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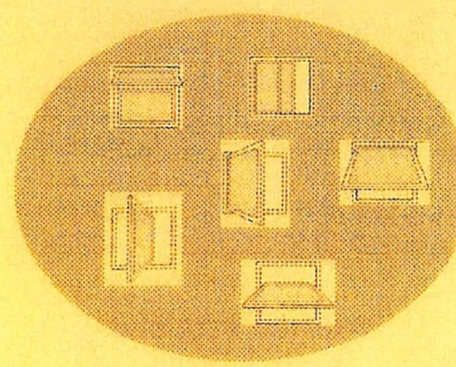

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Hybrid Ventilation and the Consequences on the Development of the Facade.

By Per Heiselberg, Aalborg University, Denmark

Introduction

For many years mechanical and natural ventilation systems have developed separately. Mechanical ventilation has developed from constant air flow systems through systems with extensive heat recovery and demand-controlled air flows to energy-optimized low pressure ventilation systems. Natural ventilation has in the same period developed from being considered only as air infiltration through cracks and airing through windows to be a demand- controlled ventilation system with cooling capabilities, heat recovery and air cleaning possibilities. The focus in the development has for both systems been to minimize energy consumption while maintaining a comfortable and healthy indoor environment. Naturally, the next step in this development is to develop ventilation concepts that utilise and combine the best features from each system to create a new type of ventilation system – Hybrid Ventilation.

The key difference between natural and mechanical ventilation air flow processes lies in the fact that neither volume flow rate nor flow direction at the ventilation openings are predetermined in the former system. Natural forces drive natural ventilation. The stack pressure is determined by the temperature difference between the indoor and outdoor air, which is, in turn, affected by ventilation flow rates. The wind pressure is strongly affected by the microclimate around the buildings, which is again affected by landforms, vegetation and other surrounding buildings. Natural ventilation driving forces is highly unsteady and both flow rates and air flow directions can vary considerably during the running period and not necessarily in phase with the occupants needs. This can be solved to some extent in the design of the building and the facades as well as the natural ventilation and control system. In hybrid ventilation additional mechanical systems are installed to solve the remaining problems as for example too low volume flow rates in summer, dehumidification of humid air and/or unwanted flow directions in occupied hours.

Hybrid Ventilation Concept

Definition

Hybrid ventilation systems can be described as systems providing a comfortable internal environment using both natural ventilation and mechanical systems, but using different features of the systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two-mode system. The basic philosophy is to maintain a satisfactory indoor environment by alternating between and combining these two modes to avoid the cost, the energy penalty and the consequentially environmental effects of full year-round air conditioning. The operating mode varies according to the season, and within individual days, thus the current mode reflects the external environment and takes maximum advantage of ambient conditions at any point in time. The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent with control systems that automatically can switch between natural and mechanical mode in order to minimize the energy consumption.

Hybrid ventilation should dependent on building design, internal loads, natural driving forces, outdoor conditions and season fulfil the immediate demands on the indoor environment in the most energy-efficient manner. The control strategies for hybrid ventilation systems in office buildings should maximize the use of ambient energy with an effective balance between the use of advanced automatic control of passive devices and the opportunity for the users of the building to exercise direct control of their environment. The control strategies should also establish the desired air flow rates and air flow patterns at the lowest possible energy consumption.

Design challenges

Ventilation of buildings is an important aspect of all building projects. Today, the purpose of the ventilation system is in many projects not only to control indoor air quality but also in summer in an energy-efficient way to achieve thermal comfort through natural cooling. In design of hybrid ventilation systems it is often necessary to separate design of ventilation for indoor air quality control and design of ventilation as a natural cooling strategy in summer. The major reason for this is the fact that devices for indoor air quality control and thermal comfort control in general are quite different, and that the potential barriers and problems to be solved, including the optimization challenge also are fundamentally different.

In optimization of ventilation for indoor air quality control the challenge is during periods of heating and cooling demands to achieve an optimal equilibrium between indoor air quality needs and energy use. This includes first of all a minimization of the necessary fresh air flow rate by reduction of pollution sources, demand control of air flow rates and optimum air supply to occupants. Secondly, it includes reduction of heating and cooling demands by heat recovery, passive cooling and/or passive heating of ventilation air. Finally, it includes reduction of the need for fan energy by low pressure duct work and other components as well as optimization of natural driving forces from stack effect and wind. During periods without heating and cooling demands there is no need to reduce air flow rates as more fresh air only will improve the indoor air quality and the optimization challenge becomes mainly a question of minimizing the use of fan energy. Besides the above-mentioned challenges the ventilation should of course be provided without creating thermal comfort problems like draught or high temperature gradients.

