

Investigation of the Impact of Natural Ventilation through Windows on the Thermal Comfort

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When talking about air-conditioning systems in buildings people argue with high energy consumption of those systems. They do not take into account that it is not possible in many climates to realise several indoor thermal conditions by merely opening windows

Within the framework of the research project SANIREV, sponsored by BMBF and ROM, the Hermann-Rietschel-Institute make tests about the use of window ventilation. For different roomloads and out-door-conditions the room conditions are determined. Now we got the first results. The limits of ventilation by opening windows are set by thermal comfort. Its parameters are temperature and air velocity.

Limits of thermal comfort

The German standard DIN 1946/2 reads that thermal comfort is fulfilled for people, if they are contented with the temperature, moisture and air velocity in their surrounding.

The thermal comfort is be influenced by the activity of the person, the clothes, the air temperature, the temperature of the surrounding surfaces, air velocity and moisture. These factors are influencing themselves mutually. Fig. 1 shows the range of thermal comfort according to DIN 1946/2.

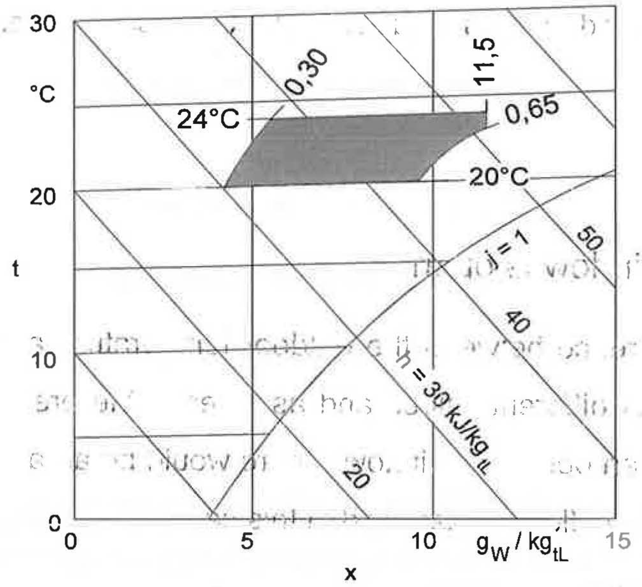

Fig. 1: h-x-diagram

This diagram shows the range of thermal comfort with the parameters temperature and humidity, for a sitting person with normal activity and clothing.

An other influence to the thermal comfort is the vertical gradient in air temperature. The limit for that rise is defined with the temperature gradient between 0.1m and 1.1m height. These are the positions of the ankle and the head. Newer publications point out that it is important to realise temperatures in the range of thermal comfort in the head and ankle area. So the influence of the temperature difference is smaller. Air velocity where a person feels comfortable depends on temperature and turbulent intensity. Normally, draught is found by air velocities above 0,15 m/s. For the thermal comfort all other parameters must be in the comfort range. It follows a list for the limits that have been set in this investigation.

Air velocity	:	0,15 m/s
air temperature	:	22 °C
temperature gradient	:	< 3 K

An other aspect for thermal comfort is the air quality in the room. A good air quality in offices is important for the feeling and health of the people. For a good air quality it is necessary to supply the room with enough fresh air. The ventilation rates depends on the building, the materials used in the rooms and the users´ behaviour. In DIN 1946/2 guidelines for the ventilation rates are given. For office rooms a minimum air volume of 30 m³/h and person and 20 m³/h for each smoker are given in that standard.

Air flow when a window is open

Because of the difference between the outdoor temperature and room temperature the density of air has different values and as a result the pressure is different. We take the example of an openable window. There would be an air exchange when the window is open. This air flow is examined in this case.

The outdoor temperature is lower than indoor temperature. The supply air comes in over the bottom part of the window and the exhausted air flows out over the top. It is allowed to set the area from the incoming air equal with the outgoing air. Fig. 2 shows the case of a room flow for a top hung.

