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EFFECT OF WINDOW BAY ON THE DOWNDRAUGHT FROM A WELL-INSULATED WINDOW

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ABSTRACT

As the climate in the Nordic countries is cold for several months a year, windows are crucial parts of building envelopes. The current trend to reduce the heat losses by building- components has resulted in many modifications of the design work of windows in order to improve the thermal performance and the indoor climate. The improvements of window constructions have resulted in a higher surface temperature on the inner pane and considerably lower downdraught, which in turn has created an opportunity to introduce unconventional design of the heating and ventilation systems.

The objectives of the present study are to investigate and improve the integration of windows in the indoor air climate and to make a survey of the general perception of windows. The unconventional system used in the present study is a well-insulated triple-glazing window with a *U*-value of about 1.0 W/m^{2}K in combination with displacement ventilation and a floor heating system. The impetus of this paper is to investigate experimentally the flow and thermal behaviour of the downdraught from the window with different widths of the window bay.

The experiments are carried out for several cases in full scale and are performed in a well-insulated room specially designed for this purpose. Velocity and temperature are measured by hot wire anemometer and thermocouples, respectively. The airflow pattern of the downdraught, mean velocity and temperature profiles as well as turbulence intensities with consideration to the width of window bay are reported.

KEYWORDS

Downdraught, well-insulated window, triple-glazing window, experimental, window bay, cold draught

INTRODUCTION

Windows are one of the most crucial areas in building envelopes in Nordic countries, as Sweden, as the climate is cold for several months a year. In Sweden research and development on glazing technology was traditionally undertaken by governmental research organisations and universities.

Today, however, there is a large amount of applied research being carried out by researchers from universities in partnership with industries. The present study is the result of such a partnership.

The current trend to reduce the heat losses by building-components has resulted in many modifications of the design work on windows in order to improve the thermal performance. In addition to the above-mentioned improvement, windows have also direct effects on the indoor climate and the thermal comfort. The development of the window construction has resulted in a surface temperature on the inner pane that is close to the room air temperature. From this follows that the strength of the downdraught from the window and the cold radiation to the surrounding surfaces are considerably reduced. Thus the unpleasant problems with downdraught and cold radiation in the occupied zone can be avoided. The improvement of the thermal performance of the windows indirectly creates an opportunity to eliminate traditional heating systems such as radiators and convectors below the window. Other, unconventional heating and ventilation systems such as heated floors in combination with displacement ventilation can be used.

It is worth mentioning that the downdraught is the cold stream of air created by the temperature difference between the room air and the surface of the window. This phenomenon can cause an uncomfortable indoor climate in the occupied zone. One of the advantages with well-insulated windows is that the downdraught velocity will be reduced, which makes it possible to design heating systems without radiators. The benefit of a system without radiators is the expansion of the occupational zone; which means, the whole floor can be furnished.

Several researchers have investigated the natural convective flow along a vertical cold plate; among the first were Eckert and Jackson (1951) and Cheesewright (1968). Peng & Peterson (1995) investigated the convection with a cold window as a vertical plate and a simulated heated floor below the window. Among others Heiselberg (1994 and 1995)has studied the influence of a created cold stream near large glazed façades and how the cold stream can be affected.

The intention of this paper is to investigate the downdraught below a well-insulated window. Measurements of the velocity and temperature in the area close to the window are performed. The experimental set-up, of interest here, is for a well-insulated triple-glazing window. The windows will be mounted in different positions inside the wall to create different widths of the window bay.

The experiments are carried out in a well-insulated test room with the window mounted in a wall, with one side against the test room and the other against a cold room. Therefore, outside temperatures down to -20°C can be simulated on one side of the window. To create different widths of the window bay, the window is moved inside the wall. The width of the window bay is varied from 0 mm to 140 mm. The ventilation of the room is executed by displacement ventilation. The supply airflow is in all cases $10 \cdot 10^{-3}$ m^3/s. Velocities and temperatures are measured in a steady-state condition. The temperature is measured with thermocouples of Copper-Constantan; the temperature measured is the room air temperature, the temperature close to the wall below the window and also the surface temperature at the windowpane and at the surrounding walls. The velocity is measured with Hot-Wire Anemometry (HWA) of the type Constant-Temperature (CT), only the velocity close to the wall below the window is measured.

