VENTILATION AND COOLING

18TH ANNUAL AIVC CONFERENCE
ATHENS, GREECE, 23-26 SEPTEMBER, 1997

Evaluation of thermal comfort impact of direct fresh air supply in Winter Part 2, Comparison of different ways of air supply to exhaust only ventilation

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1. SYNOPSIS

IEA Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems" has been engaged in developing the evaluation tools for various aspects of their performance. This paper describes the evaluation tool for thermal comfort impact by ventilation systems. The tool is based on the experiment by using a room inside artificial climate chamber, focusing upon the temperature difference and cold air supply rate into the room. As the evaluation index, the percentage of living space volume where a specified thermal comfort condition is satisfied is used. Grouping of supply air inlets is made and the score for each group can be obtained by referring tables. This tool is unique and helps practitioners very much knowing how serious or mild thermal comfort impact the ventilation system he/she is examining has.

2. INTRODUCTION

The improvement of the air tightness of building envelope in houses has made it indispensable to design rational ventilation system for houses, regardless of natural or mechanical. Although the technology for building ventilation has its long history and experiences in non residential buildings, it does not look easy to reach a solution which has satisfactory performance validated for residential building. Since man power and money available for maintaining domestic ventilation performance is limited, careful consideration for various aspects of ventilation system performance is necessary in development and design process. Thermal comfort impact of the ventilation systems is one of such aspects which sometimes determines the total performance of the ventilation system. Thermal comfort condition can be sensed sometimes much easier than quality of indoor air, and occupant's complaint about coldness due to the ventilation could make him/her to stop the system in the worst case. Designers of the domestic ventilation systems need to know what type of ventilation system has milder impact on winter indoor thermal condition, and how to minimize thermal discomfort risk for a certain type of system.

3. GROUPING OF AIR INLETS

Outdoor fresh air can be taken into rooms through various types of inlet from the view point of thermal comfort indoors. In heating season, indoor vertical temperature gradient is grown up by cold outdoor air coming into lower part of the room without being sufficiently mixed with room air, as well as by down air stream along indoor surface of outside walls caused by heat exchange. In addition, the air coming into lower part of the room contributes to make air velocity near the floor higher. For the ventilation systems of higher quality, preheating of supplied air is available in order to prevent outdoor air from disturbing indoor thermal condition in winter. In the previous paper (Sawachi T. et al. 1996), it was found that dry bulb temperature and air velocity in the lower part of the room are the critical factors when the thermal comfort impact of the ventilation systems are evaluated. Under the same air supply rate and temperature difference between indoors and outdoors, milder thermal comfort impact can be obtained by the air inlet whose shape and position contributes to better mixing of supplied fresh air and room air before its reaching the lower part of the room. There are four factors characterizing air inlets. The first one is whether air flow path is concentrated or distributed. Generally, the air inlet is a specially installed air flow path and has larger opening area than background leakage area. However, especially in exhaust only ventilation systems for houses more than two stories, additional air supply paths to the background leakage have

Table-1 Grouping of the air inlet

Generic type	flow direction	vertical position	form in Fig.-1
high induction	upward direction flow	high	(a)
	radiant flow	high	(b)
	horizontally straight	high	(c)
low induction	horizontally straight	high	(d)
	horizontally straight	medium	(e)
	horizontally straight	low	(f)
background leakage	horizontally straight	distributed	(g)

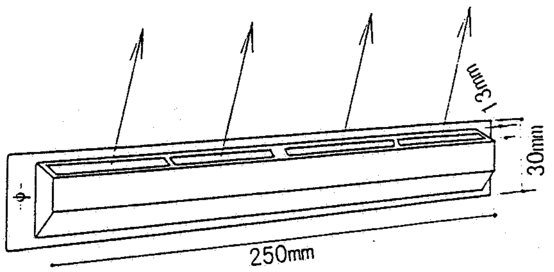
negative effect on evenly distributed fresh air supply pattern, due to stack effect. In such case, fresh air intake only through background leakage should be compared with the concentrated air inlet in addition to very small background leakage from the view point of thermal comfort impact. Secondly, the speed of incoming air is related to the extent how well the air is mixed with warmer room air. The difference can be expressed by high and low induction. Thirdly, when the air velocity is rather higher, the direction of air flow determines how much the air can be mixed before its reaching the lower part of the room. The last factor is the vertical position of the inlet. It is directly related to the distance between the air inlet and the lower part of the room.

