Tommorrow´s Architecture
and the consideration of building physics

Hans-Peter Leimer*

SUMMARY

Nowadays office buildings are more and more often required to guaranty defined climatic conditions. At the same time they are supposed to be based on new technological concepts with regard to the existing office buildings. In addition to the representative function of these buildings it is the aim to reduce the total energy consumption and the CO_2-output. The user should get the sensation of “natural ventilation”.

This type of building shall create an inner atmosphere within a surrounding cover that satisfies the highest demands of comfort and security. Due to this kind of construction it is possible to develop locations which are able to cope with difficult situations of urban development (e.g. noise immission). (1)

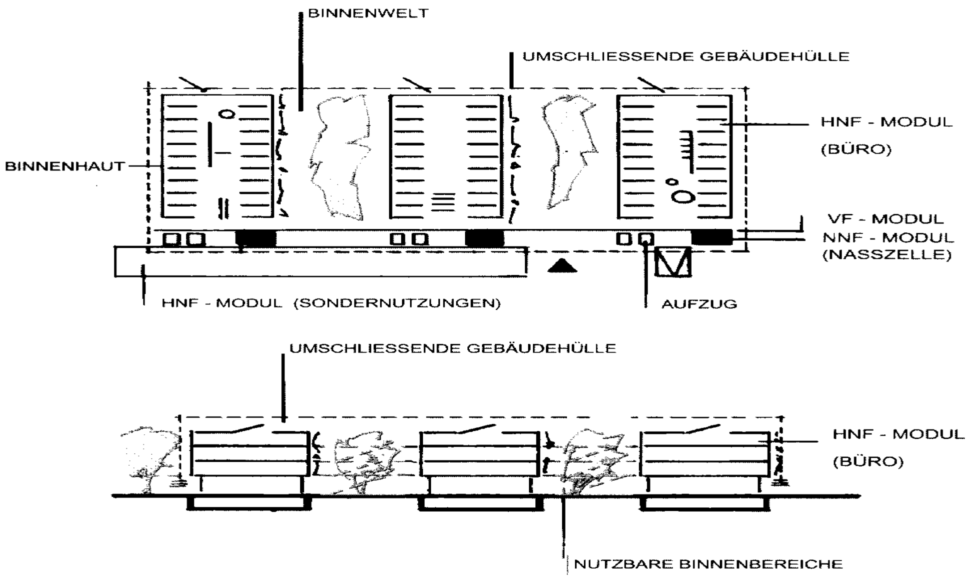

Figure 1 Company type, upper standard

One of these building types of the new generation is the construction of the LandesBauSparkasse LBS in Hannover. In accordance with the world exhibition EXPO 2000 it shall represent the innovation of buildings depending on the main idea of the EXPO “Man, Nature, Engineering”.

* Dr. Hans-Peter Leimer, BBS Ingenieurbüro, Am Forst 27, 38202 Wolfenbüttel, Germany

The new building of the LBS in Hannover-Bemerode consists of four administration units with four stories each. The cubes are divided by winter gardens and contain an atrium which is surrounded by open multifunctional offices. The whole building is covered by a steel-glass-construction. With regard to the big glazed surface of the cover the development of the temperature in the summer is a serious problem.

The knowledge of the present heat flow is of high importance for a climatic analysis. Therefore the heat losses (in general by transmission and ventilation) as well as the heat gains (in general by solar gains of components of inner heat, like people and machines) have to be taken into consideration. To analyze the climatic conditions of buildings it is necessary to have accurate data of the actual heat flow. The best results can be achieved by calculations of the unsteady state. The heat flow must be divided into heat losses (transmission and ventilation) and heat gains (solar gains and so called inner heat components like persons and machines).

The climatic room conditions are mainly influenced by the room temperature, moisture content, velocity of the air and the temperature of the surrounding surfaces. The development of the temperature in the summer can be described by the heat flow in close relationship with the storage capacity of building materials. In addition to this the temperature is influenced by solar heat gains, depending on the transmission coefficient g of the glass. Furthermore the intensity of activity, clothes and time of stay contribute to the comfort of human beings.

An **integral building model** was used to demonstrate the temperature in the courtyards, atria and offices; the air circulation in the courtyards; the daylight in the offices; the development of moisture in the construction elements considering the connected heat and moisture transport; noise insulation of the offices; room acoustics in the halls and yards.

