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CHARATERISTICS OF AIR FLOW THROUGH WINDOWS

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ABSTRACT

This paper describes the first results of a series of laboratory investigations that is performed to characterise three different window types. The results show the air flow conditions for different ventilation strategies and temperature differences. For one of the windows values of the discharge coefficient are shown for both isothermal and non-isothermal flow conditions and the thermal comfort conditions are evaluated by measurements of velocity and temperature levels in the air flow in the occupied zone.

It is demonstrated that different window types have quite different characteristics. A combination of different window types in the same natural ventilation design can by using their strong sides improve both ventilation capacity, thermal comfort and IAQ.

1 INTRODUCTION

In natural ventilation systems fresh air is often provided through opening of windows. There is a wide range of possibilities with regard to selection of window type, see figure 1, size and location. However, the knowledge of the performance of individual windows is rather limited and is based on theoretical assumptions on the main driving forces, effective areas and air flow within rooms. It is only possible in window design for natural ventilation to give rough estimates of the thermal comfort, the draught risks and the IAQ levels that can be expected. Some window types are regarded as better than others, but this is only based on qualitative measures and the differences and limitations in the application of individual window types cannot be quantified.

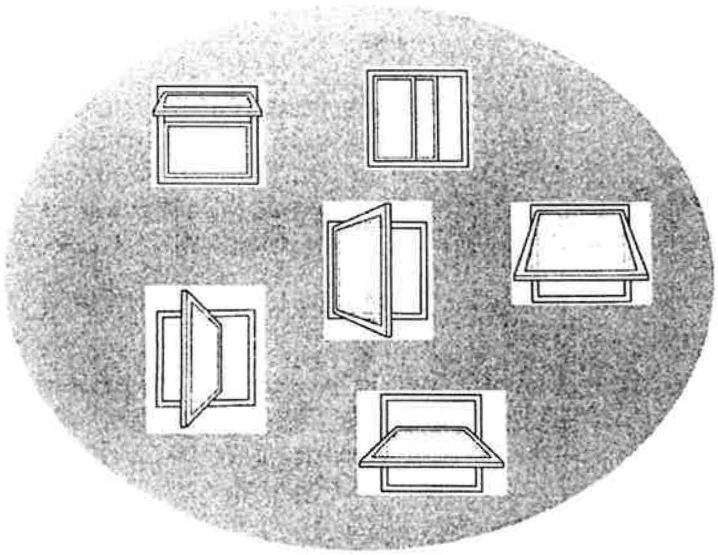

Figure 1. Examples of different window types.

Therefore, there is certainly a need for quantitative information on window performance that can improve the window design methods to a level, where they can match the design methods of air inlets in mechanical ventilation.

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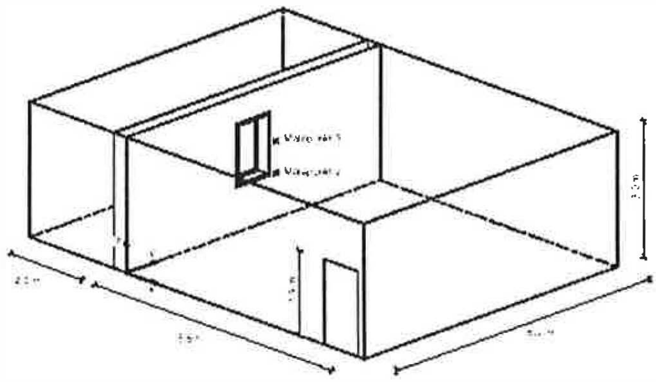
2 DESCRIPTION OF LABORATORY SET-UP

The investigations is performed in a laboratory test room with the size of Length×Width×Height = 8m × 6m × 3m, see figure 2a. The room is divided into two separate rooms by an insulated wall, see figure 2b. The small room can be cooled to a temperature of about 0°C while the large room can be kept at normal room temperature. Three different window types have been placed in the insulated wall, see figure 3a. Window type 1 is a combined side/bottom hung window that is placed close to the occupied zone. Window type 2 is a narrow window that is placed high in the room and has been used both as a top and bottom hung window. Window type 3 is a horizontal pivot window placed close to the occupied zone, see figure 3b-d.