Taking the above mentioned four factors into consideration, the grouping of the air inlet is made as shown in Table-1. An example of each group is shown in Figure-1. The inlet (a) is an example of the high induction / upward direction flow and has slit-shaped upward openings of which equivalent leakage area is 17.1 cm^2. It is usually installed above the window. The inlet (b) is an example of the high induction / radiant flow and has a round-shaped cap covering the end of cylindrical duct which is designed to make air flow going out radiantly along the wall surface. Its equivalent leakage area is 13.1 cm^2. The inlet (c) is a simple cylinder of which diameter is 50 mm. Even if the end of the cylinder is covered with a grille of which slats is horizontal, such inlet can be grouped into the same category as the inlet (c). The inlet (d), (e) and (f) are identical, but they are installed at different height of a window frame. The inlet is usually installed at the top of the window frame, but the same inlet was used to simulate rather large openings located at the center of the window and that located at the bottom of the window. Those two openings are assumed as two types of window which are opened ajar. The equivalent leakage area is 62.3 cm^2. The last category in Table-1 is the clacks that is background leakage. The inlet (g) is designed to simulate the clacks. It consists of two slits of which height, width and depth are 4 mm, 50 mm and 300 mm, respectively. In the experiment for other inlets, only one piece is used, while in the experiment for the inlet (g) ten pieces was used. A pair of slits has 1.5 cm^2 equivalent leakage area.

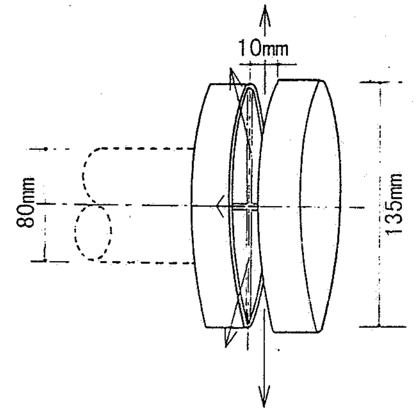
4. EVALUATION OF THERMAL COMFORT IMPACT BY AIR SUPPLY

4.1. EXPERIMENTAL METHOD

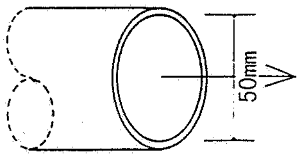
Both air flow rate and temperature of supplied air through different types of inlet are controlled. The pressure of the experimental room (2.6 m × 4.42 m × 2.55 m) is controlled by an exhaust fan to keep the pressure difference across the inlet to give air flow rate 35 m^3/h, 25 m^3/h, 15 m^3/h and 5 m^3/h (10 lit./s, 7 lit./s, 4 lit./s and 1.5 lit./s) as experimental condition. The



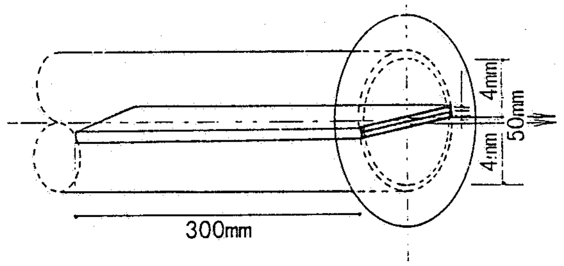
(a) high induction / upward direction flow
H=1,900 mm E.L.A.=17.1 cm^2



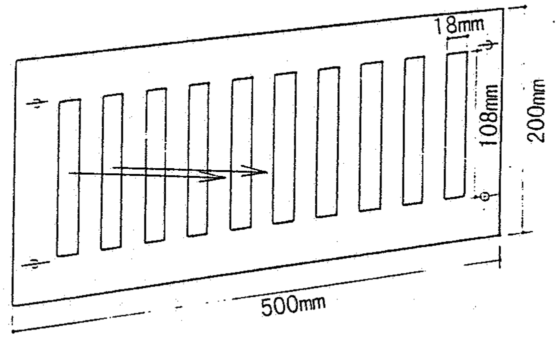
(b) high induction / radiant flow
H=1,900 mm E.L.A.=13.1 cm^2



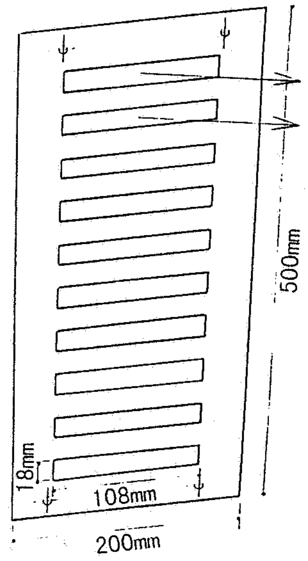
(c) high induction / horizontally straight flow
H=1,900 mm E.L.A.=15.5 cm^2



