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Building planning and ventilation: Effects of natural ventilation via windows and doors linked by corridor/passage-way

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BUILDING PLANNING AND VENTILATION: EFFECTS OF NATURAL VENTILATION VIA WINDOWS AND DOORS LINKED BY CORRIDOR/PASSAGE-WAY

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SUMMARY

A series of ventilation rates measurements have been carried out using a single tracer gas (Carbon Dioxide) of a lecture/seminar room during the period between March to December 1989. The test room is situated on the extreme east side of the Meteorology Department at the University of Reading. The room is linked to a main entrance door via a middle passage-way or corridor serving other smaller rooms on both sides. The air-change rates due to various windows opening positions and locations are presented. Applying statistical methods, formulae expressing the ventilation rate in terms of the meteorological parameters are derived and graphs in relation to dominancy factors such as wind and buoyancy effects, are given. Assessements of thermal comfort using a thermal comfort meter and occupancy odour or freshness were also conducted. Freshness assessments are carried out by extrapolating values from previous work such as Fanger(1), Yaglou(2), Muhaxheri(3) and Narasaki(4).

1.Introduction

As buildings become better insulated the energy demand becomes more dependent upon ventilation losses. However, if the building is too tight this may result in a deficiency because the fresh air supply has to be sufficient to ensure a comfortable and healthy indoor climate. If this can be achieved using naturally ventilated buildings, then this is more energy and cost effective. Body odour is the major pollutant in spaces with high levels of occupancy, such as classrooms, theatres and auditoria.

The essence of this study is to investigate ventilation characteristics and hence the effects of natural ventilation via windows, doors and spaces linked by corridor or passage-way. This particular lay-out is common in school buildings. Once schools are built the floor plan is rarely changed so that the effects of natural ventilation via windows and doors linked by corridor and entrances takes on particular characteristics for each location. This effect plus the occupancy behaviour and the effects of building orientation, meteorological and surrounding terrains can account for significant differences in ventilation characteristics, and hence the indoor climate and energy needs between otherwise similar school buildings.

