#6090

Ventilation for Energy Efficiency and Optimum Indoor Air Quality
13th AIVC Conference, Nice, France
15-18 September 1992

Poster 2

Air Movements & Air Change Rates Within Nucleus Hospitals.

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Abstract

The Nucleus Hospital programme has been progressed by the Department of Health for over a decade. The Maidstone District General Hospital was the first project which involved the construction of a complete hospital using the Nucleus design concept. Within a hospital, air movement patterns and air change rates are a prime concern in the case of Maidstone, the interest in these parameters was much greater in view of the fact that a natural ventilation strategy had been chosen for ward units.

This paper describes a series of measurements made at Maidstone using the UMIST PCS multiple tracer gas system, and discusses the results obtained.

Introduction

The Department of Health has had a long standing interest in the Nucleus system of hospital design. Under this system, the main medical services are located within the core of the hospital, whilst ward units spread out from the central core; in effect, the Nucleus system is modular, with clear advantages in terms of simplicity of layout and ease of extension. The first prototype ward was constructed at Pinderfields Hospital, Wakefield, whilst the first stand alone hospital unit was built at Maidstone, Kent.

It was intended that the fresh air requirements of ward units be met by natural ventilation. Because of this, the Department of Health was keen to quantify the relative contributions of various air leakage paths to the total air leakage rate, and also to determine the nature and magnitude of air movement routes form ward units to adjacent cells within the building envelope. To this end, the Department of Building Engineering at UMIST was commissioned to undertake a series of fan pressurisation and multiple tracer gas tests within a ward unit at the Maidstone Hospital.

Experimental details

1) Test ward

The ward unit tested is situated on the first floor of the hospital (Figure 1), and lies on the east face of the building. It communicates with the adjacent corridor via double self-closing doors on the north side of the ward, whilst the adjacent ward on the south side is connected by means of double fire escape doors which are normally kept closed. The ward has a suspended T-frame ceiling with lightweight vein finished tiles spring-clipped into position. The roof void above the suspended ceiling is ventilated by means of a continuous ventilation opening at ridge height.

As has been previously mentioned, ward units within the Maidstone Hospital were so designed as to be ventilated naturally. The test ward has three louvred windows within the east facing wall: in addition, three remotely controlled opening roof lights are available to provide high level ventilation.

2) Tests performed

The schedule of tests performed can be conveniently divided into five groups:

Group 1:	air leakage testing to determine the contributions of a range of fabric components to background air leakage. These tests were undertaken using standard fan pressurisation equipment;
Group 2:	tracer gas decay tests to determine air infiltration rates within the ward, and to demonstrate the effects of door opening, window opening, and the influence of air infiltration through the suspended ceiling;
Group 3:	tracer gas tests to determine the air flows from ward to ceiling void;
Group 4:	tracer gas tests to determine air movements between the ward and the adjacent corridor, and to demonstrate the effects of door and window opening;
Group 5:	tracer gas tests to determine air movements between the ward ceiling void and the ceiling void over the adjacent corridor, and to demonstrate the effect of opening the ward windows.

All the tests in Groups 2 to 4 were performed using the parallel column system (PCS) tracer gas equipment developed at UMIST. This equipment is well documented in the literature (for example, reference 1) and will not be described here.

Results and Discussion

The results of the group 1 tests are summarised in Table 1. It should be noted that the upper limit of the range of applied pressure differentials used during the test programme was limited to approximately 30 Pascals, due to the suspended ceiling showing signs of buckling. Values of Q_{50} have been obtained by using the extrapolation procedure described by Kronvall (2).

The results show that the ceiling construction provides 41% of the air leakage paths within the ward fabric. Crackage around doors provides 27% of the total, whilst the remaining

31% can be attributed to the external fabric, gaps around windows, service duct and pipe entries, and light fittings in the ceiling.