A



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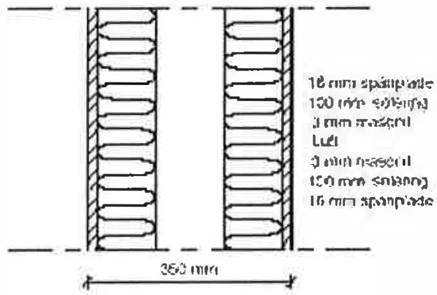
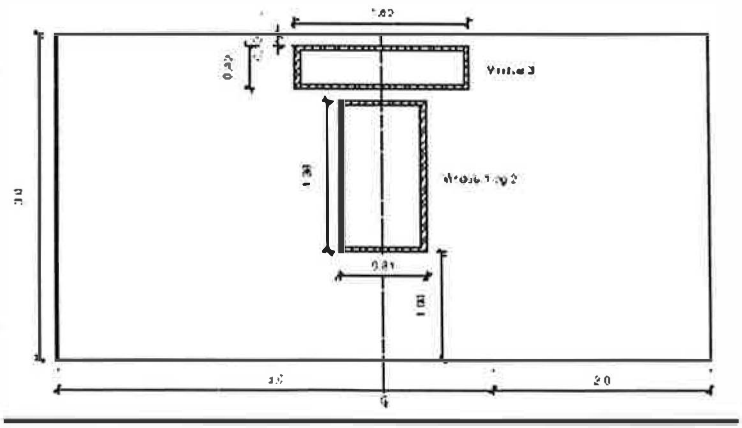


Figure 2. A) Sketch of laboratory test room. B) Sketch of insulated wall construction.

A



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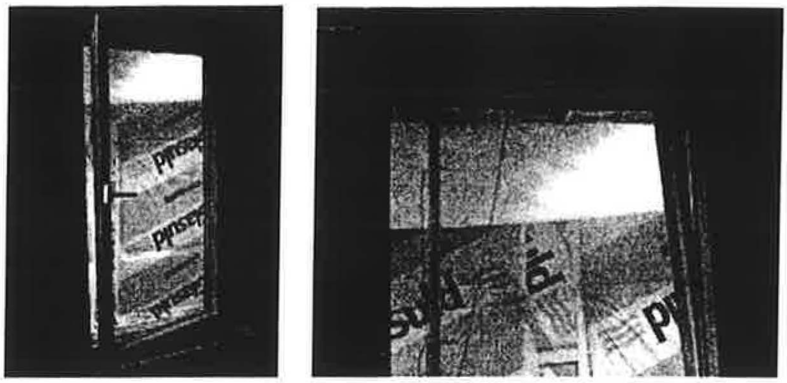

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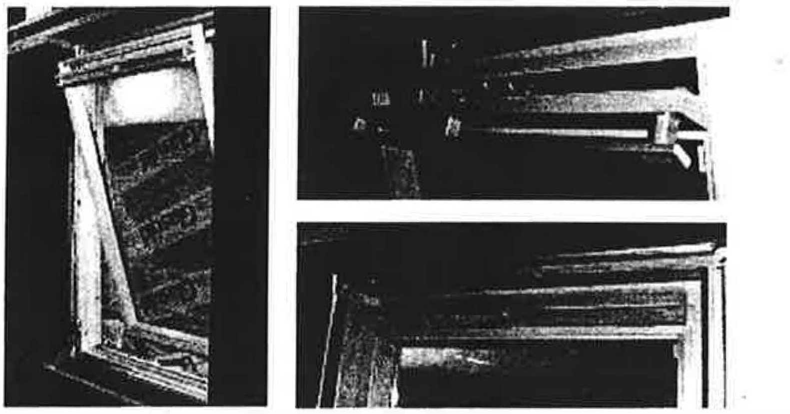

