# The Role of Ventilation
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## Measuring Subfloor Ventilation Rates

R Hartless, M K White

Building Research Establishment, Garston, Watford,
Herts WD2 7JR, United Kingdom

## SYNOPSIS

This paper reports on ventilation measurements taken beneath a suspended timber floor of a BRE/DoE energy and environment test house. Sulphur hexafluoride was introduced into the subfloor void at a constant rate and the resulting concentration measured. Wind speed, wind direction, and internal, external and subfloor temperatures were also recorded. A range of air brick locations were used for each run which lasted two to three days. Analysis of the data shows that subfloor ventilation rates in this test house fluctuated widely, ranging from about 3 air changes per hour (ach) to over 13 ach. Also, the subfloor ventilation rate for this house seems to be heavily influenced by the subfloor/external temperature difference rather than the wind speed, particularly when air bricks are located on sheltered subfloor walls. The main reason for this stack dependence is that there is a significant leakage path at the wall/floor junction with air moving from the subfloor void to the gap behind the plasterboard lining.

## 1. INTRODUCTION

In the UK naturally ventilated floors are used to control water vapour from the ground. Building Regulations for England and Wales recommend that for suspended timber floors air bricks be distributed over the subfloor walls with a minimum open area of 1500mm² per meter run of wall and a vapour barrier be provided [1]. Suspended concrete floors can be used to control water vapour as well as gaseous contaminants (e.g. radon and landfill gas) in which case they should be ventilated to the above provision. To control water vapour, BS5250 [2] recommends that the void beneath a suspended concrete floor should be ventilated. Further, the void beneath a suspended timber floor should be ventilated with an area of 1500mm² per meter run of wall or 500mm² per m² of floor area whichever is the greater, as well as having a vapour barrier [2]. However, the subfloor air change rate that these ventilation provisions will give is unknown. The purpose of this work, therefore, is to measure the air change rates beneath a suspended floor of a house with these ventilation provisions and to relate these measurements to the two driving forces for natural ventilation: stack effect and wind speed.

## 2. THEORY

The subfloor ventilation rate ($Q_V$) depends on wind speed (U), wind direction ($\phi$) and temperature difference ($\Delta T$) as well as other factors such as air brick area, degree of local shelter, leakiness of floor etc. The two driving pressure differences for (subfloor) ventilation are stack, $\Delta P_B$, and wind, $\Delta P_W$, which, to a good approximation, can be treated separately and simply added together to give a total driving pressure difference [3]:

$$\Delta P_T = \Delta P_B + \Delta P_W = k_B \Delta T g h + k_W U^2 \quad (1)$$

where, h is the stack height (approximated by the depth of the subfloor void), g is the acceleration due to gravity and $k_B$ and $k_W$ are both constants encompassing all of the factors such as floor tightness etc. Now, leakage measurements of buildings have shown that the volume flow rate, Q, through the building envelope can be related to the pressure drop, $\Delta P$, across it using the equation [4]:

$$Q = K \Delta P^n \quad (2)$$

where K is a constant and n is a flow exponent (range 0.5 to 1) both of which are determined from the leakage measurement. Using this means that the total ventilation rate can be expressed as the combined stack and wind induced ventilation rates [3], i.e.

$$Q_V = (Q_B^{1/n} + Q_W^{1/n})^n \tag{3}$$

However, for subfloor ventilation much of the air flow is likely to be through air bricks which have a measured flow exponent of about 0.5. Therefore, equation (3) can be simplified to:

$$Q_V = (Q_B^2 + Q_W^2)^{½} \tag{4}$$

Combining equations (1), (2) and (4) gives the subfloor ventilation rate as:

$$Q_V^2 = K_B \Delta T + K_W U^2 \tag{5}$$

where $K_B$ and $K_W$ are both constants. (The above method can also be used to model passive stack ventilation systems [5].) Equation (5) can be rewritten in two other forms by dividing through either by $U^2$ or $\Delta T$. Using these forms it is possible to plot ventilation measurements to determine the relative importance of the wind and stack driven terms. For example, plotting $(Q_V/U)^2$ against $\Delta T/U^2$ will give a straight line with gradient $K_B$ and intercept $K_W$. It is likely that there will be a certain amount of scatter when plotting $Q_V^2/\Delta T$ against $U^2/\Delta T$ due to the dependence of subfloor ventilation on wind direction.

