INFLUENCE OF AIR FLOW PATTERNS IN A ROOM ON EVAPORATION AND HUMIDITY DISTRIBUTION AROUND A HEATED WET CYLINDER

Klaus Fitzner, Olaf Zeidler, Kai Kriegel

Hermann-Rietschel-Institute for Heating and Air-Conditioning
Technical University Berlin, Germany

ABSTRACT

Air flow patterns in rooms can roughly be classified as one of three types: Displacement flow, source flow and mixed flow. Displacement flow in its original meaning is only used in special applications like clean rooms. Mixed flow is generally found in air-conditioned spaces, source flow which is frequently also called "displacement flow" is the usual type of flow in naturally ventilated spaces. This type has become more and more common in air-conditioned spaces in recent years. It is well known that mixed and source flow differ considerably from each other which can be expressed by the vertical profiles of temperature, velocity and concentration of air contaminants for the two types of flow in a room. But there is not much knowledge about the differences of the influence on the boundary layer around a person. This paper explores these differences

DEVELOPMENT OF THE INVESTIGATIONS ON AIR FLOW IN ROOMS

Although source flow is the original type of air flow in rooms mixed flow was the main subject of all former investigations in the field of air-conditioning. Since the invention of motor-driven fans at the end of the last century mixed flow was the prevailing type of air flow patterns in air-conditioned spaces. The roughly uniform conditions of temperature and concentration in the entire room were advantagous for the design. Only the balance conditions at the air outlets in the walls of the room were important and needed to be calculated. But step by step the target of investigations moved from the walls to the interior of the room. Draft problems were solved by investigating air velocity limits for the empty room [1] already taking the influence of cooling load into account. The investigations are now more and more being focussed on the interior of the room, particularly on the walls of the subjects in the room, such as human beings.

TYPICAL DIFFERENCES IN AIR FLOW PATTERNS

Mixed flow can hardly be made visible by smoke because smoke is distributed in the room in a very short time and looks like fog. Formerly it was visualized by flakelike particles or bubbles distributed in the air. Their traces were made visible by taking photos with shutter times in a range of seconds. Fig. 1 shows such a type of flow. The flow pattern consists of a larger number of large and small sized vortices. The air is introduced by nozzles from the side walls.

Laminar displacement flow can be made visible by smoke threads produced by evaporation of wax droplets from a heated wire. The flow in fig. 2 is laminarly moving from the ceiling to the floor in a typical clean room setup. The air flow is unidirectional like a piston and is laminar which is not necessary for the displacement flow but for the visualization. Fig. 3 shows the typical flow pattern of a source flow vizualized by smoke being introduced isothermally into the supply air.