This paper reports the results from an ongoing research project on the improvement of the thermal performance of well-insulated windows, see Larsson et al. (1998, 1999 and 2000). The results show that the influence from an increasing width of the window bay on the downdraught is both positive and negative. An increasing width of the window bay decreases the velocity and turbulence intensity in the downdraught. The temperature in the downdraught will also increase with an increasing width of the window bay. The.increasing width of the window bay changes the path of the downdraught negatively instead of dropping to the floor the window bay will direct it into the occupied zone.

EXPERIMENTAL SET-UP

The experiments were carried out in a well-insulated full-scale test room, see figure 1, at the department of Built Environment, Royal Institute of Technology, Gävle, Sweden. The ceiling, floor and walls in the test room are well insulated with mineral wool and have a *U*-value of 0.18 W/m^{2}K except for the wall against the cold room where the *U*-value is 0.12 W/m^{2}K. Next to the test room is a cold room. The rooms are separated by a well-insulated wall on which the window is mounted. With this set-up, the outdoor climate can be simulated on one side of the window and the indoor climate on the other. The ventilation system in the test room is a displacement ventilation system. To compensate for the heat loss, a mat of electric resistance covers the floor, thus simulating a heated floor. The size of the test room is (L×W×H) 4.1×3.4×2.7 m. The dimension of the window is 1.0×1.2 m. The origin of the co-ordinate system is on the outer wall in the middle of the window, at the same height as the window bay. The y-direction is from the window bay and against the floor and x-direction is from the wall and out to the room. Temperatures and velocities are measured at different heights below the window where downdraught problems can arise. Several thermocouples are used to measure the room air temperature, the window surface temperature and the room surfaces. The air velocities within the downdraught are measured with a hot-wire anemometer. Only the velocities close to the wall below the window are investigated in the present study. For this paper, a well-insulated triple-glazing window were used, made by Elitfönster, Lenhovda, Sweden. The well-insulated window has an inert gas between the panes and an emissive layer coating on the outside of the inner pane. The *U*-value is about 1.0 W/m^{2}K, see Larsson et al. (1999). All measurements are performed with an outside temperature of about –20°C. For a more detailed information about the experimental set-up and the performance of the measurements, see Larsson et al. (2000).

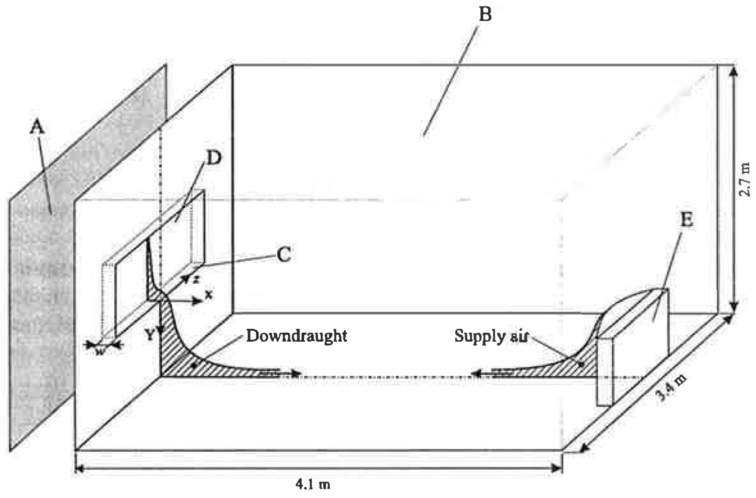

Figure 1: The test room. A-cold room, B-well insulated room, C-window bay, D-window, E-displacement ventilation.

RESULTS

The intention of this paper is to investigate the behaviour of the downdraught due to the temperature difference between the inner pane of the window and the room air and the effect on the indoor climate. The downdraught is a convective flow caused by the window. This flow can be very unpleasant near and below the window. There are several parameters that influence the thermal behaviour of the downdraught, for example the height of the window, the temperature difference between the inner pane and the room air and the width of the window bay. However, here only results for different widths of the window bay will be presented, as the other parameters have been held constant during the measurement. Detailed measurements of the velocity and the temperature below the window have been performed for a well-insulated window with different window bays.

Figure 2 shows the principle of the flow characteristics of the downdraught observed by smoke visualisation technique. Figure 2 also shows how the width of the window bay affects the path of the convective flow from the window. A re-circulation cell is shown at the lower corner of the window. This re-circulation cell becomes larger with the increasing width of the window bay. It is also shown that the convective flow from the window bay has a tendency to reattach to the wall below the window when the bay is narrow. This reattaching is well known as the Coanda-effect. This effect arises due to the interference of ambient air in the flow. If the ambient air interferes only from one side, in this case from the outside, the flow will be pressed against the wall. However, with an increasing window bay, the Coanda-effect will decrease.