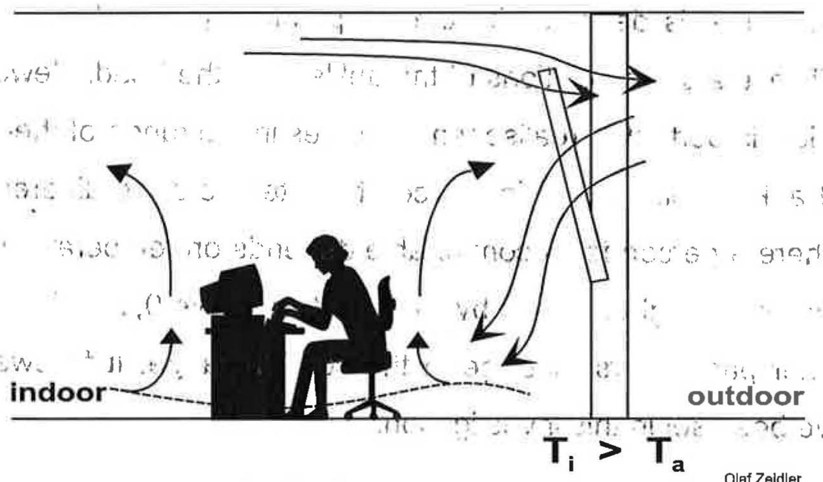

***Fig 2:** room flow when a window is open*

Similarly to the displacement flow it creates a see of fresh air across the floor. At warm objects or persons we get a buoyancy flow. The warm air under the ceiling flows over the top of the window in the surroundings.

Model for the flow-calculation

For the calculation of the flow the following suppositions were made:

1) - The forcing parameter for the incoming air results from the different densities between indoor air and outdoor.

The outdoor temperature is lower than the indoor temperature.

- The volume of the incoming air is equal to That of the outgoing air

No crossover air supply (not two windows open)

2) - The inlet area is equal to the outlet area

3) - The incoming air is symmetrically distributed over the inlet area

4) - ~~Warm objets are distributed regular over the room~~

5) - The air flow is not obstructed by furniture

6) - The influence of the wind is ignored

Air volume

The air volume is calculated with the half of the windows opening area and the air velocity at the inlet area. The air velocity at the inlet is defined by the different densities between room and surrounding and the effective height. The effective height is the distance between the lines of the centre area in inlet and outlet flow. The pressure balance between the inside and the outside is made by air exchange. Temperature and density of the air connect with the following equation

$$\Delta \rho/\rho \approx |\Delta T|/T \quad (1)$$

ρ, $\Delta \rho$ = density, -difference

T; Δ T = absolute temperature, -difference

When air is flowing through an open window, there is a loss of pressure. The equation for the calculation of the velocity of the incoming air in the open area of the window includes a drag coefficient ζ = 1,25.

$$w_X = \sqrt{2 * g * h * \frac{1}{(1+\zeta)} * \frac{\Delta T}{T_A}} \qquad (4)$$

h = effective distance

ζ = drag coefficient

T_A = outside temperature

The supposition No. 3 said, air velocity of incoming and outgoing air is equally distributed over the specific area. Therefore the calculation of the airflow takes the middle velocity in the centre of the area.

The inlet area is half of the total opening area (supposition No. 3). For a tilt window the equation for the opening area is

$$E = a^2 * \sin \beta + \frac{1}{2} * b * c \qquad (2)$$

a = height of the window

b = width of the window

c = edge in the flow

ß = opening angle

The equation of the airflow is:

$$\dot{V}_{zu} = E * \overline{w}_x \qquad (3)$$

Cooling power when the window is open

When the window is open, the airflow has to neutralise the cooling load. If the temperature in the outside is lower then in the inside, a cooling power depends on the range of the opening area and the temperature difference between inside and outside. The equation 4 shows the calculation

$$\dot{Q} = \dot{V}_{zu} * \rho_L * c_{pL} * \Delta T \quad (4)$$

c_{pL} = heat capacity

ρ_L = air density

Air velocity above the ground

The thermal comfort depends on the air velocity in the room. For non isothermal flow the equation No. 5 shows the calculation of velocity in the ground area. This empirical equation is the result of investigations in displacement flow.

$$w_B = \sqrt[3]{\dot{q}\frac{2*g*h_z}{\rho_L * c_{pL} * T}} \quad (5)$$

$\dot{q} = \frac{\dot{Q}}{A}$ = relative cooling load

h_Z = distance above te floor

A = ground area

Temperature above the ground

The density of the incoming air is higher than the density of the air in the room. The cool incoming air sinks down to the ground. On the way down its temperature is rising. Against the thermal buoyancy there is a slowdown because the incoming air mixes with-room air. The temperature above the ground is calculated with the following empiric equation.

$$T_{LB} = T_R - C * \frac{\dot{Q}_K}{\rho_L * c_{PL} * \dot{V}_{zu}} \quad (6)$$

T_R = air temperature in 1.1 m

T_{LB} = airtemperature in 0,1 m

C = parameter for the distribution of the cooling load

Calculations

The equations that have been presented permit to calculate room-air velocity and the maximum of specific cooling power under given exterior air conditions. The program used is based on a spread sheet calculation program. Exterior temperatures and the window's opening angles can be varied. The exchanged air volume and the resulting specific cooling power can be determined this way. The results of the calculations will be presented in the chapter results.