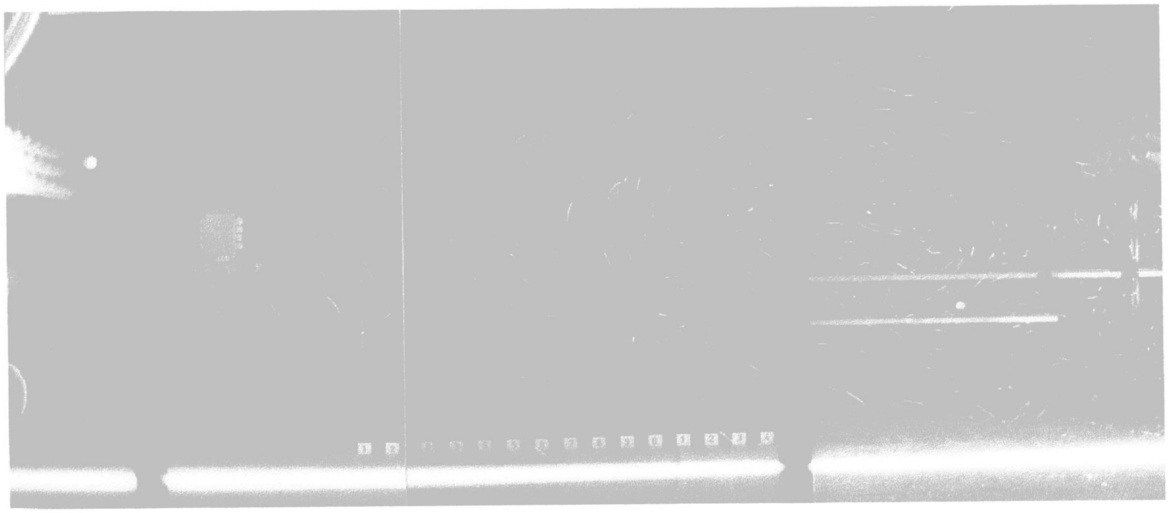

Fig. 1: Mixed flow made visibel by flocky particles in a slit of light

Fig. 2: Displacement flow from the ceiling visualized by smoke threads from a heated wire

Fig. 3: Source flow made visible by smoke introduced isothermally into the supply air

VERTICAL AND HORIZONTAL PROFILES OF TEMPERATURE, VELOCITY AND CONCENTRATION

The differences between mixed and source flow can best be characterized by the vertical profiles of temperature, concentration and velocities as shown in fig. 4.

The air temperature and the concentration of any contaminant in mixed flow is roughly uniformly distributed throughout the entire room. The temperatures of all surfaces in the room if they are not cooled are warmer than the air. Their overtemperature is growing with the cooling load. It is the aim of the design and the location of the air outlets to minimize the air velocities in the occupation zone. But the velocities of the air depend on the cooling load [1].

In a source flow the air temperature is nearly linearly growing from the supply to the exhaust opening at the ceiling. The air temperature is higher than the wall temperature in the upper part of the room. The contamination is lower in the inferior part of the room. Velocities are smaller than in mixed flow and they may only become a problem in the vicinity of air outlets.

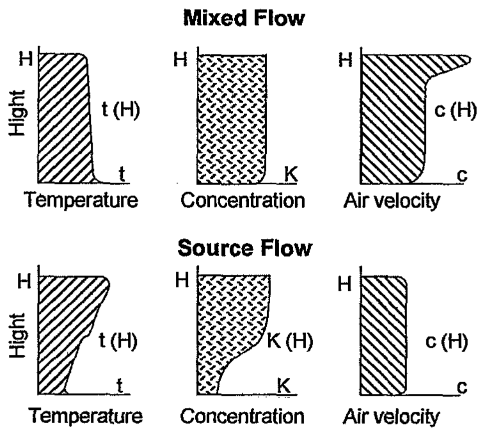

Fig. 4: Vertical profiles of temperature, concentration and velocities in mixed and source flow

More detailes about the differences of the temperature and the concentration profiles are explained in [2]. The main advantage is hidden in the concentration profile. Mixed and source flow have the same concentration of contaminants in the exhaust air. In source flow the concentration is generally lower particularly in the inferior part of the room which is expressed by a degree of contamination lower than 1.0 in the occupation zone. Although the supply air is flowing along the floor its quality remains better than in mixed flow.

The horizontal spread of air contaminants in rooms like large scale offices is also very different in the two types of flow. In the case of mixed flow the concentration related to the exhaust air concentration is higher and the decay is smaller. In the source flow the decay depends on the number of heat sources. But the concentration is generally lower roughly by a factor of 5. That means that a partition of a room into smoker and non smoker areas is more successfull when source flow is applied.

INFLUENCE ON THE BOUNDARY LAYER AROUND A HEATED CYLINDER

Several investigations like [4] come to the conclusion that people complain less about dry air in naturally ventilated rooms than in air conditioned spaces even if the relative humidity in the naturally ventilated rooms is lower. There may be several explanation for this phenomenon, but it is very likely that the difference in the air flow pattern in the rooms influences the evaporation or generally the mass exchange between air and surface.