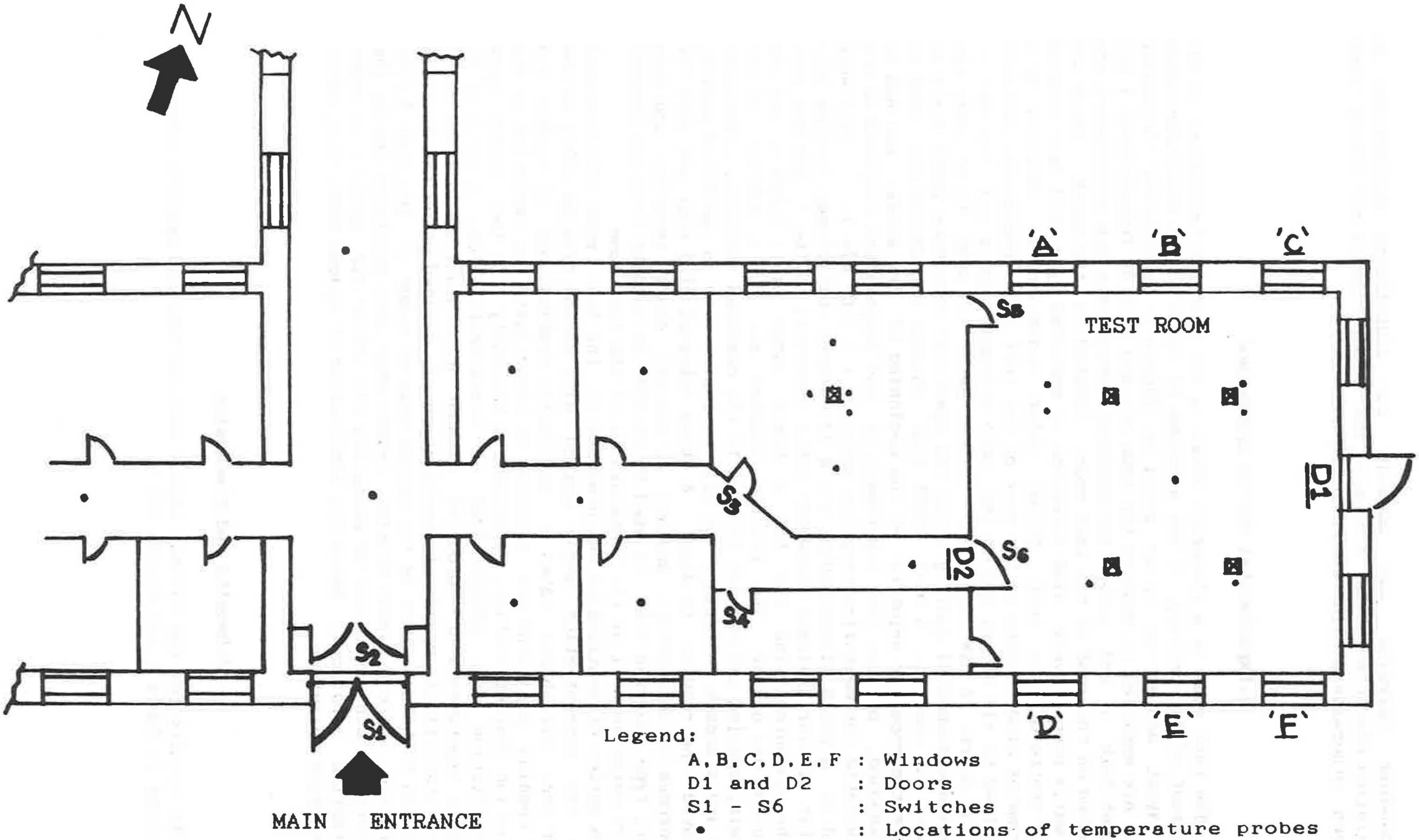
2.Experimental Set-up and Method

The test room is a classroom known as the Synoptic Laboratory in the Department of Meteorology; it has a volume of 384 m^3 . The experimentation plan layout and set-up is as shown in Figure 1. Twenty-four thermistor probes are employed to measure the room air and outside temperatures (dry and wet-bulb) and globe temperatures. Three vane cup anemometers are installed on the roof of the test room, located on the north, south and east walls respectively. Wind direction is measured by a wind vane located on the centre of the roof. Global solar radiation is measured by a solarimeter also located on the roof of the test room. Resistance switches are fitted to six doors; two on the main entrance doors and the rest on interior doors. A B&K Type 1212 Comfort Meter is used to evaluate the thermal environmental quality using the predicted mean vote (pmv) scale as an index of comfort. A DISA 55D05 Type thermal anemometer was used to measure the room air velocity at the beginning of the study, but had to be abandoned, because the instrument is not temperature compensated and not suitable for measuring very low velocity (< 0.05 m/s). Data were logged on a BBC B microcomputer via a 32-channel multiplexer feeding into a 13-bit bipolar analogue converter (ADC) connected to the 1 MHz bus port of the computer. The ADC has a basic range of + 2.048 V, and its resolution was 0.5 mV. The program scanned all or a sub-set of the channels, applied calibration factors to the measured voltages, calculated means and standard deviations of all variables over a specified period, and saved the results to disc. A time interval of 1 hour was used for the purpose of this study. Another 32-channel chart recorder and data logger, type Molytek 2702 is used to record the outputs from the thermal comfort meter as well as the temperatures of the test room.

A series of ventilation measurements of the test room are conducted using the concentration decay method with carbon dioxide (CO2) as the tracer gas. Air change rates of particular combinations of windows and their opening positions are measured to investigate the variation in the ventilation characteristics, representing basically the two common types of ventilation i.e. single-sided or cross-ventilation. A total of 72 identical experiments are conducted without opening any windows and doors and a statistical model of ventilation is derived using the multiple regression technique. This is the normal mode of usage of the room during the heating season. Carbon dioxide levels were also monitored during the occupancy periods as a means of assessing the indoor air quality in order to establish a rational basis for ventilation of spaces where body odour is the major pollutant.

3.Results and Discussion

The results for the various window combinations and opening modes are summarised in Table 1 and Fig.2a and 2c.



Legend:

A, B, C, D, E, F	:	Windows
D1 and D2	:	Doors
S1 - S6	:	Switches
•	:	Locations of temperature probes
⊠	:	Columns

Fig.1. Test room and experimental set-up

Table 1. Air change rate for various window and door combinations and opening position

Air change rate (h)	Window/ Door Combn.	Opening position (deg)	Wind speed (m/s)	Wind dirn. (deg)	Temp. diff. (K)
		Window			
9.6	A,B,C, D,E,F	1/3 open	1.41	80	7.3
11.6*	same	same	1.84	64	9.0
3.3	A&D	1/2 open	0.84	70	-5.1
4.0	B&E	same	0.89	70	2.0
5.2	C&F	same	2.21	201	4.3
5.8	A,B,C	Fully open	1.16	60	10.8
7.2	same	1/3 open	1.28	71	10.1
8.8	same	1/2 open	1.13	73	9.2
5.4	D,E,F	Fully open	2.23	287	7.4
2.8	same	1/3 open	1.96	251	10.8
3.8	same	1/2 open	2.11	296	6.5
2.4	C&D	1/2 open	0.75	250	0.1
3.3	same	same	1.65	285	0.5
3.3	same	same	1.43	230	0.6
2.6	same	same	1.47	147	1.7

Note: All doors were closed, except for case *, where internal door (D2) was fully opened.

Air change rate (h)	Window/ Door Combn.	Opening position (deg)	Wind speed (m/s)	Wind dirn. (deg)	Temp. diff. (K)
		Door			
2.9	D1&D2	Fully open	1.93	215	8.5
5 4	same	1/2 open	1.57	274	9.1
2.4	D1	Fully open	1.98	241	7.9
1.8	same	1/2 open	1.40	251	7.5
0.3	D2	Fully open	2.44	242	0.5
0.8	same	1/2 open	2.20	257	5.2

Note: All windows were closed

Air change rate between 2.4 - 11.6 per hour (232 - 1121 l/s) is attainable for various windows combinations and opening modes and wind speed ranging 0.84 - 2.22 m/s, direction 60 - 296 deg.

The larger figure is obtained when all windows on the north and south walls are opened by one-third of full opening position simultaneously and the main door of the test room (D2) is fully opened. The lower figure is attained when the main door is closed. This to some extent indicate the effect of the corridor which linked the test room to the main entrance. This condition is shown as item 1 in Fig.2a.

Item 2 on Fig.2a. shows that by opening two windows which are directly opposite to each other i.e A&D, B&E and C&F, the air change rate varies between 3.3 - 5.5 per hour (322 - 531 l/s), for wind speed ranging 0.84 - 2.21 m/s and direction of 70 and 201 deg. respectively.

