Window ventilation and human behaviour

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Abstract

Ventilation needs can be identified from a study of people's behaviour. Regular systematic observations of open windows in a group of Scottish houses confirmed earlier work in Britain. The number of open windows was a direct function of outdoor temperature or moisture content. This number was also influenced by air speed with a smaller number of windows being open in windy weather. Large families opened their windows more frequently than small families.

The work suggests that moisture control in houses is desirable.

1. Introduction

The ventilation of a house depends on both weather and people. The weather can induce a cross flow of air by wind pressure over the house. It can also create an upflow of air through the house due to the buoyancy of the warmer internal air with respect to the colder, more dense outside air. The magnitude of the infiltration is a function of the size, form and disposition of small gaps in the building fabric. Modern British houses in average winter weather have ventilation rates which vary from 0.4 to 1.2 air changes/hour, when doors and windows are closed, Warren (1975).

In practice the occupants of houses often choose to have a higher ventilation rate and they achieve it by opening the windows. Early studies by Dick & Thomas, 1951 in two groups of experimental houses in England, showed open windows to be commonplace in winter. One group of twenty houses was observed in detail. There was a linear relationship between the number of windows open and the mean outdoor temperature figure 1. This accounted for 70% of the observed variation. A further 10% variance could be attributed to wind speed with the number of open windows reducing with increasing wind speed. However these houses only contained one heated room and the results were thought to be inapplicable to modern, centrally heated houses.

Observational studies over a year of one hundred and twenty-three centrally heated houses at Chester, England, showed a remarkably similar pattern,

Brundrett 1977, figure 1. This revealed that the window opening behaviour in houses occupied during the day correlated more strongly with the outdoor moisture content than air temperature. Since the outdoor air is almost saturated with water vapour in winter, then there is a close relationship with moisture content and outdoor dry bulb temperature (Heap 1973).

The study showed that most open windows were found in bedrooms, a slightly smaller number in the bathroom, thereafter decreasing for the lounge, kitchen, and dining room. Two important family characteristics influenced the behaviour. The first was the housewife's occupation. Those housewives out at work were associated with only half the number of open windows compared with the number opened by those who stayed at home. The second characteristic was size of the family. Analysis of the habits of those housewives who stayed at home showed the number of rooms with open windows increased with the number in the family.

No physical measurements were taken in those houses and the selection technique could be criticized because the houses were not thermostatically controlled. Furthermore the weather data did not include solar irradiance but treated sunshine in terms of cloud cover. The results could therefore be explained in terms either of moisture or poor temperature control in the houses combined with solar overheating.

A new experiment was therefore undertaken to monitor houses where

a. The occupants were at home all day, preferably with children.
b. The heating was thermostatically controlled.
c. Some physical measurements could be undertaken.
d. Solar irradiance was measured.
e. The normal infiltration was low and hence ventilation needs would be reflected in window opening habits.

2. Houses and occupants

The site was Aberdeen, Scotland, on level ground adjacent to a river and at the foot of a hill.

The houses were all wooden, prefabricated Norwegian houses. They were highly insulated, double

glazed and weatherstripped. They had 3 or 4 bedrooms. Forty-two families participated in the interviews and spot measurements in houses and the open windows of twenty-four of these were observed. Fifteen houses were semi-detached or end of terrace houses, seventeen were terraced and ten were detached houses.

The heating systems were mainly direct acting electric convector panels with sensitive thermistor proportional control thermostat, associated individually with each panel. Most houses had a supplementary electric radiant fire in the living room.

The occupants were mainly young married couples with children. Some 76% of the occupants were less than 35 years old. Families with one child formed 21% of the sample, with two 60%, with three 12% and with four 7%.

3. Outline of experiment

Three types of assessment were employed:

a. Observation of open windows. A random visit to the same group of houses was made each day for one winter, 1977/78, and rooms with an open window recorded.

b. Physical measurements. Systematic recording of the weather parameters included wind speed, outdoor air temperature and humidity, rainfall and solar irradiance on the horizontal surface. The first four factors were taken from the nearby Meteorological Station. The daily irradiance was recorded at the housing site. Spot checks of air temperature and humidity were recorded in the houses at three points, living room, hall and top of stairs. The ventilation characteristics of the houses were also identified by gas tracer and pressure test techniques (Skinner 1975).

c. Interviews. Market research interviews were undertaken to establish basic data on family size and occupation. The interview also elicited information on the family's window and door habits and their use of the space heating.