The results of the Group 2 tests are shown in Figure 2, plotted against mean wind velocity at roof height. (Internal/external pressure differences and temperature differences were also recorded during the study, but are not considered here). Unsealing the suspended ceiling increases the air change rate within the ward by approximately 50%; when the doors are unsealed, the ward air change rate increases on average by approximately 52%. The results for the ceiling unsealed case correlated very closely with the air leakage tests in Group 1. This is not the case for the data generated with the ceiling and doors unsealed. It should be noted, however, that the mean wind speeds experienced during these latter tests were rather higher than for the former. Pressure data taken during these tests show a positive pressure difference of between 2 and 4 Pascals between the outside face of the building and the ward, and a negative pressure difference of between 0.05 and 0.3 Pascals between the ceiling void and the ward. The existence of the positive pressure difference across the leeward face of the building probably owes its existence to a vortex in the courtyard adjacent to the ward. The negative pressure difference between ward ceiling void and ward is almost certainly caused by the continuous ridge ventilator. No low level openings are provided to encourage cross-flow ventilation. In the light of the recommendations given in reference 3, it is highly likely that the use of high level ventilation on its own is resulting in depressurisation of the ceiling void.

The results of the Group 3 tests are shown in Figure 3. With the door and window shut a 35–45m^3/hr air flow exists between ward to ward ceiling void; in other words, approximately 50% of the air leaving the ward does so through the suspended ceiling. When the doors and windows are opened, the proportion of air leaving the ward via the suspended ceiling drops to between 20% and 40%.

Group 4 test results are presented in Figure 4. It is apparent that a two directional air flow exists between the ward and the adjacent corridor, and that the relative sizes of the two air flow components are dependent upon window and door openings. When the doors and windows are closed, the outflow from ward to corridor is between 64 and 80m^3/hr, and the inflow from corridor to ward is between 14 and 36m^3/hr. When the doors to the corridor and the ward windows are opened, the outflow increases to between 107 and 150m^3/hr, whilst the inflow falls to between 6.5 and 10m^3/hr.

Consideration of subsidiary data not presented in this paper reveals that ward and corridor air temperatures are essentially the same, whilst a positive pressure difference of between 3 and 9 Pascals exists between the ward and corridor. The test data is broadly in agreement with the work of Shaw (4, 5) and Lidwell (6); careful study to these three references is commended to any reader interested in the influence of pressure and temperature differentials upon two-way air flows through openings.

The results for the Group 5 tests (Figure 5) are interesting, since they reveal that a one-directional air flow exists between the ward ceiling void and the ceiling void above the adjacent corridor. The magnitude of the air flow is influenced very strongly by the opening of ward windows. With the windows closed the air flow is between 60 and 85m^3/hr; with the windows open, the air flow increases to between 81 and 118m^3/hr. Inspection of pressure data relevant to the test periods show increased positive pressure differences between ward and ward ceiling void, and between ward ceiling void and corridor ceiling void. Inspection of the partition wall between the two ceiling voids reveals potential air flow paths in the form of large gaps around service pipes. Although time constraints curtailed suitable tracer gas tests from being performed, it is the opinion of the authors that better sealing around service pipe penetrations would significantly reduce the air flow.

Conclusions

The air flows between interconnected cells within the Maidstone Nucleus Hospital have been shown to be influenced by wind speed, wind direction, temperature differences and door/window opening patterns. The clearest finding is that the suspended ceiling constitutes an extremely important air leakage path, and that the nature of the void above not only results in the flow of air from the ward upwards, but also from the void to the adjacent corridor roof void.

Acknowledgement

This programme of work was commissioned by the NHS Estates Agency of the Department of Health and this paper is published with their permission.

References

1) C Irwin and R E Edwards, "The measurement of air flows using a rapid response tracer gas technique", BSER&T, Vol. 6, No. 4, pp145–152, 1985

2) J Kronvall, PhD Thesis, 1981.

3) British Standards Institution, "Control of Condensation in Buildings", BS 5250, 1989.

4) B H Shaw, "Heat and mass transfer by natural convection and combined natural convection with forced air flow through a large rectangular opening in a vertical partition", Institute of Mechanical Engineers Conference, Volume C819, 1972.

5) B H Shaw and W Whyte, "Air movement through doorways", Building Services Engineer, Vol. 42, 1974.

6) O M Lidwell, "Airborne infection in a fully air conditioned hospital", Journal of Hygiene, 75, p.141, 1977.

Table 1: Results of pressurisation tests performed at Maidstone Hospital.