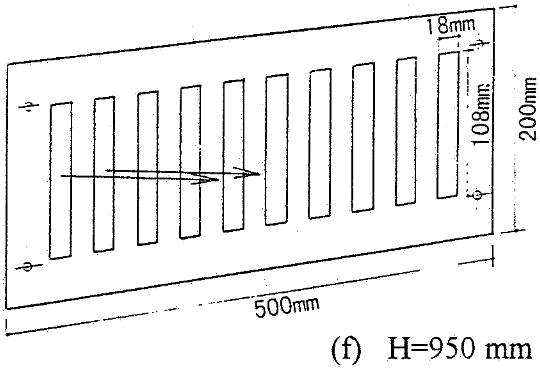
(g) background leakage simulated by deep slits
H=255 mm ~ 2,295 mm E.L.A.=1.5 cm^2 × 10



(d) H=1,900 mm



(e) H=1,425 mm



(f) H=950 mm

(d)(e)(f) common low induction inlet
installed at different height
E.L.A.=62.3 cm^2

H: height above the floor E.L.A.: equivalent leakage area

Figure-1 Forms of the inlets used in the experiment temperature outside the experimental room is controlled -10°C, 0°C, 10°C, and that inside the room is controlled to keep PMV (Fanger P.O. 1970) equal to zero at the center of the room by using two electric radiant heaters put below windows. Even though thermal comfort condition at the center of the room is kept nearly constant throughout whole series of experiment for different inlets, the distribution of thermal factors varies widely depending upon the route of cold air supplied through the inlets. Dry bulb temperature, globe temperature, air velocity and turbulence intensity are measured at one hundred and twelve points ($7 \times 4 \times 4 = 112$). The lowest position of the measurement is 10 cm above the floor.

4.2. EVALUATION INDEX

Thermal comfort impact by cold air supply can be evaluated by the number of points where the relatively large deviation from comfort condition is observed. As the criteria of the comfort condition, PMV and PD (Fanger P.O. et al. 1988) are used. The PD is a predicted percentage of occupants who feel uncomfortable due to draught, and is expressed as a function of air velocity, turbulence intensity and dry bulb temperature. Among one hundred and twelve points, the points where both conditions for PMV and PD expressed by inequalities (1) and (2) are satisfied are counted, and the percentage of the points is used as an index to evaluate the thermal comfort impact by the ventilation systems.

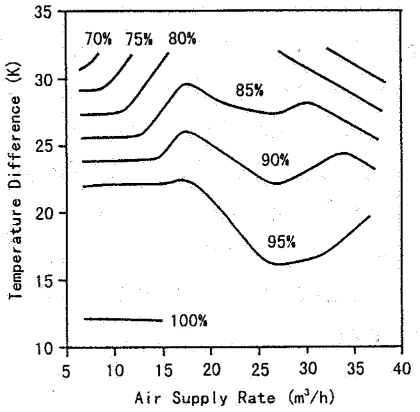
$-0.2 < PMV < +0.2$ ($PPD < 7$ %) ...... (1)

$PD < 15$ % ...... (2)

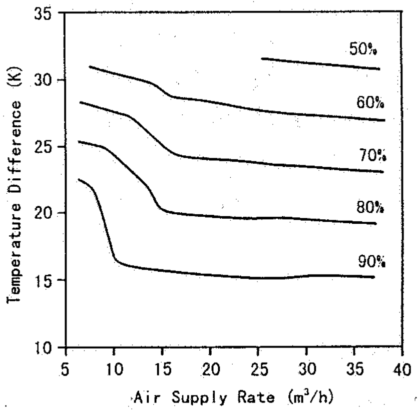
4.3. BASIC DATA FOR THE EVALUATION AND ITS EXTENTION

The percentage of the points where both conditions (1) and (2) are satisfied is calculated for each combination of the air supply rate and the indoor-outdoor temperature difference. One hundred percent means the least impact of ventilation system and that at *all* of the one hundred and twelve points in the experimental room the deviations of PMV from the center and PD values are in the range of inequalities (1) and (2), respectively. On the other hand, smaller percentage means larger impact and extension of the space with difficulty to keep thermal comfort condition. In Figure-2, the contour lines of the percentage are drawn on air supply rate and temperature difference plane for each group of inlet.

