represent increases in the lower surface resistance governing the transfer of heat between the bottom of the floor and the air in the under-floor space. The values of this heat transfer coefficient have been calculated. (Table 1 and Figure 3.)

Conclusions

The relationship between heat loss and ventilation rate under a suspended floor was measured under a range of controlled conditions in a full-size test room. The airflow rate was found to vary substantially over the area of the floor, depending on the location of the inlet and outlet vents, and the average ventilation rate. Simultaneous measurements of the heat losses from the lower surface of the floor indicate corresponding spatial fluctuations in the effective U-value of the floor. Parts of the under-floor space experience significantly lower air change rates than others, and where there is a risk of condensation and damp rot this will have implications for a minimum safe ventilation rate.

Acknowledgements

The authors wish to acknowledge the financial support of the Science and Engineering Council of the U.K. for this work.

References

1. National House Building Council Standards. "Suspended Ground Floors." NHBC. 1992.
2. CIBSE Guide. Chartered Institute of Building Services Engineers. 1985.
3. Macey, H.H. "Heat Loss Through a Solid Floor." J.Inst. Fuel. 22. pp369-371. 1949.
4. Billington, N.S. "Heat Loss Through Solid Ground Floors." J. Inst Heating Ventil. Eng. 19. pp351-372. 1951.
5. Spooner, D.C. "Heat Loss Measurements Through an Insulated Domestic Ground Floor." Building Services Engineering Research and Technology. Vol. 3. No 4. pp147-151. 1982.
6. Delsante, A.E. "A Comparison Between Measured and Calculated Heat Losses Through a Slab on Ground Floor." Building & Env. Vol 25, No.1. pp25-31. 1990.
7. Ambrose, C.W. "Modelling Losses From Solid Floors." Building & Environment. Vol. 16. No. 4. pp251-258. 1981.
8. Anderson, B.R. "U-values of Uninsulated Ground Floors: Relationship with Floor Dimensions." BSERT 12(3) 103-105 (1991).
9. Lacey, R.E. Climate and Building in Britain. HMSO, London. 1977.

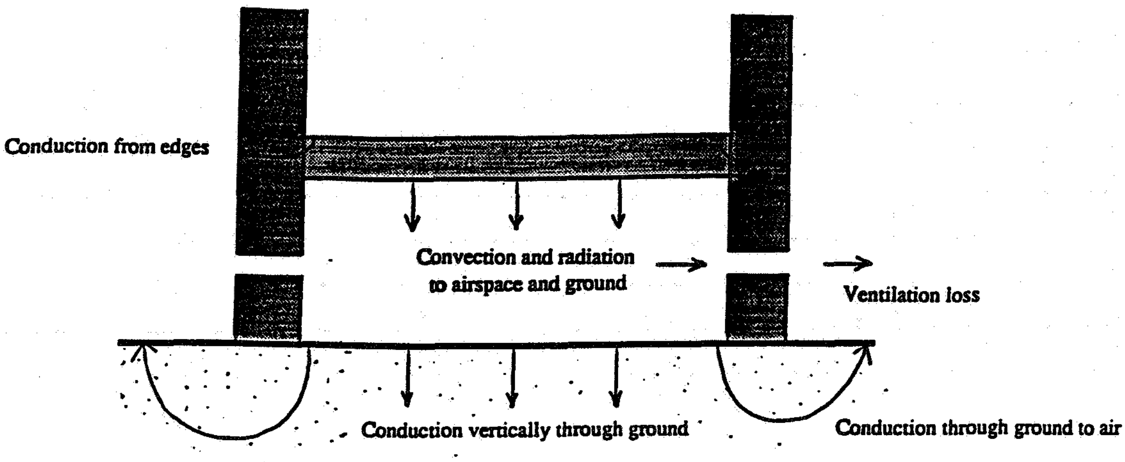


Figure 1. The Principal Heat Loss Routes From a Suspended Floor.

