Proc. CIBSE A: Building Serv. Eng. Res. Technol. **18**(2) 115–124 (1997) Printed in Great Britain B412

Summary Comfort conditions in rooms ventilated by trickle vents were investigated experimentally. The conclusion that head-to-ankle temperature gradient is altered by the location of radiators within a room was borne out in this study for single-, double- and triple-glazed windows. At typical external wind speeds, threshold draught air velocity (0.3 m s^{-1}) is not exceeded by the use of either 4000 or 8000 mm^2 vents, although to a limited extent the more stringent ASHRAE standard (0.15 m s^{-1}) is not met by the use of 8000 m^2 vents. In both cases Fanger's external comfort criteria were satisfied. The tests generally showed a decrease in head-to-ankle temperature gradient when air was entering the room through the vents at higher velocities. The room air and the plume of air rising off the radiators mixed more thoroughly at the surface of the window when located at the room side of the opening, illustrated in this case by tests on 'double' windows. Iso-PMV contour diagrams were used to show the uniformity of pattern where, for example, air is vented from the room rather than supplied to it, and when ventilation air is supplied at low rather than high level. The latter had a marked negative impact on the HAT gradient whereas changing the height of the window sill above the floor had little effect. The gradient was reduced by adding extra layers of glass into the window. Marked local effects were observed as a result of splaying the top and side reveals.

Influence of window form and location and the provision of background ventilation on comfort within rooms

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Received 18 July 1996, in final form 31 December 1996

1 Introduction

Recent concern about indoor pollution in houses (because of toxins found in contemporary building materials and the health hazards posed by micro-organisms and condensation) led to the recent revision of the UK Building Regulations requiring an increased volume of background winter ventilation. In the absence of a completely mechanical ventilation system this is customarily provided by trickle vents above windows. The most recent changes have required the use of 8000 mm^2 vents, double the previous size.

This is an experimental study of the impact of increased ventilation volume on comfort conditions in rooms. The methodology is a simplification from previous work at the UK Building Services Research and Information Association[1,2] on 4000mm^2 trickle vents in single-glazed windows. It was concluded that surface heat transfer at the face of windows is a complex fluid dynamics problem as follows:

(*a*) When radiators are located below windows the interaction between the plume of warm air rising relative to the layer of cold air adjacent to the window is modified by the size of the sill, the shape of the window, the type of curtaining and the use of trickle vents.

(*b*) Configurations which encourage a mixing of the warm and cold air at the face of the window incur higher levels of heat loss through the window but more satisfactory temperature gradients within the room.

(*c*) Infiltration of air into a room through trickle ventilators moves the plume of warm air away from the window, reducing the extent of heat loss. The temperature gradi-

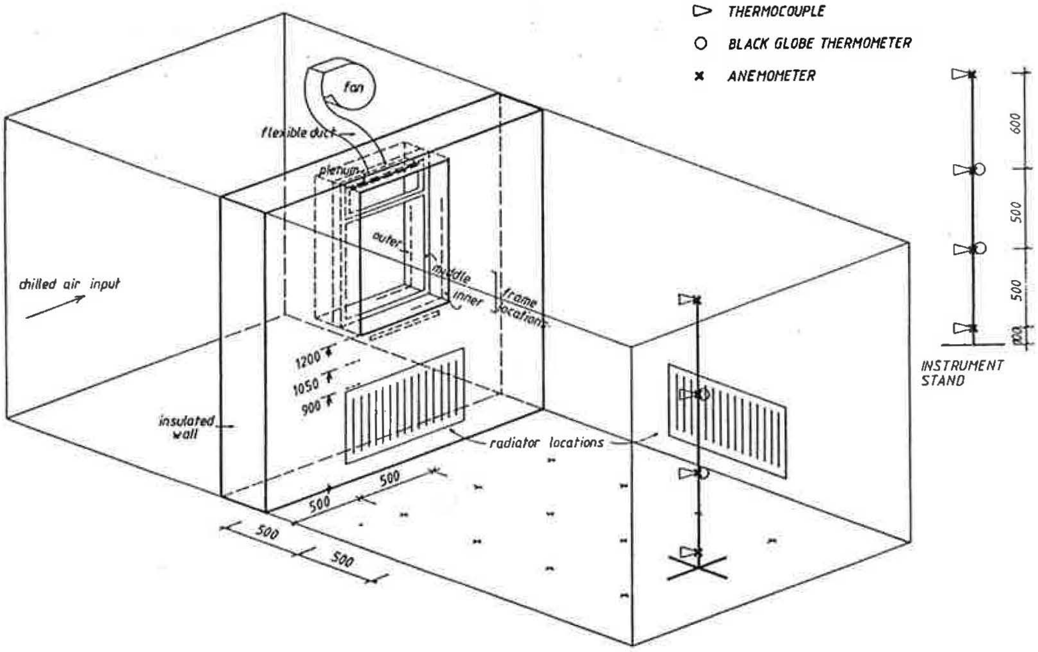

Figure 1 Thermal chamber and equipment

ent within the space is satisfactory if radiators are located below windows but unsatisfactory if on a side wall.

(*d*) Heat loss is reduced when windows are located to the outside of the wall (which gives sufficient sill depth for the layer of cold air to be undisturbed). To the outside, middle or inside face, the thermal gradient in the room is consistent and satisfactory for windows with a radiator beneath them, but too high when radiators are located on side walls.

An initial series of tests (on single-glazed windows with 4000 mm^2. trickle vents) was conducted to verify the BSRIA results using current methodology and apparatus. So as to reduce the number of variables to be addressed, the following situations were isolated:

(i) A window of conventional size and vertical emphasis suitable for a kitchen, bathroom or small bedroom. The window was mounted at the outer face of the opening, the middle of the opening and the inside face of the opening. Air was delivered by trickle vents at the head of the window or beneath the sill (as is customary in Scandinavian houses) (Figure 2).

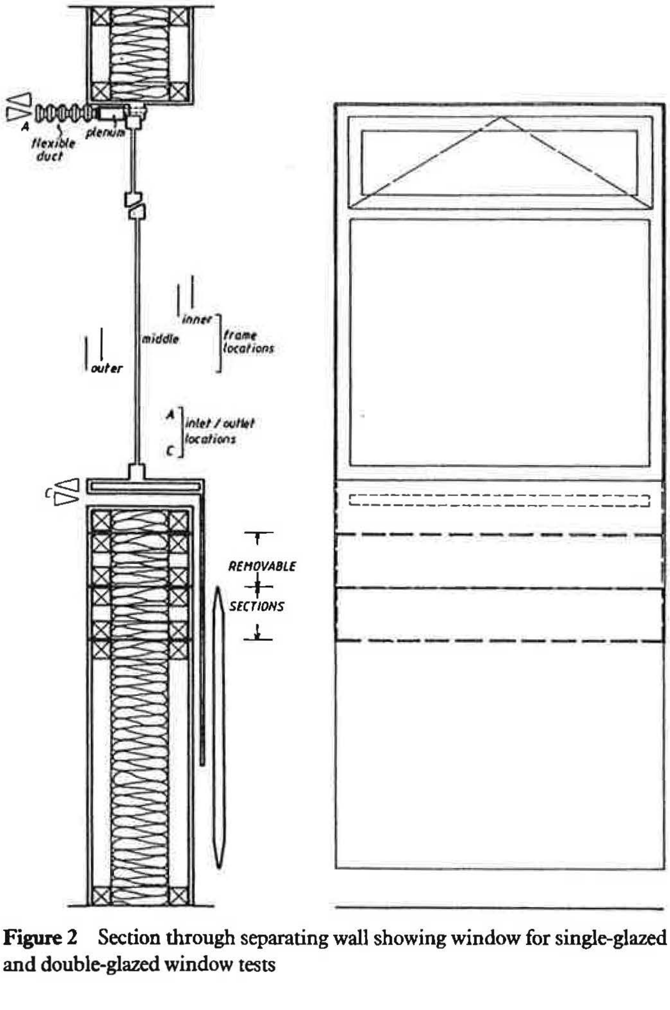

Figure 2 Section through separating wall showing window for single-glazed and double-glazed window tests

(ii) A 'frameless' window with splayed inner reveals, to the same proportion as no. (i) but with background ventilation directed above the opening to the inner face of the wall (Figure 3).

