MUST COLD AIR DOWNDRAUGHTS BE COMPENSATED WHEN USING HIGHLY INSULATING WINDOWS?

T Rueegg[1], V Dorer[1] and U Steinemann[2]

[1]EMPA Swiss Federal Laboratories for Materials Testing and Research, Duebendorf, CH
[2]US Engineering, Wollerau, CH

Keywords: chamber study, convection, modelling, schools, thermal comfort

ABSTRACT

Rooms with high windows are likely to have comfort problems caused by cold air downdraught, which are usually solved by placing heating appliances underneath the windows. In the city of Zug, Switzerland, a highly insulated educational building with a concrete core system for heating and cooling is planned. The purpose of our investigation was to find out whether any measures are necessary in this building to compensate the effects of downdraught in the occupied zone. Special attention has been paid to the effect of passive measures like air flow obstacles or openings in the window sill. Experiments were carried out in a room climate laboratory on 1:1 scale to measure the downdraught and the thermal comfort in the occupied zone. Several configurations of window sizes, insulating standards and outside temperatures were investigated. In addition the results were compared to values obtained from analytical calculations and from literature.

INTRODUCTION

Rooms with high windows are likely to have comfort problems by cold air downdraught. Until now the problem has mostly been solved by placing heating appliances underneath the windows. The heat insulation capability of today's windows and frames has been strongly improved so one expects that the downdraught problems should have decreased. This question has become more important in buildings with concrete core and other systems where no additional appliances at the window are needed for heating the building.

Downdraught velocities have been investigated by different authors by analytical treatment using different assumptions [1], [2], by setting up empirical equations based on measurements [3], and by determining the effects of humidity on the boundary layer flow [4]. The findings agree only partially and realistic geometries like window sills are not considered.

For a new educational building in the city of Zug, Switzerland, a concrete core system is planned to heat and cool the building. The purpose of our investigation was to find out if there will be draught problems when using highly insulating windows with no additional means to compensate downdraught and, if yes, whether passive means like air flow obstacles or openings in the window sill are sufficient to avoid the draught problem.

The judgement of the thermal comfort is based on the resulting air velocity in the occupied zone. As limit a velocity of 0.15 m/s in a distance of 1 m from the window was defined. Assuming a turbulence intensity of 40 % this requirement corresponds to a draught risk of 20 % (category B) according to the new CEN-report 1752 [5].

The results of our investigation can generally be helpful in planning highly insulated buildings with no heating appliances at the window. Such examples are buildings with a concrete core system for heating, with radiators on the inner walls or with a floor heating system.

MEASUREMENT SETUP

A part (6.2 m x 4.6 m) of a standard classroom containing the glazed north facade was chosen from the planned building. This part was set up in a room climate laboratory in a 1:1 scale. Figure 1 shows a section through the facade displaying also details such as the window sill and the window frame. The inner surface temperatures of the facade wall, the opposite wall, the floor and the ceiling were kept constant and controlled to match the thermal conditions of the classroom. The other two walls were modelled as adiabatic walls by placing heat insulation plates on their outside. A temperature difference of - 5.2 K between the inner window surface and the room air at the height of 1.2 m corresponded to an outside temperature of - 10°C and a U-value of 1.4 $W/m^2/K$, which corresponds to the window frame in the project. The heat loads consisted of 3 person simulators, i.e. black tubes with a surface area of 1.8 m^2, 2 computers and 2 additional tubes representing the balance of the planned total heat load for the class rooms. All the above mentioned loads were distributed evenly on the floor with the person simulators having 1.1 m distance to the glazing.