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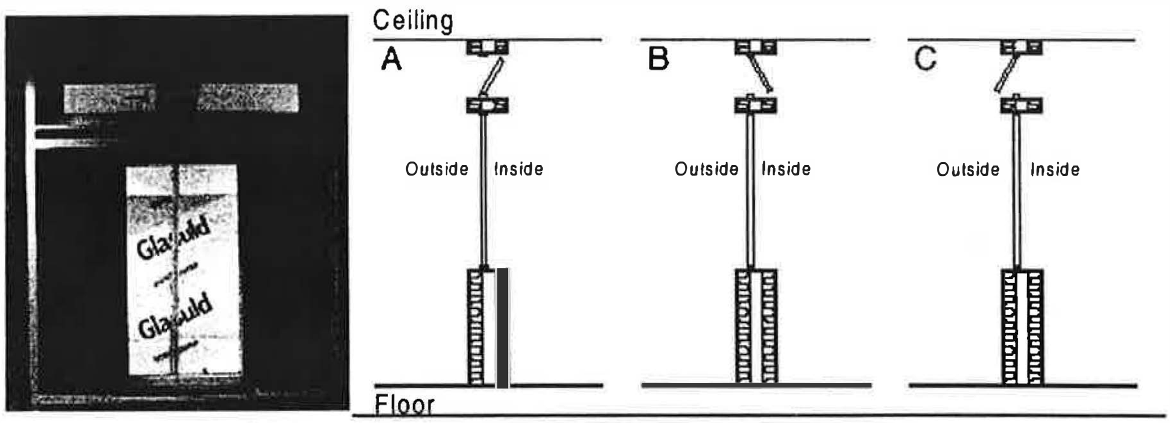

Figure 3. A) Sketch of window location in insulated wall. B) Photo of window type 1, C) Photo of window type 2 and D) Photo of window type 3 (top window) with indication of the three configurations used in the investigation.

3 AIR FLOW THROUGH WINDOWS

The air flow through a window depends on the chosen natural ventilation strategy, see figure 4. Single sided ventilation relies on openings being on only one side of the ventilated enclosure. A close approximation is a cellular building with opening 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 top half of the window. The main driving force in summer will be the wind turbulence. Compared with other strategies, lower ventilation rates are generated. Stack induced flows increase with the vertical separation of the openings. Window type 2, with the main opening area divided between the top and the bottom of the window, is therefore more effective than types 1 and 3, where the main opening area is concentrated either in the top or the bottom of the window.

In cross- and stack-ventilation there are ventilation openings on both sides of a space. Air flow 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 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.

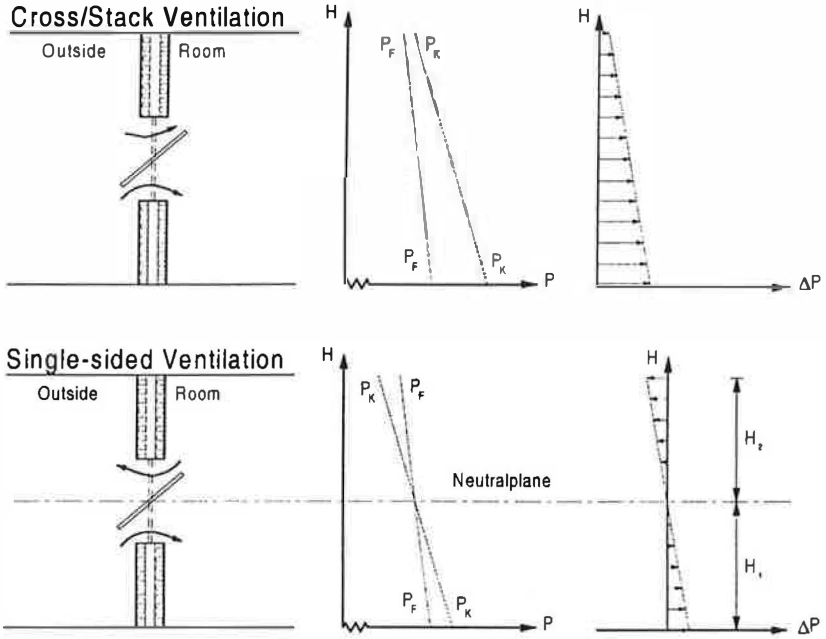

Figure 4. Air flow through a window with a single sided and a cross ventilation strategy, respectively

4 AIR FLOW INSIDE ROOM

The air flow in the room was investigated by smoke tests for both a single-sided and a cross/stack ventilation strategy for all three window types.