(iii) As no. (ii) but with an additional inner window fixed at the inside face of the wall to form a 'double' window (Figure 3).

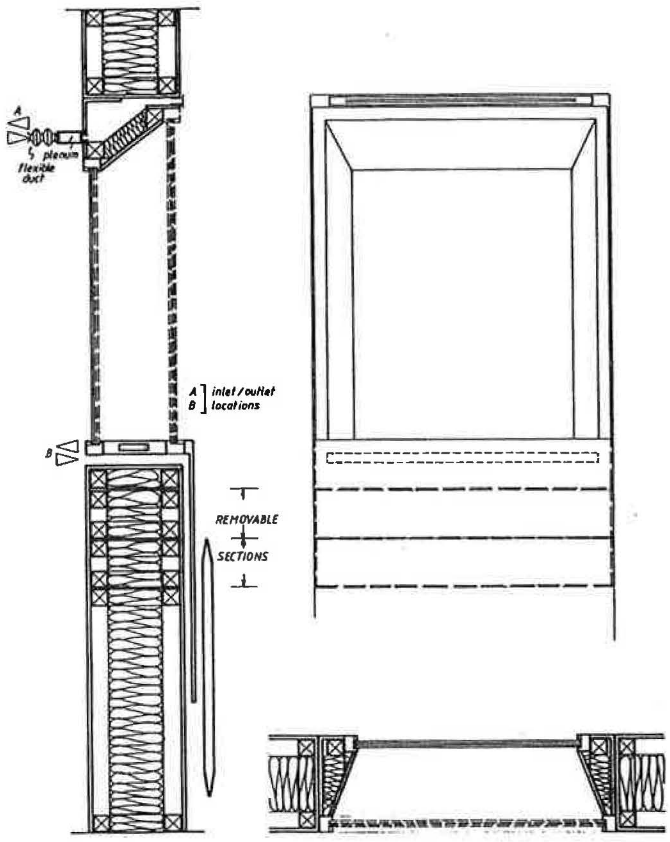

Figure 3 Section through separating wall showing 'splayed reveal' window and 'double' window

(iv) (i)–(iii) repeated with the radiator on a side wall rather than under the window, and with air exhausted through the trickle ventilators rather than their acting as inlets.

(v) Readings were taken at external air temperatures between –1 and 7°C. and with flow rates through the trickle vents of 7.5 and 9.8 $l\,s^{-1}$ (corresponding with average wind speeds of 3 and 4 $m\,s^{-1}$) and with the height of the sill at 900, 1050 and 1200 mm.

The previous experiments at BSRIA were based on flow rates of 2.5 $l\,s^{-1}$ (corresponding to a wind speed of 1 $m\,s^{-1}$), and 7.5 $l\,s^{-1}$ (corresponding to a wind speed of 3 $m\,s^{-1}$). A 2.5 $l\,s^{-1}$ flow rate induces air speeds too low to be measured with the equipment available on this occasion. Instead 3 $m\,s^{-1}$ and 4 $m\,s^{-1}$ have been used. The latter is the typical wind speed employed in other domestic ventilation studies[3] Both the flow rates employed for the current experiments were then comparable with the *CIBSE Guide* recommendation of 8 $l\,s^{-1}$ per person.

2 Methodology

The tests were carried out in a thermal chamber subdivided by a wall 300 mm thick. Each face was constructed from hardboard on a timber frame with glass fibre insulation at the inner side (see Figures 1 and 4.) The *U*-value of the wall was calculated to achieve a value of 0.25 Wm^2K^{-1}, in excess of current UK Building Regulations requirements but corresponding to recent recommendations[4]. The wall incorporated removable sections to vary the height of the window sill.

The room space was heated by two twin-element electric fires located either beneath the window or at the side wall of the room. The output of the fires was controlled by a variac and measured using a wattmeter. The settings corresponded to