1 CALCULATION OF DYNAMIC BUILDING SIMULATIONS

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For the calculation the program TRNSYS (Transient System Simulation Program/ University of Wisconsin) was used. This program simulates thermal unsteady systems in consideration of actual data. The variation of boundary conditions allows the evaluation of the design and construction and its influence on the room climate.

Climate: To simulate the outside climate the data is based on the test-reference-year of zone 2 -TRY 02- in accordance with the measurements of the weather station in Hannover-Langenhagen.

Building model: The building was generated in accordance with its location in Hannover-Bemerode, position to earth, in consideration of its geometry, building units and building materials, use and outside climate.

Building units and building materials: The following attributes of building material are taken into consideration: absorption (outwards building units); thermal conductivity; thermal storage; absorption, reflection and transmission of glasses. Shadows in areas of glazed surfaces are also considered. Sun protection will be employed at the western offices when radiation exceeds 200 W/m².

Comfort/ boundary temperature/ critical hours: To evaluate the comfort of the room zones the PMV-value is calculated in accordance with DIN EN ISO 7730. Therefore the middle boundary temperature for “comfortable” is 27°C and for “warm” 29°C. Following the universally accepted rules for comfortable conditions it is suggested not to exceed the room temperature of 26°C. This temperature should not or just for a short time be exceeded because otherwise a comfortable sensation can not be obtained. The critical hours indicate the amount of time in which the room temperature is above the boundary temperature. Of course the time should be as little as possible.

Use of building: The use of a building has a strong influence on the climatic conditions in the room zones, especially by heating and cooling, interior heat sources and ventilation. These factors can have a positive or negative effect depending on the season. For this calculation a special ventilation concept is used.

<u>1st variant</u>

- natural ventilation of the offices, mechanical ventilation of the atria and combined working-zones
- exhaust air of offices, atria and combi-zones by mechanical exhauster

General

- western offices obtain fresh air by natural ventilation (windows)
- The calculation is based on a required air flow of 60 m3/h per office and person following DIN 1946 T2

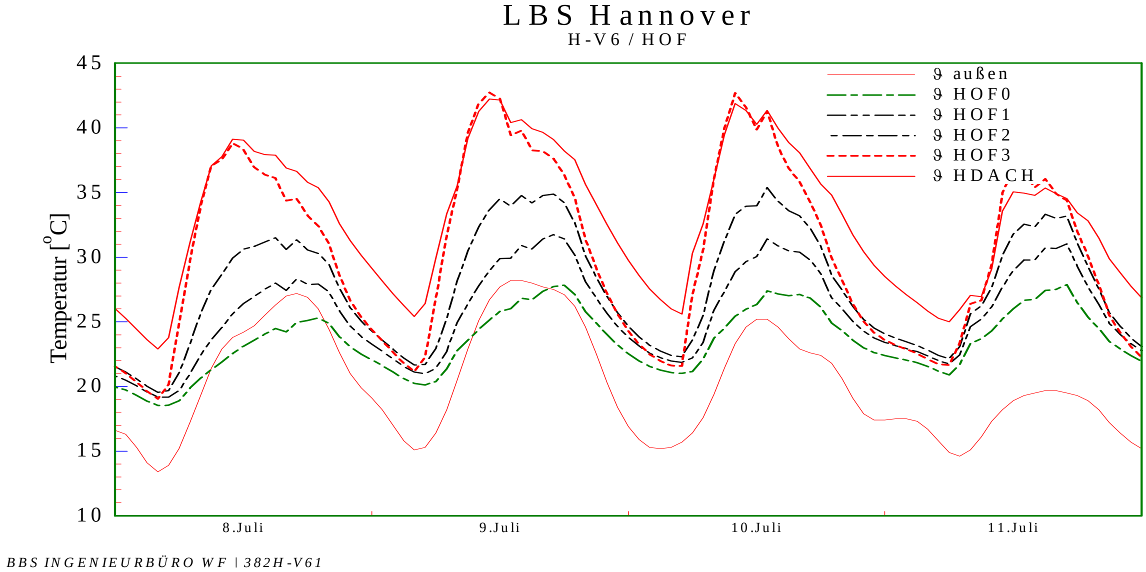
If the temperature in office "SOUTH/ floor 3" exceeds 20°C the ventilation at night will be activated. In this case the flap of the vertical courtyard facades, the windows of the offices and the flaps in the atria will be opened. The openings in the area of the courtyard will remain closed to force an air movement through the offices.