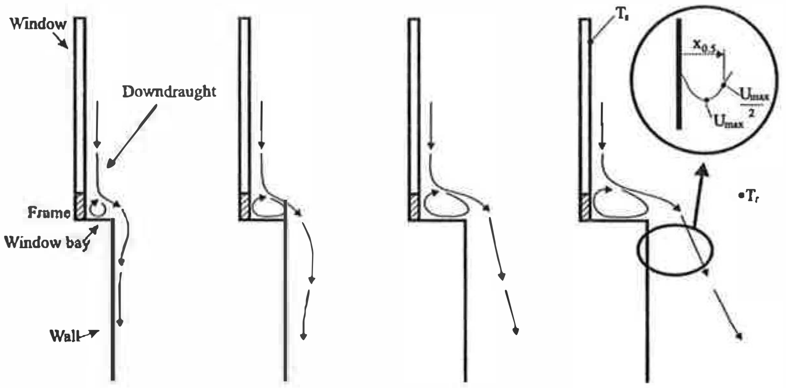

Figure 2: Principle of the cold downdraught from a window with bays of different widths.

Figure 3 shows how the temperature in the downdraught varies with the distance from the wall. The temperature was normalised by dividing the difference between the local temperature, T, and the surface temperature on the inner pane, T_s, with the temperature difference between the room air, T_r, and the surface. Temperature slopes for three different window bays, w, are presented: 35, 87.5 and 140 mm. The distance below the window bay, y, is constantly 60mm. According to figure 3 the temperature increases in the downdraught with an increasing width of the window bay.

Figure 4 is constructed as figure 3, but with a varying height below the window bay. The different heights are 20, 60 and 100mm. The window bay width is constantly 87.5 mm. Figure 4 shows that the temperature increases with an increasing distance from the window bay. The increasing temperature in the downdraught depending of the window width and distance from the window bay can be explained by interference of the surrounding air with the downdraught.

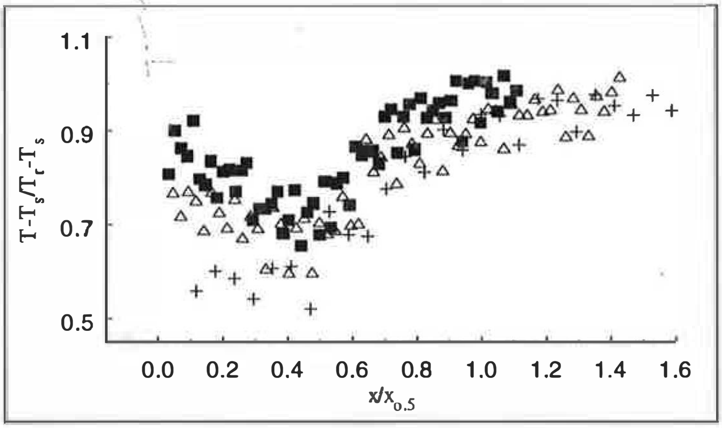

Figure 3: The normalised temperature profile for different widths of the window bay and with a constant height of 60 mm below the window bay. Plus, triangle and solid square represent the widths of the window bay, 35, 87.5 and 140 mm respectively.

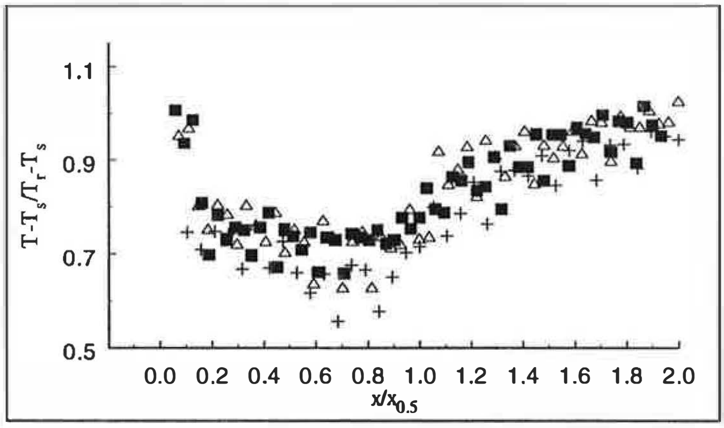

Figure 4: The normalised temperature profile for different heights below the window bay and with a constant width of 87.5 mm. Plus, triangle and solid square represents the heights below the window bay, 20, 60 and 100 mm respectively.