To find out whether the boundary layer conditions are different in these two types of flow the amount of evaporated water from a surface of a heated cylinder with a wet surface was investigated. A heated cylinder like it is used to simulate a person in air flow investigations was covered by a wetted fabric. Different to a real person the entire surface was wet. The cylinder was positioned on a scale in the center of a laboratory room. The scale enabled to assess the evaporation by measuring the weight loss. The setup is shown in fig. 5. Four additional cylinders which were only heated are situated in the room to introduce the cooling load. An air outlet on floor level is used as source flow outlet and a radial air diffuser at the center of the ceiling is used for the mixed flow experiments. More details about the setup are given in [3].

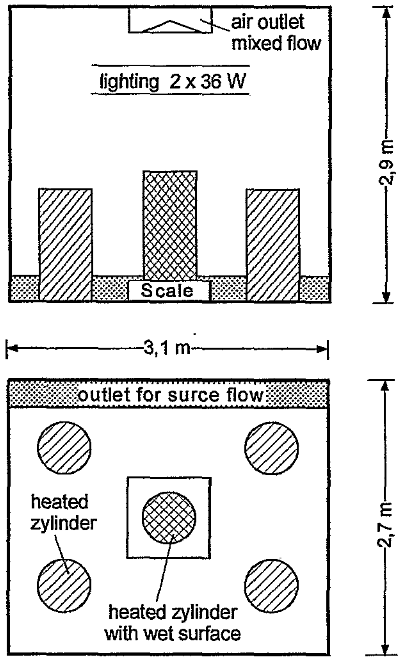

Fig. 5: Set up to measure the evaporation from a wet surface of a heated cylinder

Fig. 6 shows the result. The data are related to the evaporation in source flow with high load. Comparing the evaporation for cooling loads between 20 and 100 W/m² shows an increase of about 30% for both types of flow.

DIFFERRENT EVAPORATION FOR MIXED AND SOURCE FLOW

A remarkable result is that first the evaporation is growing with the cooling load in the room and that secondly there is a difference of about 20 % between mixed flow and source flow. In a range of 100 W/m² the evaporation becomes constant in source flow but is still growing with the cooling load in mixed flow.

LARGER LOCAL EVAPORATION AT HEAD LEVEL

Figure 6 shows a comparison of the total amount of evaporation across the total surface. Additionally the distribution of the local values is differing. In the mixed flow the rate of exchanged vapor will be nearly constant vs. height. In the source flow at inferior level the evaporation is higher than at head level. During the investigations in the source flow for example the lower part of the wetted surface earlier became dry than ast head level. In this investigation additionally to the overall values of evaporation the humidity and the temperature were measured at head level at three locations: in a height of 1.2 m at the surface, 5 mm apart from the surface and in the room. The relative humidity at the wet surface is assumed to be 100%.

In one series of measurements with a cooling load of 100 W/m² the values shown in Table 1 were measured.

Figure 6: Evaporation vs. cooling load in the room at the surface of a wet cylinder for the two types of air flow.

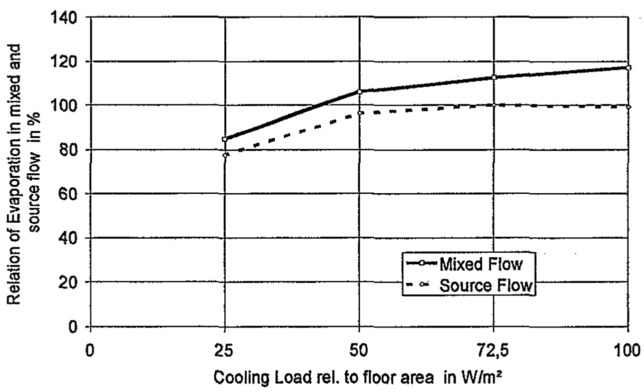

Table 1: Measured temperatures and humidity

		Unit	Source flow	mixed flow
Evaporation	total surface	g/h	109	128
Temperature H =1.2 m	Surface of the cylinder 5 mm apart Room	°C	30.7 25.5 25.0	30.2 25.5 25.4
Relative humidity	Surface of the cylinder 5 mm apart Room	%	100 74 38	100 55 38
Absolute humidity	Surface of the cylinder 5 mm apart Room	g/kg	29 15.2 7.5	28 11.3 7.8

The results confirm that the boundary layer of humidity is thicker than the temperature boundary layer. The relative humidity is dropping from 100 % at the wet surface to 74% (source flow) and 55 % (mixed flow) in 5 mm distance.