1.1 Simulation calculation for the summer season

The calculation was carried out with TRY 2. Thus the temperatures consider a representative summer situation. Of course higher temperatures, e.g. in summer 1997, or lower temperatures during a rainy summer are possible.

In consideration of the mentioned boundary values the development of the interior temperatures of the different room zones is calculated. In general the room temperature is the decisive criteria, but for the office zones it is the felt temperature (mean value of air temperature and radiation temperature).

So the maximum room temperature as absolute value is measured. In addition to this the time in which the temperature is above the boundary temperature is measured. The measurement data offer precise information about the climatic situation and the comfort in the rooms. The development of the temperature in the courtyards is shown in the following figures for the different floors.



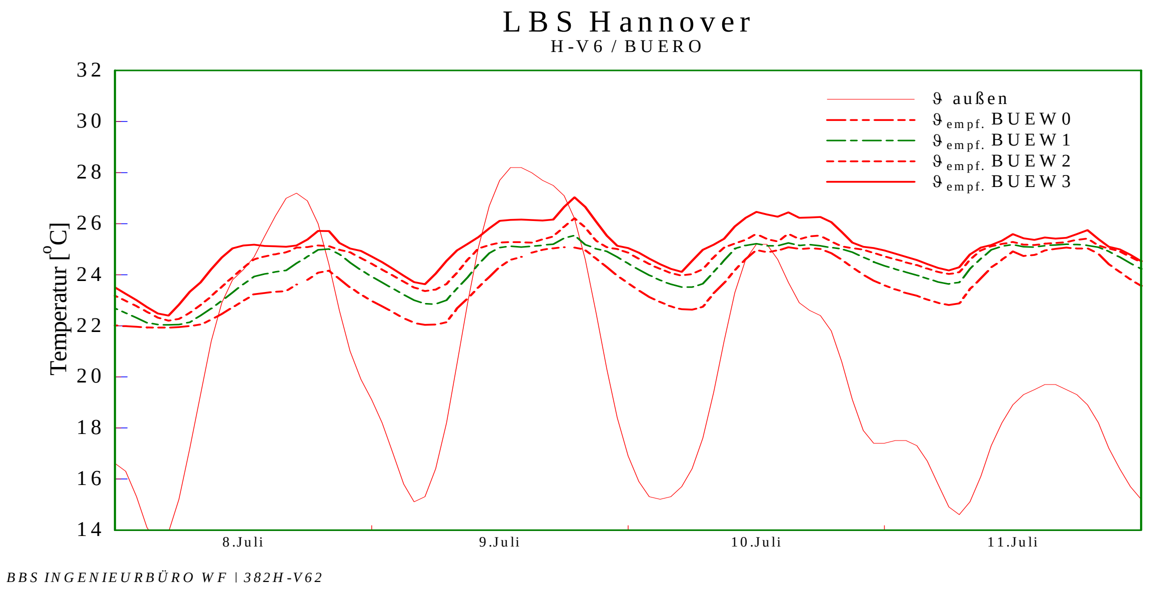
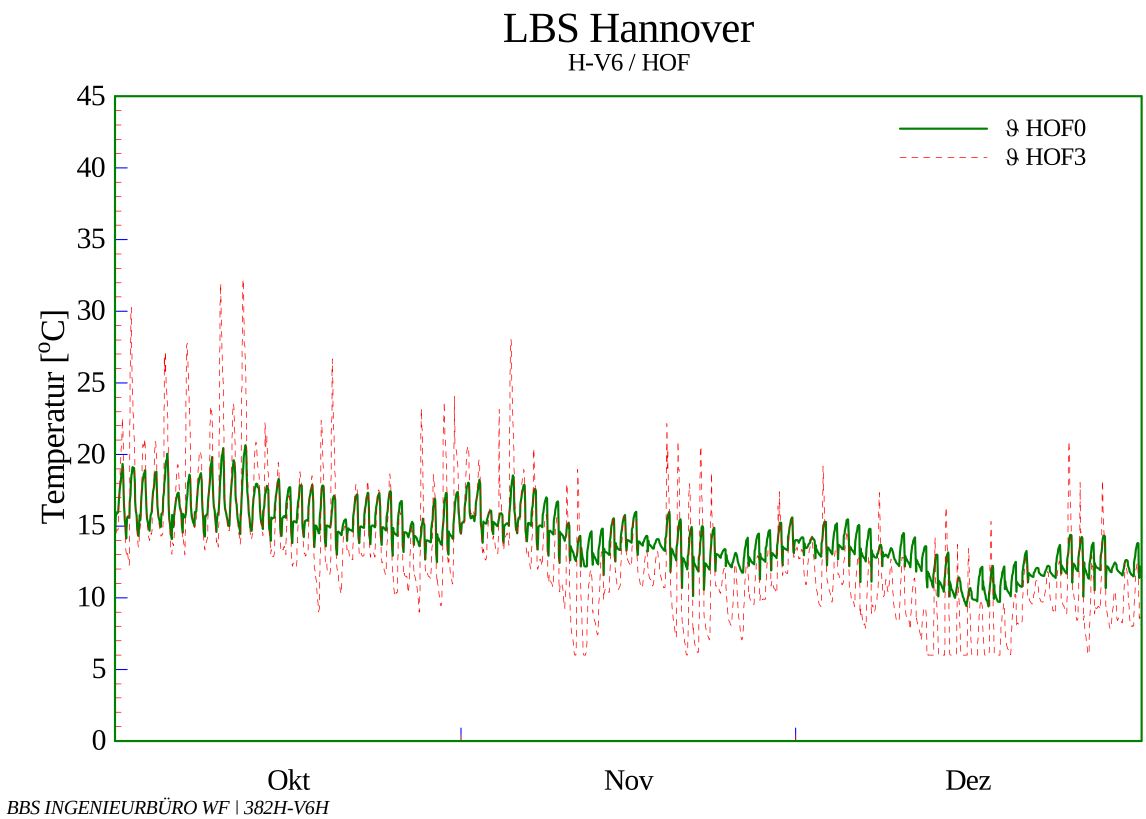


