Healthy Buildings and Air Distribution in Rooms

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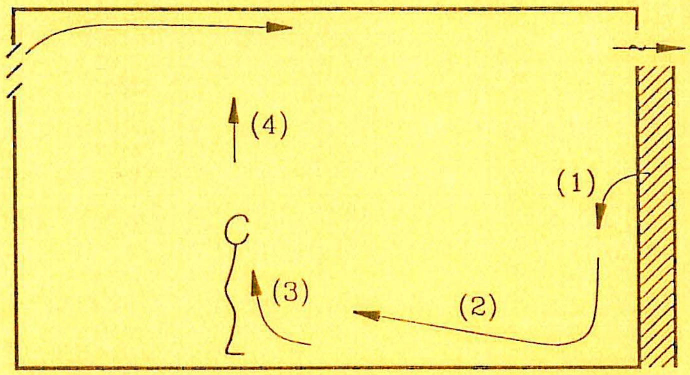

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 51

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HEALTHY BUILDINGS AND AIR DISTRIBUTION IN ROOMS

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INTRODUCTION

Healthy buildings are to a great extent a question of indoor air quality. The processes involved in air quality can be looked upon as a number of links in a chain. Typical links will be emission from building materials, convection and diffusion in the room, local airflow around a person, personal exposure and at last the effect of the air quality on the occupant. The best results will obviously be obtained by using building materials with low emission. However, there will always exist some emission and the ventilation will consequently be an important link.

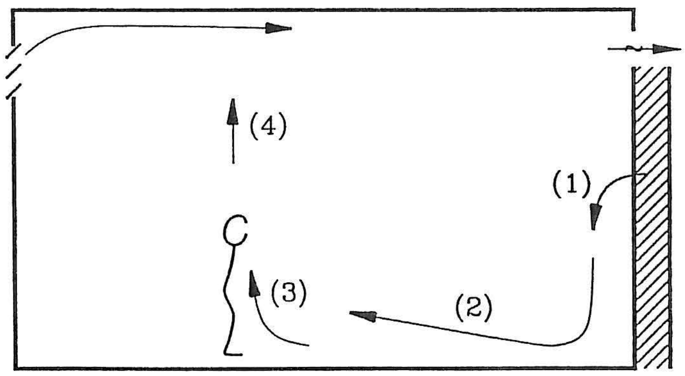

Figure 1. Transport processes in a room.

Aalborg University has worked with several links as shown in figure 1. The elements in a model for emission from building materials (1) will be discussed in the first chapter of this paper. Transport by convection and diffusion (2) will be addressed in the following chapter, and the flow around a person (3) will be handled in a third chapter. An occupant's role as emission source (4) is described by examples in the last chapter.

EMISSION FROM MATERIALS

Many building materials as for example paint, linoleum, carpets, sealant and lacquer will give an emission of volatile organic compounds (VOCs). This is a chain-like process starting with organic vapour production inside the material and diffusion transport through the material. The emission will cross the physical barrier and it will be influenced by the boundary layer flow close to the surface of the material.

The emission from different materials has traditionally been divided into diffusion controlled emission and evaporation controlled emission dependent on the process in the chain with the lowest emission rate.

The measurements of emission from indoor building materials is made in small test chambers[1]. It is possible to control the temperature, humidity, concentration and air velocity. Materials which are fully or partly evaporation controlled have to be tested with boundary layer conditions which are identical with full-scale conditions and this is one of the problems discussed in this chapter.

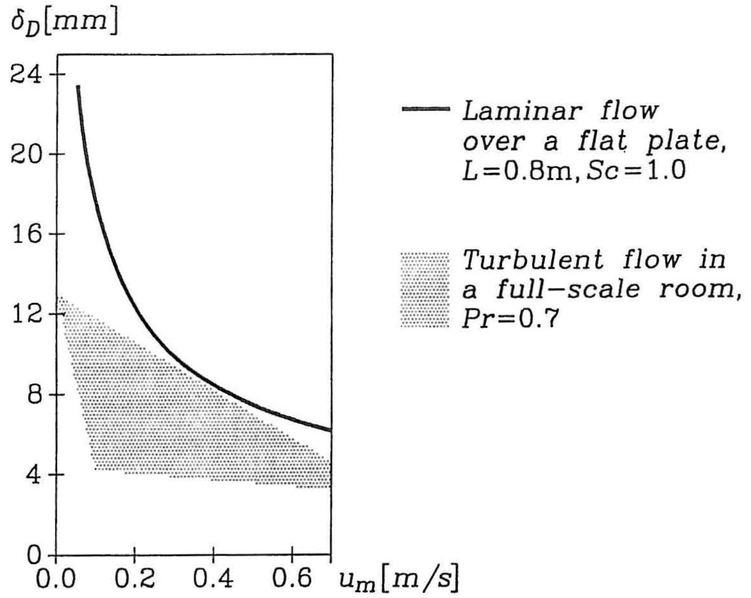

Figure 2. Diffusion layer thickness versus air velocity in different geometries.