Test No.	**Condition**	**Leakage rate**
45	Doors and ceiling sealed	0.667m^3/s at 50 Pa
46	Doors only sealed	1.567m^3/s at 50 Pa
47	Ceiling sealed, doors unsealed	1.083m^3/s at 50 Pa
48	No sealing	2.133m^3/s at 50 Pa

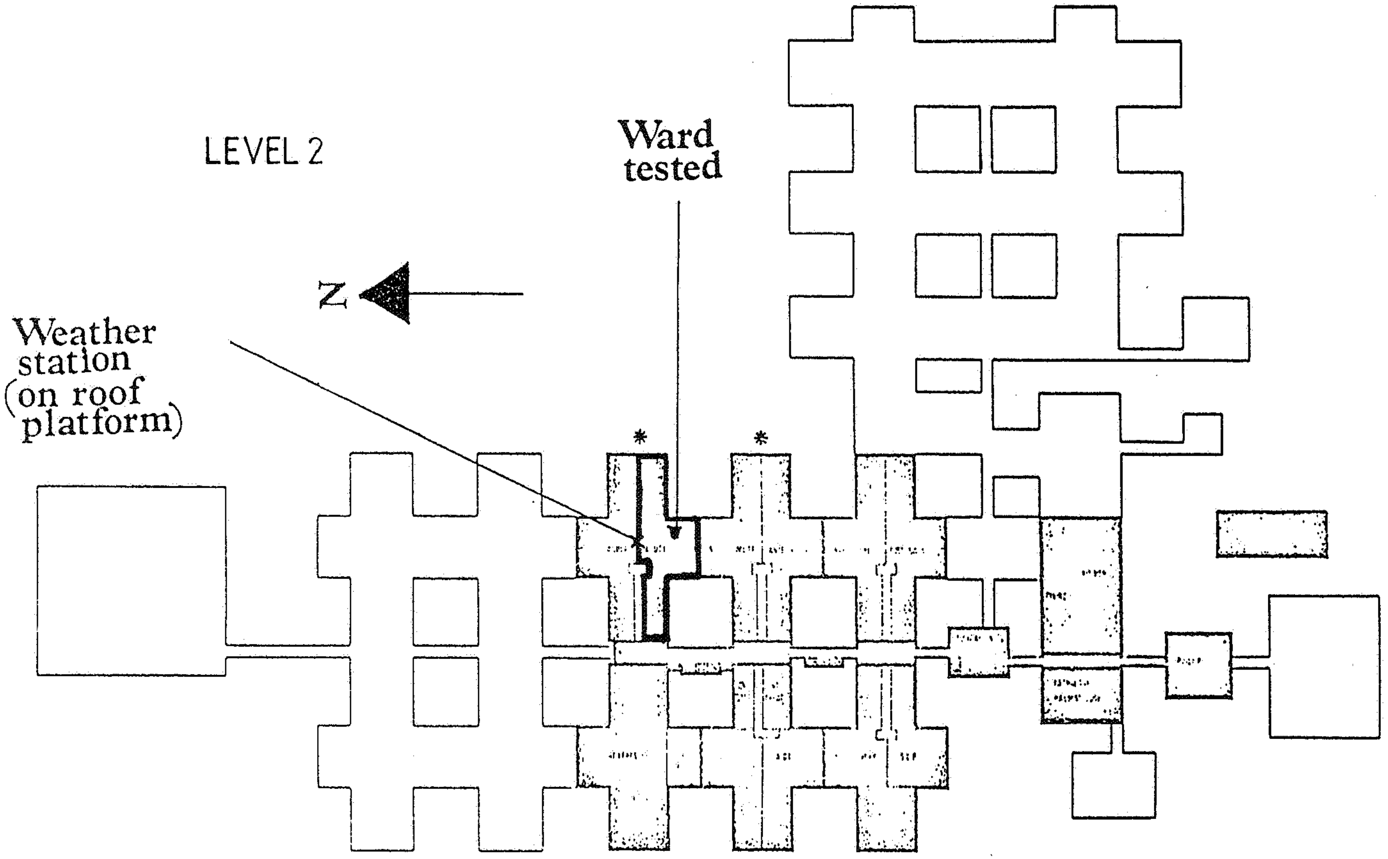

FIGURE1

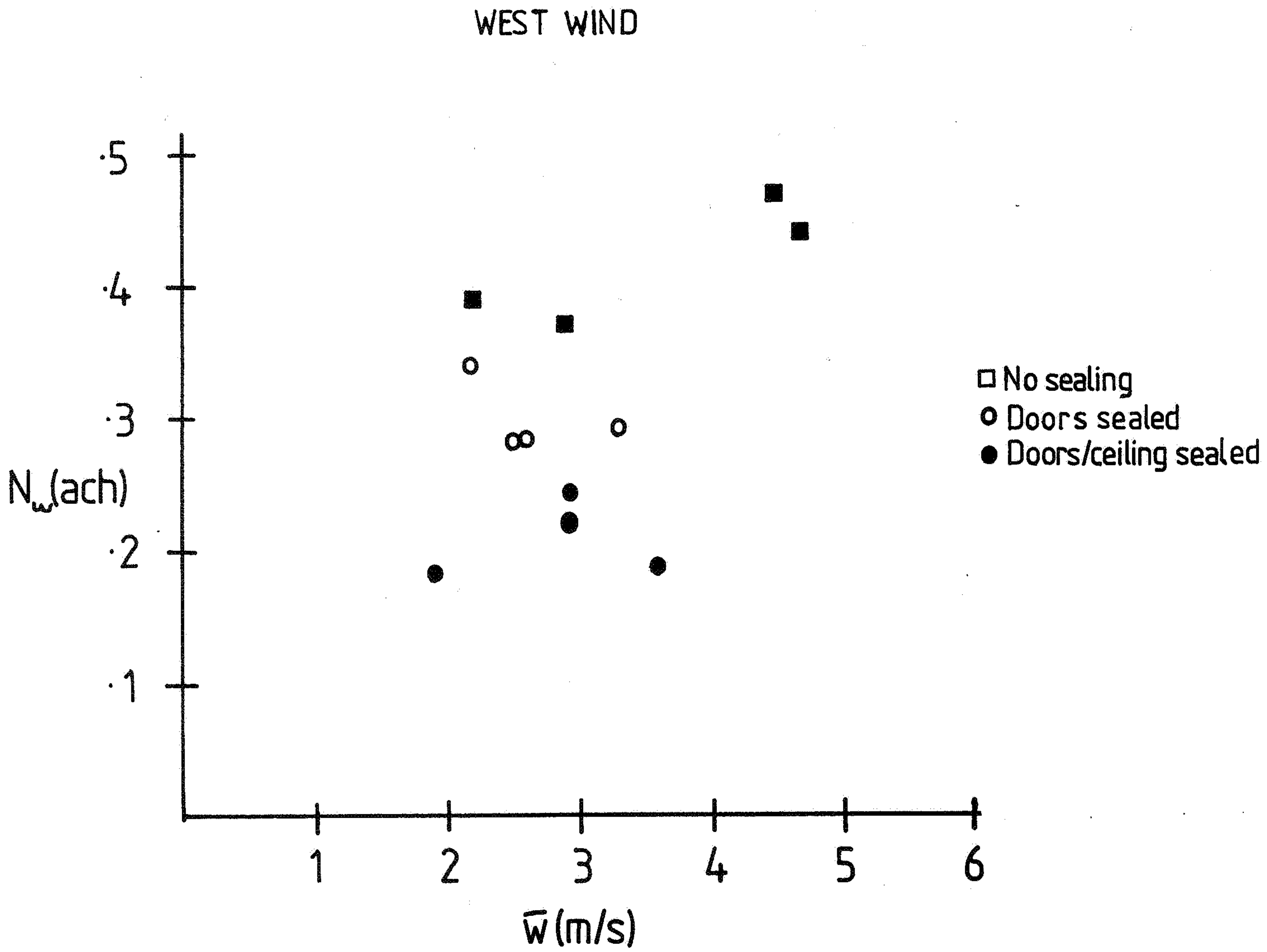
WEST WIND
·5
·4
·3
·2
·1
N_ω(ach)
1
2
3
4
5
6
$\bar{w}$(m/s)
□ No sealing
o Doors sealed
● Doors/ceiling sealed