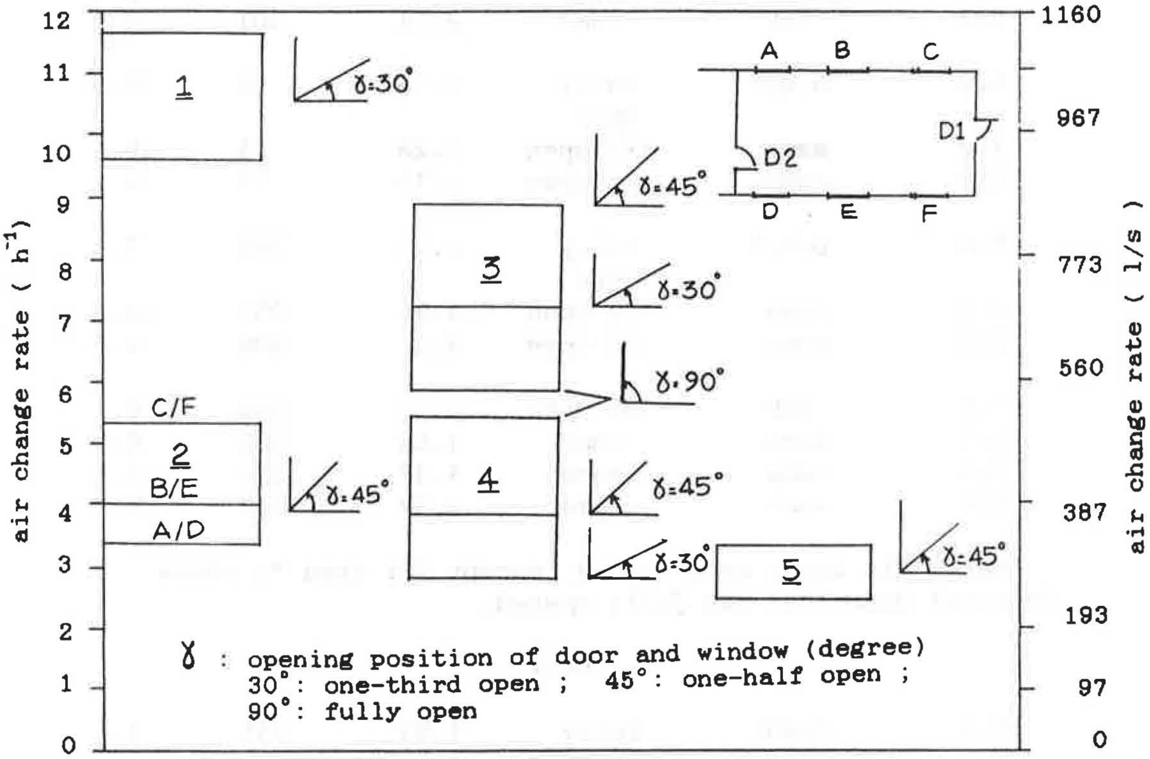


Fig.2a. Ventilation characteristic of windows
Local Wind speed: 0.8 - 2.2 m/s, measured at roof-top (4.5 m)
Legend:
1: All windows on north and south walls are opened
2: Directly opposite windows are opened - one pair at a time ; A&D, B&E and C&F; doors closed
3: All windows on north wall are opened simultaneously - A,B & C; doors are closed
4: All windows on south wall are opened simultaneously - D,E & F; doors are closed
5: Diagonally opposite windows are opened -C/D; doors closed

Another form of cross-ventilation mode is investigated by opening two diagonally opposite windows i.e. windows C&D at mid- opening position (see item 5 in Fig.2a.). The air change rate obtained is between 2.4 - 3.3 per hour (232 - 319 l/s) for wind speed ranging 0.75 - 1.63 m/s, direction 147 - 285 deg.

The air change rate obtained by single-sided ventilation mode is between 5.8 - 8.8 per hour (560 - 851 l/s) when the windows on the north wall were opened at three different opening positions. The larger figure is obtained when the windows were opened one-half of full opening position. Opening the windows fully open does not necessarily result in bigger air change rate for the case of the north facing windows. Referring to Fig.2b., where the wind directions for the 3 window opening positions are related to the windows. Also a point to note, is that the north wall is not completely exposed to the wind path. It is sheltered by a similar wall about 7 m apart. As such, except for the case of a south-westerly wind, negative pressure region (i.e - ive Cp) will be created in the vicinity of the windows. For windows opening positions of one-half and one-third, this may result in better channelling effects compared to the fully opened position.

The air change rate for the south facing windows ranges between 2.8-5.4 per hour (271 - 522 l/s) at full and one-third opening positions respectively. (See items 3 and 4 in Fig.2a.)

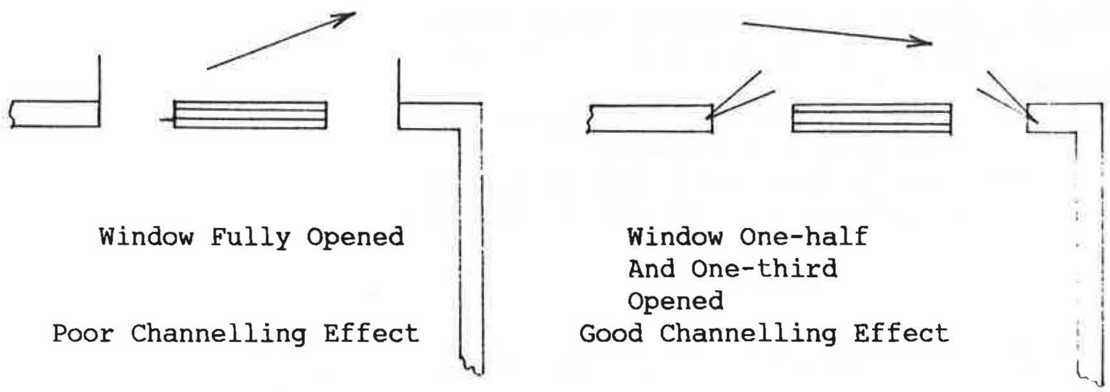


Fig.2b. Window opening positions and wind path i.e. directions for north facing windows

Ventilation effect of doors is shown as items 6, 7 and 8 in Fig.2c. Maximum value of 5.4 air change per hour (522 l/s) was obtained when both the external and internal doors (D1 and D2) are opened in the mid-position. Once again, by opening the doors in the fully opened position does not result in bigger air change rate. This is clearly shown in Fig.2d. In the fully-opened position, the door acts as an obstacle to the wind flow while in the mid-opening position it behaves as a channelling effect. Single-sided ventilation through opening the external door (D1) results in an air change between 1.8 - 2.4 (174 - 232 l/s) for one-half and full opening positions respectively. The air change rate is not much affected by opening only the internal door.