4. Results

a. Window opening observations (24 houses, September 1977-April 1978)

The relationship between open windows and outdoor air temperature is plotted in figure 1. The solid

dots represent days of wind speeds averaging greater than 5 m/s. A stepwise, multiple regression confirms that there are two key factors. The first is outdoor air temperature, with open windows increasing with rising temperatures. The second factor is wind speed with open windows reducing in number as the wind speed rises. Table 1.

Open windows are found most commonly in the bedrooms, particularly the main bedroom. In decreasing frequency we then have the bathroom, the sitting room, the kitchen and finally the dining room. Table 2.

Family size had an influence with larger families tending to have more rooms with open windows. Table 3.

There was no simple relationship between the frequency of open windows and the moisture and temperature measurements taken on the spot check inside the houses.

b. Measurements in the houses (42 houses which include the above 24; sampled mid-December)

Spot checks on the sitting room temperature are compared with the room thermostat setting in figure 2. The bulk of measured temperatures are well below the set values. Only in one case is there sign of overheating above the occupant's chosen temperature setting. The housewives were asked if they normally kept the sitting room door open or closed. The closed doors are shown as solid squares.

Measurements of temperature and humidity in the sitting rooms of these houses are illustrated in figure 3. Three reference lines are superimposed. The upper one is the water content of air when the air is saturated (relative humidity = 100%). Lines at 70% r.h. and 40% r.h. define the recommended upper and lower limits of relative humidity. Values higher than 70% run the risk of creating a mould problem inside the house (Loudon 1971). Values below 40% are likely to introduce electrostatic shocks when walking on the carpet (Brundrett 1976). This band, 40-70%, is also the one recommended for comfort (IHVE 1970).

No values below 40% r.h. were recorded in the houses. However a quarter of the houses measured had sitting rooms above 70% r.h. and could therefore be at risk for mould growth.

The spot measurements therefore suggested a tendency to moisture problems in the sitting room but did not show any trend to overheating.

c. Housewives' comments

The interview summary is listed in Table 4. Most housewives said they open their living room window during winter. While almost 40% say that they only open the window for less than an hour, 19% said they did so for longer than four hours. The majority of the families said that they kept their living room door closed and did so to save energy and avoid draughts.

Reports of condensation are high ($\sim$70%) although this reduces to only 10% of the households when asked if such condensation created a problem. Simultaneously some 36% reported the air to be too dry.

5. Discussion

This third study confirms that windows are often open in winter in Britain. The three studies cover locations in the north, midlands and southern part of Britain, span almost thirty years, and involve very varied heating systems. The similarity of results is remarkable with outdoor air temperature or moisture being the dominant weather parameter modified by wind. In winter the window opening is not affected directly by sunshine although this would be expected to occur in summer.

Bedrooms are the rooms most usually ventilated. The occurrence of open windows increases with growing family size. However measurements inside the houses do not simply relate to the open windows. This may be because there is no relationship or because the housewife is elegantly maintaining satisfactory indoor conditions despite the vagaries of the weather. In only one house was the temperature significantly above the thermostat setting. Most houses were actually running well below this setting. This may be inaccuracies in thermostat calibration, energy control by time clock switching which prevents the thermostat from functioning, or temperature gradients within the room. The results deserve field work to explore them further.

One hypothesis for the housewife's behaviour is moisture control. The ventilation requirements for

an adult are outlined in figure 4. Further studies are needed to see if this behaviour is unique to Britain and its damp, mild climate. More work on dehumidification and the energy implications of open windows is now essential.

6. Conclusions

People leave windows open in winter. They do so in a systematic way which is related to the outdoor air temperature or moisture and tempered by wind speed. Bedrooms are the rooms most often ventilated. The frequency of open windows increases with growing family size.

Measurements inside these houses dispel fears of overheating in winter and highlight the risk of condensation and mould growth.

More work is needed to resolve the energy implications of this behaviour and to examine the effectiveness of dehumidification.