Table 1. Standard conditions

Surface	temperatures
Glazing	15°C
Opposite wall	19°C
Floor	20°C
Ceiling	22°C
Other walls	adiabatic
Other	**parameters**
Room air	20°C
Glazing height	2.0 m
Glazing temp. relative to room air	-5K
Heat load for room occupation of	0.25 person/m^2
- 3 person simulators	3 x 80 W
- Computers	260 W
- Total heat load	500 W
equivalent to	18 W/m^2

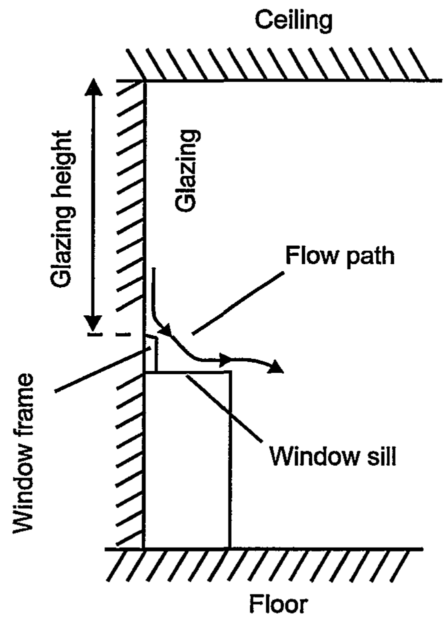

Figure 1. Section through the window

The measured room air temperature gradient was dependent on the heat load, 0.2K/m at no load to 0.6 K/m at the maximum load of 27 W/m^2. As reference temperature the room air temperature in the centre of the room at a height of 1.2 m was selected and measured with a radiation shield.

Air velocities were measured with a hot wire anemometer at the cold window surface and with combined heat film and temperature sensors at 2 positions in the room in 0.5 m and 1 m distance from the glazing surface. The sensor position at the glazing was 13 cm above the window frame, which represents a fall length of 1.9 m. The maximum errors were ±0.2 K for the temperature and ±1 to ±2 cm/s for the velocity measurements.

RESULTS

The air flowing down the window into the room was visualised with fog. Figure 1 shows a sketch of the flow path. The upper border of the window frame diverted the flow towards the middle of the window sill.

Figure 2 gives the measured velocity profiles for 2 different loads. As clearly can be seen, the thickness of the downdraught layer increases with the heat load in the room from 30 to 100 mm.

Figure 2.
Horiz. profiles of vertic. velocity of the glazing downdraught after a fall length of 1.9 m , for different loads and relative glazing temperatures $T_{glazing} - T_{room\ air}$.

Upper curve:
no load at - 7 K

Lower curve:
max. load of 27 W/m^2 at - 5.6 K

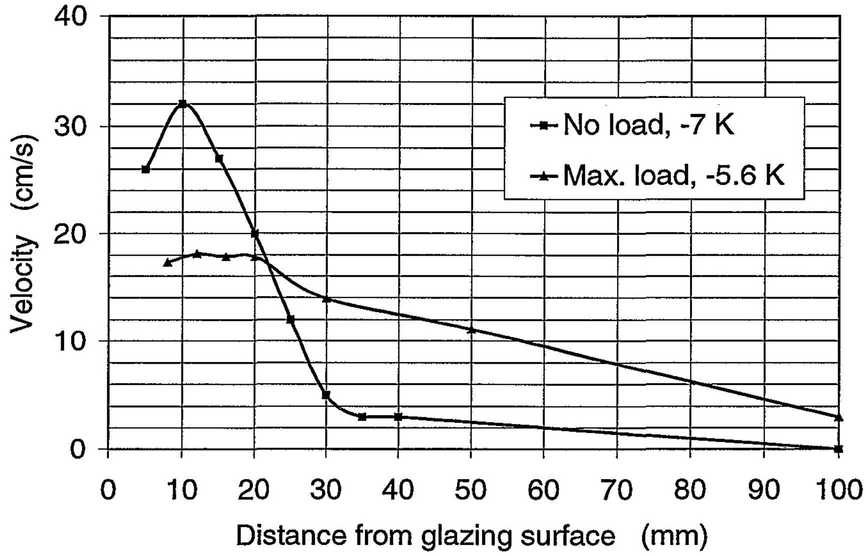

Figure 3.
Vertical profiles of absolute velocity in the room at a distance of 1 m to the glazing for different loads and relative glazing temperatures $T_{glazing} - T_{room\ air}$.