Figure 2 Temperature during the summer season in the courtyard and office WEST/ comparison of the floors

The office zones SOUTH and NORTH are influenced by the temperature (transmission and solar heat gains) of the nearby courtyard. A special emphasis has to be put on the room temperatures because the offices function as working places.

1.2 Simulation of the year

In this simulation mainly the winter season and transition period was analyzed. Just the development of the temperature in the courtyard was taken into consideration.



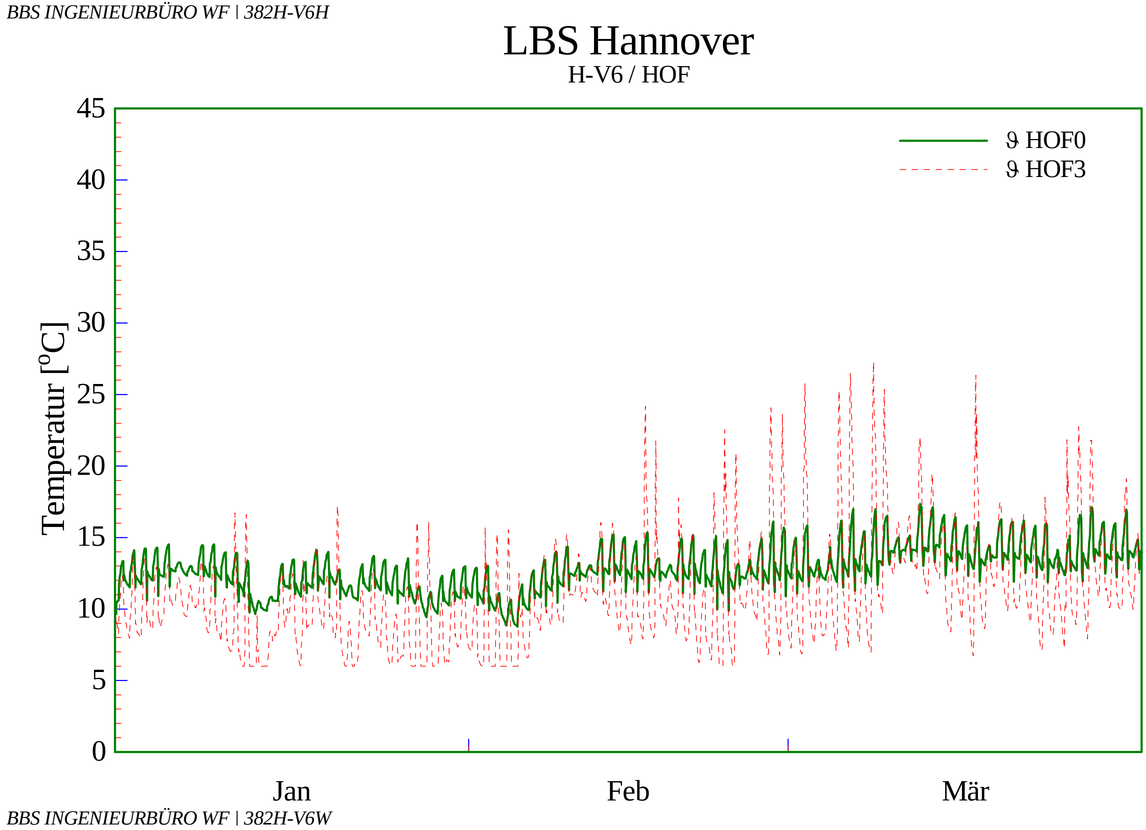


Figure 3 Temperature in the courtyard during Oct - Dec and Jan - March

The simulation results in a temperature of at least 10°C in zone courtyard-0 and -1 in the winter. The minimum temperature is calculated for the zone ROOF with 0°C, the maximum temperature can be found at COURTYARD-0 with 12°C.

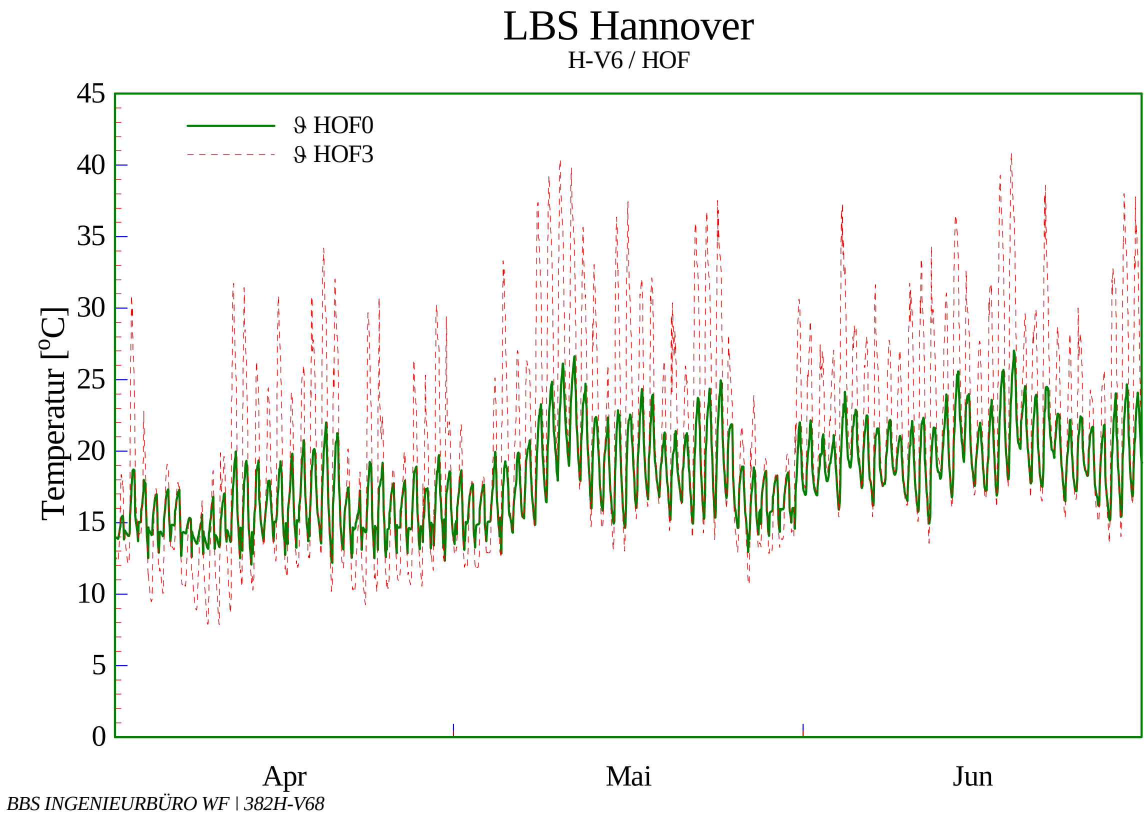


Figure 4 Temperature in the courtyard April - June

The temperature in zone COURTYARD-0 and -1 is at least 13°C during the transition period in spring and fall.