## 3. EXPERIMENTAL

### 3.1 DoE/BRE energy and environment test houses

The house used for the subfloor experiments was one of the DoE/BRE energy and environment test houses constructed at BRS Garston. They are a row of four detached houses constructed so as to be two matched pairs: one pair built to just beyond current UK Building Regulations (houses 1 and 2), the other built to Swedish standards (houses 3 and 4). For a layout of the site see figure 1. House 2 was used for all experiments.

The floor construction of all four houses is suspended timber above a concrete oversite of thickness of about 100mm, and the ground floor area of each is $42m^2$. In houses 1 and 2 the floor consists of carpet on 22mm chipboard supported on 150mm joists set 400mm apart. The insulation is 75mm thick and supported between joists on 50 x 50mm treated softwood battens fixed to the joists. The depth of the subfloor void (i.e. height of the bottom of the joists above the concrete oversite) is on average 22cm (figure 2). This gives a total subfloor void volume of $10.19m^3$ (void plus air spaces between the joists beneath the insulation). In addition there is a foundation (sleeper) wall running E-W through the middle of the subfloor void. To assist cross ventilation this wall has slots (5 x 30cm) at about 2m centres. Four floor hatches (one in each room) provide access to the void which helped us to position equipment. The void was ventilated using plastic air bricks fitted with a cavity sleeve for which air flow rate measurements gave an equivalent area of $4420mm^2$. Sixteen of these air bricks are evenly located around the perimeter of each house to give a ventilation provision of about $2450mm^2$ per metre run of external wall.

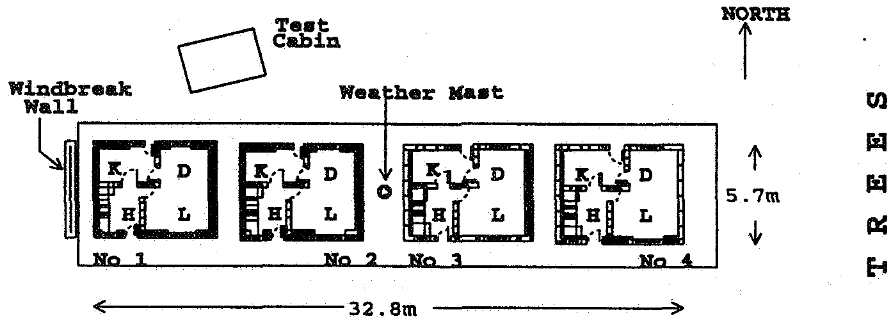
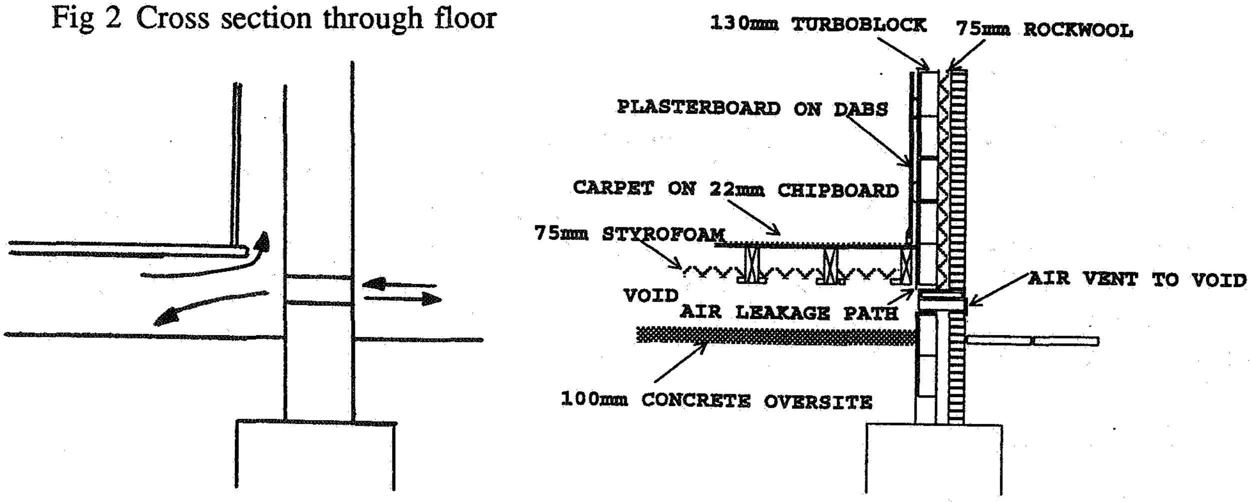