In optimization of ventilation as a natural cooling strategy the challenge is to achieve an optimal equilibrium between cooling capacity, cooling load and thermal comfort. This includes first of all reduction of internal and external heat loads by application of low energy equipment, by utilization of daylight and by effective solar shading. Secondly, it includes application of the thermal mass of the building as a heat buffer which absorbs and stores heat during occupied hours and returns it to the space during unoccupied hours with night ventilation. Finally, it includes reduction of the need for fan energy by low pressure duct work and other components as well as optimization of natural driving forces from stack effect and wind. The major issues of concern with regard to thermal comfort are avoidance of too low temperatures at the start of the working hours and acceptable temperature increase during working hours.

The issues of concern in optimization of hybrid ventilation for indoor air quality control and natural cooling are summarized in table 1.

Table 1. Issues of concern in optimization of hybrid ventilation for indoor air quality control and natural cooling.

Indoor Air Quality Control	***Natural Cooling***
• Limitation of pollution sources (building materials, equipment, local exhaust, etc.)	• Limitation of heat load (low energy equipment, solar shading, daylight)
• Choice of appropriate indoor air quality targets and related air flow rates	• Choice of appropriate thermal comfort targets (min. and max. values)
• Optimum air supply to occupants and removal of pollutants (ventilation efficiency)	• Optimum air supply to occupants (temperature efficiency, moderate velocities)
• Minimize heating and cooling energy (heat recovery, passive heating, passive cooling, etc.)	• Minimize cooling load (thermal mass, night ventilation)
• Minimize fan energy (low pressure duct work and components, natural driving forces, etc.)	• Minimize fan energy (low pressure duct work and components, natural driving forces, etc.)
• Adapting air flow rates to indoor air quality needs (control strategy, demand-controlled ventilation)	

Ventilation strategies

There is a whole range of hybrid ventilation principles and strategies and it is impossible to make a complete catalogue. The main hybrid ventilation principles are:

- **Alternating natural and mechanical ventilation**
  This principle is based on a combination of two fully autonomous systems where the control strategy consists of switching between both systems. It covers for example systems with natural ventilation in intermediate seasons and mechanical ventilation during midsummer and/or midwinter. It can also be systems with mechanical ventilation during occupied hours and natural ventilation for night cooling.

- **Fan assisted natural ventilation**
  This principle is based on a natural ventilation system combined with an extract or supply fan. It covers natural ventilation systems, which during periods of weak natural driving forces or periods of increased demands can enhance pressure differences by mechanical fan assistance.

- **Stack and wind supported mechanical ventilation**
  This principle is based on a mechanical ventilation system, which makes optimal use of natural driving forces. It covers mechanical ventilation systems with very small pressure losses where natural driving forces can account for a considerable part of the necessary pressure difference.

Building Facades - an Important Hybrid Ventilation Component

In hybrid ventilation systems the facade is often an important ventilation component as both air supply and exhaust is provided through openings in it. This puts additional requirements to the performance of the facade - requirements that usually are associated with a ventilation system. These additional requirements can include

- Possibility for preheating of supply air
- Possibility for air filtration
- A low pressure drop for air flow across the facade
- Possibility for enhancement of driving forces like increasing buoyancy forces by solar chimneys, increasing of wind forces by opening design or increasing driving force in general by integration of mechanical fans.
- Provision of air without creating draughts for the occupants
- Provision of air directly to the occupants (high air exchange efficiency)
- Efficient removal of contaminants and/or excess heat (high ventilation and temperature efficiency)

The remaining part of this paper will focus on window openings for fresh air in the facade and their impact on ventilation performance. As it is seen in the following both the type and the location of the window openings are important in this regard as well as the chosen air distribution principle.

Use of Windows for Fresh Air Supply

Opening of windows in the facade is a common way of providing fresh air in hybrid ventilation systems and there is a wide range of possibilities with regard to selection of window type, size and location, see figure 1.