7. Acknowledgments

The success of this study is due to the large amount of help given by many colleagues. The houses are owned by the Gordon District Council, under the supervision of Mr. P. Donaldson; the local window observations were organised by the North of Scotland Hydro-Electricity Board through Mr. T. Martin and Mr. J. Birnie; the questionnaire interviews and spot measurements were directed by Mrs. Joan Macfarlane Smith of Gordon Simmons Fieldwork Limited; the weather data was provided from Dyce Airport by the Meteorological Office; ventilation calibration of the houses was undertaken by Dr. D.J. Dickson of ECRC; mathematical correlations were organised by Mr. R. Hodgkins and Mr. J. Waddington ECRC.

Finally I must acknowledge with thanks the friendly co-operation and tolerance of the householders who took part.

8. References

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Stepwise linear multiple regression (24 houses; 137 days)						
Constant term	Mean daily air temp. T_a °C	Mean daily windspeed V m/s	Daily sunshine kWh/day/m^2	Mean daily dewpoint T_d °C	Daily rain mm	Correlation coefficient
+ 21	+ 1.7					0.47
+ 33	+ 2.3	- 3.3				0.71
+ 30	+ 2.3	- 3.3	+ 3.4			0.75
+ 29	+ 3.1	- 3.5	+ 3.2	- 0.8		0.76
+ 29	+ 2.9	- 3.4	+ 3.1	- 0.6	- 0.1	0.76

Table 1. Rooms with open windows as a function of the weather

Room	Average number of rooms with open window/day over winter period (156 days)
Sitting room	0.06
Dining room	0.02
Kitchen	0.06
Bedroom 1	0.32
Bedroom 2	0.26
Bedroom 3	0.28
Bathroom	0.22

Table 2. Which rooms are ventilated

Size of family	No. in sample	Average number of rooms with open window - winter period (156 days)
Two person	2	1.2
Three person	5	1.0
Four person	10	1.2
Five person	3	1.3
Six person	2	1.7
Seven person	1	2.0

Table 3. Influence of family size on open windows

(a) Freguency of opening living room windows (N = 42)

Frequency	Never	Only in summer	Occasion-ally	Some-times	Once/ week	Twice/ week	Daily
% response	26	5	2	14	2	2	45

(b) Duration of leaving living room windows open (N = 42)

Duration	Nil	<½h	½-1h	1-2h	2-3h	3-4h	>4h
% response	26	17	21	5	7	2	19

(c) Internal door to living room (N = 42)

Left open 7%
Fully closed 79%
Almost closed 2%
Open in day, closed in evening . . 12%

(d) Experience of condensation (N = 42)

Condensation on windows . . . . . 67% yes
Condensation in rooms . . . . . 71% yes
Condensation creating a problem . . 10% yes

(e) Experience of the air being too dry (N = 42)