Fig 1 The DoE/BRE Energy and environment test houses

Fig 2 Cross section through floor




## 3.2 Equipment to measure subfloor ventilation

The constant emission technique was chosen to measure the subfloor ventilation rate [6]. For the purposes of this experiment the subfloor void of house 2 was divided into four comparably sized zones. Into the middle of each of the four zones the selected tracer gas, sulphur hexafluoride ($SF_6$), was injected at a constant flow rate from a gas cylinder by way of a mass flow controller and its associated control unit. Using data on likely subfloor ventilation rates from other studies [7], the flow rate chosen was 6 ml/minute into each half so that the resulting $SF_6$ concentration within the void would fall within the detection range (0-50ppm) of the infra-red analyser that was used. By using four injection points it was hoped to ensure an even distribution of tracer gas throughout the void without the need for mixing fans. However, preliminary results showed that mixing fans were necessary.

In each of the four zones was also a gas sampling point. Air from each point was drawn back from each point using a gas handling unit on a six minute cycle. A data logger was used to record $SF_6$ concentration as well as the subfloor temperature, measured using thermistors. All of the above equipment was housed in a test cabin (see figure 1). A 15m mast was used for wind speed and direction, and a Stevenson screen for external temperature. Thermistors were also used to obtain an average internal temperature. These data were recorded every ten minutes: the wind speed as an average over the preceding ten minutes, the wind direction and all temperatures as spot measurements. The subfloor ventilation rate was an average of the four zones, and linear interpolation was used to calculate a 10 minute average.

## 4. MEASUREMENTS OF SUBFLOOR VENTILATION

Half of the air bricks were always blocked to give a ventilation provision of 1230mm$^2$ per meter run of wall. Using two pairs of 6-inch fans (one pair in each half of the void) ensured good mixing but results indicated that they might be affecting the subfloor ventilation rate. Using one fan in each half still gave good mixing whilst not affecting the ventilation rate. Therefore, for subsequent runs only two fans were used and these were directed to blow away from open air bricks. The gas analyser was zeroed using nitrogen and the span established using cylinders of 50ppm $SF_6$ in air. It was also necessary to check the filter regularly because the subfloor void was dusty. As each run lasted between one and three days the zero and span of the gas analyser was re-checked to see how much they had drifted. If they had changed, all concentration readings were corrected assuming a linear drift from the start to the end of the run. This drift was generally quite small though.

In all six runs were carried out each lasting two to three days. However, because of the large quantity of data that this generated, only two of the runs are summarised here. For Run 1 air bricks were open on the East and West facing walls, and for Run 2 they were open on the North and South facing walls. Graphs 1a and 1b show the average subfloor ventilation rate plotted with wind speed and subfloor/external temperature difference respectively for Run 1. Graphs 2a and 2b show the same data for Run 2. Graphs 3a and 3b are plots of equation (5) for Run 1. Graphs 4a and 4b are the equivalent for Run 2.

A variable not so far considered is wind direction. This is likely to be very important if air bricks are only located on subfloor walls which are sheltered from the wind. To bring wind direction into the analysis we resolved the wind velocity vector into two perpendicular components, one along an axis for which the ventilation rate would be maximised (i.e. wind blowing directly onto air bricks) and the other along an axis for which the ventilation rate would be minimised or, preferably, zeroed. For Run 2 this means that the minimum axis runs E-W and the maximum axis runs N-S. For Run 1 the maximum axis was assumed to run NE-SW. Graphs 5 and 6 are duplicates of graphs 1a and 2a respectively except that wind speed is replaced by component wind speed and the data are 30 minute averages.