Construction of the testing plant

The results of the presented equations have been checked experimentally. This has been done in a specially equipped room of the Hermann-Rietschel-Institute. For further study of the room flow caused by an open window a testing plant is constructed. The results of former experimentation and calculations serve as a basis. The testing plant is divided in two areas by a facade element. In one of these areas (outside) an outdoor atmosphere is created by an air cooler. The cooler works in the split principle. The larger area represents an office with its sources of heat.

Measures of air velocity and temperature are processed while windows are open. Fig. 3 shows the ground plan of the testing plant.

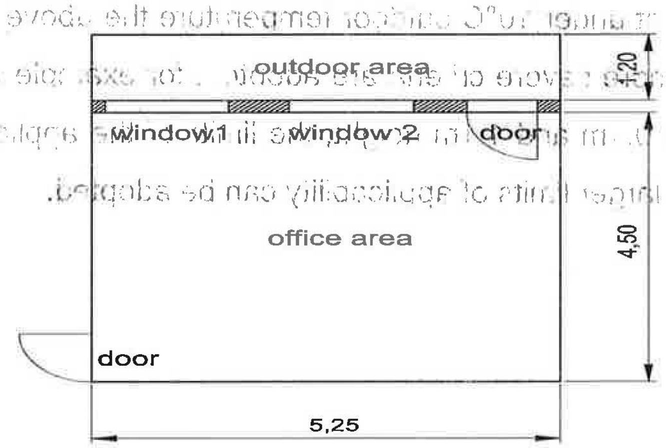

Fig. 3: ground plan of the testing plant

The facade element is composed of two differently sized windows. One is a tilt window the other is a rotative one. The fig. 4 shows the view to the facade element from the office area.

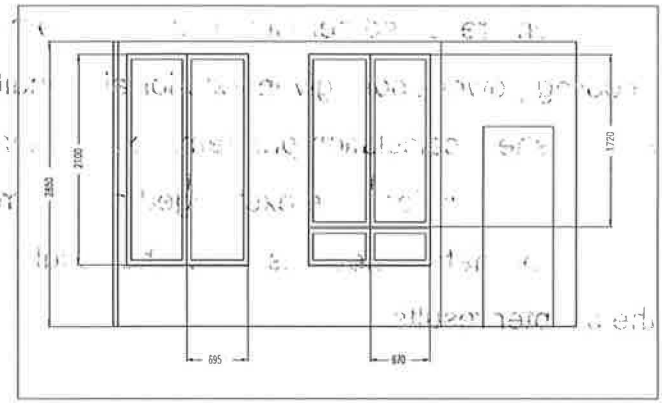

Fig.4: view of the facade element

Results

The resulting displacement flow caused by an open window is calculated with the given data and methods. At different outdoor temperatures the air volume is calculated. In Fig.5 you find air volume over outdoor temperature. The air velocity at floor level as well as the temperature differences between floor level and 1.1m are given as parameters.

It can be noticed that under 10°C outdoor temperature the above fixed comfort limits cannot be held. If more savere criteria are adopted, for example for the temperature difference between 0.1m and 1.1m height, the limits of the applicability is 14°C. For less severe criteria larger limits of applicability can be adopted.