FIGURE 2

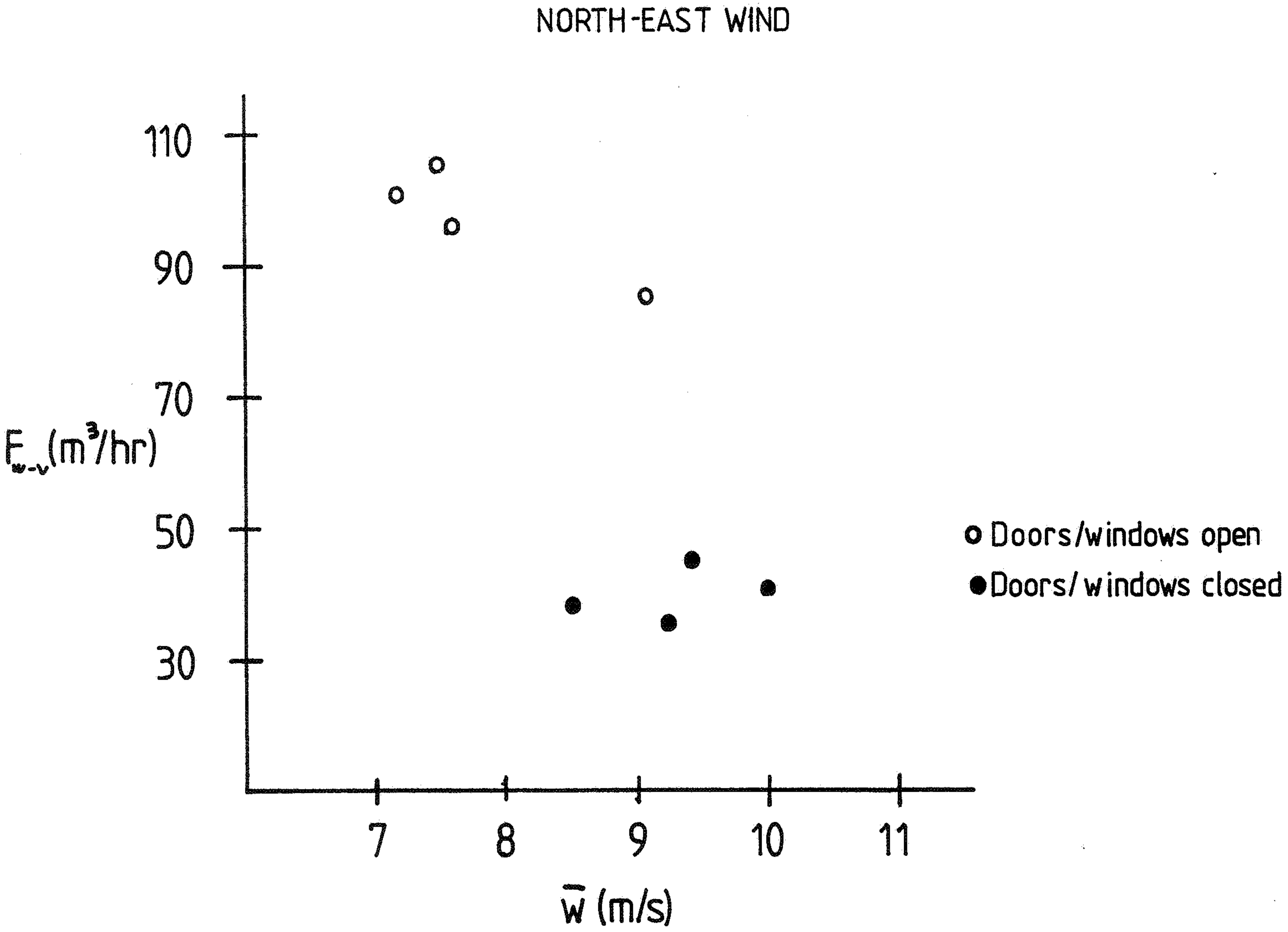
NORTH-EAST WIND
110
90
70
50
30
E_{w-v}(m³/hr)
7
8
9
10
11
$\bar{w}$ (m/s)
○ Doors/windows open
● Doors/windows closed