## 5. DISCUSSION

Overall, the subfloor ventilation rate measured for this house fluctuated widely over time ranging from 3 to as high as 13ach. Graphs 1a and 1b show that the subfloor ventilation rate for Run 1 is heavily influenced by temperature difference and is negatively correlated with wind speed. This is not the case for Run 2. Graph 3a shows good correlation between subfloor ventilation and subfloor/external temperature difference except when this difference becomes negative. (A better correlation is achieved using the internal/external temperature difference which was always positive.) Graph 3b is for negative temperature differences only and shows a reasonable correlation between subfloor ventilation rate and wind speed. The equivalent graphs for Run 2 show a similar pattern except the wind speed correlation is better. Finally, graphs 5 and 6 show that for Run 1 the subfloor ventilation rate still does not appear to follow changes in component wind speed whereas it does for Run 2 for part of the time.

The most important observation from the data is that temperature difference appears to play a major role in the subfloor ventilation rates seen in this house. Whilst the internal and external temperatures moved through their usual daily cycles the subfloor temperature remained constant at about 16°C because the subfloor air is primarily warmed by the large concrete slab whose temperature is only likely to change on a seasonal basis. (Subfloor temperature measurements in April and May support this.) As a result, the subfloor/external temperature difference becomes negative in the early morning reaching a peak at midday; thereafter it rises becoming positive again in the evening reaching a peak after midnight. Conversely, the wind speed falls to relatively low levels (0-2m/s) in the night, with generally higher levels during the day. This means that subfloor ventilation in this test house is influenced by the wind during the day but is dominated by temperature difference during the night. This is clearly shown in graph 6. When the air bricks are located on the sheltered walls though the wind speed appears to have little effect on subfloor ventilation (graph 5).

However, even though a temperature difference exists this will not drive air flow unless there is a height difference between subfloor air bricks. Therefore, there must be a flow path through the floor: infra-red thermography shows that air is moving up from the subfloor void into the gap behind the plasterboard (figure 2). This problem has been observed in a number of UK houses [8], and it could help to explain the high subfloor ventilation rates seen here.

Further work in this area is planned. This will include repeat measurements of subfloor ventilation now that the wall/floor junction has been sealed using expanding polyurethane foam. Tests with all of the air bricks closed are also planned so that the floor tightness can be assessed. A wider range of air brick configurations and areas will also be tried.