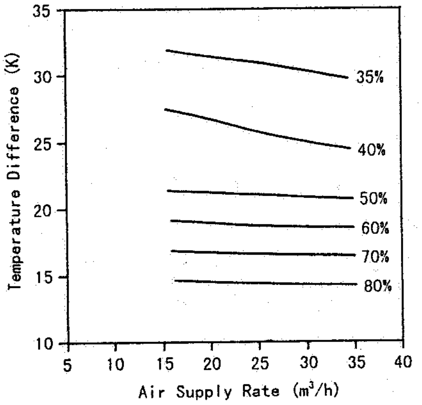
For the high induction / radiant flow inlet (b), the percentage becomes lower in higher air supply rate and larger temperature difference area. On the contrary, for the high induction / upper flow inlet, higher air supply rate does not necessary make the percentage lower, while larger temperature difference steadily makes the percentage lower. Higher air supply rate can contribute to mix supply air with room air and to weaken the cold air impact. It is general that the temperature difference is more influential on the percentage than the air supply rate. Among three directions of high induction inlets, thermal comfort impact by straight air flow is the largest one. For example, at 25 m^3/h and 20 K, the percentage for high induction / straight flow inlet is approximately 55%, while the percentage for high induction / upper flow inlet is more than 90%. Comparing three positions of low induction inlet, the highest position (d) gives the least thermal comfort impact. It confirms the rule that the inlet of cold fresh air should be installed at higher position to avoid serious thermal comfort impact. Even when the same amount of air is supplied through distributed small clacks, the percentage is not higher than that for general types of inlet (a), (b) and (d). The rather high impact on thermal comfort by clacks seems to come from air supply through clack at lower position of the wall. In the



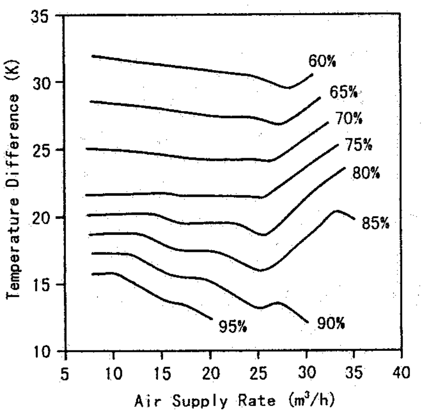
(a) high induction / upward direction



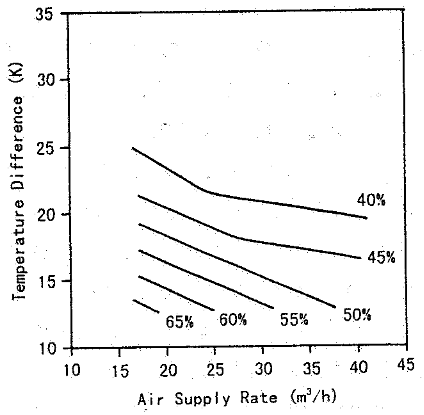
(b) high induction / radiant flow



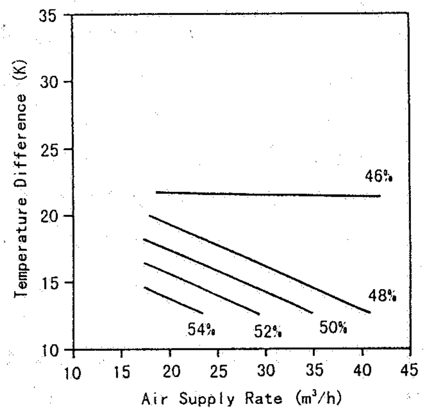
(c) high induction / horizontally straight



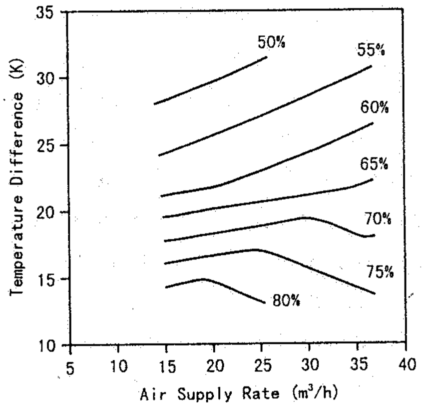
(d) low induction / high position



(e) low induction / medium position



(f) low induction / low position



(g) background leakage

Figure-2
Contour maps of the evaluation index drawn on the outdoor/indoor temperature difference and supply rate plane

experiment, ten clack-simulating slits were evenly distributed at different height. It means that a concentrated inlet in place of distributed clacks relieves the cold air impact on thermal comfort condition.