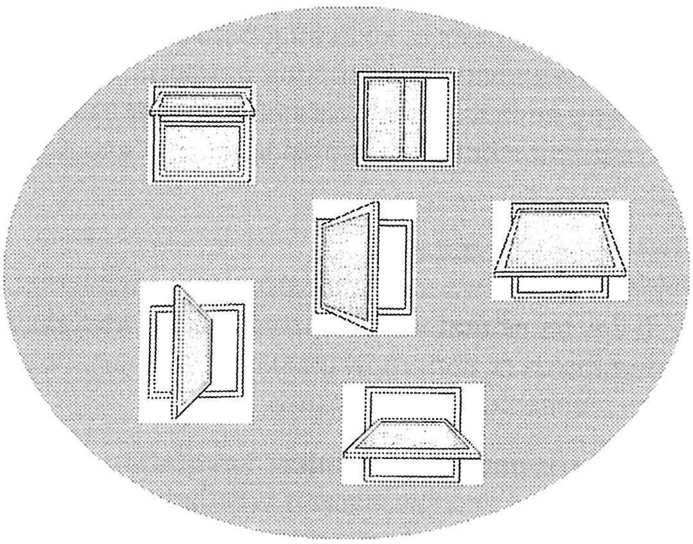

Figure 1. Examples of different window types.

The air flow rate and flow conditions through a window depends on the chosen natural ventilation strategy, see figure 2, on the available pressure difference and on the air temperature.

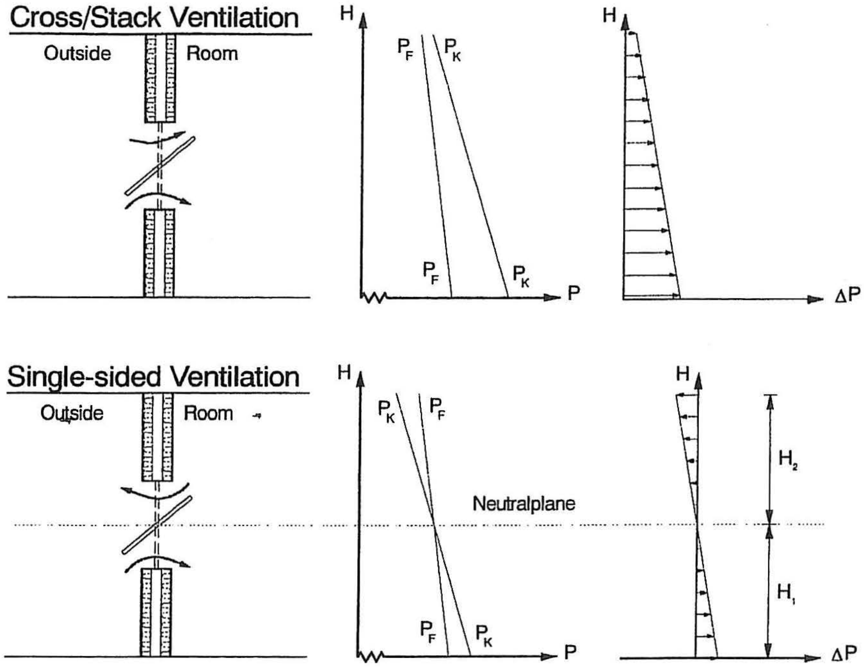

Figure 2. Air flow through a window with a single sided and a cross ventilation strategy, respectively

Single sided ventilation relies on openings being on only one side of the ventilated enclosure. A close approximation is a cellular building with windows on one side and closed internal doors on the other side. With a single opening in the room the main driving force for natural ventilation in winter is the thermal stack effect, where the air will flow into the room in the bottom half of the window and out of the room in the top half of the window, or in through a low positioned window and out through a high positioned window. The main driving force in summer will be the wind turbulence. Compared with other strategies, lower ventilation rates are generated. Stack induced flows will increase with the vertical separation of the openings. Horizontal pivot windows, with the main opening area divided between the top and the bottom of the window, is therefore more effective than bottom or top hung windows, where the main opening area is concentrated either in the top or the bottom of the window. On the other hand air flow control can be difficult as the opening area increases fast with opening angle. The pressure difference across the window will be quite low and so will the air velocities. If the inlet temperature is lower than the room air temperature, the fresh air will drop towards the floor and the air distribution in the room will function as displacement ventilation, see next section.