## ACKNOWLEDGEMENTS

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## REFERENCES

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(2) **British Standards Institution** "Control of condensation in buildings". BS 5250: 1989.
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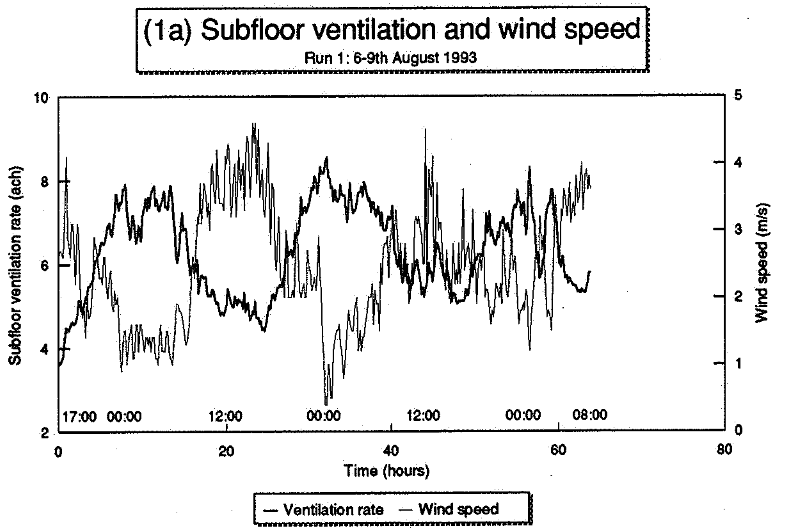
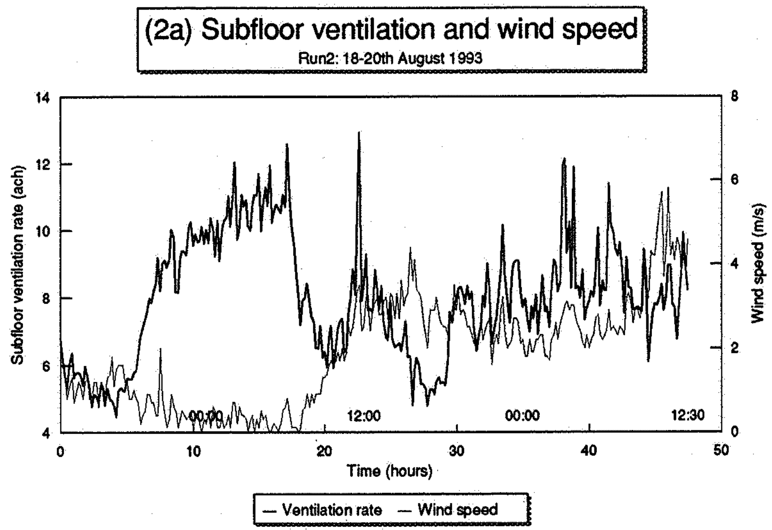
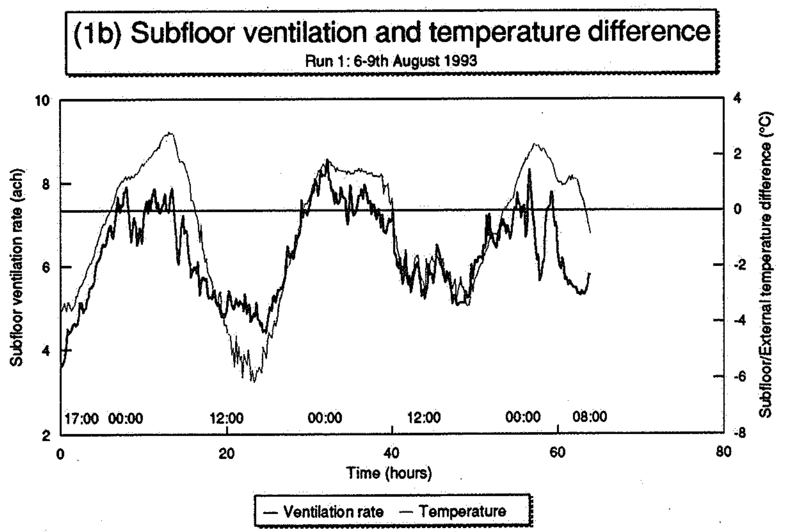
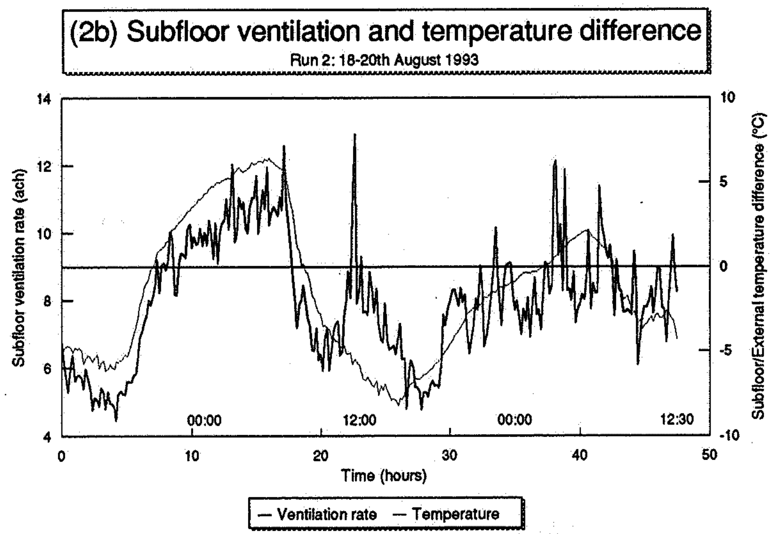
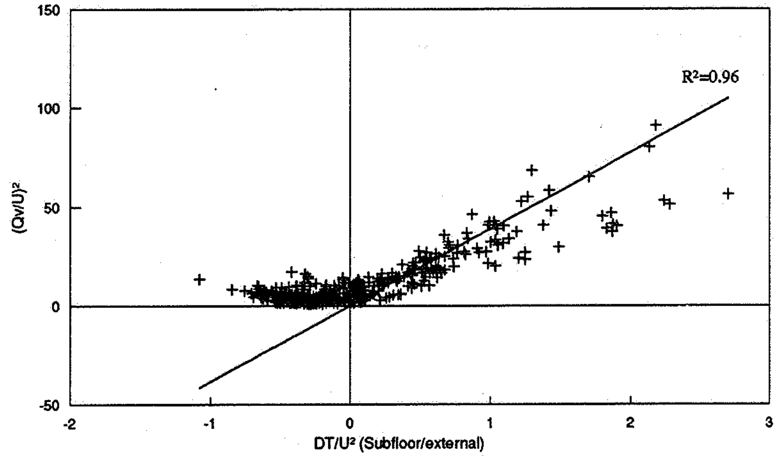