2 SIMULATION OF THE FLOW

The analysis of the flow is carried out with program FLOVENT. It makes the calculation of the distribution of flow, temperature and pollutants of the glazed surfaces possible.

The movement of the air is calculated in accordance with the knowledge of 3-dimensional flow (Computational Fluid Dynamics, CFD).

The aim is to simulate the movement of the air in dependence of the ventilation of the courtyard, the offices and the atria/combined working-zones. Within this optimizing process it is possible to define the necessary ventilation for hygienic conditions. Finally the location and size of the flaps can be determined.

2.1 Basic information

Outer air: Outside a static pressure of 1013,3 mbar and a temperature of 29,2°C is determined. The wind velocity is set to zero.

Surface temperature: For all building units except the offices in the courtyard and the parapets and walls of the exemplary offices a surface temperature was determined. The offices are examined under adiabatic conditions that basically function as flow resistance. The surface temperature results from the thermal simulation. Proceeding this way the building units do not have to be defined exactly by the material data.

2.2 Calculations

2.2.1 Courtyard flow

The areas of the courtyard with the offices nearby were generated in 3-D. All openings of the building are determined as windows or roof-flaps that are opened with a 30° angle. The office rooms (North) are connected with the air space of the courtyard by opened windows.

The exhaust ventilation in all of the office rooms is set to a flow of 60 m^3/h.