For a single sided ventilation strategy air flow through window type 1 and 2 was supplied 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 5. 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.

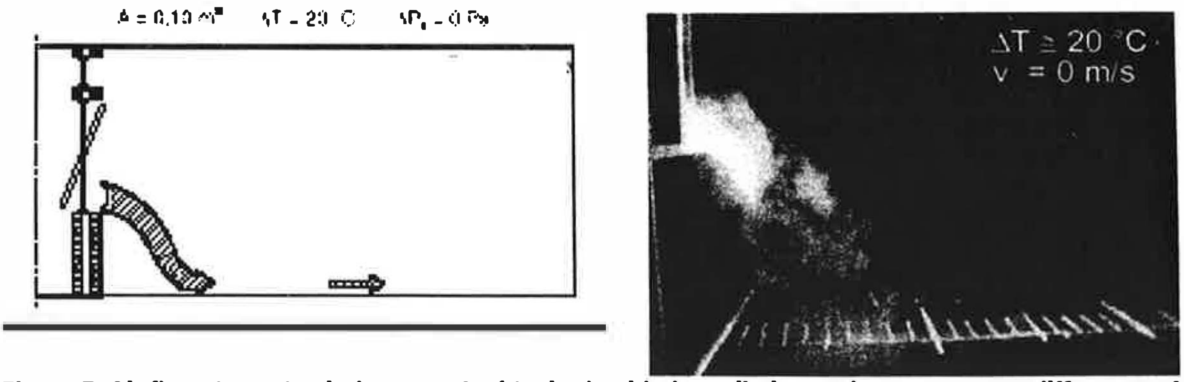

Figure 5. Air flow through window type 2 with single sided ventilation and a temperature difference of 20°C.

For a single sided ventilation strategy the air flow through window type 3 was almost identical for all three configurations on figure 3D. 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 6.