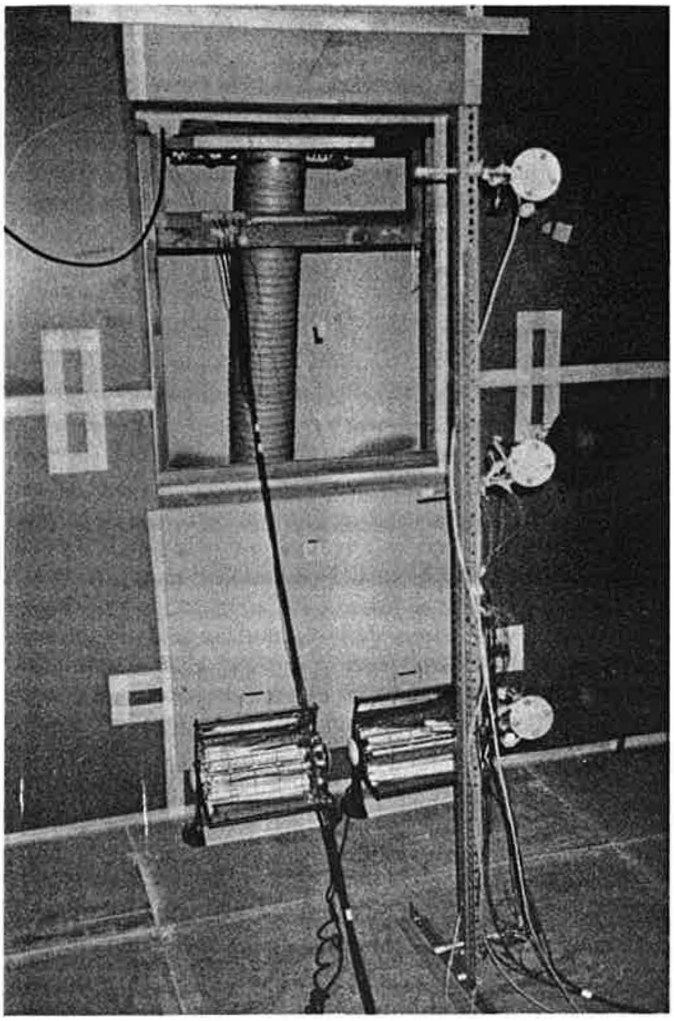

Figure 4 Thermal chamber and equipment

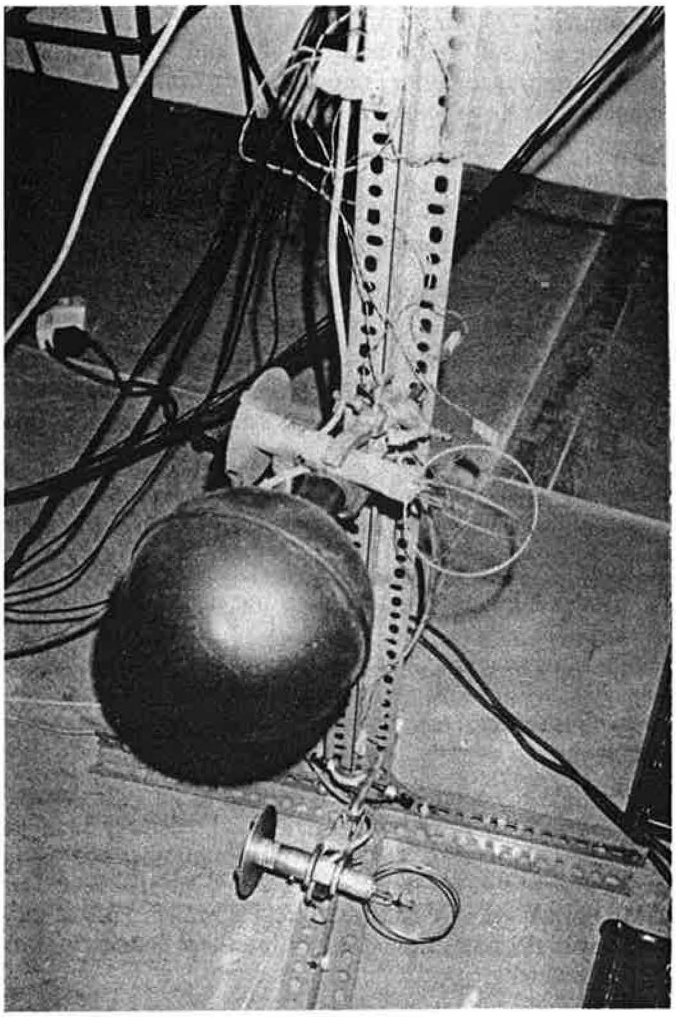

Figure 5 Instrument stand

the steady-state conditions that may be anticipated at alternative differences in temperature between the inside and outside of the room, and to alternative wind speeds corresponding with calculated rates of admission of cold air through the trickle vents. The void beyond the wall was cooled by a ducted chilled air system, boosted by an open chest freezer located within the space. The floor within the room was divided into a 500 mm. square grid to locate a movable instrument stand (Figure 5) equipped to measure the air temperature (thermocouples at 100 mm, 600 mm, 1100 mm and 1700 mm above floor level), dry resultant temperature (black globe thermometers at 600 and 1100 mm above floor level) and mean air velocity (Dantec omnidirectional spherical probes, accurate from 0.05 to 1 m s^{-1}, connected to a multichannel flow analyser, located at 100 mm, 600 mm, 1100 mm and 1700 mm above floor level). In addition thermocouples were located around the room at the separating partition and within the cooled space.

Air was delivered to the trickle ventilator locations by a plenum connected by flexible ducting to a small fan within the cooled void. The fan speed was regulated by variac. The pressure difference across the vents was measured using an inclined-tube manometer. The variac was set to levels corresponding with external wind speeds of 3 and 4 m s^{-1}. A thermocouple within the plenum measured the temperature of air being admitted or removed from the room. The humidity (constant throughout the room) was determined by a hygrometer.

3 Measurements for room comfort analysis

The above instruments were used to determine the air temperature, air speed, dry resultant temperature, humidity and mean radiant temperature

The room conditions were analysed under the variety of conditions listed above in relation to the universal environmental index derived by Fanger[5]. This relates the several variables measured at grid points within the room, assuming in this case a metabolic rate of 70 W m^{-2}, i.e. sedentary activity (1.2 met), and light work clothing (0.75 clo, 0.12 m^2 kW^{-1}).

A spreadsheet was used to calculate the mean radiant temperature at each grid location and the BASIC computer program described in ISO standard 7730[6] was used to derive the predicted mean vote (PMV.) The correlation of the ratio of those expressing dissatisfaction (the predicted percentage of dissatisfied or PPD) at each grid point is derived from the PMV using the BASIC program. The minimum possible percentage of dissatisfied subjects is 5%, an ideal environment.

PMV and PPD values outside the recommended range were adjusted by varying the room temperature by calculation to give a zero average PMV. A measure of the thermal uniformity of the room was determined by subtracting the mean PMV value from the PMV values at each grid location and recalculating the PPD at each point. The average of these revised PPDs is the lowest possible percentage of dissatisfied (LPPD.) Iso-PMV contours were drawn for each test to describe graphically the extent or lack of uniformity for each condition.

ISO standard 7730[5] recommends a PPD limit of 10% corresponding to a PMV range between −0.5 and +0.5, whereas Fanger recommends a PPD limit of 6% for rooms in sedentary occupation.

The other principal measures of thermal comfort are the HAT (head-to ankle-temperature gradient) which, as defined by ASHRAE standard 55-1981[7], is to be not more than 3 K between 1.7 and 0.1 m above floor level†.

The time-mean air velocity should not exceed 0.35 m s^{-1} (draught limit)‡.

Also the recommended range of floor temperatures is to between 19–26 °C in winter for light, mainly sedentary activity[5]

The air diffusion performance index (ADPI) for a room is a measure of thermal comfort in relation to air movements within the space and is a function of the effective draught temperature values.

The effective draught temperature q was determined at each grid location:

$$\theta = (T_r - T_{av}) - 8(v - 0.15)$$

where Tr is the local temperature (°C), T_{av} is the average room temperature (°C), v is the local air velocity (m s^{-1}).

The draught temperature limit is defined as 1.1 K for warm sensation and −1.7 K for cool sensation and sedentary occupation. The ADPI is equal to the percentage number of points satisfying comfort conditions from 1.1 K to −1.7 K and a maximum air velocity not exceeding 0.35 m s^{-1}. 80% of the locations in the room should fall within these boundaries for the environment to be considered satisfactory.

4 Test results

4.1 Preliminary tests on a single-glazed window with a 4000 mm². trickle vent (Figure 6)

The initial tests were intended to calibrate the equipment, to determine the experimental procedure and to verify the results of the previous work at BSRIA[1,2], whose study concluded that:

(*a*) In all cases, average thermal comfort was satisfactory, i.e. the LPPD was less than 10%.

(*b*) The head-to-ankle temperature difference showed significant variation. Unacceptable or critical values occurred when the radiator was on the side wall.

(*c*) Reduced HAT gradients resulted when the warm air from the heaters was taken to the glass surface, i.e. when the window is located on the room side of the structural opening. Trickle vents tend to move the warm air away from the window surface.

†For sedentary activity Reference 7 specifies 'head height' to be 1.1 m. above floor level but BSRIA's figures for head-to-ankle gradient were measured at 1.7 m. above floor level. For comparison the HATs quoted here are also those measured at standing height. The gradient is reduced on average by 20% if temperatures are recorded at the lower (seating) level.