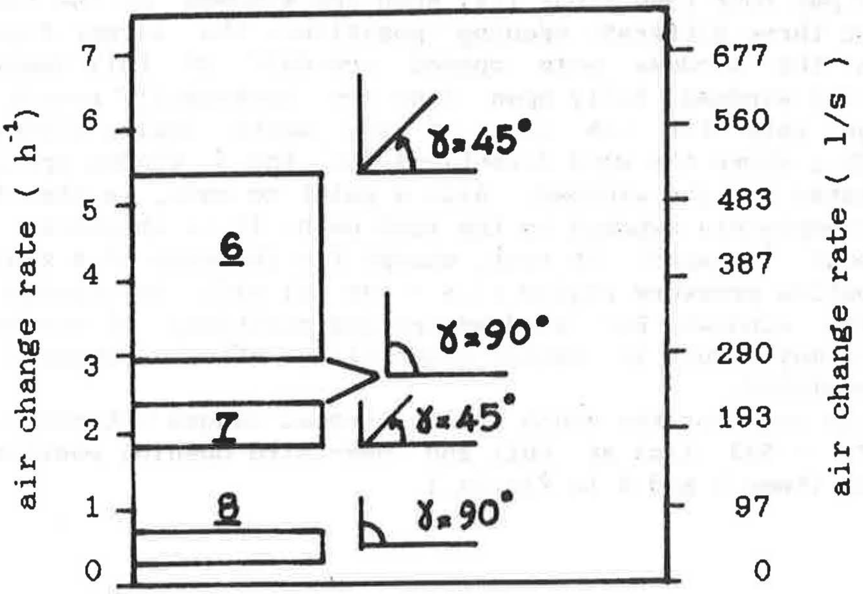


Fig.2c. Ventilation characteristic of doors
Local wind speed : 0.8 - 2.2 m/s

Legend:
- 6 : Both external and internal doors (D1 & D2) are opened
- 7 : Only external door (D1) is opened
- 8 : Only internal door (D2) is opened

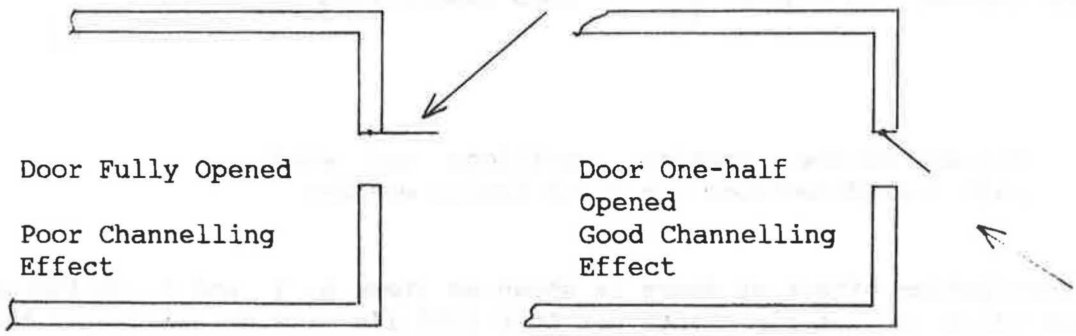


Fig.2d. Door opening positions and wind path

Ventilation characteristic of the test room under it's normal operating mode i.e. when all windows are closed and internal door (D2) occasionally opened was studied by conducting a total of 72 measurements of air change rate. Applying the multiple-regression technique the correlation between the air change rate with the local wind speed and temperature difference, is given by the following equation:

$$N = 0.129 + (0.17 \times 10^{-3} \Delta T) + (20.56 \times 10^{-3} U^2) \quad (1)$$

where:

N : air change rate (h^{-1})

ΔT : deference between indoor and outdoor temperature (K)

U : Local wind speed (m/s)

From the test of significance i.e. the t-test as shown in Table 2, the air change rate is much influenced by the wind factor rather than the temperature difference. This is shown as 5.7 for the wind parameter.

Table 2. Regression Coefficients

Y-variate : N

Parameter	Estimate	SE	t
Constant	0.12947	0.0449	2.9
ΔT	0.00017	0.00397	0.0
U^2	0.02056	0.00361	5.7

A plot of air change rate for a range of wind speeds and temperature difference ΔT, 0, 7.5, 15.0 and 20.0 K is given in Fig.3 and the results of Navrala & Etherridge (9) is also inserted as comparison.