In cross- and stack-ventilation ventilation openings are on both sides of a space. Air flows from one side of the building to the other and leaves through another window or door. Cross ventilation is usually wind driven while stack ventilation is thermal (and wind) driven. With such ventilation strategies there will only be an inflow of air through the window and the available pressure difference will be much higher. The capacity of the opening will not depend on the distribution of the opening area, but only on the total area. The control of window opening angle must be much more precise as even small changes have a large impact on the air flow rate. Inlet air velocities will be much higher and the air will be supplied in the form of jets as in mixing ventilation, see next section.

The knowledge of the performance of individual windows is rather limited and is today based on theoretical assumptions on the main driving forces, effective areas and air flow within rooms. It is only possible in window design for hybrid ventilation to give rough estimates of thermal comfort, draught risks and IAQ levels that can be expected. Some window types are regarded as better than others, but this is only based on qualitative measures and differences and limitations in the application of individual window types cannot be quantified precisely.

The next sections show the results of a series of laboratory investigations that is performed to characterise different window types, see /1/. The results show air flow conditions for different ventilation strategies and temperature differences, and thermal comfort conditions are evaluated by measurements of velocity and temperature levels in the air flow in the occupied zone. This can be seen as a first step in providing the necessary quantitative information on window performance that can improve window design to a level that can match the design of air inlets in mechanical ventilation.

Air Flow Inside Rooms

Air flow in the room is investigated by smoke tests for both a single-sided and a cross/stack ventilation strategy for three window types – Type 1: Horizontal pivot window, Type 2: Side hung window and Type 3: Tilting top vent, see figure 3.

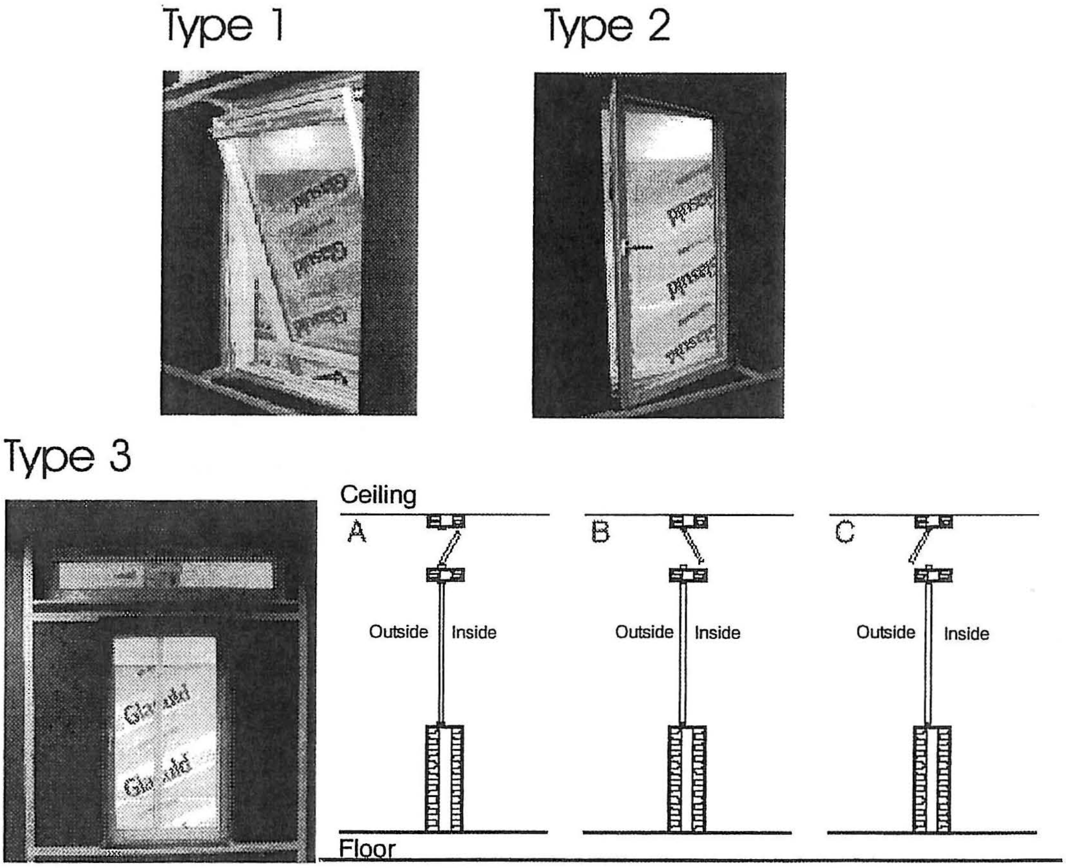

Figure 3. Window types investigated. Type 1: Horizontal pivot window, Type 2: Side hung window and Type 3: Tilting top vent.