Upper curve:
no load at - 4.7 K,

lower curve:
standard load of 18 W/m^2 at -5.2 K

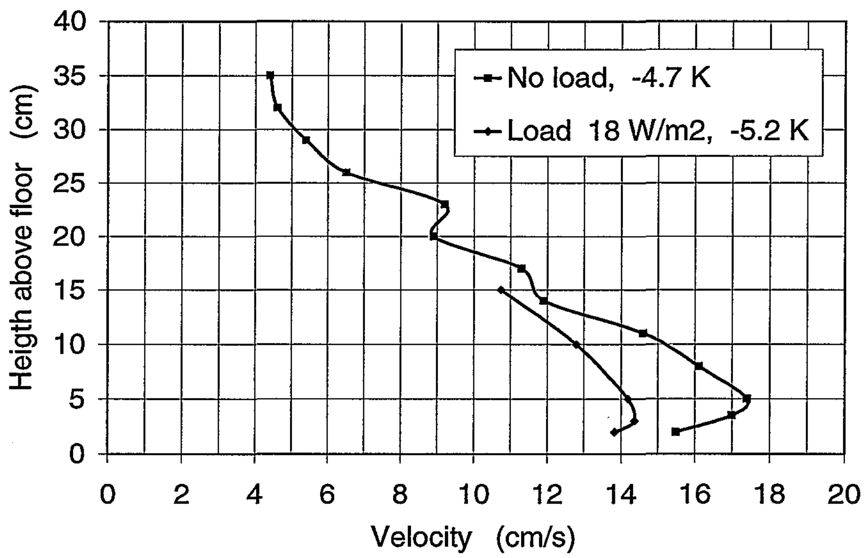

Figure 3 gives velocities in the room at a distance of 1 m from the glazing. The dependence on the load is reverse, i.e. the velocities became smaller with higher load. Table 2 contains the measured peak velocities for different conditions.

Passive Measures

In order to reduce the peak velocities passive measures like flow obstacles on the sill surface or openings in the sill were investigated. Flow obstacles of 19 to 38 mm height caused a small velocity reduction at the window distance of 0.5 m, but none at the larger distance of 1m.

Openings were made in the window sill to take up the downdraught and to release it again at a lower speed through a perforated metal sheet mounted below the sill, see figure 4. The upper openings in the sill could be realised in the real building by thin, inclined metal stripes running parallel to the window and having a high percentage of open area. The area percentage of the upper openings and of the perforations in the metal sheet were chosen in order to match their pressure drops.

Table 2. Measured peak velocities for different loads and glazing heights and temperatures

glazing height	[m]	2.0	2.0	2.0	2.0	2.0	2.0	1.4	1.4
relative glazing temperature	[K]	7	4.7	5.2	5.6	3.7	2.8	5.3	2.9
heat load	[W/m^2]	0	0	18	27	18	18	18	18
peak velocity at the glazing	[cm/s]	32	26	23	18	13	14	16	11
peak velocity at 0.5 m distance	[cm/s]		18	16	17	16	16	16	12
peak velocity at 1.0 m distance	[cm/s]		17	15	15	12	11	15	11

Figure 4.
Openings in the window sill;
perforated metal sheet as front cover with square holes of 5 mm and 44% of open area

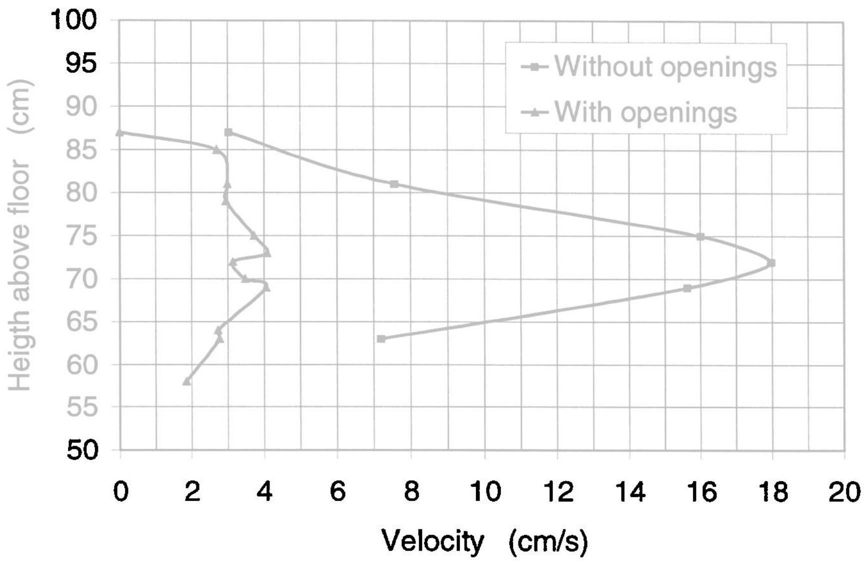

Figure 5.
Vertical velocity profiles in the room at a distance of 0.5 m to the glazing,
with and without openings in the window sill,
standard conditions (2m, -5.2 K, 18 W/m^2).

