OPTIMUM VENTILATION AND AIR FLOW
CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden,
17-20 September, 1996

A TECHNIQUE TO IMPROVE THE PERFORMANCE OF DISPLACEMENT VENTILATION DURING COLD CLIMATE CONDITIONS

Peter Hansson*, Hans Stymne

The Royal Institute of Technology
Dept of Built Environment, Box 88, S 801 02 Gävle, Sweden

* Affiliated to: University College of Gavle-Sandviken,
S 80176 Gävle, Sweden

A technique to improve the performance of displacement ventilation during cold climate conditions

Peter Hansson* and Hans Stymne
The Royal Institute of Technology
Department of Built Environment
Box 88, S-801 02 Gävle, Sweden

*Affiliated to:
University College of Gävle-Sandviken
S-80176 Gävle, Sweden

Synopsis

Ventilation by displacement is a type of ventilation where the air flow is thermally driven. By this arrangement one obtains two zones in the room - a lower zone with supply air conditions and an upper recirculation zone with extract air conditions. Cold climate causes downdraught from windows and external walls and results in a mixing of air from the upper into the lower zone. To avoid this problem during cold climate a new principle for ventilation by displacement is tested. Excess heat from the upper zone of the room is used for heating cold surfaces. The principle involves creation of a narrow space in front of the exterior wall, separating the cold wall from direct contact with room air. Extract air from the ceiling level is forced down through this space by an extraction fan. This method can advantageously be applied in large buildings where an external wall mainly consists of glass panes. In this case it might be appropriate to utilise the space between the inner couple of glasses for extract air. Tracer gas and temperature measurements were carried out in a test-room. The result shows that the ventilation efficiency improves when using the new principle. The thermal climate also improves due to less down-draught and higher surface temperatures.

1 Introduction

The main purpose for a ventilation system is to provide good indoor air quality for people. Ventilation by displacement is one of the most effective principles considering the ability to remove contaminants emitted from humans and other heat sources. The ideal function of displacement ventilation in a room is showed in figure 1. The air flow is thermally driven by buoyancy forces (induced by heat sources like occupants and machines). Two different air zones develop in the room -a lower zone with supply air conditions and an upper recirculation zone with extract air conditions, where extract air is warm and contaminated by compounds originating from humans, appliances, building materials etc.

The interface between the upper and lower zone is stabilised due to a temperature stratification. It is important to maintain this stable interface, otherwise the lower zone gets contaminated and the advantage of ventilation by displacement is lost. Cold climate causes down-draught from windows and external walls and results in a mixing of air from the upper into the lower zone. The air in the lower zone will thus be contaminated and the ventilation efficiency will decrease (figure 2).

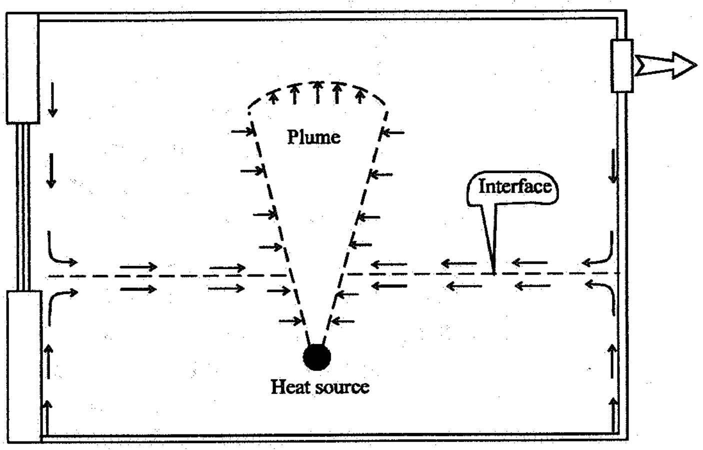

Figure 1 Ideal displacement ventilation.

To avoid this problem during cold climate a new principle for ventilation by displacement is tested. Excess heat from the upper zone of the room is used for heating cold surfaces. Normally extract air leaves the room by the extract air device at ceiling level. The new principle involves creation of a narrow space in front of the outer wall, separating the cold wall from direct contact with room air. Extract air from the ceiling level is forced down through this space by an extraction fan.