Figure 5 is designed to show the relations between the local velocity in the downdraught to the distance from the wall for different widths of the window bay. The local velocity, U, is normalised by dividing it by the maximum velocity, U_{max}, in the downdraught for each window bay. The distance from the wall, x, is normalised by dividing by the length $x_{0.5}$, which is the distance from the wall where the maximum velocity has fallen to half, see figure 1. The height below the window bay, y, is constantly 60mm for all three widths of the window bay. The results presented in figure 4 show that $x/x_{0.5}$ decreases with an increasing width of the window bay. This depends on an increasing $x_{0.5}$, which points out an increasing deflection length with an increasing width of the window bay. The deflection length is the distance from the wall where the downdraught turns from x-direction to y-direction after leaving the window bay.

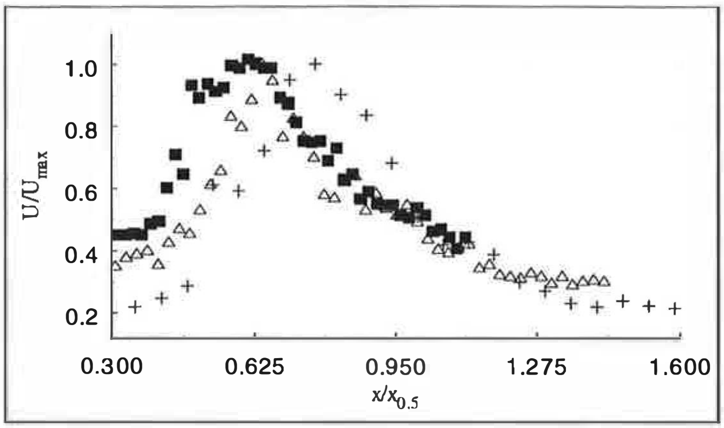

Figure 5: The normalised velocity profile for different widths of the window bay and with a constant height of 60 mm below the window bay. Plus, triangle and solid square represent the widths of the window bay, 35, 87.5 and 140 mm respectively.

Figure 6 is designed in the same way as figure 5, but with constant width of the window bay of 87.5 mm, and the distance below the window bay as the varying parameter. Figure 6 shows an increasing width of the downdraught with an increasing distance below the window bay, which can be explained by the increasing interference of the ambient air with the downdraught. Table 1 and 2 show that the velocities in figure 5 and 6 decrease with the increasing width and distance from the window bay, respectively. The tables also show that the path of the downdraught goes from the wall into the occupied area in the room. Figure 2 shows an outline of the width effect on the path of the downdraught and for a width of 87.5 mm the downdraught divergence from the wall. For smaller widths than about 70 mm, the downdraught will converge to the wall.

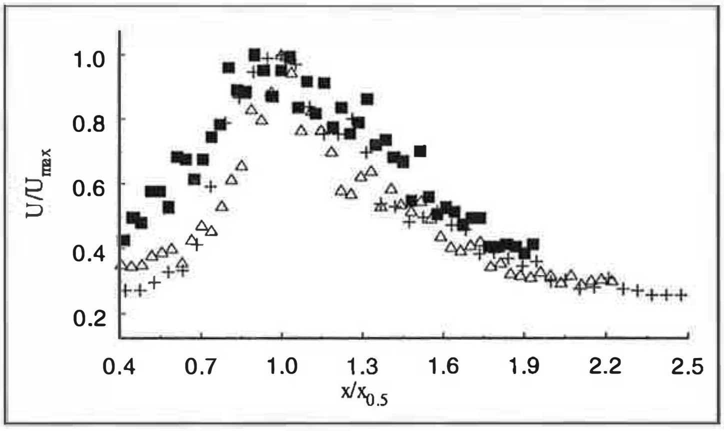

Figure 6: The normalised velocity profile for different heights below the window bay and with a constant width of the window bay, 87.5 mm. Plus, triangle and solid square represents the heights below the window bay, 20, 60 and 100 mm respectively.