For a single sided ventilation strategy air through window type 1 and 2 was flowing directly to the occupied zone and dependent on temperature difference and window opening area the air reached the floor from 0,5 – 1.5 m from the window, see figure 4. The air flow along the floor could be characterised as stratified flow. Even very small opening angles resulted in large air flows and high velocity levels in the occupied zone.

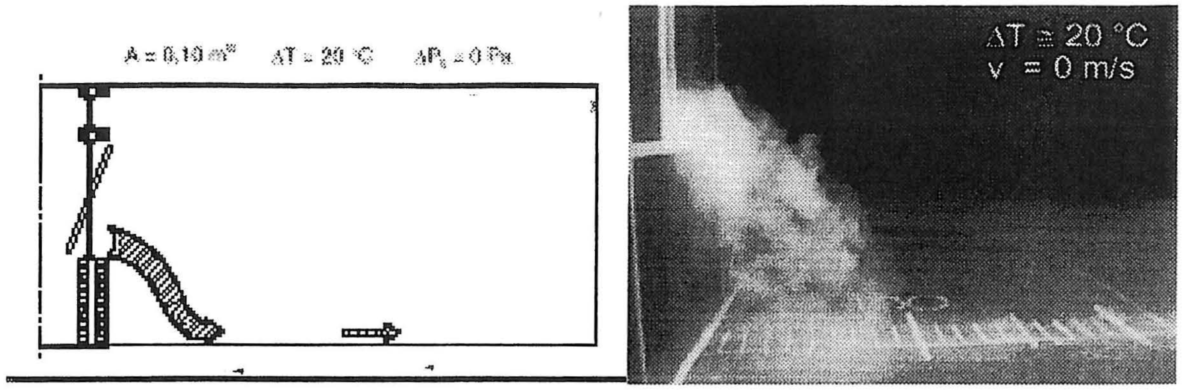

Figure 4. Air flow through window type 1 with single sided ventilation and a temperature difference of 20 °C, /1/.

For a single sided ventilation strategy the air flow through window type 3 was almost identical for all three configurations on figure 3. At small opening angles only a very small amount of air entered the room at low velocity. With increasing opening angles the air flow and velocity level increased. In all cases the air flow was downwards along the wall and at large opening angles the air reached the floor and turned into the occupied zone as stratified air flow along the floor, see figure 5.