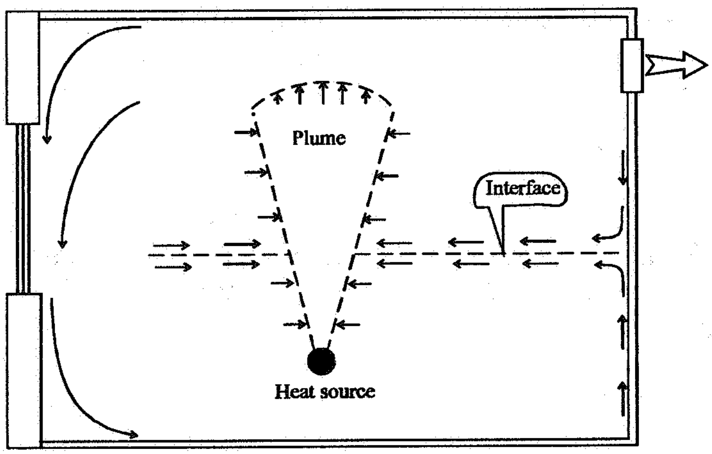

Figure 2 Ordinary displacement ventilation under cold climate conditions.

2 Experimental set-up

A full-scale test room with the dimensions $4.2 \times 3.6 \times 2.8$ m ($L \times W \times H$) is used (figure 3). The outer wall is a common well insulated (U-value = 0.27 W/m^{2}K) wall in the Nordic countries equipped with two triple glass windows (U-value = 2.0 W/m^{2}K). A narrow space was built in front of the external wall of the room, the space was constructed by use of a polyethylene film, spanned over wood strips. At ceiling level of the construction there is an opening so that air from here can be forced down through the space in front of the wall by an extraction fan connected to a perforated metal tube mounted at the bottom of the space.

The wall is connected to a cooling chamber ran at a temperature of -20 °C and 0 °C . At the middle of the test room a dummy was positioned. The dummy is made of metal tubes and has an internal heat production of 100 W, simulating a human. The supply air temperature was held at 17 °C and the air flow rate was 16 l/s. Air was distributed to the room via a low velocity device at floor level. Tracer gas and temperature measurements were carried out in order to investigate the performance of the new principle. Temperature gradients were measured at five different locations. Tracer gas was released at constant mass flow rate through a tube fixed to the dummy at the height of a mouth of a human. Thus, it should simulate a contaminant originating from a human (e.g. a smoker). The tracer gas concentration was measured at four different heights and locations in the room. The ventilation efficiency was calculated from tracer gas steady state values (steady state occurs after approx. $4 \times \tau_n$, where $\tau_n = \frac{Room\_volume}{Air\_flow}$ [h]). The ventilation efficiency describes how well a ventilation system can reduce pollutants in the indoor environment. Calculations of the height of the interface separating the two zones was made in order to verify tracer gas concentration gradients. Furthermore indoor climate parameters such as the effective under-temperature and the air velocity of downdraught were calculated.

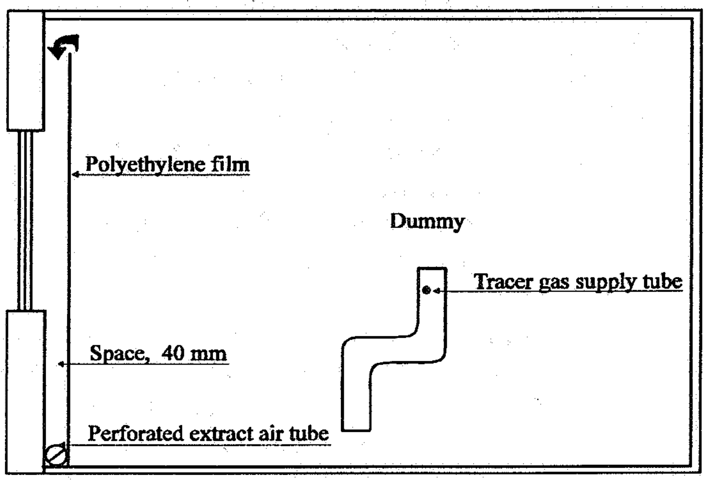

Figure 3 The test room.