The visualisation showed that approximately half of the downdraught flowed through the openings and the rest over the sill as before. But the measured velocities displayed in figure 5 were strongly reduced at the short glazing distance. Even at a distance of 1 m there was still a velocity reduction of 2 to 4 cm/s. The reason for the higher velocities at this distance than at 0.5 m was thought to be the gravity accelerating the cold air towards the floor. To further reduce the air velocity at 1 m distance the so to call downdraught channel below the window sill would therefore better be extended to the floor with the perforated metal sheet placed on the lower part of the front cover.

COMPARISON WITH ANALYTICAL VALUES

Boundary layer flow along the vertical surface

According to Eckert [1], the velocity profile of the turbulent boundary layer flow along a vertical surface can be described as:

$$w(z,y) = \frac{\nu}{z} \cdot 1.005 \cdot Gr_z^{1/2} \cdot \left(\frac{y}{\delta_s}\right)^{1/7} \cdot \left(1 - \frac{y}{\delta_s}\right)^4, \qquad \delta_s = 0.595 \cdot z \cdot Gr_z^{-1/10} \cdot \qquad (1)$$

with Gr_z Grashof number (related to ΔT, the temperature difference between window pane surface temperature and average room air temperature [K], and to z), y horizontal distance from wall [m], z downstream boundary layer position [m], δ_s velocity boundary layer thickness [m], ν kinematic viscosity [m2/sec].

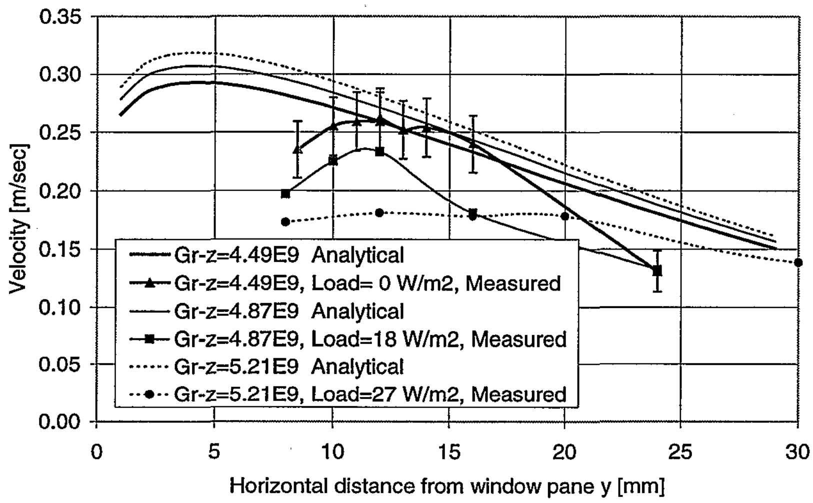

Figure 6.
Velocity profile in the down draught flow at z= 1.9 m (lower end of window) for three different Gr_z numbers. Analytical values and measured values for three different internal load conditions.
For clarification, error bars for the measured values are given only for one case.