‡This recommendation is made in Reference 8, whereas 0.3 ms^{-1} is the commonly accepted draught threshold[9]; see for example Reference 10. References 6 and 7 do however specify a winter maximum air speed of 0.15 m s^{-1}. This more onerous criterion was slightly exceeded when supplying air through 8000 mm² trickle vents, the exception being the triple-glazed window tests.

max. HAT (o C)	1.3
PMV	-5e-1
PPD	12.325
LPPD	5.6166
ADPI	91.7

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)
window

PMV =	-0.7	-0.8	-0.9	-0.7	-0.7
PPD	16	19.5	20.7	15.3	15.8
HAT	1.2	1.1	1.3	0.3	0.4
eff. dr.	1.8e-1	-4e-1	8.5e-2	3.2e-1	1.9e-1
PMV =	-0.7	-0.6	-0.6	-0.6	-0.6
PPD	15.8	12.5	13.4	12.4	12.2
HAT	0.9	1	0.9	0.5	0.5
eff. dr.	4.9e-1	2.6e-1	6.4e-1	6.4e-1	6.0e-1
PMV =	-0.8		-0.6		-0.6
PPD	20		13.4		11.7
HAT	0.8		0.5		0.5
eff. dr.	5.7e-1		5.6e-1		5.4e-1
PMV =			-0.6		
PPD			11.6		
HAT			0.7		
eff. dr.			6.3e-1		
PMV =	-0.4		-0.5		-0.4
PPD	9		9.5		9
HAT	0.7		0.7		0.5
eff. dr.	9.3e-1		8.7e-1		8.7e-1
PMV =			-0.4		
PPD			8.5		
HAT			0.7		
eff. dr.			9.8e-1		
PMV =	-0.4		-0.4		-0.4
PPD	7.6		7.6		7.6
HAT	0.8		0.6		0.4
eff. dr.	1.2375		9.6e-1		9.1e-1

*eff. dr. = effective draught temperature °K

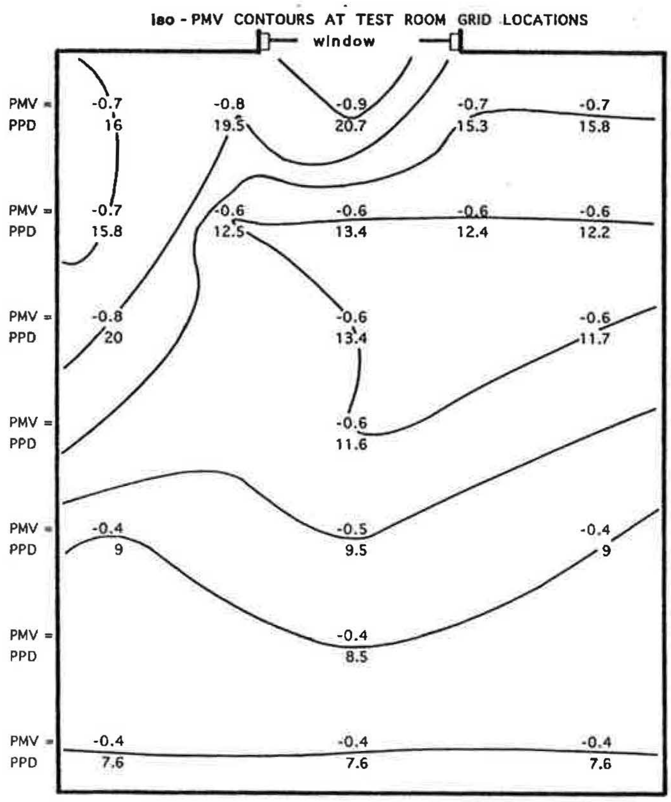

Figure 6 Preliminary tests on a single glazed window with a 4000 mm² trickle vent

(*d*) Trickle vents at higher infiltration rates resulted in a reduced HAT. No evidence of cold draughts was found.

Using the equipment currently available, the maximum achievable temperature difference between inside and outside was approximately 18 K. This was the closest approximation that could be made to the conditions employed at BSRIA[1,2]. In equivalent tests it was determined that higher velocities do occur in the area around the windows, but that these are nowhere greater than 0.25 m s^{-1} in the investigated area of the occupied zone. This was also borne out by the results from current tests.

Even so, the glass internal temperatures recorded at BSRIA were approximately 5 K lower than could be achieved given the equipment available for the current tests. BSRIA's external air temperature was generally −1°C (resulting in an inside/outside temperature difference of 23–25°C). Some tests were carried out at +5°C (an approximate inside/outside temperature difference of 18°C). On this occasion the maximum temperature drop achieved was approximately 18°C but the majority of the tests had a lower temperature drop, closer to average UK winter conditions. Also because the *U*-value of the insulated wall was higher this time (0.25 Wm^{-2}K^{-1} as compared with BSRIA's 0.47 Wm^{-2}K^{-1},) lower temperature gradients were observed. For example a maximum HAT of 1.7 was recorded as against BSRIA's equivalent HAT ratings of 3.43 and 3.39. The present investigations do however confirm their contention that the HAT when the heaters are located on the side wall is significantly higher than when they are located beneath the windows.

In all cases LPPD values were less than 6% and the ADPI was greater than 80%, indicating satisfactory comfort conditions. In no case were air velocities in excess of draught speed (0.3 m s^{-1}). The iso-PMV contours showed a very different pattern when the heaters were located beneath the window as compared with those when the heaters were located at the side wall. In the former case the contours bunched significantly directly adjacent to the window. The contours were wider spaced when air was supplied into the room at the higher velocity (corresponding to a wind speed of 4.0 m s^{-1}; the revised PPD figure was 7.0 at the grid location closest to the window). The contour pattern when the heaters were located at the side wall clearly related to the position of the heaters at the centre of the wall, and the HAT gradient was greatest at the opposite wall. At the increased flow rate, lower HAT figures were recorded, as observed at BSRIA.

All the iso-PMV contours have a degree of asymmetry due to the location of the access door to the thermal chamber, which leaks air to and from the room (located in the left-hand corner of the rear wall.)

4.2 Tests on a single glazed window with air extracted from the room by a 4000 mm² trickle vent (Figure 7)

The external temperature for these tests was approximately 5°C. Extracting warm air into the cooled void made it difficult to attain a large temperature drop with the equipment being used. The HAT figures were however relatively high and the highest (1.7 °C) was recorded when the heaters were located at the side rather than at the front wall. All these tests were carried out with the higher pressure drop across the trickle vents of 9.6 Pa, representing an external wind speed of 4 m s^{-1}. Even so, the air speeds in the room were very slow and in many cases were below 0.05 m s^{-1} (the minimum reliable measurement for Dantec hot film anemometers.) In all three cases, the highest air speeds were recorded at floor level directly behind the door to the room, although these were not above draught speed (0.3 m s^{-1}). The iso-PMV contours were characteristically dispersed and the LPPD reflects the uniformity within the room.

max. HAT (o C)	1.5
PMV	-0.925
PPD	23.075
LPPD	5.025
ADPI	100

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)

window

PMV =	-0.9	-1	-1	-0.9	-0.9
PPD	23.5	24.5	27.2	23.5	23.8
HAT	1.1	1.3	0.5	0.3	1
eff. dr.	6.4e-1	7.6e-1	3.5e-1	6.7e-1	7.9e-1
PMV =	-0.9	-0.9	-0.9	-0.9	-0.9
PPD	23.3	23.7	22.7	21.8	22.3
HAT	1.1	1.1	0.8	0.7	1
eff. dr.	8.4e-1	7.1e-1	8.2e-1	9.4e-1	8.6e-1
PMV =	-1		-1		-0.9
PPD	24.3		24.2		23
HAT	1.5		1.2		0.9
eff. dr.	1.0485		8.7e-1		8.9e-1
PMV =			-0.9		
PPD			22		
HAT			0.9		
eff. dr.			8.4e-1		
PMV =	-0.9		-0.9		-0.9
PPD	22.1		21.7		22.5
HAT	1.2		1.2		1.2
eff. dr.	8.1e-1		7.9e-1		9.4e-1
PMV =			-0.9		
PPD			21.8		
HAT			1.3		
eff. dr.			9.8e-1		
PMV =	-0.9		-0.9		-0.9
PPD	21.7		21.2		21.7
HAT	1.3		1.2		1.3
eff. dr.	9.9e-1		7.8e-1		8.9e-1