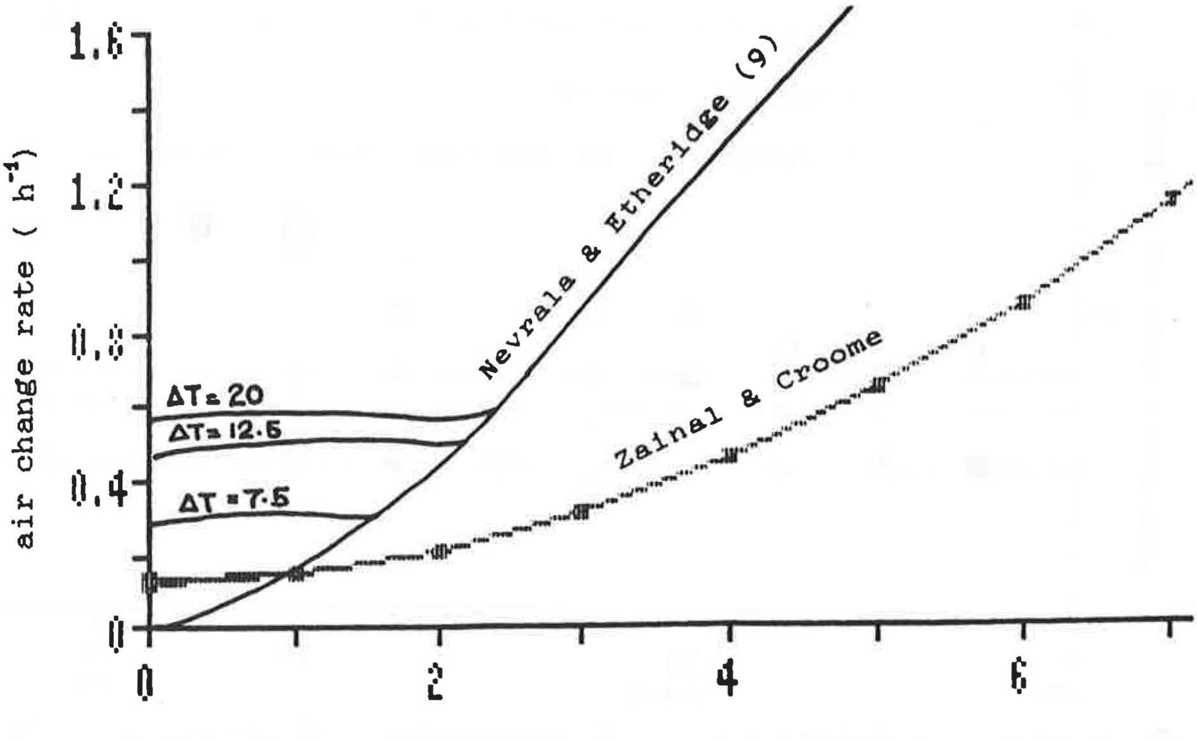


Fig.3. Predicted variation of test room air change rate with wind speed and temperature difference. Insert is the result from study by Nevrala & Etheridge (9) in well-insulated houses.

The mean value of air change rate attainable during a normal operating mode of the test room is 0.2 per hour(19.5 l/s). It is far too low as compared to the recommendations by ASHRAE (7) and CIBSE (8) for the minimum fresh air requirement for the control of body odour. According to both recommendations, for the test room, the minimum air change rate of the order 2.89 (280.0 l/s) and 2.72 (262.5 l/s) per hour is required respectively. (Refer to Appendix 1 for calculation). This could be achieved by either opening all windows on the south wall to the one-third opening position (item 4, Fig.2a) or two diagonally opposite windows (item 5, Fig.2a). The very low supply or ingress of fresh air in the test room is definitely to cause thermal discomfort as well as discomfort due to body odour.

Fig.4a. shows the variation in the measured predicted mean vote (pmv) using a comfort meter of the test room during a normal occupancy period (9.00 a.m. to 5.00 p.m.) over a week. During this period all the windows and external door are closed with the internal door (D2) occasionally opened. The mean value of pmv is found to be -0.3, indicating that about 8% of the occupants will be dissatisfied with the indoor environment i.e. feeling of slight cold. In the earlier part of the day (9.00 - 11.00 a.m.) about 12% (pmv = -0.5) of the occupants is likely to be thermally uncomfortable. While in the later part of the day about 6% of the occupants is likely to complain of slight coldness (pmv = -0.2). On the overall, the test room environment will satisfy majority of its occupants thermally.

