Limits of Natural Ventilation through Windows in Office Buildings

Olaf Zeidler, Klaus Fitzner

Hermann-Rietschel-Institute
Technical University Berlin

ABSTRACT

Many HVAC systems built in the time between 1960 and 1980 have now reached the end of their lifetime and require retrofitting. When HVAC retrofits are performed in connection with building renovation, there is often a potential for reduction of thermal loads. The question whether a renovated building should have an airconditioning plant or free ventilation often revolves around arguments of energy consumption and investment. However it is not taken into account that there can be no thermal comfort in many cases of cooling loads and outdoor temperatures. For the buildings with HVAC-systems the room air flow is well known, but the flow when an open window is mostly unknown.

In this research project at the Hermann-Rietschel-Institute investigations are made on ventilation by opening the windows. The limits of free ventilation with windows are given by air temperature and air velocity. Now we have first results of the still ongoing investigations.

POTENTIAL OF RETROFITTING HVAC-SYSTEMS IN GERMANY

Since the 1960's in Germany office buildings were built with HVAC-Systems. These systems reach the end of their lifetime after 20..30 years of operation. The conditions of many systems are bad and ineffective. Retrofitting of HVAC-systems built in 1960-1980 is necessary. First one has to know how many HVAC-systems were built in these years. Therefore data from statistical year books and data about the trade in the HVAC business were taken to calculate the number of HVAC systems.

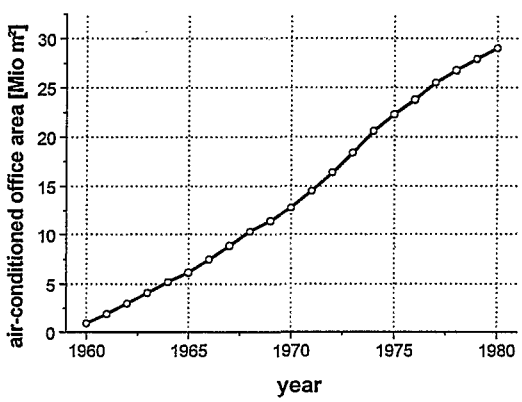

Fig. 1: Cumulated air-conditioned office area in Germany

In Fig.1 the cumulated air-conditioned office area built between 1960 and 1980 in Germany is shown. Until the year 1980 there are 28 Million m² office area served by HVAC-Systems. Market analysis of different HVAC-Systems showed that about 20 Million m² useable floor space in office buildings is served by HVAC-systems that have to be retrofitted. By setting an

average of 2000 m² for each system, there will be about 10.000 systems that have to be retrofitted in the next years.

TESTING PLANT

The air distribution in buildings with HVAC-systems is well known, but the air flow and the application limits for ventilation by windows are mostly unknown.

Within the framework of the research project SANIREV, which deals with retrofitting of HVAC-systems, investigations about airflow in a room when the window is open are made. The values of air velocity and air temperature will be measured for different roomloads and outdoor temperatures. The limits of ventilating with windows are set by a maximum for air velocity and a minimum for air temperature.

For the study of the room air flow with open windows, a test chamber was constructed. The test chamber has two areas. One of these areas simulates outdoor conditions using a cooling or heating coil. The second larger area represents an office with its heat sources. Fig. 1 shows the layout of the test chamber.

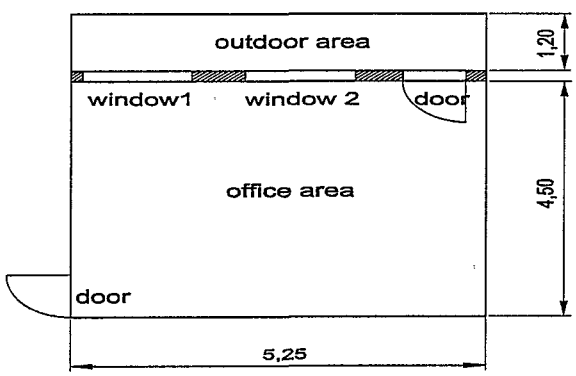

Fig. 2: Layout of the test chamber

There are two windows in the envelope element. The right window on each side can be tilted or opened fully. The left ones open fully and the lower right windows are non-operable. Fig. 2 shows the elevation of the facade, viewed from the office area.

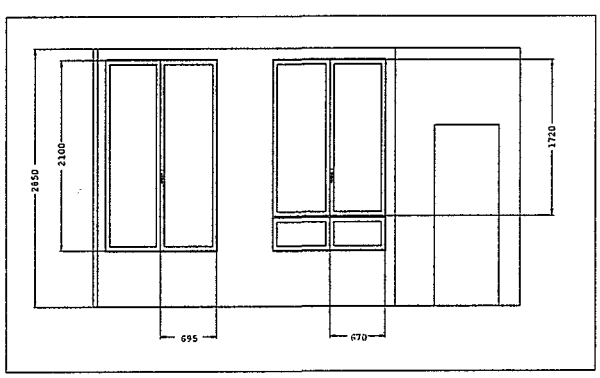

Fig.3: View of the facade element (interior elevation)

AIRFLOW WHEN A WINDOW IS OPEN

The air flow is a result of wind and thermal buoyancy. If the wind is too strong, windows will be closed anyway. Therefore, the most critical cases are the ventilation through the window by thermal buoyancy. Fig. 4 shows the important cases for the investigation.