*eff. dr. = effective draught temperature °K

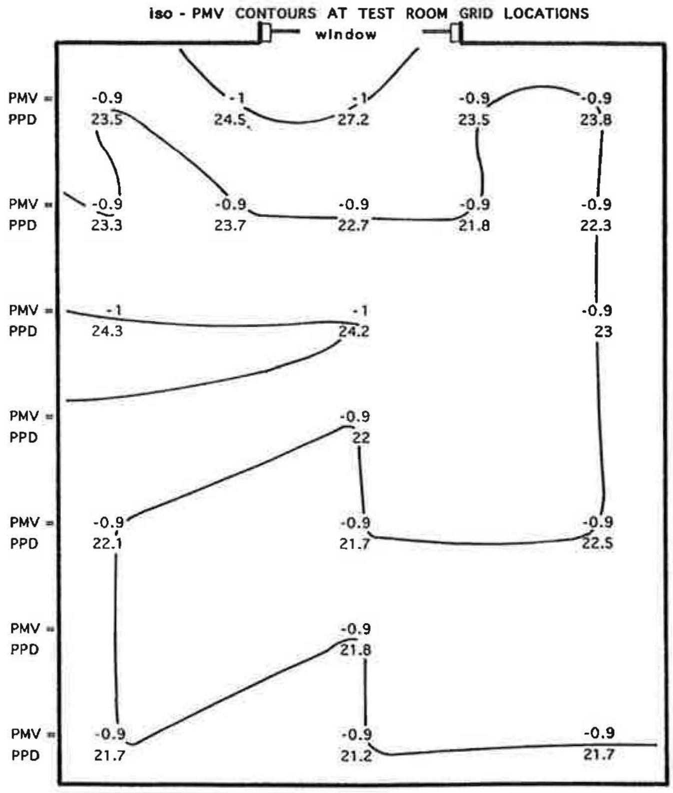

Figure 7 Typical test on a single glazed window with air extracted from the room by a 4000 mm² trickle vent

4.3 Tests on a double glazed window with air supplied to the room by a 8000 mm² trickle vent (Figure 8)

max. HAT (o C) 1.3
PMV -1.233
PPD 37.583
LPPD 5.0583
ADPI 100

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)
window

PMV =	-1.2	-1.4	-1.5	-1.2	-1.2
PPD	36.9	46.8	51	33.5	36.4
HAT	0.8	0.9	0.8	0.6	1
eff. dr.	2.4e-1	-2e-1	2.6e-2	6.5e-1	6.0e-1
PMV =	-1.2	-1.2	-1.2	-1.1	-1.2
PPD	36.2	36.2	33.6	32.2	33.6
HAT	1.1	0.7	1.3	0.8	1.1
eff. dr.	9.1e-1	7.7e-1	9.1e-1	1.2063	1.1293
PMV =	-1.2		-1.2		-1.2
PPD	36.2		35.3		34.6
HAT	1.2		1.2		0.8
eff. dr.	7.3e-1		8.0e-1		9.8e-1
PMV =			-1.2		
PPD			36.3		
HAT			0.9		
eff. dr.			5.7e-1		
PMV =	-1.2		-1.2		-1.2
PPD	35.7		35.7		36.1
HAT	1.3		1		1.1
eff. dr.	6.1e-1		6.1e-1		5.0e-1
PMV =			-1.2		
PPD			35.4		
HAT			1.1		
eff. dr.			5.5e-1		
PMV =	-1.2		-1.2		-1.3
PPD	35.4		35.4		42.3
HAT	1		0.8		0.8
eff. dr.	5.6e-1		5.5e-1		5.2e-1

*eff. dr. = effective draught temperature °K

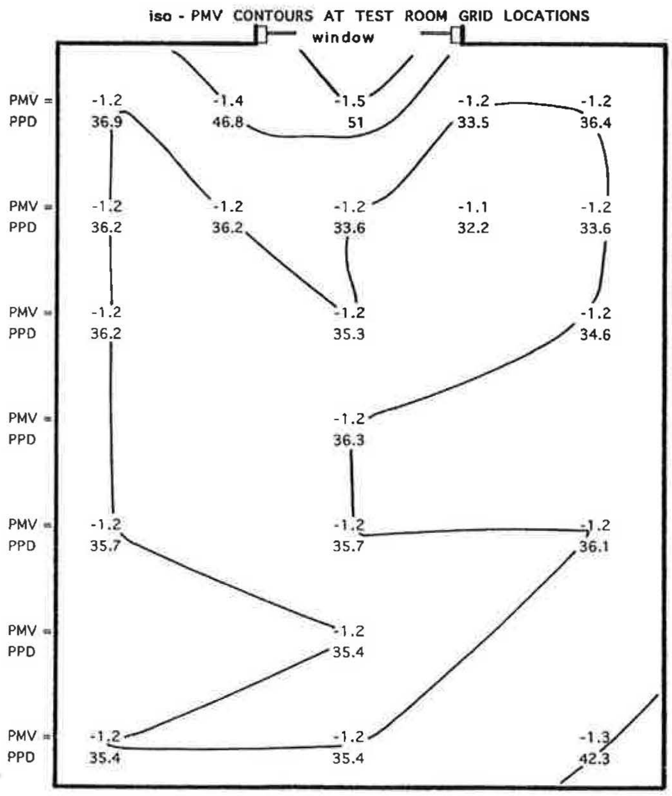

Figure 8 Typical test on a double glazed window with air supplied to the room by a 8000 mm² trickle vent

Modification of the cooling system allowed these tests to be carried out at lower external temperatures. The same general pattern was observed as previously. HAT values were markedly higher when the heaters were located at the side wall rather than at the window. Similarly the ADPI was lower (closer to or below 80%) in this location. The same gradation of iso-PMV contours was evident when the window was located at the outside of the opening, but not when the heaters were located at the side wall.

The difference in pattern as between window location at the inside face of the wall and at the middle of the wall was apparent, confirming that greater mixing at the plane of the window produces increased thermal uniformity in the room. The assertion that the HAT is reduced when the window is located at the room side of the opening was verified for these double-glazed windows at both air supply velocities and both heater locations. In all cases, the LPPD and HAT ratings were within comfort limits. At the grid location directly adjacent to the window, air speeds of 0.25 m s^{-1} were recorded but only in one instance was this over the draught limit of 0.3 m s^{-1}. The velocities were, however, higher than observed in relation to 4000 mm² vents and slightly in excess of ASHRAE's recommended maximum of 0.15 m s^{-1}.

4.4 Tests on a double-glazed window with air extracted from the room by a 8000 mm² trickle vent (Figure 9)

The extract tests for double-glazed windows were made with a higher temperature differential than had been achieved previously. All the comfort indices were diminished, but only the ADPI measurements were just below satisfactory. HAT readings were highest once again when the heaters were located to the side wall.

As previously, the greatest air speeds were recorded at floor level directly behind the door at the back of the room. Otherwise, as was the case for the extract tests for single glazed windows, the air speeds were generally very low. In many cases they were below the 0.05 m s^{-1} minimum for reliable measurement by the Dantec hot film anemometers.