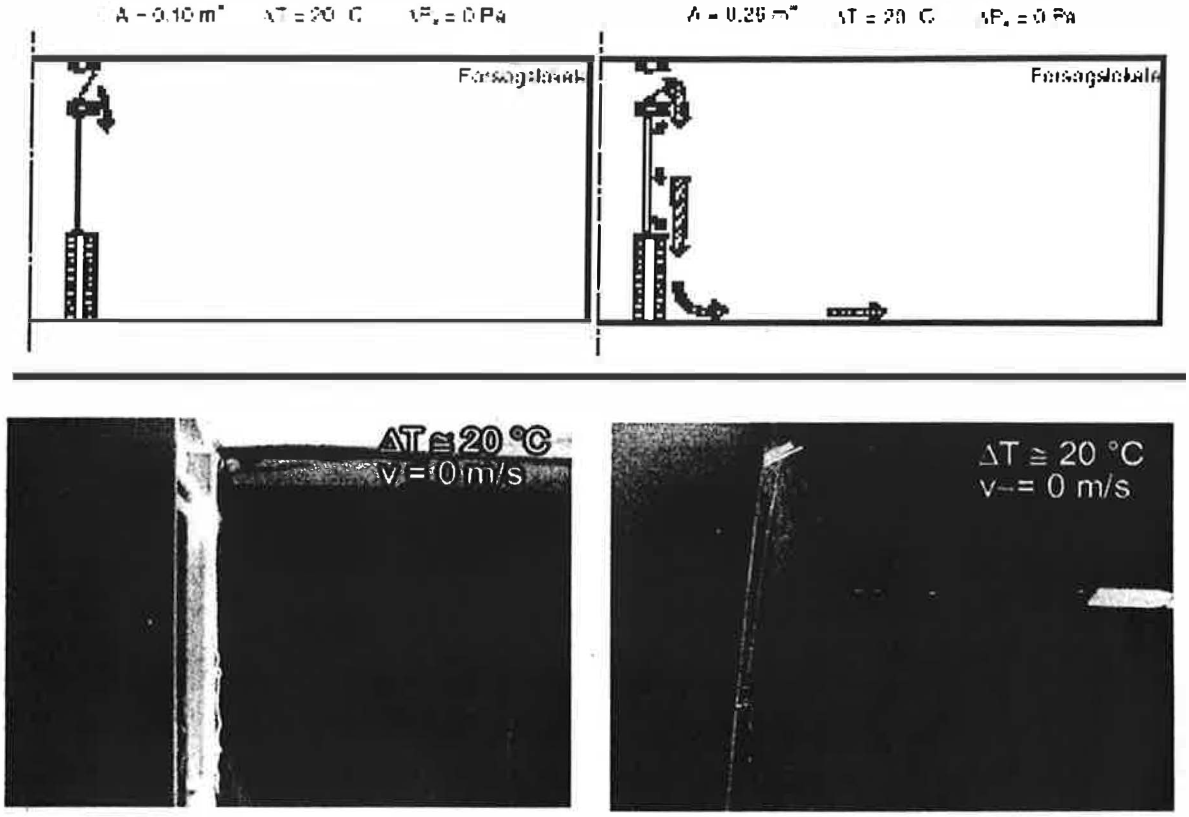

Figure 6. Air flow through window type 3 with single sided ventilation and a temperature difference of 20°C.

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 increased. 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 window opening in and a top hung window 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 window, resulting in lower velocities in the occupied zone. For the top hung window 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 7.

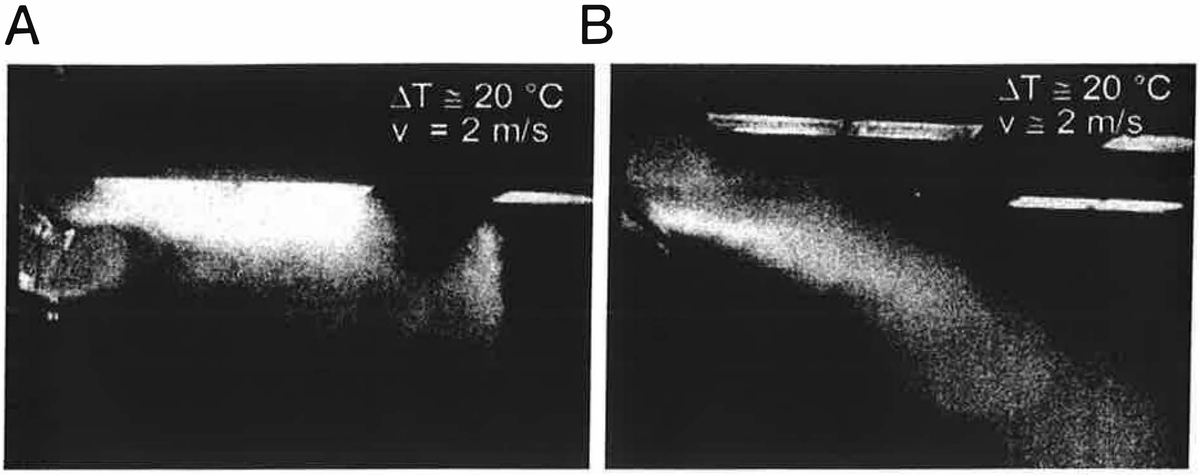

Figure 7. Air flow through window type 3 with cross- or stackventilation and a temperature difference of 20°C. A) Bottom hung, opening in. B) top hung, opening in.

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.

5 WINDOW AIR FLOW CAPACITY

The air flow through a window can be estimated by equation (1)

$$Q = C_d A \sqrt{\frac{2\Delta P}{\rho}} \quad (1)$$

where Q is volume flow rate (m^3/s)
C_d is discharge coefficient (-)
A is geometrical window opening area
Δp is pressure difference across the window (pa)
ρ is density of air (kg/m^3)

The discharge coefficient is a characteristic parameter for a specific window and takes both the contraction and the friction loss in the window opening into account. The size of the coefficient is only known for very simple opening types. For windows, which have a very complicated geometrical structure, the size of the coefficient is unknown and its dependence on parameters like for example opening area, velocity level (pressure difference) and temperature difference is not known either.