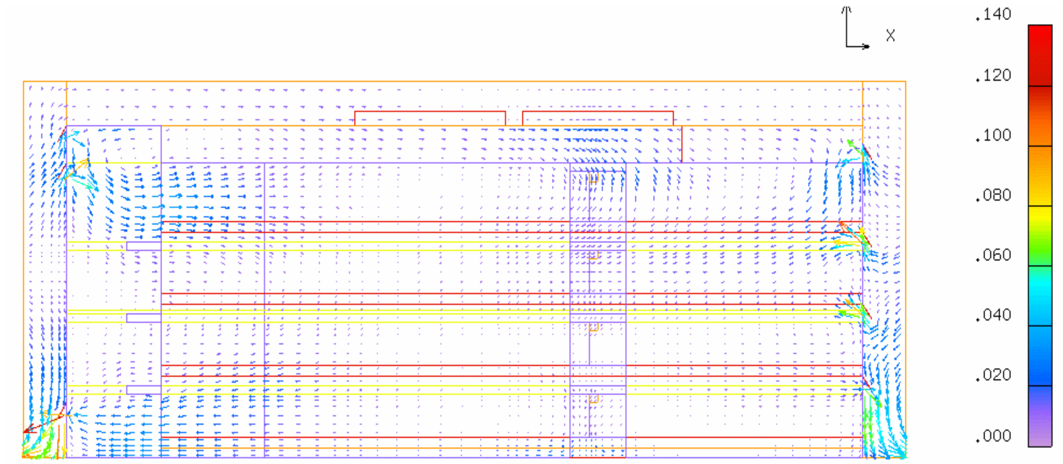


Figure 5 Vectors of air flow, opened facades, East-West direction

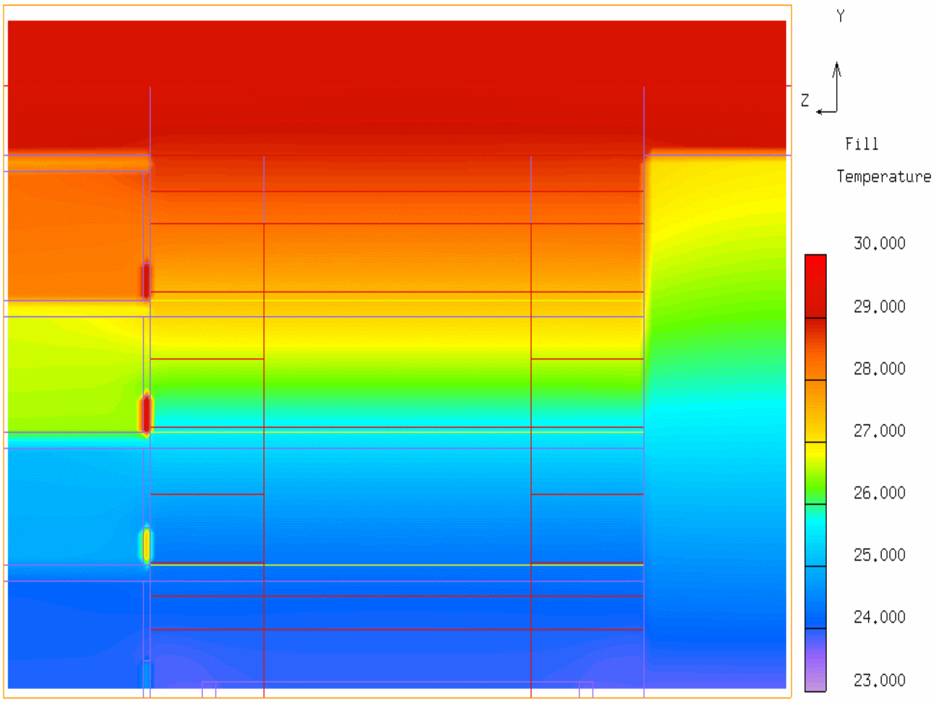


Figure 6 Diagram of temperatures, closed facades, North-South direction

There is an air flow through the big upper windows (figure 5) of the eastern facade into the courtyard. This air flow influences the building within a length of 17 m. Slowly the air falls down, turns around and flows out through the lower windows of the eastern facade.

On the western facade air moves into the courtyard through the upper three windows. At a height of about 9 m the air influences the building within a length of 18 m. One part of the air falls down, turns around and leaves through the lower windows of the facades analogous to the process at the eastern facade. The rest of the air moves upwards and builds a 6m high vortex. On the inside of the vortex the air slowly moves to the outsides in northern or southern direction. It flows out through the roof openings. In the vortex no local turbulent flow occurs. The air velocity does not exceed the boundary velocity for comfort of 0,2 m/s. The air exchange rate is approximately 1,3 h^{-1}.

2.2.2 Air exchange with the offices

All openings in the facades are closed. On the floor there are 0,4 m high bounds around the green spaces. Vertical openings for fresh air are integrated in the bounds directed towards the office buildings. The amount of fresh and exhaust air is 5280 m^3/h. The temperature of the fresh air is nearby 23,8°C.

Because of the openings the air flow is mainly relevant at the facades. In the center of the room a laminar air flow with just minor irregularities can be assumed. The air temperatures of the lower offices (figure 5) are equal to the temperatures of the courtyard at middle height. The air temperature of the offices on floor 3 is slightly higher than the temperatures at the same height of the courtyard. The low air velocity with an air exchange rate of 0,7 h^{-1} in the courtyard is confirmed. In the offices no air velocities occur that exceed the boundary for comfortable