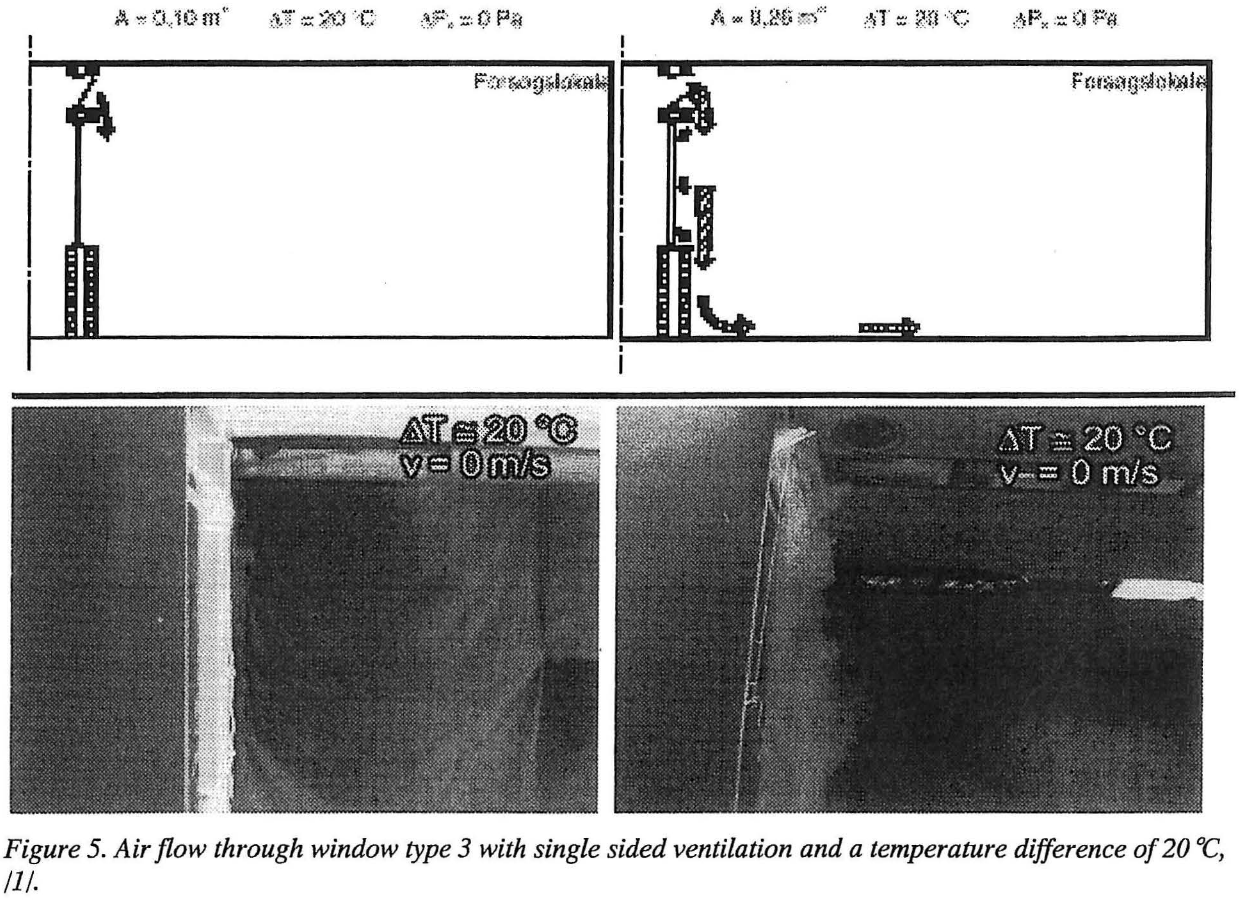

Figure 5. Air flow through window type 3 with single sided ventilation and a temperature difference of 20 °C, /1/.

For a single sided ventilation strategy window type 3 is the best choice in winter because the air is supplied outside the occupied zone and can be controlled by changing the opening angle. Window type 1 and 2 is not a good choice as the air is supplied directly to the occupied zone and is difficult to control because the amount of air and the velocity levels increase very rapidly with increasing opening angles. In summer with small temperature differences window type 3 will not be able to supply enough air to the room, but will have to be combined with window type 1 or 2.

For a cross- or stack-ventilation strategy the available pressure difference across the openings is generally much higher. For window type 1 and 2 the air flow into the room acted as a thermal jet that reached the floor in a certain distance dependent on temperature difference, pressure difference and opening angle. The problems under winter conditions with high air velocities and with a proper control of the air flow is therefore much more severe. The air flow conditions for window type 3 showed large differences for the three configurations. Generally the air flow acted as a thermal jet. For both a bottom hung opening in and a top hung opening out the air flow acted as a thermal wall (ceiling) jet. However, the distance from the wall where the jet separated from the ceiling was larger for the bottom hung opening, resulting in lower velocities in the occupied zone. For the top hung opening in the air flow acted as a free thermal jet and reached quickly the occupied zone resulting in very high air velocities, see figure 6.