Note: When no separating space is used extract air leaves the room via an ordinary extract air device at ceiling level.

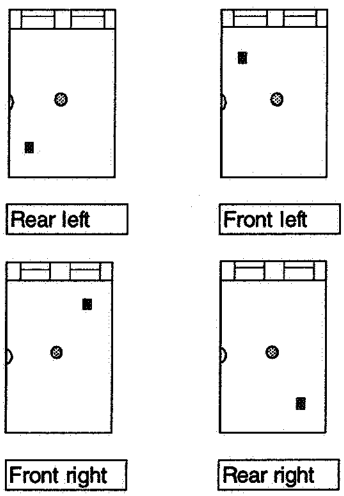

Figure 4 Top view of the test room. The squares represent tracer gas and temperature gradient measuring points in the occupied zone. The circle represents the heated dummy.

3 Results and discussion

3.1 Ventilation effectiveness

The ventilation efficiency can be defined as:

$$\bar{\varepsilon} = \left(\frac{\dot{m}/q}{\bar{C}} \right) \times 100\% \qquad (1)$$

Where $\dot{m}$ = mass flow rate of tracer gas into the room, q = supply air flow rate and $\bar{C}$ = average concentration of tracer gas in the room measured at 0.5, 1.0, 1.5 and 2.0 m height.

The ventilation efficiency with the uppermost measuring point in the room as a reference can be defined as:

$$\bar{\varepsilon}_{2.0} = \left(\frac{C_{2.0}}{\bar{C}} \right) \times 100\% \qquad (2)$$

Where $C_{2.0}$ = concentration of tracer gas at 2.0 m height.

Table 1 Ventilation efficiency

		Ventilation efficiency $\bar{\varepsilon}$ [%]			
Cooling chamber temperature		0 °C		-20 °C	
Case		Space	No space	Space	No space
Measurement point	*Front left*	132	124	130	134
	Front right	149	129	138	114
	Rear left	218	163	-	-
	Rear right	209	152	192	-
Mean value for the room		177	142	153	-

Table 2 Ventilation efficiency with the uppermost measuring point in the room as a reference

		Ventilation efficiency $\bar{\varepsilon}_{2.0}$ [%]			
Cooling chamber temperature		0 °C		-20 °C	
Case		Space	No space	Space	No space
Measurement point	*Front left*	121	122	120	130
	Front right	130	119	118	115
	Rear left	183	160	-	-
	Rear right	164	143	153	-
Mean value for the room		150	136	130	-

The result shows that ventilation efficiency improves when using the new principle. The ventilation efficiency is significantly higher in the rear region of the room. The heat production in the room approximately covers heat losses at 0 °C cooling chamber temperature.

3.2 Tracer gas concentration gradients

Figure 5 shows that the concentration gradient is more ideal when using the space. It is evident that contaminated air has moved from the upper zone of the room to floor level due to down draught from the external wall without space. A person sitting at that place would inhale contaminated air because air from floor level rises up along the human body to the nose. Furthermore, the interface has raised and is located at a higher level compared to the case with a space.