conditions. In the lower three offices the air flows at the upper and lower edge of the windows into the room. The upper air flows underneath the ceiling into the opening for exhaust air. The lower air flows along the floor to the wall, moves up and forms a vortex. In the top offices the air just flows through the upper edge of the window. This air flow is strengthened by the natural vortex that forms above the offices. The air flows underneath the wall towards the next opposite wall, falls down and flows back towards the window.

3 ANALYSIS OF THE MOISTURE CONTENT IN THE COURTYARDS

The considered air concept is based on the fresh air supply of the offices by the courtyards. The planned intensive green spaces in this area cause additional moisture by watering and evaporation. These moisture content depends on the season; they reach the maximum in the summer.

The high temperatures in the office sections are lowered by cooling ceilings. But the efficiency of cooling ceilings is primarily limited by the room humidity. For this reason the development of the humidity in the courtyards and its influence on the room climate in the offices must be analyzed.

In accordance with the air exchange, the outer conditions and the amount of evaporation it is possible to calculate the room humidity in the courtyards and the fresh air of the offices.

3.1 Development of the moisture content in the courtyards

Approximately the absolute amount of moisture content can be calculated with the following formula depending on the amount of fresh air and evaporation and air exchange :

$$m_{H_2O,ab} = m_{H_2O,zu} + m_{H_2O,evaportation} \qquad X_i = X_a + \frac{m_{H_2O,evap.}}{V_{LW}}$$

The amount of evaporation can be estimated by the following mathematical approach:

$$m_{H_2O,evaporation} = \square \cdot \rho H_2O \cdot A$$

The evaporation factor and the evaporation surface A depend on the vegetation and as a result can not be defined exactly. According to the statement of a designer of green spaces the watering has to be about 2,5 l/m²d for an extreme situation of p_{max} = 1,2 kPa.