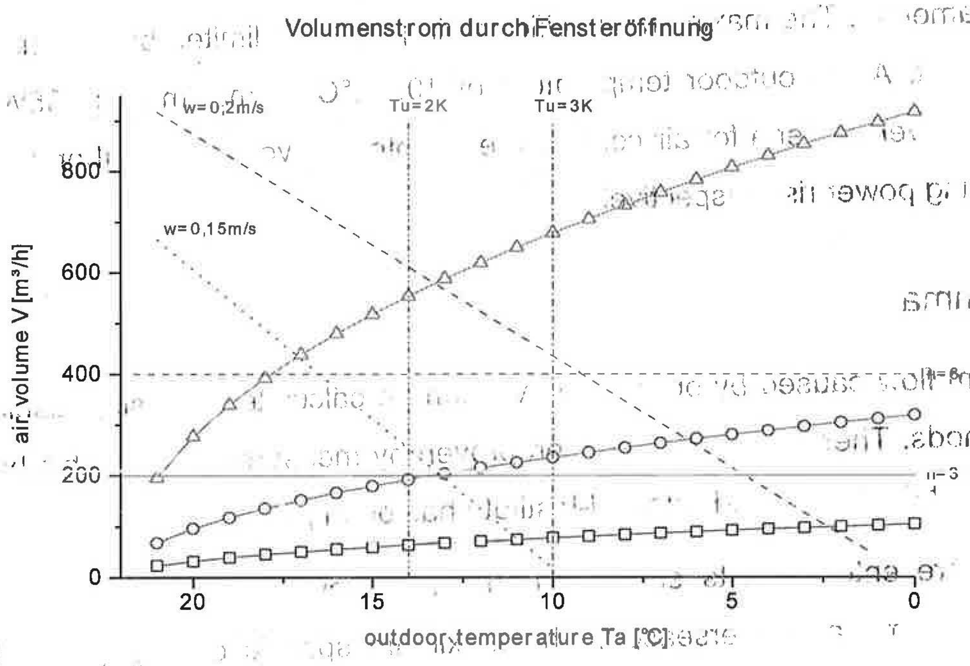

Fig 5: air volume-outdoor temperature

In summertime often thermal loads have to be transported. In fig. 6 you find the specific cooling power for different opening angles of the window as a function of the outdoor temperature.

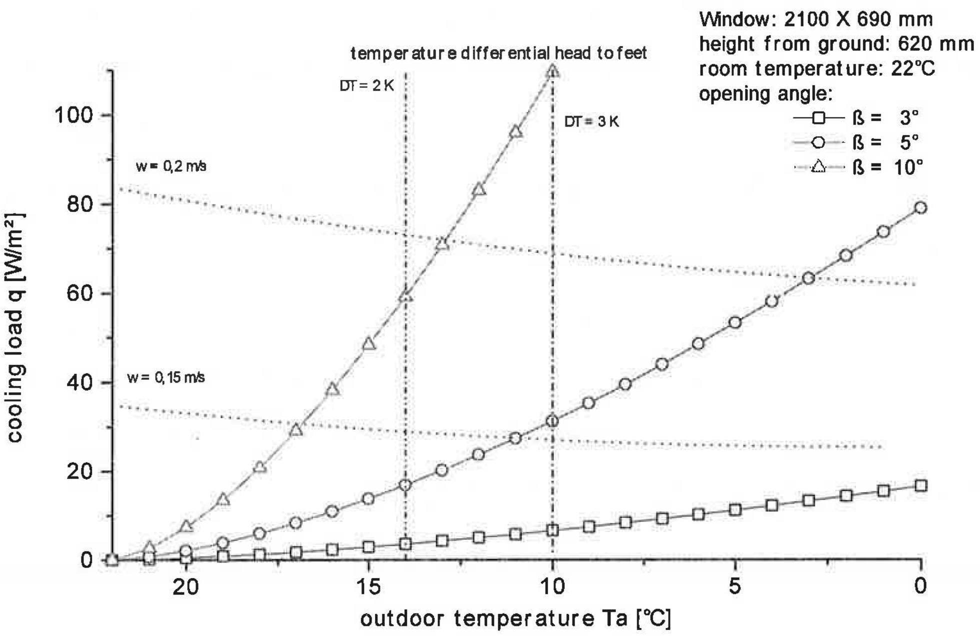

Fig 6: specific cooling load

In this figure you can find also air velocity and the temperature difference as parameters. The maximum specific cooling power is limited by the criteria of thermal comfort. At an outdoor temperature of 10..22°C its maximum is 35W/m². Again, it less savere criteria for air comfort are adopted air volume and therefore the specific cooling power rise respectively.

Summary

Room flow caused by open Windows can be calculated by using displacement flow methods. These results have been proven by measurement. On this basis a testing plant at the Hermann-Rietschel-Institute has been put up.

The presented results show , an open window can transport cooling loads in summertime and interseason. The maximum specific cooling power is 35 W/m². Below 10°C outdoor temperature thermal comfort can be no longer guaranteed. Opening windows in office buildings have an limited application area. The thermal comfort is more important than the cooling power, in summertime a higher temperature is more acceptable as draught in the cool seasons.