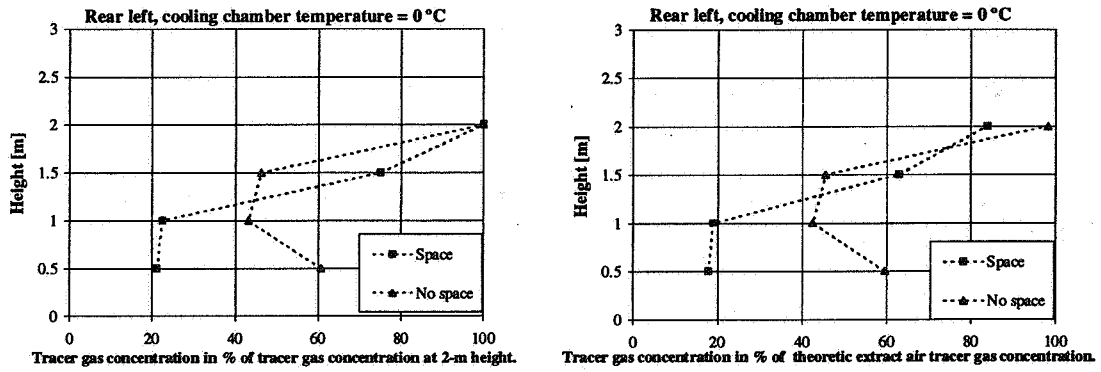

Figure 5 Tracer gas concentration gradients measured at rear left in the room.

3.3 Temperature measurements

Figure 6 shows one example of temperature gradients in the room where the measuring points for air temperature are at rear left. The result is evident; The surface temperature of the polyethylene film is higher in all measurement points when using the new principle. Note that even if downdraught is decreased, the ideal temperature gradient is not obtained with the new principle. The ideal case would be higher polyethylene film temperature than room air temperature below the interface (height level approx. 0.9 - 1.0 m, section 3.5). Thus above the interface, surface temperatures should be lower than room air temperature. The tested space had the same width from bottom to top. In order to provide more heat exchange at the lower part of the film one could make the space more narrow there.

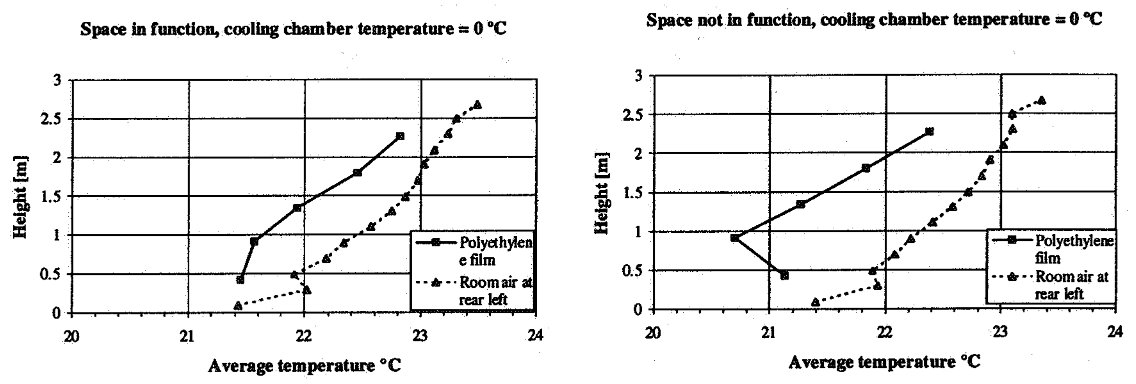

Figure 6 Temperature gradients (polyethylene film respectively room air).

3.4 Thermal climate

Cold climate causes down draught from windows and external walls. In order to calculate the maximum velocity of the air stream one can use:

$$u_{max} = 0.10\sqrt{x(t_r - t_v)} \quad [m/s] \qquad (3)$$

(Rydberg 1963 based upon the work of Eckert and Thomas 1951). Where x = distance from top, t_r = room temperature and t_v = average surface temperature. A measure of influence of temperature and velocity on the human body can be expressed:

$$\vartheta = 0.4(t_r - t_v) + 0.8\sqrt{x(t_r - t_v)} \quad [K] \qquad (4)$$

(Rydberg 1963). Where delta is called "the effective under-temperature". The effective under-temperature tells how large temperature difference still air needs, to cause the same cooling effect on the human body as air in movement. The downdraught flow is according to (Rydberg 1963) and (Mundt 1994):

$$\upsilon = 10(t_r - t_v)^{0.4} x^{1.2} \quad [m^3/h \text{ and m wall width}] \qquad (5)$$

Table 3 Thermal climate parameters (measurement point, front right).