36% reported the air too dry

Table 4. Housewives' Reports

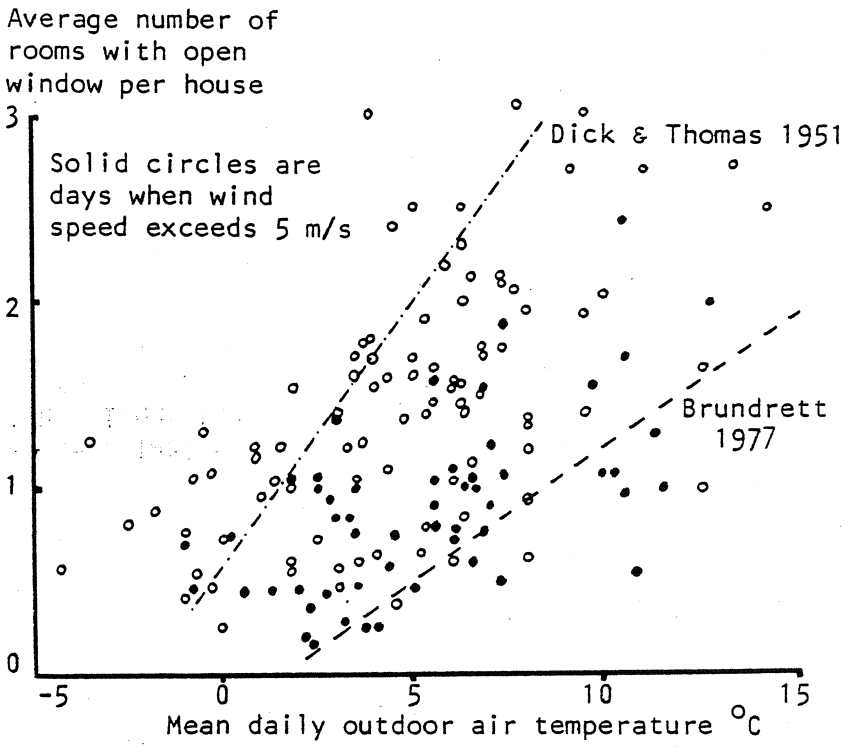

Figure 1. Relationship between open windows and outdoor air temperature

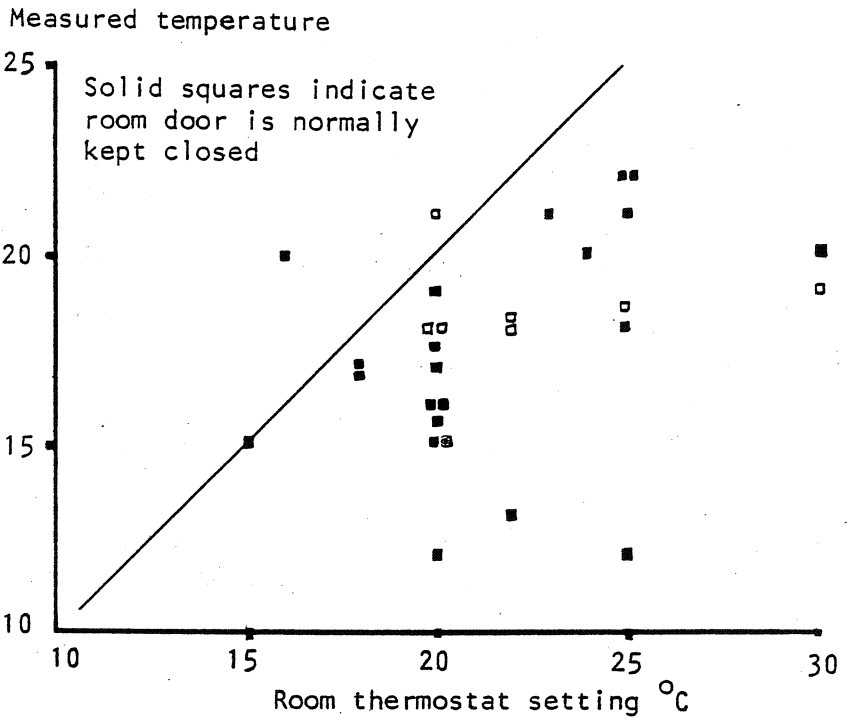

Figure 2. Relationships between measured and thermostat reading in sitting room

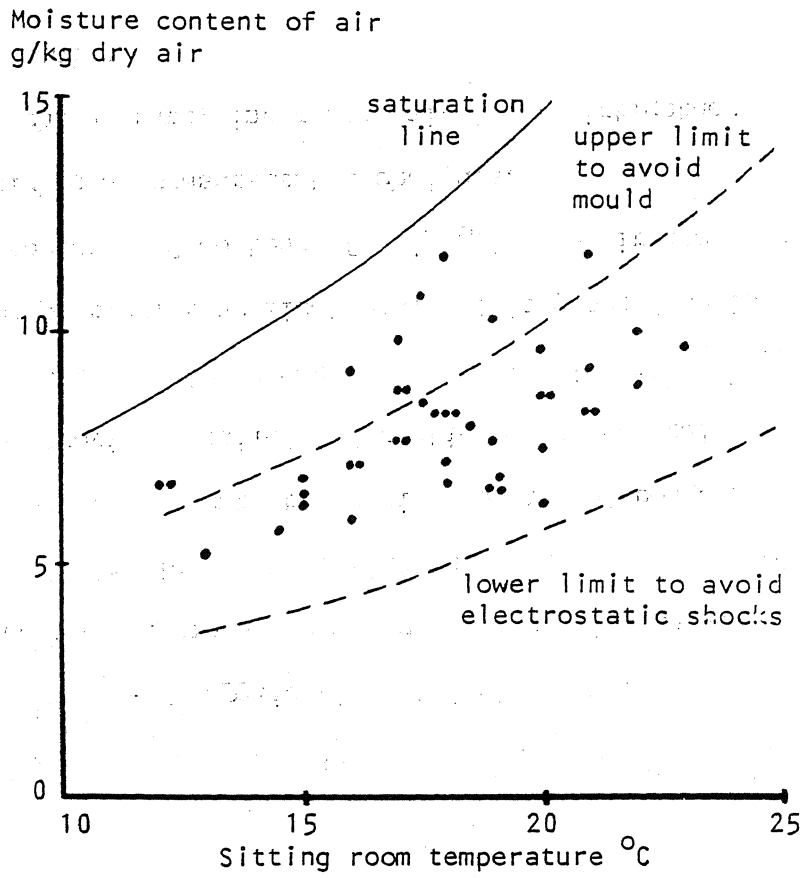

Figure 3. Spot measurements taken in the sitting room (N = 42)