Preliminary measurements on window type 1 with a side hung opening shows some interesting characteristics of the discharge coefficient. The estimation of the geometrical opening area of the window is very difficult because of the complicated geometry and the uncertainty is especially high at small opening angles. The absolute value of the discharge coefficient is therefore uncertain especially at small opening angles and measured values above 1 must primarily be caused by incorrect estimation of the opening area.

Figure 8 shows the discharge coefficient as a function of the pressure difference across the opening for different opening areas, Figure 9 as a function of the opening area of the window and Figure 10 as a function of a reduced Archimedes number ($\Delta T/Q^2$).

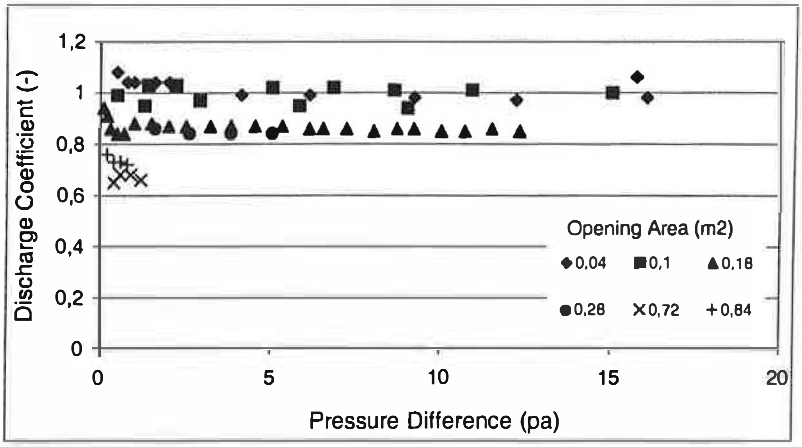

Figure 8. Discharge Coefficient, C_d, for window type 1 (side hung) as a function of pressure and for different opening areas.

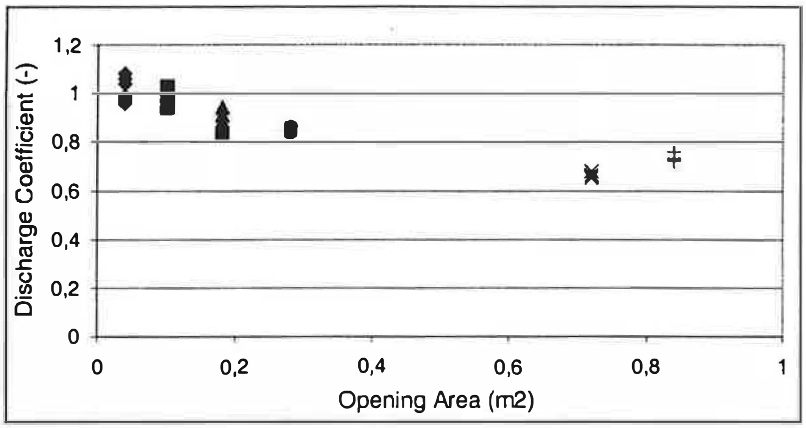

Figure 9. Discharge Coefficient, C_d, for window type 1 (side hung) as a function of the opening area.