The evaporation emission rate can be given by the mass transfer coefficient or it can be expressed by a diffusion boundary layer thickness, δ_D, which is the VOCs diffusivity divided by the mass transfer coefficient as for example shown by Tichenor et al.[2].

Figure 2 shows the diffusion thickness, δ_D, for different geometries. The curve for laminar flow parallel with a flat plate is typical of many small test chambers. It is obvious that δ_D decreases with increasing velocity which corresponds to an increasing mass transfer coefficient. The turbulent flow in a room will decrease the diffusion boundary layer thickness as shown in the figure, although the dimensions are much larger. There is an analogy between heat transfer and mass transfer which is used to predict the full-scale values in figure 2 from measured heat transfer coefficients[3]. The values are confirmed by Tichenor et al.[2] who show a large difference in boundary layer thickness measured in a small test chamber compared with boundary layer thickness measured in an IAQ test house.

Different flow configurations in test chambers may explain some of the large deviations in the measured emission obtained by the European interlaboratory measurements on small test chambers[1].

The large variation in boundary layer thickness shown in figure 2 necessitates a method to transfer results from small scale tests to full scale. Jensen and Nielsen[4] show a method which is based on Computational Fluid Dynamics. The emission rate is calculated as a function of local parameters in the boundary layer, e.g. velocity, temperature and concentration. The total emission in a room is predicted from an integration of the corresponding local emission.

CONVECTION AND DIFFUSION IN A SPACE

The transport of pollution in a space is described by transport equations and the distribution is found by Computational Fluid Dynamics (CFD) as described by for example Patankar[5]. Each source must be described by its own distribution and the exposure is given as the total sum of contaminant from all sources.

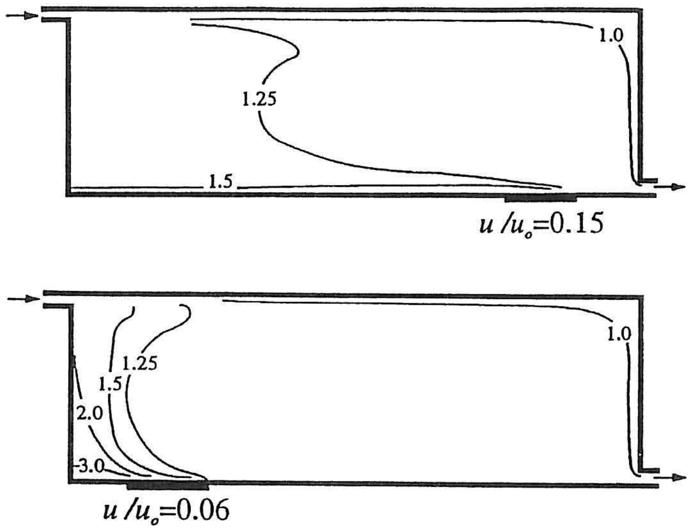

Figure 3. Concentration distribution for two different locations of a source[6].

Figure 3 shows the concentration distribution for a single emission source. The concentration level is divided by the fully mixed value (concentration in the return opening). It is first and foremost important to notice that the concentration can be very different from the fully mixed value. This is a general experience and a guideline for ventilation requirements in buildings[7] indicates deviations up to 2.5 times the fully mixed value in rooms with mixing ventilation and up to 5.0 times the fully mixed value in rooms with an inefficient use of displacement ventilation.

It can be seen in figure 3 that the location of the contaminant source is important for the concentration distribution and the concentration level. In the upper sketch the source is located close to the area with the maximum velocity in the occupied zone (u is local velocity and u_o is supply velocity). The maximum value of the concentration has a level of 1.25 - 1.5 times the fully mixed value in the area below the supply slot. The concentration will increase to a level of 3.0 times the fully mixed value if the source is located below the supply slot in the stagnant air as shown in the lower sketch. It is assumed that the source is a diffusion controlled source with a constant emission rate independent of the boundary layer thickness in both situations in figure 3.

Prediction of pollution distribution in sensory terms has been shown by Bluyssen and Lemaire[8], and the prediction of benzene or methanol distribution from a latex paint on a vertical wall has been addressed by Béghein et al.[9]. The CFD method can also be extended to handle pollution with small and large particles[10].