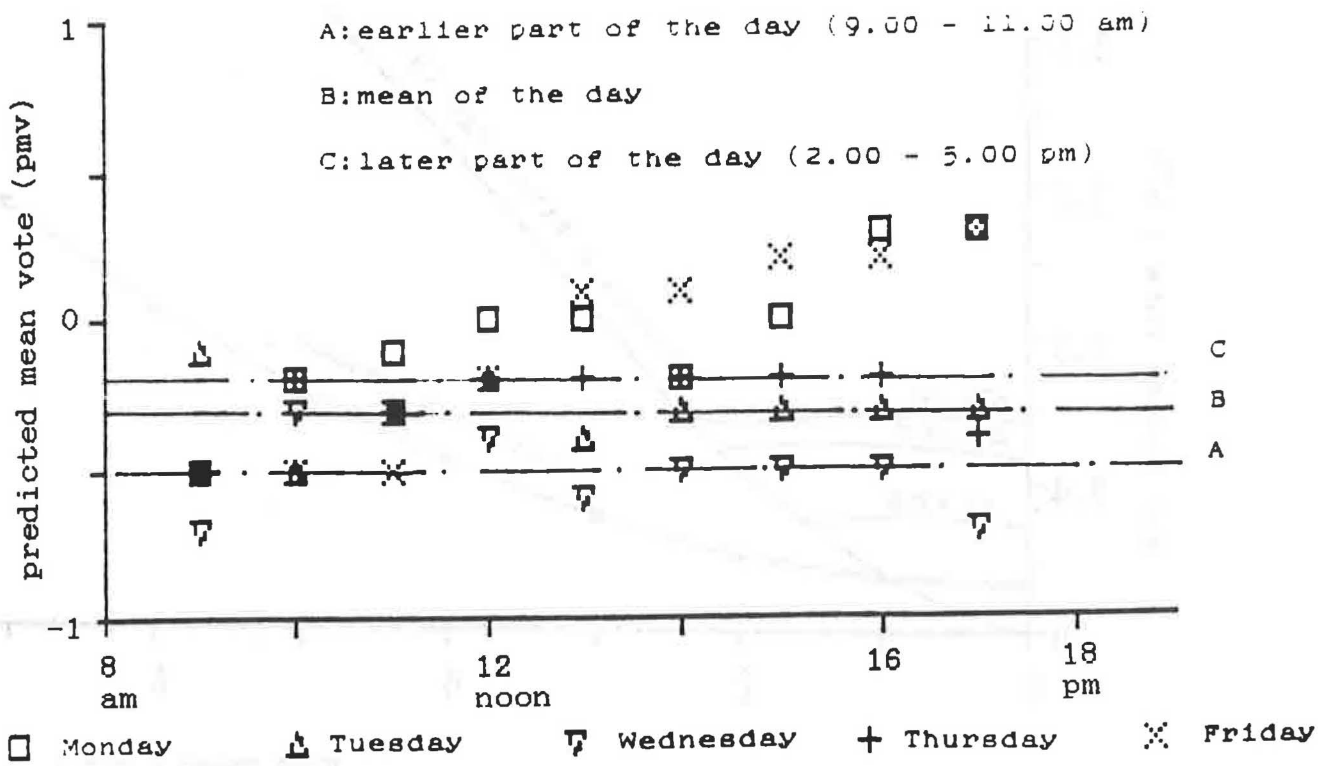


Fig.4a. Measured predicted mean vote (pmv) during normal occupancy period (9.00 am - 5.00 pm) over a week corresponding to 0.2 air change / hour

The variation in the CO2 levels during a normal occupancy period over a week is as shown in Fig.4b. The mean value of CO2 level was found to be 1500 ppm. Using this value, the approximate intensity and the discomfort of body odour are extracted from the works of Fanger(1), Muhaxheri(3), Narasaki (4) and Yaglou (2) i.e. from Fig.4c,d,e,f. It is envisaged that between 10 - 30% of the occupants is likely to be dissatisfied with the built-in environment corresponding to odour intensity ranging 1.5 - 3.1. This is summarised in Table 3.

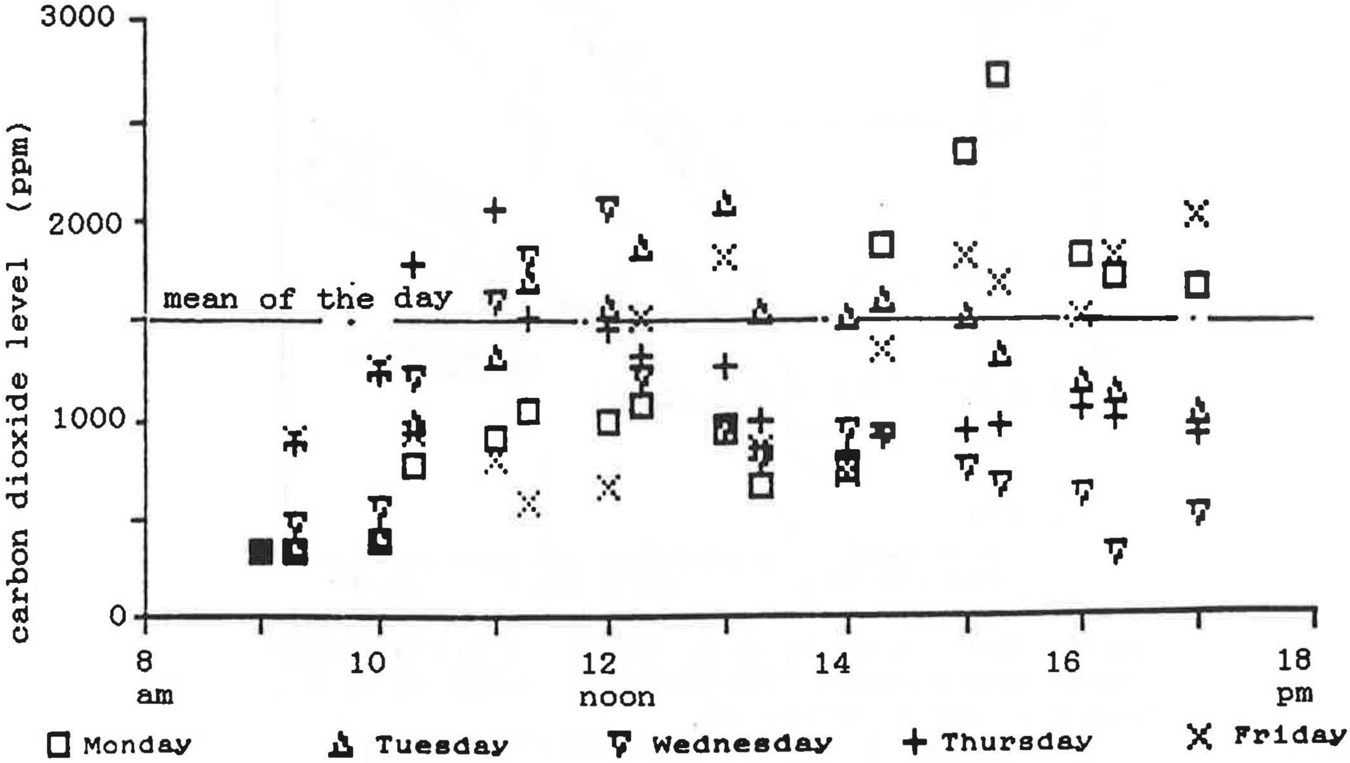


Fig.4b.Variation in test room CO2 level during a normal occupancy period (9.00 am - 5.00 pm) over a week corresponding to 0.2 air change / hour (19.5 l /s)