TABLE 1

Summary of results for the window bay widths 35, 87.5 and 140 mm at a height of 60 mm below the window bay, $y = 60$ mm.

w (mm)	T_s (°C)	T_r (°C)	$x_{0.5}$ (mm)	U_{max} (m/s)
35	16.71	21.9	42.5	0.255
87.5	17.28	22.4	105	0.183
140	16.85	22.0	135	0.158

TABLE 2

Summary of results for the heights 20, 60 and 100 mm below the window bay at a window bay width of 87.5 mm.

y (mm)	T_s (°C)	T_r (°C)	$x_{0.5}$ (mm)	U_{max} (m/s)
20	17.28	22.5	72.5	0.213
60	17.28	22.4	105	0.183
100	17.28	22.4	127.5	0.148

Figure 7 shows how the velocity fluctuations from the mean velocity, U_{rms}, varies with the distance from the wall, x, and with different widths of the window bay. The slope of the velocity fluctuations follows the same profile as the one for velocity. It is also shown that the velocity fluctuations decreases with an increasing width of the window bay, which is the same behaviour as for the velocity, see table 1.

Figure 8 illustrates how the velocity fluctuations varies as a function of distance from the wall at different downstream locations. In the beginning, the velocity fluctuations increases by the distance from the wall at all heights with great similarity. At a certain distance from the wall, it starts falling and then it diverges. It is worth pointing out that the velocity fluctuations, after passing the maximum value, has a tendency to fall slower with increasing distance below the window bay, or in other words: higher velocity fluctuations is observed at lower distances from the window bay.

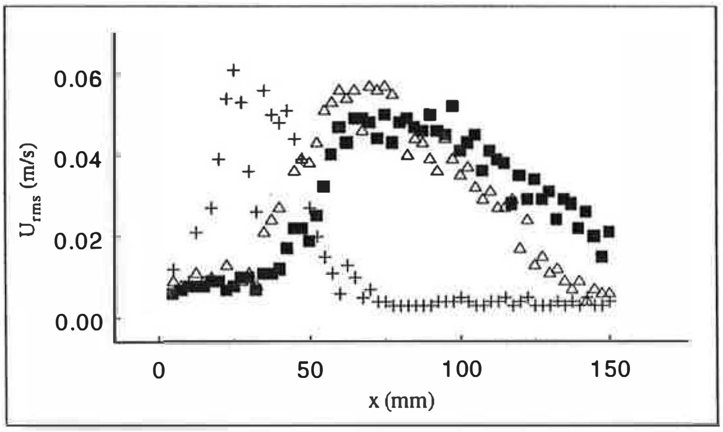

Figure 7: The velocity fluctuations profile for different widths of the window bay and with a constant height below the window bay of 60 mm.. Plus, triangle and solid square represent the widths of the window bay, 35, 87.5 and 140 mm respectively.

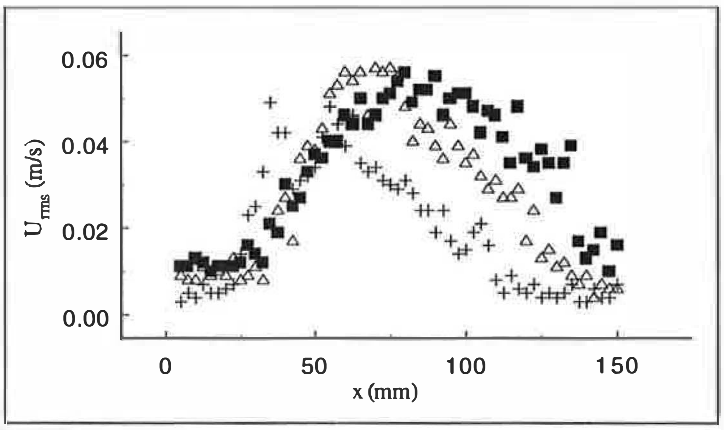

Figure 8: The velocity fluctuations profile for different heights below the window bay and with constant width of the window bay, 87.5 mm. Plus, triangle and solid square represents the height below the window bay, 20, 60 and 100 mm respectively.

CONCLUSION

The present results show:

- The temperature in the downdraught increases with the increasing width of the window bay. I also increases with the distance from the window bay. This tendency is positive wit consideration to people's perception of downdraught from windows.

- The velocity in the downdraught decreases both with an increasing width of the window bay an an increasing distance below the window bay. This behaviour shows an interference of th ambient air into the downdraught. A decreasing velocity in the downdraught is positive for th experience of it.

- The slope of velocity fluctuations in the downdraught follows the same profile as the one for th velocity, it decreases with an increasing width of the window bay. Opposite the velocity th velocity fluctuations will increase with the distance below the window bay. This indicates th the flow will be more unstable with the distance from the window bay. This result shows positive effect of the increasing width of the window bay on the velocity fluctuations in th downdraught.

- The most negative effect of the increasing width of the window bay is the influence of the path the downdraught. At a certain width of the window bay the downdraught path will be directe against the occupied zone instead of dropped against the floor.

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