An evaporation coefficient of σ = 13 [kg/m²h]can be concluded from the linear dependence of the partial pressure difference in accordance with the difference of the absolute moisture content (x_i) and the amount of moisture at the evaporation surface(x_o).

$$x_i = \frac{x_a + x_o \cdot \left[\frac{\square A}{\square_L V n}\right]}{1 + \left[\frac{\square A}{\square_L V n}\right]}$$

$x_{0,max} = x_s(\vartheta_i)$ equivalent to the moist surface

$x_{i,\,min} = x_s(\vartheta_i = 30°C, \varphi = 50\%)$

For the calculation of different weather situations the following extreme climates are taken into consideration:

1 . humid summer day, cloudy, while watering

2 . warm summer day, cloudy, while watering

3 . cold winter day, sunny, while watering

4 . night, transition period, while watering

weather situation	θ_a [°C]	ω_a [%]	x_a [g/kg$_{Luft}$]	θ_i [°C]	ω_L [%]	x_0 [g/kg$_{Luft}$]	air exchange rate [1/h]			
							0,50	1,00	3,00	5,00
							φ_i [%]			
1	25,00	85,00	20,50	26,00	1,20	22,00	97,00	96,00	94,50	94,00
2	20,00	50,00	7,40	22,00	1,20	17,00	77,00	67,00	54,50	51,00
3	-10,00	70,00	1,00	6,00	1,10	6,00	56,00	minimum air exchange		
4	10,00	75,00	5,90	10,00	1,10	7,70	88,00	minimum air exchange		

Table 1 Estimation of the development of the moisture content in the courtyards

Already at an outside temperature of 18°C in the courtyards there will occur a very high moisture content because of the abundant vegetation. Even at the highest air exchange rate the “greenhouse-effect” can not be avoided.

For weather situation 3 the dew point temperature falls underneath the limit at the glazed surface and the facade close to thermal bridges. In this case water drops down from the glass roof into the courtyard.

3.2 Development of the relative moisture content in the offices

The concept suggests a cooling ceiling to control the climate in the offices. From this concept restrictions for the surface temperatures and for the efficiency of the system results. For a minimized humidity of 50 % in the courtyards the relative moisture content is about 75% when there is need for cooling. As a result the efficiency of the cooling ceiling is limited to:

$$P_{cooling} = \alpha \cdot A \cdot \left[\theta_i - \theta_{dewpoint}\right] \quad \text{with} \quad \alpha = 7,7\,\frac{W}{m^2K} \quad \theta_i = 26^\circ C \quad \theta_{dewpoint} = 23^\circ C$$

Accordingly the efficiency of the cooling ceiling is limited to 20 W/m² for a high moisture content of fresh air from the courtyards. Regularly it is limited to 75 W/m².

3.3 Influence on the ventilation concept

The abundant vegetation of the courtyard occurs a high moisture content of the air. Therefore it can not be used to provide the offices with fresh air.

To make use of the energetic and visual advantages of the open glass architecture a change of the ventilation concept is necessary. A central station supplies all offices with fresh air. The air is evacuated from the offices through the courtyards.

4 THERMAL AND MOISTURE BEHAVIOUR

The thermal and moisturebehaviour of the facades towards the courtyards are analyzed. Therefore the determined data of the climate simulation of the courtyards and offices is used for the outside or inside climate.

In opposition to the steady state calculations of a building unit following DIN 4108 the used program WUFI developed by the Fraunhofer Gesellschaft - Institute for building physics – also considers unsteady state, absorbing and capillary flow processes.

The boundary conditions were set for temperature, radiation, rain, relative humidity following own definitions or test reference years. The moisture content inside the building units are simulated for one or more years under room climatic conditions. Unfortunately processes of air flow can not be simulated because this is a multi-dimensional problem. This simulation is based on the calculated climate data of four years.

In the following the observed processes are described:

Layer	Moisture content [kg/m³]	Moisture content [M-%]	Remarks
Veneered laminated timber towards the courtyard	40 - 79	10 - 19.7	Seasonally differences of Δu = ± 5%.
Plasterboard towards the offices	2.5 – 10.5	0.2 - 1.2	minor seasonally differences

Table 2 Calculation of the moisture content of the facades

The calculations indicate that the building units regulate their moisture content in accordance with the surrounding humidity.

In the timber layer there are seasonally differences of Δu = ± 5 M-%. The maximum water content is u = 19.7 M-%. Consequently the limit of u ≤ 20 M-% set by DIN 68800 is not exceeded.

The moisture content of the plasterboard varies from 0.2 to 1.2 M-% within the compensation boundaries.