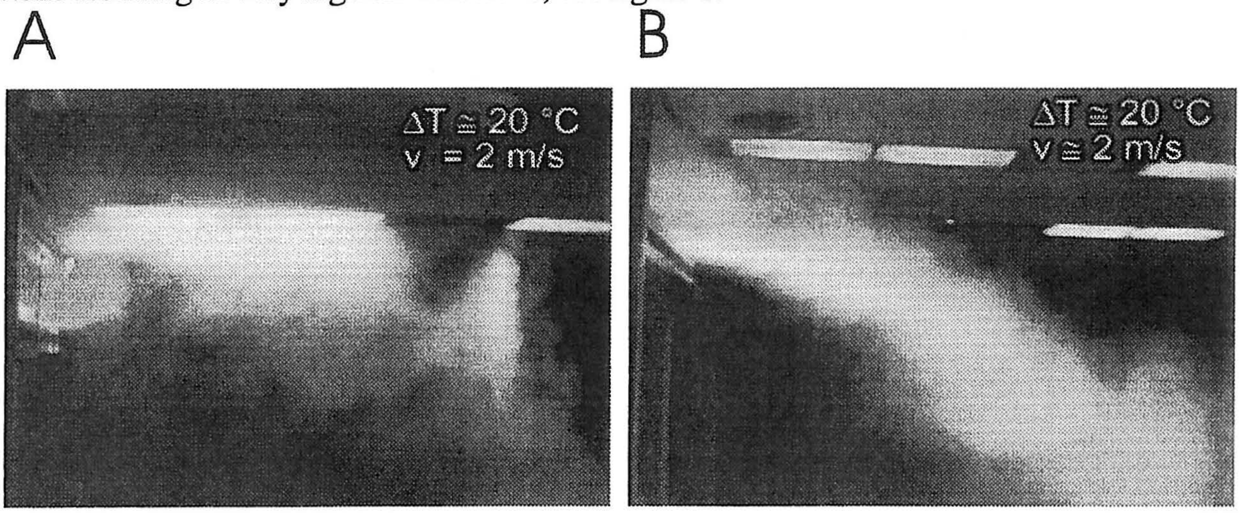

Figure 6. Air flow through window type 3 with cross- or stackventilation and a temperature difference of 20 °C. A) Bottom hung, opening in. B) top hung, opening in, /1/.

For a cross- or stackventilation strategy window type 3 in a bottom hung configuration is the best choice in winter because the air travels the largest distance before it reaches the occupied zone and the velocity levels therefore will be the lowest. Window type 1 and 2 is not a good choice as the air is supplied directly to the occupied zone at very high velocities and is very difficult to control because the amount of air and the velocity levels increase very rapidly with increasing opening angles.

Air Velocities in the Occupied Zone

The air flow from window type 1 and 2 will drop to the floor and cause a radial flow along the floor. This is a flow behaviour similar to the one obtained from a wall-mounted low velocity diffuser for displacement ventilation, see /2/ for more information. Figure 7 shows that the maximum velocity in the air flow along the floor also will be dependent on the air flow rate and temperature difference. The velocity level increases with increasing air flow rate and increasing temperature difference, but decreases with increasing distance to the wall. This is a very typical result for stratified flow conditions.

Analysis of measurement result have showed that it is possible to develop an equation system that can be used to predict the velocity level in the occupied zone as a function of opening area, pressure difference and temperature difference. The equation system can be used to predict the comfort performance of window openings and estimate the limitations of a specific window type. In this way the design of window openings for natural ventilation becomes not only a question of providing the necessary opening area to ensure satisfactory capacity but also a question of selecting the optimum window type for thermal comfort. The analysis also shows that the performance of windows with regard to providing thermal comfort is not as good as the performance of air diffusers.

In /2/ an example of such a design tool for the calculation of the air velocity in the occupied zone is shown for a case of single-sided ventilation with an side hung open window.