(1a) Subfloor ventilation and wind speed
Run 1: 6-9th August 1993
Subfloor ventilation rate (ach)
Wind speed (m/s)
17:00 00:00 12:00 00:00 12:00 00:00 08:00
Time (hours)
— Ventilation rate — Wind speed


(2a) Subfloor ventilation and wind speed
Run2: 18-20th August 1993
Subfloor ventilation rate (ach)
Wind speed (m/s)
00:00 12:00 00:00 12:30
Time (hours)
— Ventilation rate — Wind speed

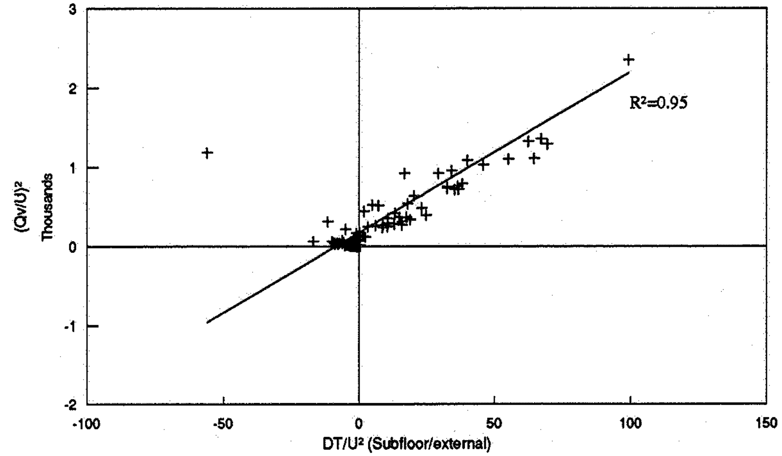

(1b) Subfloor ventilation and temperature difference
Run 1: 6-9th August 1993
Subfloor ventilation rate (ach)
Subfloor/External temperature difference (°C)
17:00 00:00 12:00 00:00 12:00 00:00 08:00
Time (hours)
— Ventilation rate — Temperature


(2b) Subfloor ventilation and temperature difference
Run 2: 18-20th August 1993
Subfloor ventilation rate (ach)
Subfloor/External temperature difference (°C)
00:00 12:00 00:00 12:30
Time (hours)
— Ventilation rate — Temperature

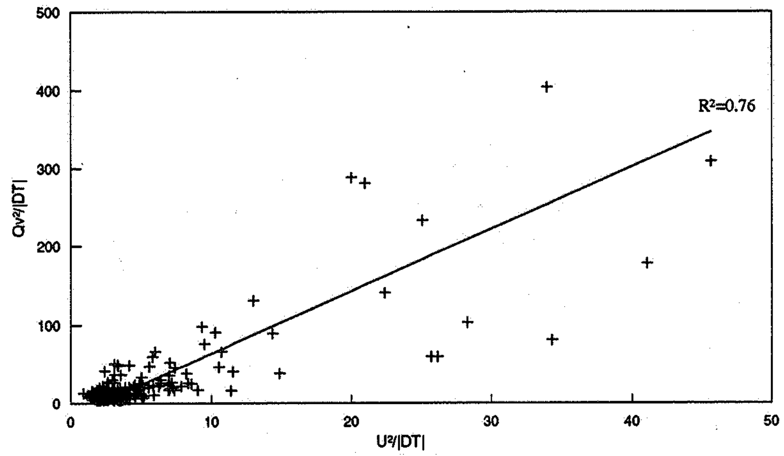
(3a) DEPENDENCE OF SUBFLOOR VENTILATION ON TEMPERATURE DIFFERENCE
Run 1: 6-9th August 1993