When the heaters were located on the side wall, the iso-PMV contours became widely spaced and without any distortion of the pattern adjacent to the window. The most 'animated' pattern of contours occurred when the window was located to the room side of the structural opening, presumably due to the lack of 'funnelling' of the air flow provided by the depth of the reveals when the window is located to the outside of the opening. The contour patterns were generally similar to those for the corresponding tests on single-glazed windows.

4.5 Tests on double-glazed windows with sill at 1050 mm and 1200 mm above floor level and air supplied by a 8000 mm² trickle vent (Figure 10)

These tests repeated those with the window sill at 900 mm above floor level. The change in sill level and the height above the floor at which the trickle vents delivered air to the room seem to make little appreciable difference to the comfort indices, and the iso-PMV contours were similar to those observed previously.

As before, the highest HAT values were recorded when the heaters were placed at the side of the room, and the least satisfactory ADPI ratings were also at this location. The location of the heaters was a more significant factor than were increased wind speed and supply rate of air to the room. HAT values

max. HAT (o C) 2.2
PMV -1.316
PPD 40.866
LPPD 5.0166
ADPI 75

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)

window

PMV =	-1.3	-1.3	-1.4	-1.3	-1.3
PPD	41	41.1	45.2	40.1	40.1
HAT	1.4	1.7	0.5	0.5	0.7
eff. dr.	5.0e-1	8.8e-1	-7e-2	4.5e-1	6.8e-1
PMV =	-1.3	-1.3	-1.3	-1.2	-1.2
PPD	40.4	41.4	37.7	36.8	37.3
HAT	1.8	1.8	1	1	1.3
eff. dr.	1.0889	1.1101	1.0755	1.4260	1.3676
PMV =	-1.4		-1.3		-1.3
PPD	43.2		40.9		40.5
HAT	2.2		1.7		1.2
eff. dr.	1.3743		1.3371		1.3479
PMV =			-1.3		
PPD			41.8		
HAT			1.8		
eff. dr.			8.2e-1		
PMV =	-1.3		-1.3		-1.3
PPD	40.8		40.7		40.4
HAT	2.1		1.7		1.5
eff. dr.	8.1e-1		7.7e-1		6.9e-1
PMV =			-1.3		
PPD			39		
HAT			1.7		
eff. dr.			6.7e-1		
PMV =	-1.3		-1.3		-1.3
PPD	39		39		39.6
HAT	1.9		1.5		1.7
eff. dr.	6.3e-1		6.2e-1		7.1e-1

*eff. dr. = effective draught temperature °K

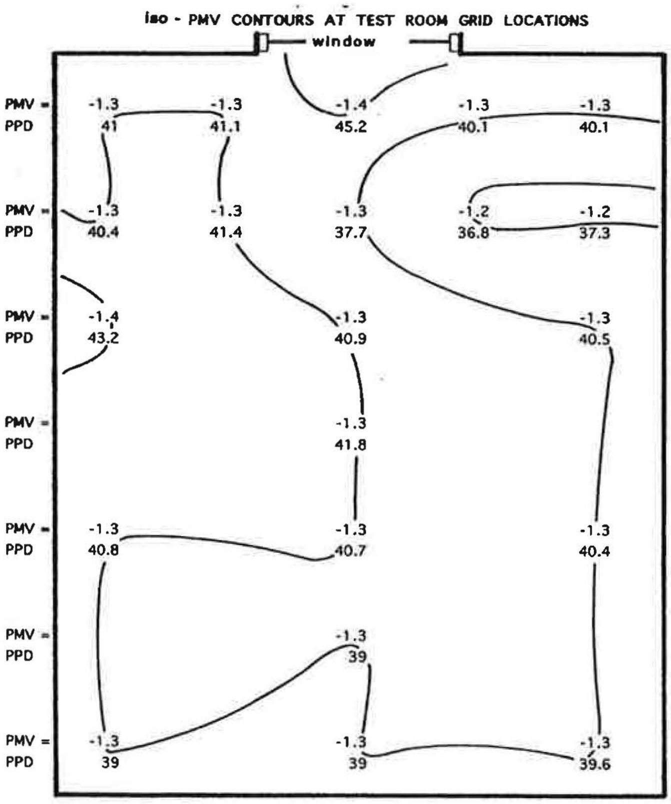

Figure 9 Typical test on a double-glazed window with air extracted from the room by a 8000mm² trickle vent

were lower for both levels of sill when the air supply rate to the room was higher.

max. HAT (o C) 2.2
PMV -1.275
PPD 40.158
LPPD 5.1083
ADPI 83.4

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)

window

PMV =	-1.4	-1.5	-1.3	-1.4	-1.4
PPD	44.8	52.3	42.7	46.9	45.6
HAT	1.8	1.8	1.2	1.7	1.7
eff. dr.	-3e-2	-1e-1	-1e-1	3.4e-2	-5e-2
PMV =	-1.3	-1.3	-1.3	-1.4	-1.3
PPD	42.1	41.3	42.6	43.2	42.7
HAT	2	2.1	1.8	1.9	1.7
eff. dr.	3.3e-1	3.3e-1	-1e-1	-4e-2	2.8e-1
PMV =	-1.3		-1.3		-1.3
PPD	42		42.3		40.2
HAT	2		2.1		1.6
eff. dr.	6.8e-1		5.8e-1		5.0e-1
PMV =			-1.3		
PPD			40.2		
HAT			2.2		
eff. dr.			9.1e-1		
PMV =	-1.2		-1.3		-1.2
PPD	35.8		39.4		37.2
HAT	2		2		1.8
eff. dr.	1.5100		1.1067		1.0245
PMV =			-1.3		
PPD			37.8		
HAT			2		
eff. dr.			1.2722		
PMV =	-1.2		-1.2		-1.2
PPD	37.6		37.6		36.7
HAT	2		1.8		1.7
eff. dr.	1.0666		1.0836		1.0786

*eff. dr. = effective draught temperature °K

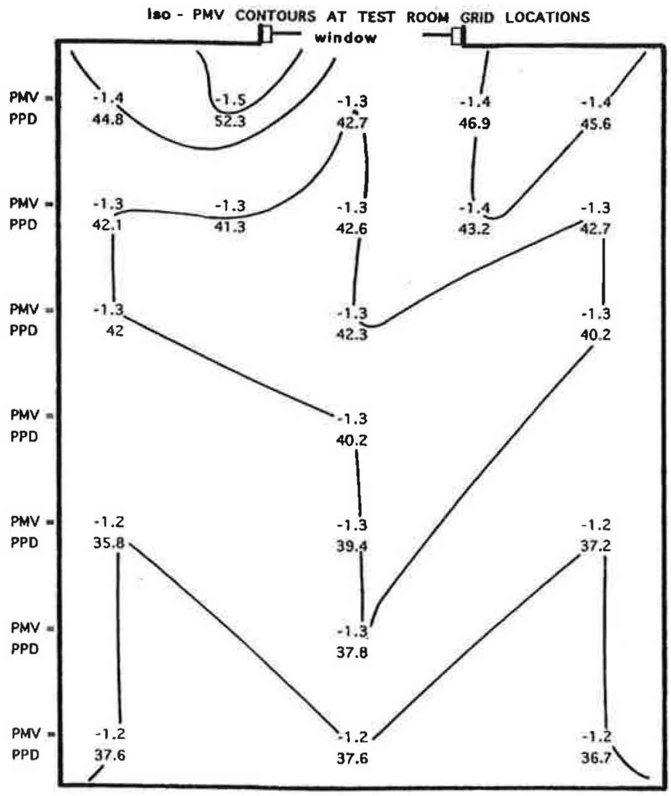

Figure 10 Typical test on double-glazed windows with sill at 1050 mm above floor level and air supplied by a 8000 mm² trickle vent and heaters located at side wall)