Table 3.Odour Intensity (I) and Percentage Dissatisfied (PD) Votes of the test room

Odour Intensity (I)	Percentage Dissatisfied (PD)	Source
1.9	28 %	Fanger&Berg-Munch (1)
1.8, 2.5, 3.1	n.a.	Yaglou (2)
1.5, 2.8	n.a.	Narasaki (4)
1.5	12 %	Muhaxheri (3)
n.a.	22 %	Cain -et al (5)
n.a	6 - 12 %	Comfort Meter

According to Fanger and Cains' the indoor air quality of the test room is not acceptable i.e. more than 20% of the occupant is likely to complain or feeling dissatisfied due to odour. However from Muhaxheri's finding the indoor air of the test room is acceptable.

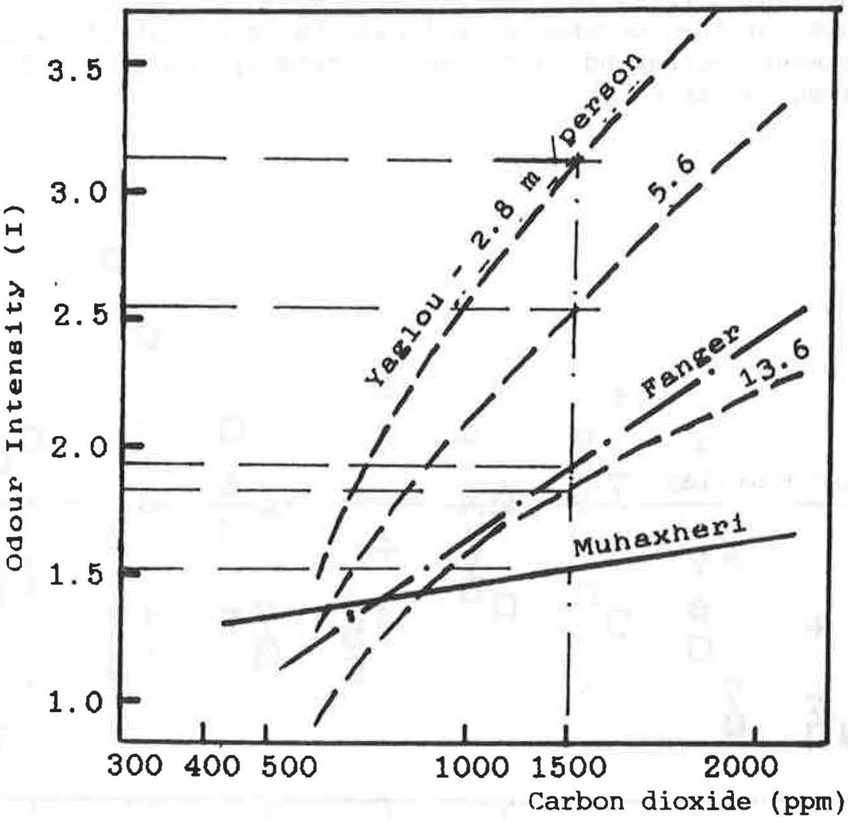


Fig.4c. Odour intensity as a function of carbon dioxide concentrations. Taken from studies by Fanger et al (1), Yaglou (2) and Muhaxheri (3)

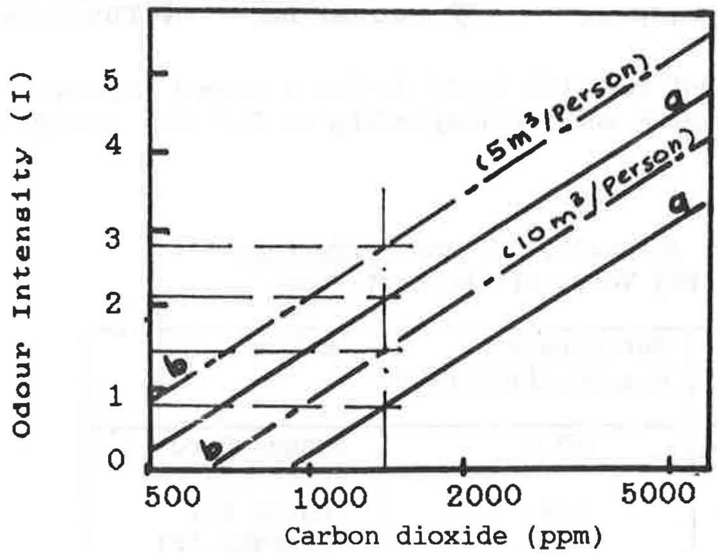


Fig.4d. Odour Intensity as a function of carbon dioxide level for two levels of occupancy densities (5 and 10 m^3/person).