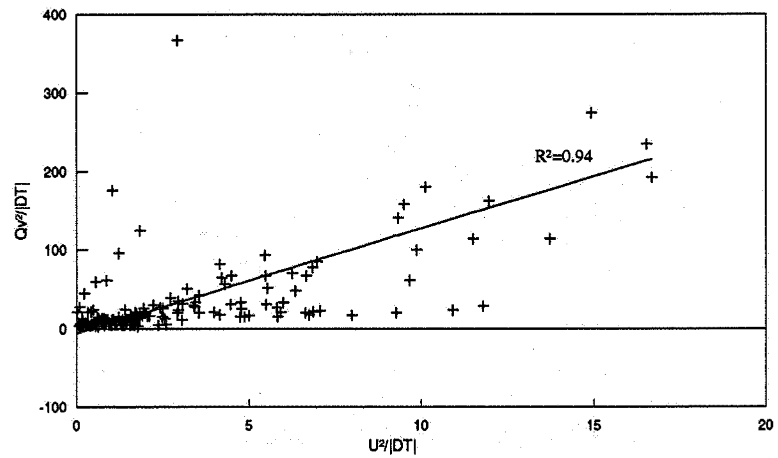

(4a) DEPENDENCE OF SUBFLOOR VENTILATION ON TEMPERATURE DIFFERENCE
Run 2: 18-20th August 1993




(3b) DEPENDENCE OF SUBFLOOR VENTILATION ON WIND SPEED
Run 1: 6-9th August 1993

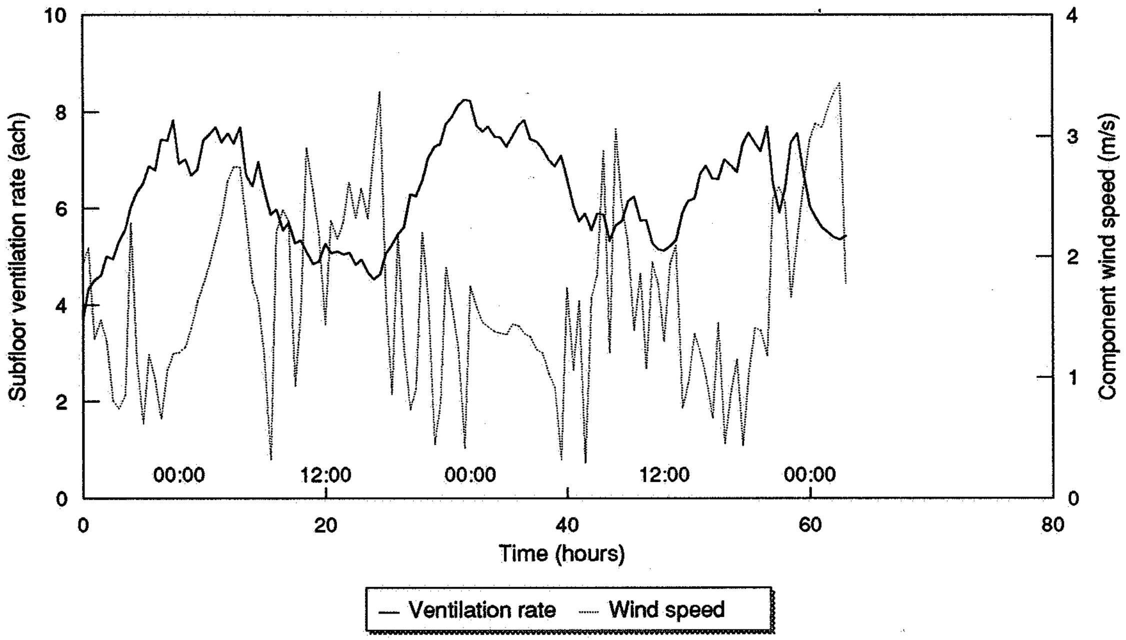



(4b) DEPENDENCE OF SUBFLOOR VENTILATION ON WIND SPEED
Run 2: 18-20th August 1993



(5) Subfloor ventilation and component wind speed

Run 1: 6-9th August 1993




(6) Subfloor ventilation and component wind speed

Run 2: 18-20th August 1993