4.6 Tests on a double-glazed window with air supply at low level by a 8000 mm² vent (Figure 11)

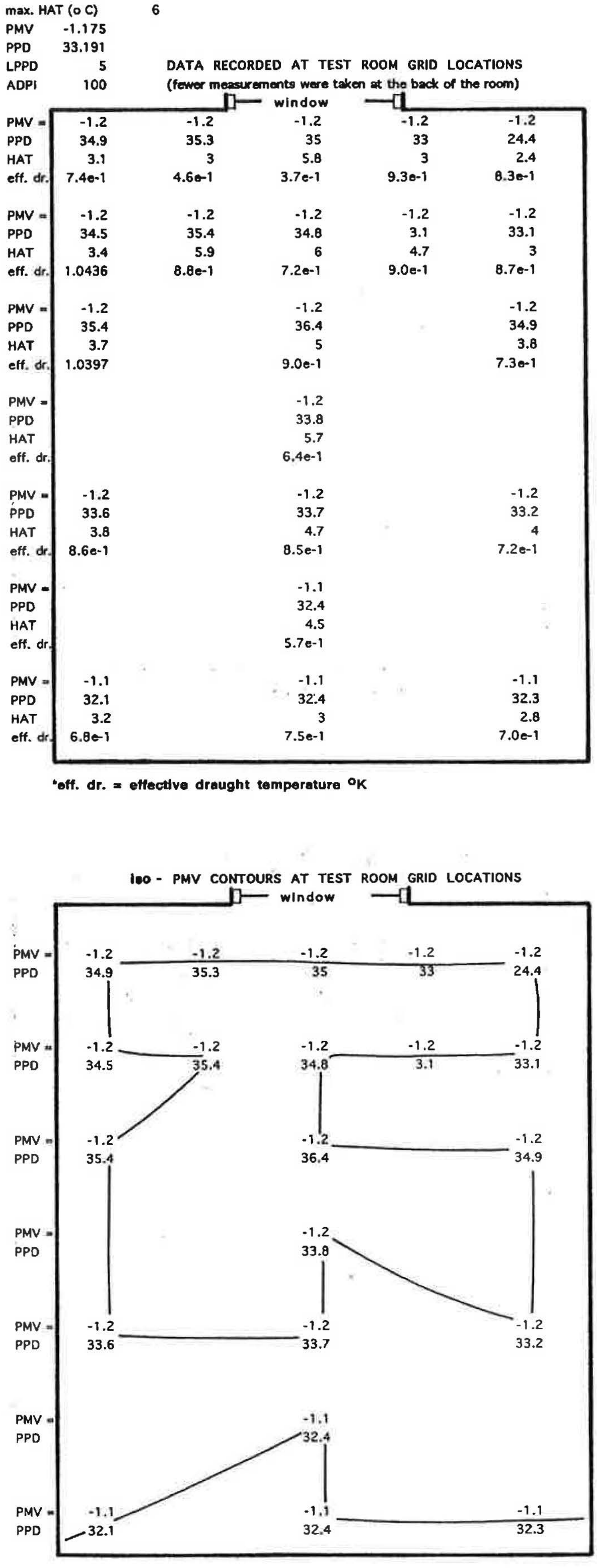

Figure 11 Typical test on a double glazed window with air supply at low level by a 8000 mm² vent

Supplying air to the room at low level had a dramatic influence on the HAT gradient which was very unsatisfactory in all three cases. In this instance increasing the external wind speed/ rate of air supply had a more marked effect than locating the heaters at the side wall. The iso-PMV contours were closer packed at the higher wind speeds but the air velocities were generally very low. The heaters used were less than ideal for this application. Panel radiators would have been more suitable in order to preheat the air before entering the room.

4.7 Tests on a single glazed splayed reveal window with air supplied by a 4000 mm² trickle vent (Figure 12)

The results for the tests on the splayed reveal window were generally comparable with those for the tests on the other single glazed windows. The side wall location for the heaters once again had a significant effect on the HAT figures. At 3.0, these bordered on unsatisfactory. The external temperatures in this case were comparable with those in BSRIA's tests. It could not however be concluded from these tests that HATs are lower at increased air flow rates through the trickle vents. At the higher air speed the splayed reveals 'focussed' the air intake to the room, so relatively high velocities were recorded at the grid location centred directly at the window. The adjusted PPD figure at this point was in excess of the 6% which is considered satisfactory for sedentary occupation (an exaggeration of the similar effect observable for the equivalent single glazed window).

4.8 Tests on a double window: Double-glazed outer pane + single glazed inner pane with air supplied by a 8000 mm² trickle vent and repeated with single glazed outer pane + single glazed inner pane (Figure 13)

The data for both single-plus-single and double-plus-single-glazed 'double' windows was comparable with the results from equivalent tests for double glazing, but the uniformity of the corrected PPD figures was very high for the double windows as compared with the results for other types. When comparing the iso-PMV contours, the additional pane of glass for the triple-glazed windows resulted in a smoothing out of the contours across the room and air speeds were then below 0.15 ms^{-1}.

Even so, the location of the heaters was still significant. The highest HAT figures were recorded for the tests with heaters at this location. The HATs were lower for the double-plus-single glazed windows, i.e. the extra glazing reduced the vertical temperature gradient. For both window types, lower HATs were recorded at the higher supply velocities.

5 Conclusions

This experiment duplicated and verified the conclusions of previous work carried out at BSRIA in relation to single glazed windows.

(*a*) Vertical temperature gradients are significantly higher when heaters are located at a side wall rather than under a window. This was a consistent result not only for the single-glazed windows tested but also for double- and triple-glazed windows and despite the highly insulated wall construction used for this experiment. It has been maintained that radiator location is insignificant under these circumstances but this appears not to be the case when windows incorporate trickle vents.

max. HAT (o C)	1.5
PMV	-1.283
PPD	39.6
LPPD	5.3
ADPI	75

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)

window

PMV =	-1.3	-1.4	-1.7	-1.4	-1.3
PPD	39.3	46.4	60.9	46.5	38.8
HAT	1.4	1.3	1.5	0.7	1
eff. dr.	9.6e-2	2.9e-1	-2.139	5.2e-1	5.4e-1
PMV =	-1.3	-1.5	-1.2	-1.2	-1.2
PPD	37.7	48.6	34.9	35.1	35
HAT	1	1.1	0.9	1.1	1
eff. dr.	1.0596	8.3e-1	1.1011	1.4792	1.5323
PMV =	-1.2		-1.2		-1.3
PPD	37.3		37.1		39.7
HAT	1.1		0.8		0.9
eff. dr.	1.4970		1.4623		1.0124
PMV =			-1.3		
PPD			38.8		
HAT			0.8		
eff. dr.			9.6e-1		
PMV =	-1.3		-1.3		-1.2
PPD	37.9		37.8		37.4
HAT	1		1		0.7
eff. dr.	9.6e-1		9.5e-1		6.7e-1
PMV =			-1.2		
PPD			36.9		
HAT			1		
eff. dr.			7.4e-1		
PMV =	-1.2		-1.2		-1.2
PPD	36.4		36.8		35.8
HAT	1		0.9		0.8
eff. dr.	6.4e-1		7.5e-1		5.1e-1