Cooling chamber temperature	**0 °C**		**-20 °C**	
Case	**Space**	**No space**	**Space**	**No space**
***u_{max}* [m/s]**	0.07	0.21	0.14	0.31
***Effective under- temperature* [K]**	0.65	2.26	1.38	3.79
***Downdraught flow* [l/s]**	16.83	40.05	28.22	54.97

The lowest maximum velocity appears when the space is used. The effective under-temperature should be in the range of 0.5 - 1.0 K for a sitting office worker (Rydberg). Only the case with space and 0 °C cooling temperature fulfils the demand. The downdraught flow is approximately doubled for the case without space compared to the case with space, this verifies the appearance of the tracer gas concentration gradients in figure 5.

3.5 The interface

The height of the interface separating the contaminated and clean zones in the room depends on: a) The supply air flow, b) the plume flow above heat sources and c) the convection air flows along vertical surfaces. The continuity equation (Sandberg 1990) is

$$Q_v = Q_p(z) \pm Q_b \qquad (6)$$

where Q_v is the supply air flow rate, $Q_p(z)$ is the plume flow rate (up) from a point source (increases with the height z). Q_b is downdraught (-) and convection air flow rates upwards (+). The plume flow above the dummy can be expressed as:

$$Qp(z) = 55(Pk)^{1/3}(Z + Zv)^{5/3} \quad [l/s] \qquad (7)$$

(Mundt 1994). Where Pk is the convective heat transfer of the dummy. [kW], Z is the height above the heat source [m] and Zv is the virtual height of the heat source [m]. Equation 5 is used for Q_b. The interface height (z) is found where the supply air flow equals the sum of plume flow and convection flows. Result of a calculation for 0°C cooling chamber temperature shows that the interface height is **1.0** m without space and **0.9** m with space. This follows the results in section 3.2 and 3.4. Without space, contaminated air flows down and penetrates the interface near the exterior wall into the cleaner lower zone. Thus the interface height increases.

3.6 Application

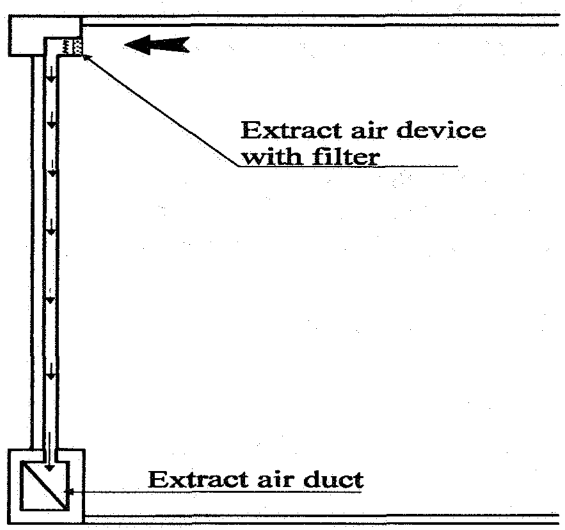

Figure 6 Application of the new principle

The new method could advantageously be applied in large buildings where an external wall mainly consists of glass panes, which often is the case in waiting rooms, air terminals etc. It might be appropriate to utilise the space between the inner couple of glasses for extract air , figure 6. The extract air device should then be equipped with a filter or/and the inner couple of glasses should be able to clean.

4 Conclusions

A suggested technique to utilise warm air at the ceiling level to heat cold surfaces has been demonstrated to improve the ventilation efficiency and the thermal climate in a test room equipped with displacement ventilation during cold climate. There is good agreement between theory and practice , the interface between the two zones in the room is displaced and downdraught is decreased when the new principle is used. The tracer gas concentration gradients verifies this fact.

References

Mundt, E., 1994 , "Convection in rooms and between rooms", Summary of hearing held at KTH in June 1994.

Rydberg, J., 1963 , "Cold downward convection currents at windows", Article in the Swedish journal VVS,vol 34 (in Swedish).

Sandberg, M., 1990 , "Stratified flow in ventilated rooms - a model study", Proc.Roomvent 90, Oslo, Norway.

Sandberg, M. , 1981 , "What is ventilation efficiency ?", Building & Environment, Vol. 16, No 2.