5. A SIMPLIFIED TOOL FOR THE THERMAL COMFORT IMPACT EVALUATION IN IEA ANNEX 27

In Annex 27 "Evaluation and Demonstration of Domestic Ventilation System", a set of simplified tools to evaluate domestic ventilation systems are being developed. Among the tools, a thermal comfort impact evaluation tool is included. As input information, type of ventilation system, outdoor temperature and air supply rate are requested. Indoor temperature is assumed to be 22 °C. The Score is expressed with five ranks from "- -" to "+ +", and is given by Table-2 and Table-3. In the tables, scores for different types of inlet and temperature have been obtained from contour maps of Figure-2.

Table-2 Thermal Comfort Impact of Fresh Air Supply **$Q=35m^3/h$ (10 l/s)**

Type of Inlet (Vent)		Outdoor Temperature (°C)						
Generic type	Specific type	-15	-10	-5	0	5	10	15
High induction	upward direction flow	-	-	0	+	++	++	++
	radiant flow	--	--	-	-	0	++	++
	horizontally straight flow	--	--	--	--	-	+	++
Low induction or Window ajar	horizontal opening, high position	--	-	-	0	+	+	++
	vertical opening, middle height	--	--	--	--	--	-	-
	horizontal opening, low position	--	--	--	--	--	-	-
Background leakage	equally distributed leakage air flow path on exterior walls	--	-	-	-	-	0	0

Criteria for Scoring the percentage of lattice points satisfying thermal comfort conditions (1) and (2):
100-95% ++ 95-85% + 85-75% 0 75-50% - 50-0% --

Table-3 Thermal Comfort Impact of Fresh Air Supply **$Q=15m^3/h$ (4 l/s)**

Type of Inlet (Vent)		Outdoor Temperature (°C)						
Generic type	Specific type	-15	-10	-5	0	5	10	15
High induction	upward direction flow	-	0	+	+	++	++	++
	radiant flow	--	-	-	0	+	++	++
	horizontally straight flow	--	--	--	--	-	+	++
Low induction or Window ajar	horizontal opening, high position	--	-	-	-	+	++	++
	vertical opening, middle height	--	--	--	--	-	-	-
	horizontal opening, low position	--	--	--	--	-	-	0
Background leakage	equally distributed leakage air flow path on exterior walls	--	--	-	-	-	0	+

Criteria for Scoring the percentage of lattice points satisfying thermal comfort conditions (1) and (2):
100-95% ++ 95-85% + 85-75% 0 75-50% - 50-0% --

(Example 1)

If a natural ventilation with a window open ajar as air supply at 1.9 m above floor is used, the air supply rate is 15 m^3/h and outdoor temperature is 10 °C, the score is "++". The opening is considered as a low induction type inlet. If the change of supply rate due to wind is not negligible, the increase of turbulence intensity of indoor air flow can make draft risk higher than the evaluation. Therefore, in such case, the score should be carefully interpreted.

(Example 2)

When an exhaust only ventilation system with high induction / radiant flow natural supply vent is used, outdoor temperature is 0 °C and air supply rate is 35 m^3/h, the score is "-", which means the percentage of lattice point without difficult to keep thermal comfort is 50-75%. Though thermal comfort situation depends not only upon ventilation system but also upon insulation, heating system etc., the percentage can be considered as an index for relative evaluation. The score, "-" means that there is still possibility for improvement.

6. SUMMARY

For domestic ventilation systems, appropriate air supply technique to avoid thermal comfort impact should be selected. The basic data from the experiment shows a wide variation of the impact by different types of inlet, even if the ventilation system is fixed. The selection of ventilation system also make the difference of thermal comfort impact. The impact can be evaluated to know the type of inlet, supply air rate and outdoor temperature by referring the tables 2 and 3.

7. ACKNOWLEDGEMENTS

This research has been done for IEA ANNEX 27 "Evaluation and Demonstration of Domestic Ventilation Systems". The fruitful discussion in the ANNEX is reflected upon the theoretical framework. The author expresses gratitude to all members of the ANNEX, especially Mr. Peter Op't Veld.

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