*eff. dr. = effective draught temperature °K

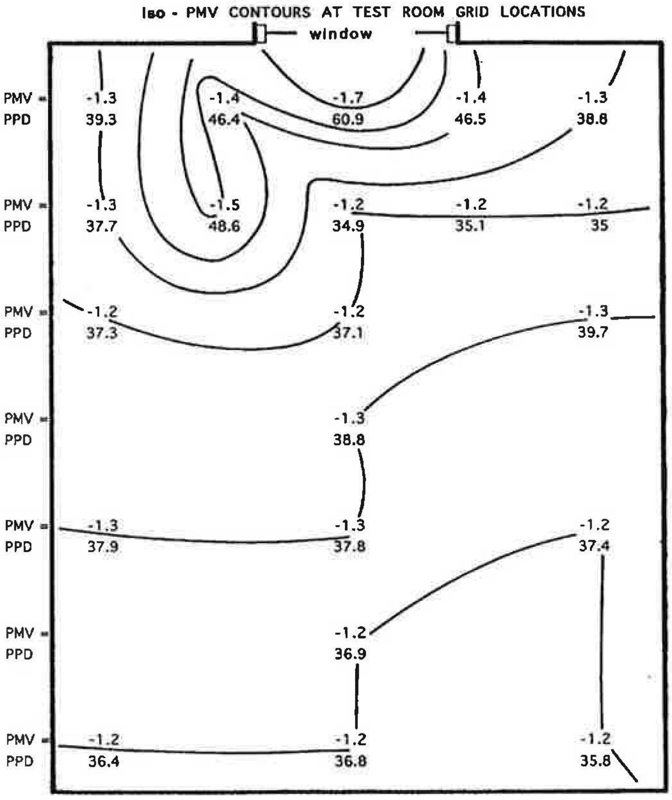

Figure 12 Typical test on a single-glazed splayed reveal window with air supplied by a 4000 mm² trickle vent

max. HAT (o C)	1
PMV	-1.391
PPD	44.716
LPPD	5.0166
ADPI	91.7

DATA RECORDED AT TEST ROOM GRID LOCATIONS
(fewer measurements were taken at the back of the room)

window

PMV =	-1.4	-1.4	-1.3	-1.3	-1.4
PPD	44.9	45.7	40.6	39.4	43.5
HAT	1	0.9	0.4	0.6	1
eff. dr.	7.1e-1	6.0e-1	1.0828	1.2203	9.5e-1
PMV =	-1.4	-1.4	-1.4	-1.3	-1.4
PPD	46.6	48	43.1	42.4	44.2
HAT	1	0.8	0.6	0.5	0.7
eff. dr.	8.0e-1	7.1e-1	7.5e-1	1.0369	1.0876
PMV =	-1.4		-1.4		-1.4
PPD	45.7		45		47.2
HAT	0.8		0.5		0.5
eff. dr.	1.1730		1.0554		7.5e-1
PMV =			-1.4		
PPD			46.5		
HAT			0.7		
eff. dr.			6.6e-1		
PMV =	-1.4		-1.4		-1.4
PPD	45.6		46.1		45.4
HAT	0.9		0.8		0.5
eff. dr.	8.3e-1		7.2e-1		5.7e-1
PMV =			-1.4		
PPD			45.7		
HAT			0.9		
eff. dr.			-1.386		
PMV =	-1.4		-1.4		-1.4
PPD	44.5		44.6		43.5
HAT	0.8		0.7		0.7
eff. dr.	3.4e-1		6.2e-1		6.2e-1

*eff. dr. = effective draught temperature °K

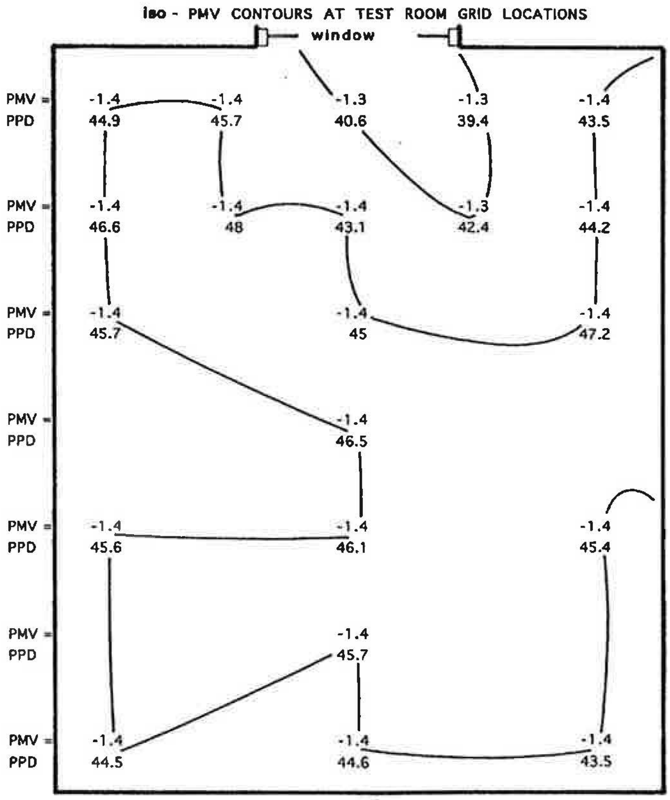

Figure 13 Typical test on a double window: Single-glazed outer pane + double-glazed inner pane with air supplied by a 8000 mm² trickle vent

(*b*) In all cases both 8000 and 4000 mm² trickle vents, tested to the wind speeds assumed at BSRIA, and the increased wind speed of 4 m s⁻¹ used for these tests, did not produce air velocities within the room in excess of draught velocity (0.3 m s⁻¹). There was one isolated exception. The use of 8000 mm² vents did however tend to produce velocities slightly in excess of the lower draught threshold of 0.15 m s^{-1}.

(*c*) LPPDs were in all cases satisfactory at less than 6%. Generally they were lower than those for the BSRIA tests, but this is due to the lower inside/outside difference in temperature that could be achieved on this occasion, and to the more highly insulated wall construction used.

(*d*) At increased air flow rates through the trickle vents, the HAT was reduced for single-glazed windows, although this could not be confirmed from the tests on single-glazed windows with splayed reveals. This conclusion was, however, also confirmed by the tests on double- and triple-glazed windows.

(*e*) The tests on double-glazed windows bear out BSRIA's finding that the location of the window to the room side rather than to the outside of the opening encourages greater mixing at the plane of the window, producing greater thermal uniformity in the room.

The iso-PMV contours were useful in establishing clear and repeated patterns of performance of similar windows under similar conditions. They showed that the tests could be replicated to arrive at similar conclusions as follows.

(i) When the trickle vents were functioning as air extracts, the air flow pattern in the room was completely different. Maximum air velocities were recorded at floor level at the door to the thermal chamber (although not in excess of draught speed.)

(ii) The use of extra glazing reduces HAT gradients. This was borne out in relation to the tests on double windows.

(iii) Changes in window sill level had negligible effect on comfort conditions within the room.

(iv) Supply of air at low level had a very marked and deleterious effect on the vertical temperature gradient. In part this was due to the type of heaters used for these experiments.

(v) The shape of the reveals was significant for the results obtained from tests on the splayed reveal window. At higher air flow velocities, through the trickle vents, the sloping sides to the window opening deflected the flow to produce some locally high velocities and PPDs in excess of comfort levels.

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