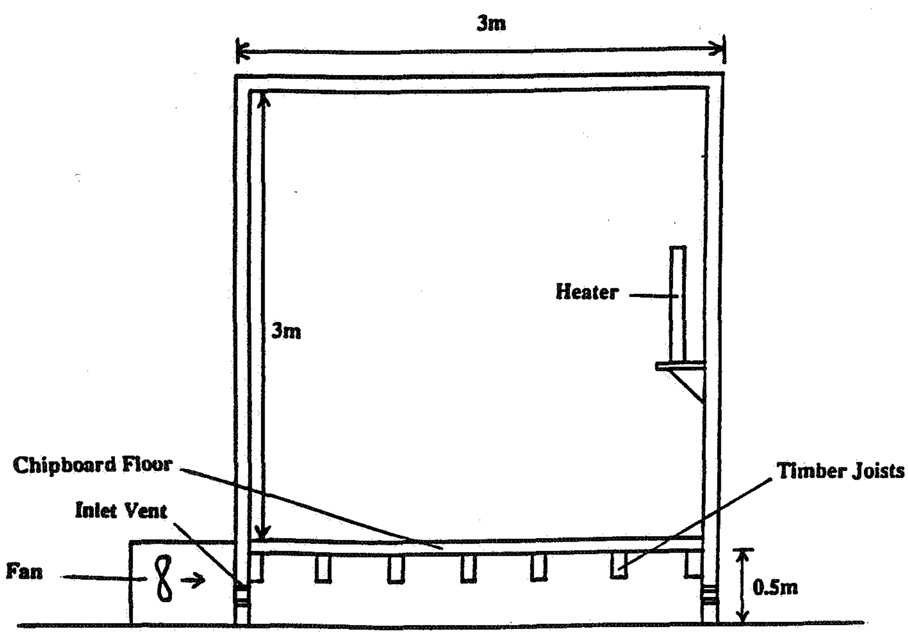
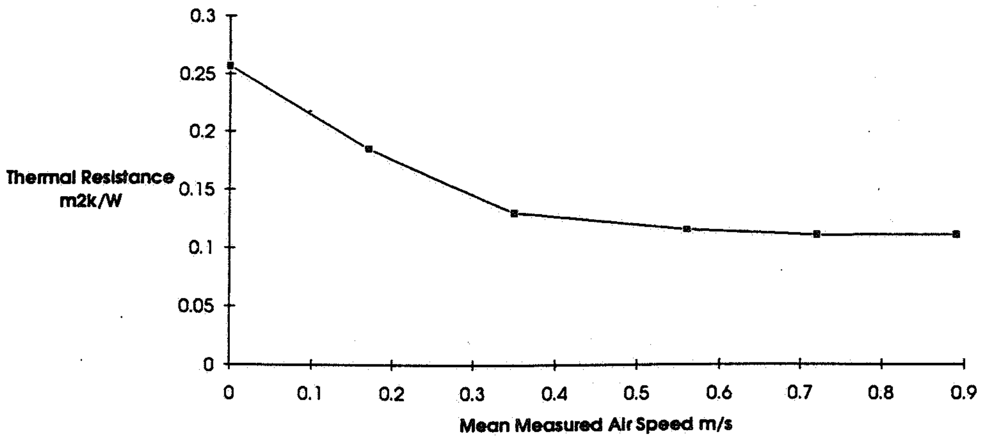


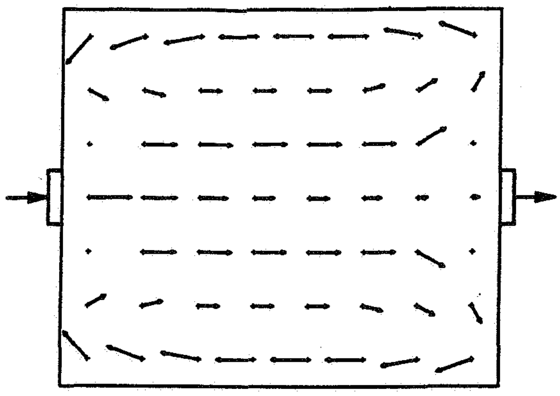
Figure 2. Section Through The Test Room.

Table 1. Effective Overall U-value of the floor at different under-floor air flow rates.

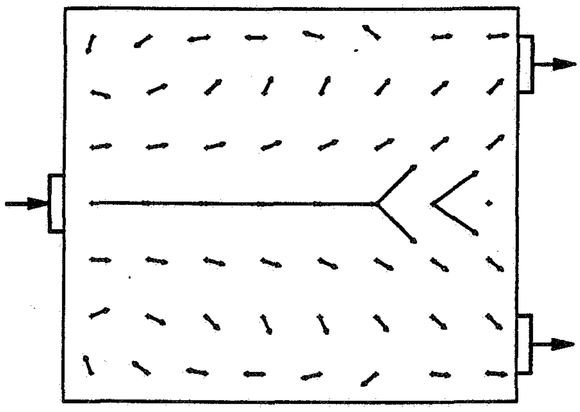
Nominal Air Speed m/s	Mean Airspeed m/s	Equivalent Air Change Rate/hr	Effective U-Value W/m^2K	Lower Thermal Resistance m^2k/W
0	0	0	0.62	0.256
1	0.17	0.6	0.76	0.185
2	0.35	1.2	0.78	0.13
3	0.56	1.9	0.83	0.115
3.5	0.72	2.5	0.84	0.11
4	0.89	3.1	0.84	0.11

Figure 3. Thermal Resistance and Mean Air Speed

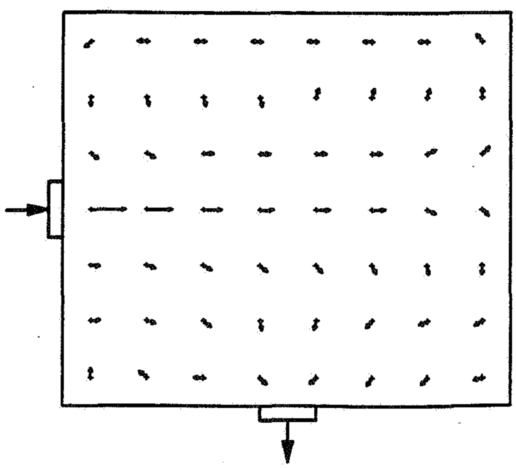




a. Centre cross-flow.



b. Corner cross-flow.



c. Inlet and outlet at right angles.

Figure 4. Airflow patterns beneath the floor at a nominal wind speed of 1m/s.