Comparing the test results with the expected values in a boundary layer of a person there may be differences. The evaporation in the boundary layer of a person is lower than in the test set up because a person's surface is normally not wet. It is also unknown whether the evaporation is controlled by the body and reduced when the mass transfer coefficient is increased. But the relation of the local evaporation between the two types of flow will be the same. Therefore particularly in mixed flow at head level better local evaporation will take place and it is very likely that the air humidity will be perceived as drier. The overall evaporation in mixed flow is nearly 20% higher than in source flow and is nearly independent of the height. The local evaporation in source flow is not constant but decreasing with height. At floor level it is similar for both types of flow. The local evaporation at head level is about 30 % higher in the mixed flow.

DISCUSSION

The evaporation of water is growing with the cooling load in a room in either type of the flow. Additionally to the advantages of source flow consisting of the lower contamination at head level and of lower velocities in the occupation zone a further advantage turns out when the mass exchange at the surface of a heated body is investigated in more detail. The overall evaporation is 20 % higher in mixed flow. In mixed flow the rate of evaporation is roughly constant vs. height. In source flow it is decreasing with height. At head level the evaporation is at least 30 % higher in mixed than in source flow.

This may explain why people are content with low relative humidities in naturally ventilated rooms (source flow) and are particularly complainig about too dry air in air-conditioned spaces (generally mixed flow) with high cooling loads even if the air is humidified. The increase of the local mass transfer coefficient by a factor of 1.3 would require to increase the relative humidity from 30 to 65 % to get the same amount of evaporation at head level for the two types of flow. This may especially explain local problems like dry eyes. The exchange of other substances from the air to the surface of a person increases analogously to the evaporation of water. Contaminants which may e. g. cause etching eyes are also better exchanged.

If our experiences about comfortable relative humidities are stemming from experiments in source flow as one can assume mixed flow combined with high thermal loads will not be able to fulfill comfort requirements.

If investigations concerning the perceived humidity are performed in a room the cooling load and the type of flow in which the investigations are performed have to be reported.

In air-conditioned rooms source flow has many advantages. On the other hand source flow may not be very suitable in an environment with relative humidities higher than 65% because the evaporation is an important contribution to the thermal balance. The reduced exchange of vapor may be a disadvantage in this case.

CONCLUSION

As is known source flow has several advantages especially on thermal comfort and air quality. This preliminary investigation shows that the total evaporation of water from a heated wet surface is growing with the cooling load in the room. It rises nearly by 30% when an increase from 20 to 100 W/m² of the cooling load takes place. The overall exchange is 20 % higher in mixed compared with source flow and the local mass exchange coefficient at head level is higher at leat by a factor of 1.3 in mixed flow.

This result encourages to perform more detailed investigations with persons especially to find out the influence of the human control system.

REFERENCES

1.) Fitzner, K.: Air Velocities in Spaces Air-Conditioned by Cooled Ceilings or Mixed Flow as a Function of the Cooling Capacity, Roomvent '96, Yokohama

2.) Fitzner, K.: Displacement Ventilation and Cooled Ceilings, Results of Laboratory Tests and Practical Installations, INDOOR AIR '96, Nagoya

3.) Zeidler, O., K. Kriegel, K. Fitzner; Unterschiede der Feuchteabgabe einer Person in Quell- und Mischlüftung, KI, Luft- und Kältetechnik, 1999/1

4.) Kröling, P.: Gesundheits- und Befindensstörungen in klimatisierten Gebäuden. Vergleichende Untersuchungen zum "building illness" Syndrom. BMFT-Projekt 01 VD 132, Verlag Zuckerschwerdt, München 1985.