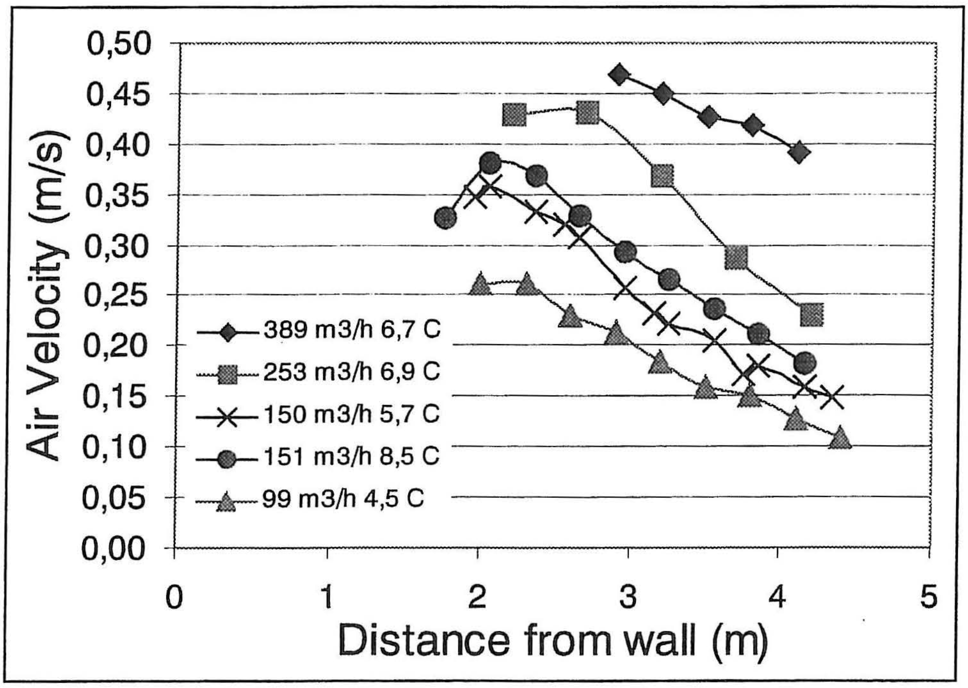

Figure 7. Velocity level in air flow along the floor from window type 2 (side hung) as a function of distance to wall, air flow rate and temperature difference.

The air flow from window type 3 with bottom hung opening will act as a thermal jet attached to the ceiling and will at a certain distance from the facade drop to the occupied zone. This is a flow behaviour similar to the one obtained from a wall-mounted diffuser located close to the ceiling in a mixing ventilation system. The distance from the wall, where the air jet no longer attaches to the ceiling will be dependent on the opening type, the pressure difference (air flow rate), the temperature difference and the opening area, see /3/ for more information. The penetration depth is generally of the same order of magnitude as it is seen for air diffusers. The velocity level in the jet will decrease in the same way as it is seen for jets from air diffusers, but the decrease is not as rapid as it is seen for modern diffusers.

The analysis of measurement results showed that it is possible to develop an equation system that can be used to predict the velocity level in the occupied zone as a function of opening area, pressure difference and temperature difference. In /3/ an example of such a design tool for the calculation of the air velocity in the occupied zone is shown for a case of cross ventilation with an bottom hung tilted vent.

Discussion

In Hybrid ventilation systems fresh air is often provided through openings in the facade and there is a wide range of possibilities with regard to selection of opening type and position of openings in the facade. Different types of grilles and/or windows have quite different characteristics and thereby very different impact on thermal comfort and indoor air quality in the occupied zone. A combination of different opening types in different positions in the facade is necessary in hybrid ventilation design to ensure acceptable ventilation capacity, thermal comfort and IAQ, and the right combination is very dependent on the selected ventilation strategy, the outdoor conditions and the available pressure difference across the facade.

Type of opening has an impact on thermal comfort like air diffusers. Measurement result showed that it is possible to develop equations systems to predict thermal comfort in the occupied zone because of air flow from window openings, which is very important for the selection of optimum window types. The results also showed that the thermal comfort performance of window openings are not at the same level as air supply diffusers for mechanical ventilation. Improved window design, which ensures a good mixing of supply air with room air, which ensures a faster decrease of velocity levels and a faster increase of temperature levels, will make it possible to use natural ventilation at lower outdoor temperatures and for higher air flow rates. This will be very important as many office buildings have a cooling need in occupied hours even at very low outdoor temperatures.. Provision of air, as much as possible and at as low temperature as possible, is an important optimization parameter for optimum use of natural ventilation and minization of energy consumption as preheating of outdoor air for comfort reasons can be avoided.

Acknowledgement

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References

1. Heiselberg P., Dam H., Sørensen L.C., Nielsen P.V. and Svidt K. (1999) Characteristics of Air Flow through Windows. Presented at the first International One Day Forum on Natural and Hybrid Ventilation, HybVent Forum '99, 09/1999, Sydney, Australia. Available at http://hybvent.civil.auc.dk.

2. Nielsen P.V., Dam H., Sørensen L.C., Svidt K. and Heiselberg P. (2000). Characteristics of Buoyant Flow from Open Windows in Naturally Ventilated Rooms. *Proceedings of ROOOMVENT 2000,* July 2000, Reading, UK.

3. Svidt K., Heiselberg P., Nielsen P.V. (2000). Characterisation of the Air Flow from a Bottom Hung Window for Natural Ventilation. *Proceedings of ROOOMVENT 2000,* July 2000, Reading, UK.

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