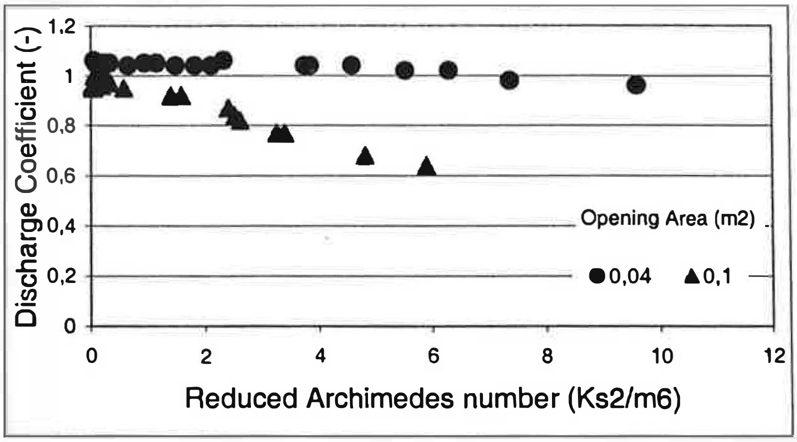

Figure 10. Discharge Coefficient, C_d, for window type 1 (side hung) as a function of a reduced Archimedes number.

The measurement results shows that the in an isothermal case the discharge coefficient is independent of the pressure difference across the window, but dependent on the opening area. In a situation with both a temperature and a pressure difference across the opening the discharge coefficient can be described as a function of the Archimedes number and the opening area. So, the use of a constant value for the discharge coefficient independent of opening area, temperature- and pressure difference can lead to serious errors in the prediction of air flow capacity of window openings.

6 AIR VELOCITIES IN THE OCCUPIED ZONE

The air flow from window type 1 with side hung opening will act as a thermal jet. The distance from the wall, where the air jet will reach the floor will be dependent on the pressure difference (air flow rate) and the temperature difference. Figure 11 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.

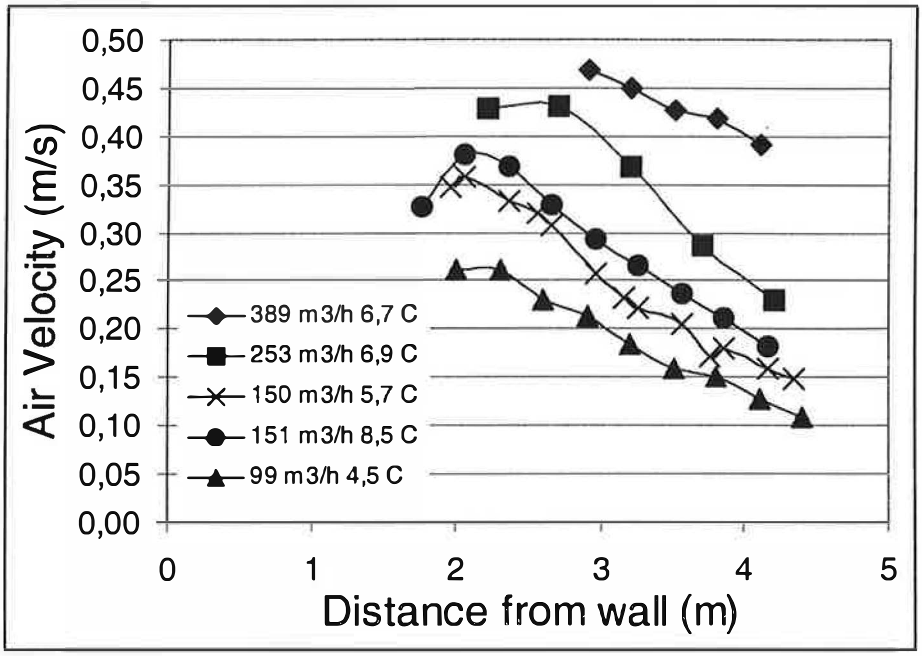

Figure 11. Velocity level in air flow along the floor from window type 1 (side hung) as a function of distance to wall, air flow rate and temperature difference.

Preliminary analysis 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. This 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.

7 CONCLUSIONS

The results have been promising and work will continue by investigation of the performance of other window types, especially those located at high levels in the room.

The results showed that the discharge coefficient for a window opening varies considerably with opening area and temperature difference and that the use of a constant value can lead to serious errors in the prediction of air flow capacity.

It should be 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.

- A further next step could be to investigate the dynamics of window opening and the performance of different control systems in controlling the air flow through the windows. But as long as we do not know the characteristics of the window, it is very difficult to define the requirements to the control system.