Figure 6 gives profiles according to (1) and the comparison with measured velocities for the same Gr_z numbers, but with increasing internal loads. While in the case of no internal load, higher Gr_z numbers result in higher velocities, in the cases with both increased Gr_z numbers and increased internal load, a decrease of the velocities is observed in the measurements.
For cases with no internal load, the measured peak velocity values are in good agreement with values using (2), postulated by Kriegel [3] for turbulent downdraughts along vertical walls:

$$w(z)_{\max} = 1.25 \cdot \frac{\nu}{z} \cdot Gr_z^{0.45} \qquad (2)$$

Flow development along the floor

For the flow development of a downdraught flow along the floor Heiselberg [6], [7] gives for the region (0.4 m < y < 2.0 m):

$$v_{\max} = 0.095 \cdot \frac{(H \cdot \Delta T)^{0.5}}{y + 1.32} \cdot \qquad (3)$$

H height of vertical cold surface (window), ΔT see above (Gr_z). Due to the set-up with the window sill, equation (3) is not directly applicable. Nevertheless, taking in equation (3) the window plus the sill height (= 0.76 m) as the relevant height (H = h + 0.76 m), close agreement with measured peak velocity values can be found, for a location close to the floor in a distance of y = 1 m from the window pane (see table 3).

DISCUSSION AND CONCLUSION

Our measurements have shown a clear effect of the heat load in the room on the velocity profile of the downdraught along the window. With no internal load our measurements

Table 3. Velocities close to the floor in a horizontal distance of 1 m from the window

Temperature difference ΔT [K]		3.7	2.8	4.7	5.2	5.6	2.9	5.3
Internal load [W/m^2]		18	18	0	18	27	18	18
Window height h [m]		2.0	2.0	2.0	2.0	2.0	1.4	1.4
Measured velocity [m/sec] Error ± 0.02		0.12	0.11	0.17	0.15	0.15	0.11	0.15
Velocity acc. to	H=h	0.11	0.10	0.13	0.13	0.14	0.08	0.11
equation (5) [m/sec]	H=h + 0.76m	0.13	0.11	0.15	0.16	0.16	0.10	0.14

showed a downdraught boundary layer thickness of about 30 mm, which is in good agreement with measurements of Braendli [4]. With the heat load the layer thickness was increased but the peak velocity was lower than in a situation with no heat production. This effect may be explained by the plumes, generated by the heat loads, which spread at the ceiling and circulate down again, partly together with the downdraught flow along the window. For the velocities along the floor Heiselberg's equation (3) gives satisfactory results, even for windows with a sill if the height from the window top to the floor is considered as the relevant height H.

Roughness elements on the window sill showed only very little effect on the air velocity in the occupied zone, but a significant reduction was achieved with openings in the window sill. However, this was only true for a region close to the window. Due to the fact that the openings could only be placed in the upper part of the window sill, the air fell down again and in 1 m distance from the window the effect was again very marginal. A further test indicated that with openings in the window sill both at the top and close to the floor, a significant reduction of the draught risk in the room could be achieved.

With respect to the specific project in Zug the finding was that an unacceptable draught risk in the occupied zone must be expected only under very extreme climatic conditions. The critical element is not the window pane itself but the window frame. Based on these results it was decided to use neither active (heating) nor passive measures (roughness elements, openings in the sill) to compensate the downdraught.

ACKNOWLEGDEMENTS

This work was conducted under the financial support of the 'Hochbauamt des Kantons Zug'.

REFERENCES

1. Eckert E R G, Jackson T W. 1951. *Analysis of turbulent free-convection boundary layer on flat plate.* NACA Report 1015
2. Merker, G P. 1987. *Konvektive Wärmeübertragung*, pp 273-314. In Wärme- und Stoffübertragung, U. Grigull, eds. Berlin: Springer-Verlag
3. Kriegel, B. 1973. *Fallströmungen vor Abkühlungsflächen in Gebäuden und mögliche Schutzmassnahmen.* PhD Thesis Technische Universität Berlin
4. Braendli, M. 1998. *Einfluss der IR-Absorption von Wasserdampf auf den laminar-turbulenten Uebergang in der Grenzschichtstroemung der Luft an vertikalen Waenden.* PhD Thesis Nr. 12926 Eidgenoessische Technische Hochschule Zuerich
5. CEN-report 1752. *Ventilation for Buildings: Design Criteria for the Indoor Environment.* Publication in progress
6. Heiselberg, P. 1994. *Draught risk from cold vertical surfaces.* Building and Environment, Vol. 29, No. 3.
7. Heiselberg, P, Overby, H and Bjørn, E. 1994. *The effect of obstacles on the boundary layer flow at a vertical surface.* Aalborg University, Denmark