FIGURE 3

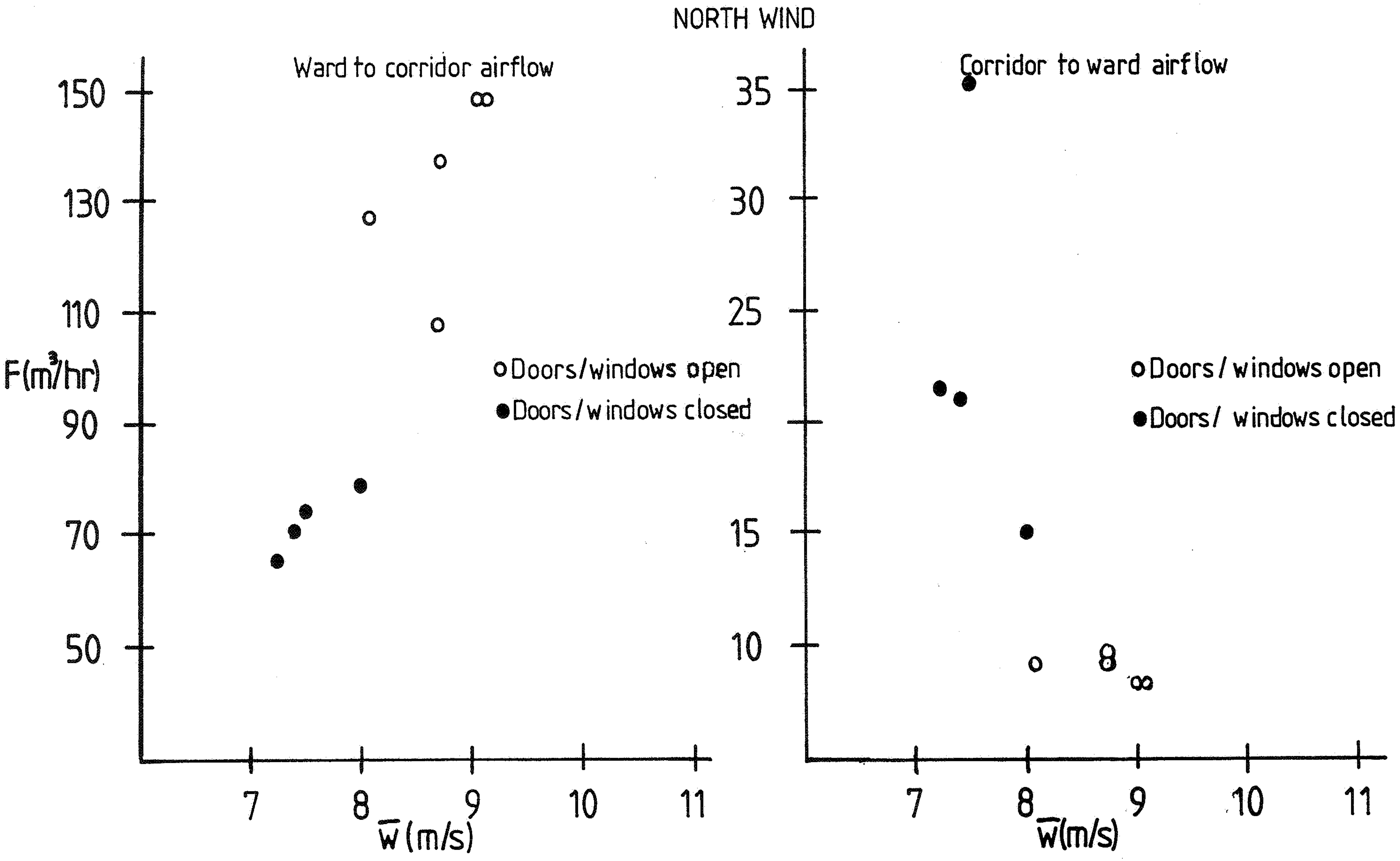
NORTH WIND
Ward to corridor airflow
Corridor to ward airflow
F(m³/hr)
150
130
110
90
70
50
35
30
25
15
10
7
8
9
10
11
$\overline{w}$(m/s)
○ Doors/windows open
● Doors/windows closed