	Summer	Winter
Wind	High air velocities ⇨ risk of draught	High air velocities ⇨ draught ⇨ low temperatures in the room
No Wind	**Low air exchange rate** ⇨ **critical case**	**High temperature differences** ⇨ **high air velocities => risk of draught** ⇨ **low temperatures in the room** ⇨ **critical case**

Fig. 4: Most critical cases

When the outdoor temperature is lower than the temperature in the room there will be a pressure difference between inside and outside. Therefore, the air flows into the room through the lower part of the open window. (Fig. 5). The supply air enters with a low impulse into the room. If a window is tilted, there will be two air streams on each side of the window. Similar to the displacement flow (source flow) the air falls down and creates a layer of fresh air across the floor.

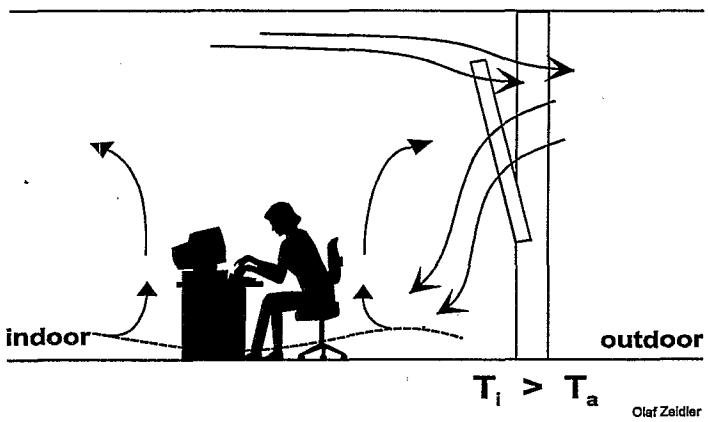

Fig. 5: Air flow in a room when a window is open

At warm objects or persons a buoyancy flow from this layer rises up. The warm air at the ceiling exits at the top of the window. Altogether the incoming mass flow is equal to the outgoing flow.

EXPERIMENTS

There are two windows in the envelope element. The windows can be tilted or opened fully. The experiments were done with one or with both windows tilted, with a variation of the opening area. Measurements were made for different outdoor temperatures and indoor cooling loads. Windows and heat sources in the room are adjusted to retain a temperature of 22 °C in the room. These measurements are made for steady state conditions.

The people in a room with ventilation by windows have the same comfort criteria as in mechanical ventilated rooms. Therefore the limits of thermal comfort in this investigation are:

- Air velocity: < 0,15 m/s
- Air temperature: 22 °C
- Temperature in 0,1 m: > 20 °C

RESULTS

The thermal comfort for the people in the room depends on the air velocity and the air temperature. If air velocities are higher than 0,15 m/s or the air temperature in floor level is below 20 °C people perceive draught.

In Fig. 6 the measured air velocities in floor level vs. the outdoor temperature are shown. The values are average values between the window and the distance of 1,3 m from the window. There are two hatched areas. They represent different relative open areas of the windows. The given area is related to a 1 m length of the window.

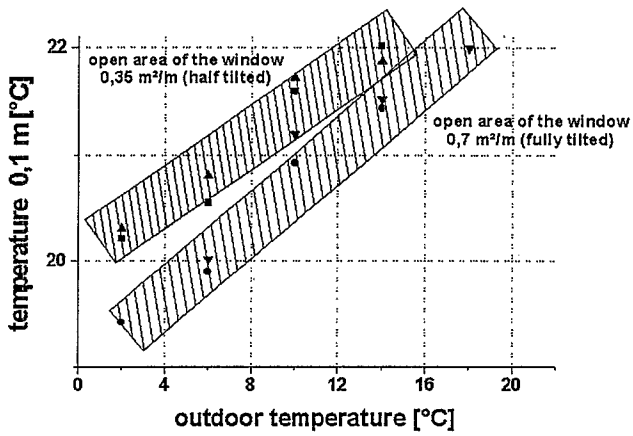

Fig. 6: Air temperatures above the floor

For an open area of 0,35 m²/m the indoor temperature above the ground will stay in the 20 °C limit until the outdoor temperature reaches the range of 0 °C. If the windows will be more opened the 20 °C limit will be reached at higher outdoor temperatures. Small openings causes a small air volume coming through each of them, therefore there will be a better temperature distribution in the room.