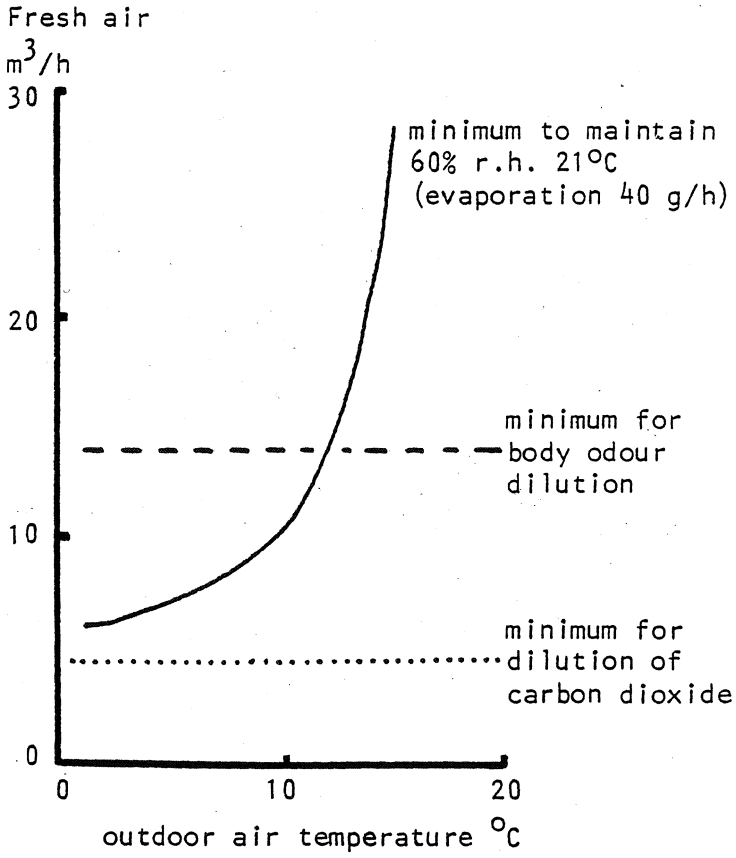

Figure 4. Ventilation needs for an adult in Britain

DISCUSSION

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The real energy loss through open windows occur when they are slightly open for a long time, rather than wide open for a short time. One way to encourage people to air out rooms rapidly and then close the window is to fit some device (e.g. a microswitch in the case of electrical heating) that switches off all heat input to the room when the window is even slightly open. This has been proposed in Sweden as an energy conservation measure. Thermostats, as fitted in the reported study, have the opposite effect, as they switch heat input full on if the window is opened.

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My preference is to match the ventilation supply as directly as possible to the needs. Brief intensive activities such as cooking deserve high ventilation rates for short periods. However I feel that continous occupation of a room is best served by a continuous supply of fresh air, possibly with a purge at the end of occupancy to leave the room fresh. I share your concern for the thermostat which strives to maintain the room temperature regardless of the ventilation rate. Perhaps an energy regulator which works on outdoor temperature may limit the maximum demand of the heating system.

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What time - and for how long - did you observe the windows? What I have in mind is that house work such as making beds, washing floors, etc. is rather heavy physical activity requiring a 3-5^{o} lower temperature for thermal comfort than sitting rest (thermostat setting 20-25^{o}C, fig. 2), and this may be what is going on in the house in the observation period.

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The windows were surveyed momentarily by a researcher walking around the houses during weekdays. The observations were taken either in the morning after 9 a.m. or in the afternoon up to 5 p.m. in equal number but randomised over the period. The housewives reported that they often flung open the bedroom windows on get-

ting up in a morning but this would normally be expected to be well before our survey time. The second stage of the research is to analyse the temperatures and energy consumption in more detail. The initial findings suggest that the living rooms are much warmer in the evening than in the daytime which supports your activity hypothesis.