FIGURE 4

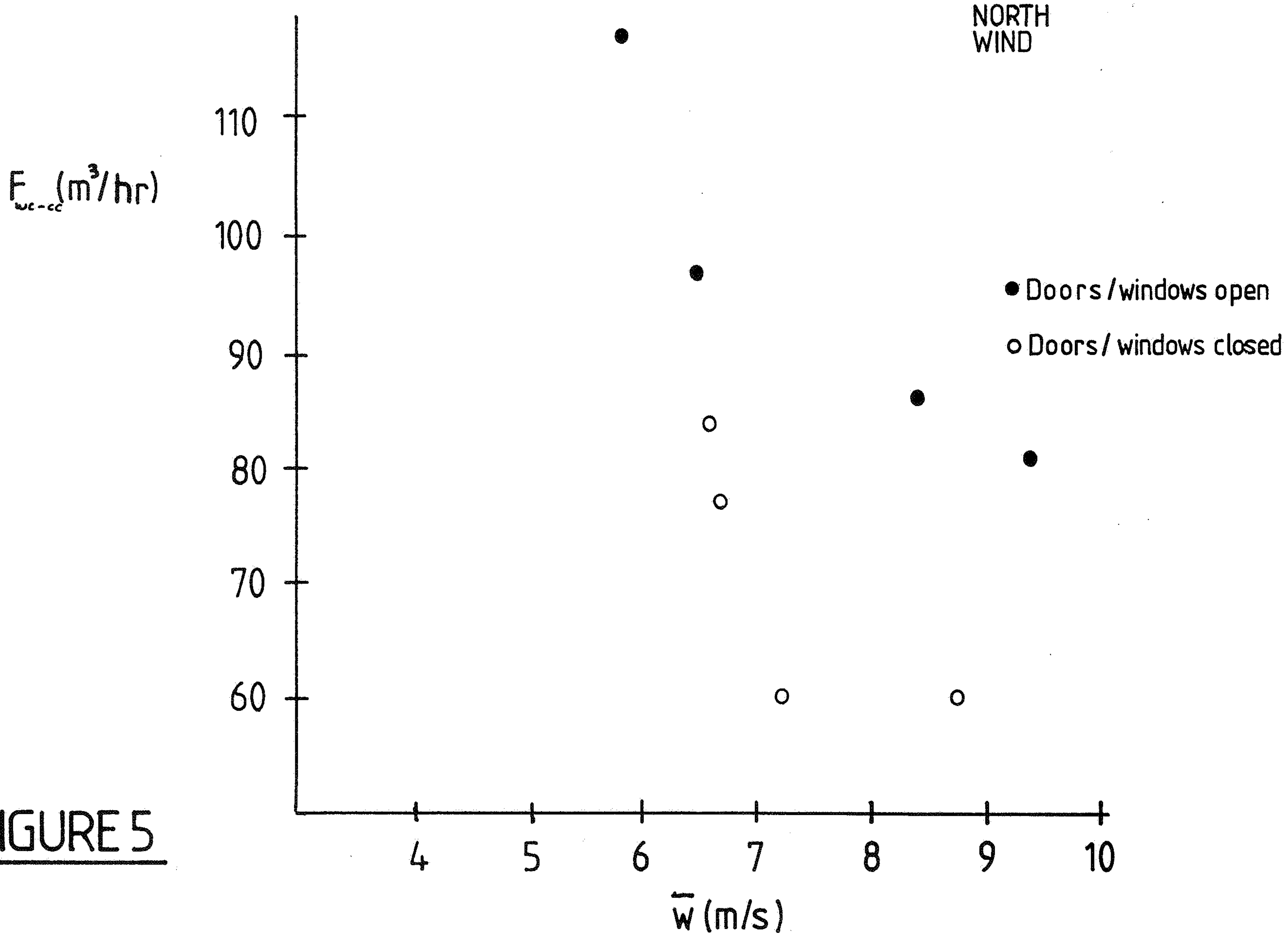
NORTH WIND
F_{wc-cc} (m³/hr)
110
100
90
80
70
60
4
5
6
7
8
9
10
$\bar{w}$ (m/s)
● Doors / windows open
○ Doors / windows closed

FIGURE 5