Fig. 7 shows the measured air velocities vs. outdoor temperature in the same style as in Fig. 6. There are two different hatched areas for the different openings.

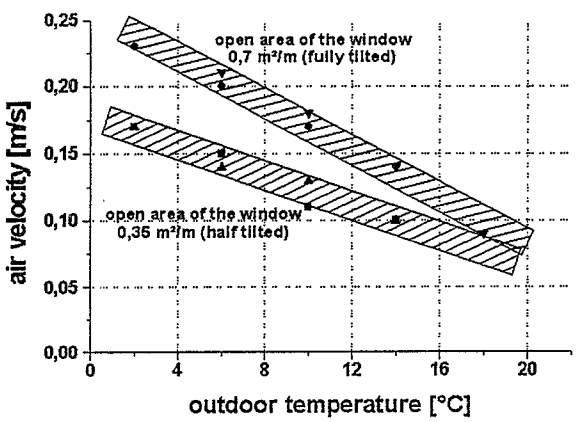

Fig. 7: Air velocity above the ground

With a related opening of 0,35 m²/m the velocity limit can be kept until outdoor temperatures of 6 °C. Wider openings causes higher air velocities. An opening of 0,7 m²/m reaches the

application area at an outdoor temperature of 10 °C. Lower outdoor temperatures causes air velocities higher than 0,15 m/s.

The air velocity in the room depends on the number of openings in the facade. A higher number of openings with the same total opening area causes a better distribution of the supplied air, therefore the measured air velocities will be lower. Fig. 8 shows the influence of the number of openings. Therefore the air velocity above the ground is shown vs. the cooling load in the room.

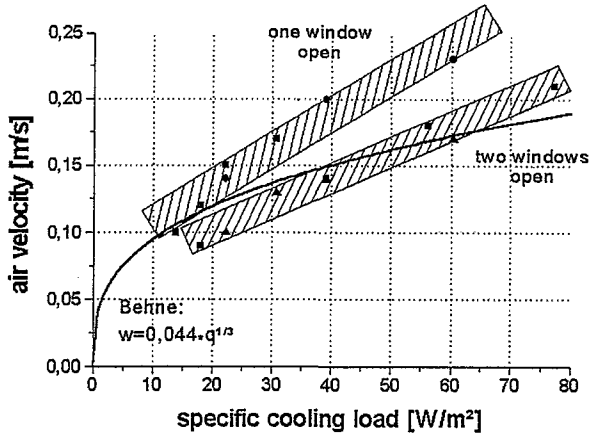

Fig. 8: Air velocity (0,1 m) depending on cooling load

In addition to the measured values the calculated line for the expected air velocities with displacement ventilation (source flow) is shown. This line is calculated by Dr. M. Behne at Hermann-Rietschel-Institute.

The measured values are placed in two significant areas. One above the calculated line and one in the same position as the line. If there is one window tilted there will be two supply air streams. One at each side of the window. When two windows are open there will be four air streams. Therefore, the distribution of the supplied air is better. For the same cooling load the expected air velocity is lower when two windows are open. The total supply air volume has to be the same, so the supply air volume through each opening is smaller. In this figure the limits for the cooling loads will be given as well. When respecting the 0,15 m/s limit the maximum cooling load is about 25..30 W/m² for one open window and about 40..45 W/m² for two windows. It will be easier to reach the comfort limits with more smaller openings then with a few bigger ones.

The German Test Reference Year (TRY) is a constructed year with outdoor temperatures and radiation. It is made of average values of the last 20 years. There are different data for different regions in Germany. In Fig. 9 the hours in which the given temperature limits are reached were counted. These values are for TRY 3 (Berlin).

Specification	Hours/Year
Office time 8°°-18°°	4015 h
8°°-18°° and 10° C-22 °C	1787 h
8°°-18°° and < 10 °C	1962 h
8°°-18°° and > 22 °C	266 h

Fig. 9: Time when ventilation by windows can be used

Figure 9 shows that in perhaps one half of the year the window should be shut because of the risk of draught and while about three weeks the outdoor temperature is too high.

Conclusion

In the next years many office buildings have to be renovated. In most of the buildings a HVAC-system is necessary. In the winter there will be the risk of draught and in summer the room temperatures can reach values higher than the limits of comfort criteria. But in the interseason cooling loads can be removed when the following points are followed.

- For one open window the limit is about 25 W/m²
- For two open windows the limit is about 40 W/m²
- The outdoor temperature should not be below 6..10 °C (depending on the construction of the windows)

A limit for the cooling load for each supply opening can be given (250..300 W/air stream). In the design of future buildings there should be windows in different sizes and with adjustable window panes. So the people can adjust the optimal supply volume. Nevertheless, ventilating by windows has a limited application area in office buildings.

Acknowledgements

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