Taken from Narasaki (4)

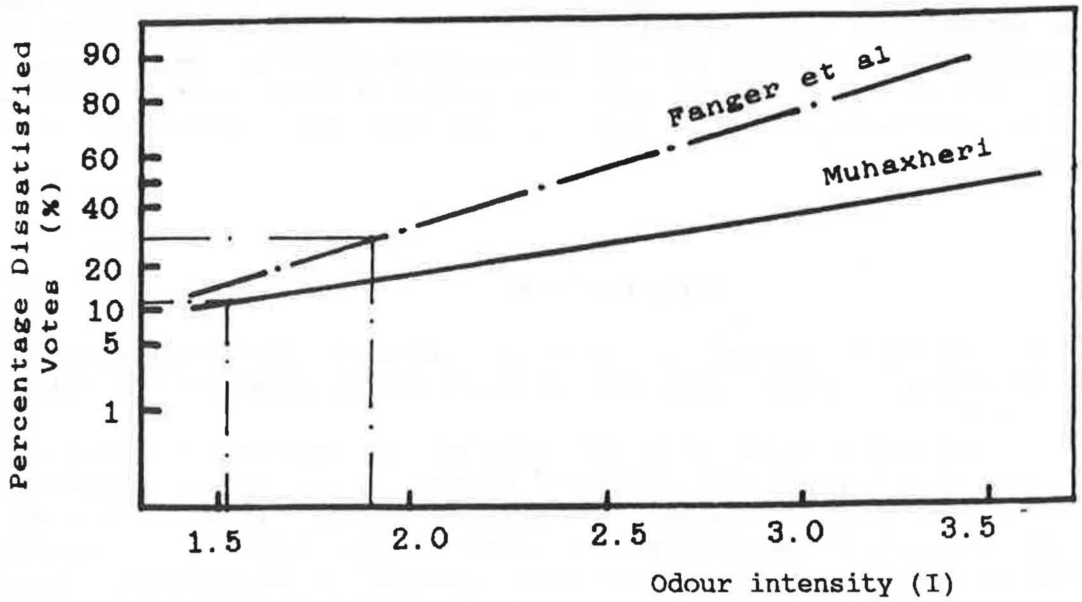


Fig.4e.Percentage of dissatisfied as a function of the mean odour intensity. Results are taken from studies of Fanger and Berg-Munch (6)

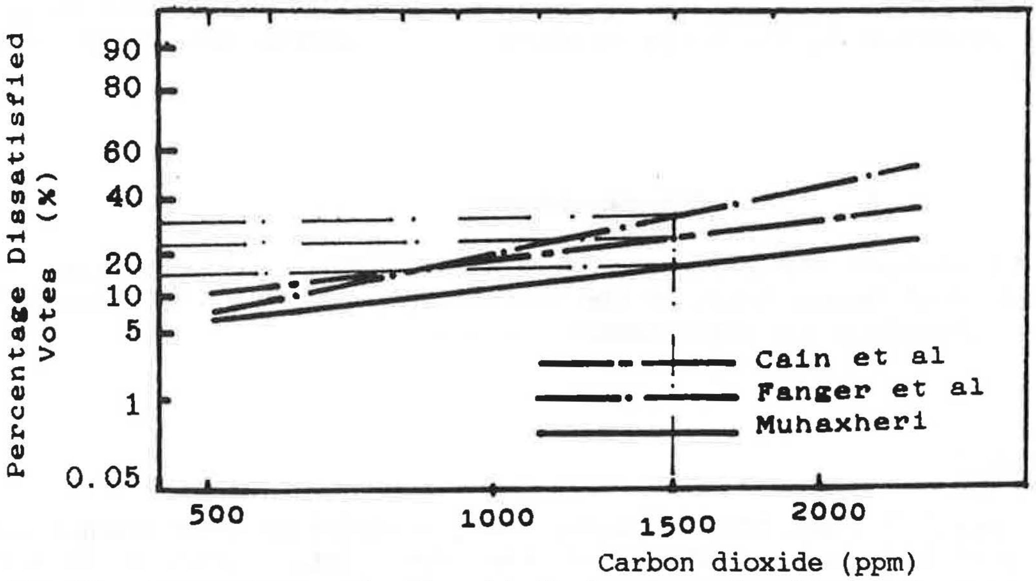


Fig.4f. Percentage of dissatisfied as a function of carbon dioxide concentration. Results are taken from studies by Fanger & Berg-Munch (6), Cain et al (5) and Muhaxheri (3)

4.Conclusions

This study shows that the ventilation characteristic of naturally ventilated spaces can be varied by particular modes of window-door opening patterns. The information gathered would be useful for managing buildings during the warm season, where some means of controlling the indoor climate can be achieved by windows ventilating. If the result of air change rate measurements for the normal mode of operation of the test room during the heating season is to hold true for school classrooms (i.e. < 0.5 air change rate per hour), this is far too deficient for health and comfort purposes.

5.Future Work

- An important aspect is room air movement due to various window types and operating modes; this has not been investigated yet but will be studied next.
- Investigation will also be carried out on other buildings with distinctive plan lay-out and different window types and arrangements. A lot of advertising literature of windows manufacturers indicates a tremendous concern for aspects such as daylighting, good weather-proofing, structural strength, suitable solar heat rejection or absorption, etc, but little is given on the air movement control quality. It is therefore important to investigate the ventilation characteristics of various styles of window in relation to air movement control for comfort conditioning.
- Both thermal comfort and freshness sensations will be studied by measuring and subjective analysis and viewed with respect to current codes/standards for fresh air as given by the ASHRAE and CIBSE (revised) Guides.

Acknowledgement

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APPENDIX 1

Estimation of the mininum fresh air requirement for test room according to ASHRAE and CIBSE recommendations (revised)

Air change rate, $N = (3600 \times Q) / V$ per hour

where:

Q : Volume flow rate of air (m^3 / s)

V : Volume of test room (m^3) (348)

ASHRAE recommendation : 8 l/s per person

CIBSE recommendation : 7.5 l/s per person

Normal occupancy of test room is 35 people

$$N \text{ (ASHRAE)} = 3600 \times 8 \times 10^{3} \times 35 \times 10^{-6} / 348 = 2.896 \text{ per hour}$$

$$N \text{ (CIBSE)} = 3600 \times 7.5 \times 10^{3} \times 35 \times 10^{-6} / 348 = 2.72 \text{ per hour}$$