LOCAL AIRFLOW AROUND A PERSON AND PERSONAL EXPOSURE

A person will modify the indoor air quality locally and affect the personal exposure when there are pollution gradients in the room. The parameters which will influence the interaction between persons and ventilation are thermal boundary layer around persons, local disturbance of the airflow, movements of persons, respiration and heat emission and contaminant emission from persons.

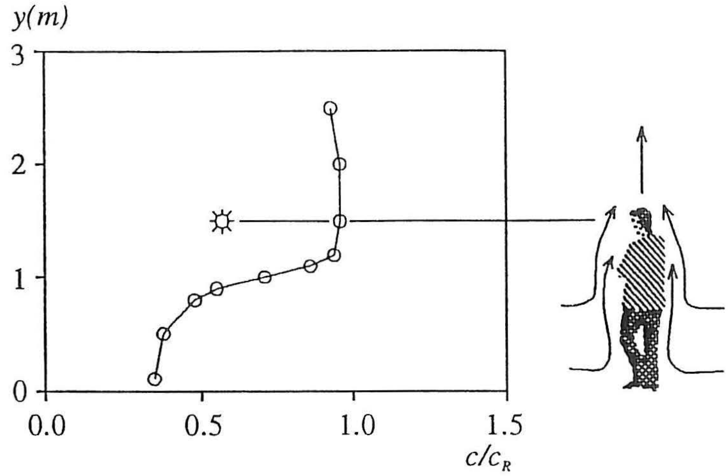

Figure 4. Local improvement of air quality for a person standing in a room with displacement ventilation and vertical pollution gradients[11]. c is local concentration and c_R is fully mixed concentration.

Figure 4 shows an example of local improvement of air quality due to the influence of free convection around the body. The inhaled concentration is only 0.6 times the fully mixed level, although this level prevails in breathing height outside the person's boundary layer. The problem is studied by Brohus and Nielsen[11,12,13] for both displacement ventilation and mixing ventilation. A thermal manikin with breathing function and CFD have been used for this research work on local airflow around persons.

EMISSION FROM PERSONS

Humans act as emission sources. Typical emissions will be heat convection and radiation, carbon dioxide and moisture from breathing, smoking and bioeffluents and moisture from the body. A few results from measurements made on a thermal manikin in situations with displacement ventilation and horizontal air movement (mixing ventilation) will be given in this chapter. All the measurements are reported by Hyldgård[14].

Figure 5A shows an example of measurement of concentration distribution when the expiration is the emission source with carbon dioxide or tobacco smoke as pollutants. The expiration leaves the nose with a high entrainment and the concentration of tracer gas reaches the level of 1.5 - 5.0 at a distance of 0.4 m from the face. The expiration will rise to the ceiling in case of quiet atmospheric conditions. The expiration generates a horizontal layer which stabilizes at face height when displacement ventilation is used due to the vertical temperature gradient. The inhaled concentration is of background level (1.0), although the face is surrounded by exhaled tracer gas because the inhaled amount of air is extracted mainly from the boundary layer flow. The inhaled air has therefore its origin from the low levels of the occupied zone in the case of quiet atmospheric conditions or displacement ventilation, see also figure 4.

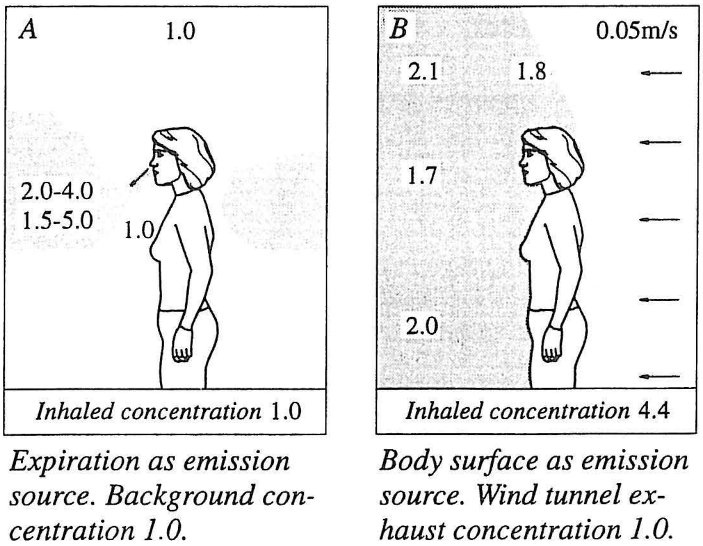

Figure 5. Concentration distribution around a thermal manikin divided by background concentration (A) or the concentration in the exhaust of the wind tunnel (B)[14].

Figure 5B shows an example of measurement of concentration distribution when the body surface is the emission source. A recirculating area is generated in front of a person when a horizontal air movement is directed towards the back of the body. The concentration will be high in the recirculating area and the inhaled concentration is high in that situation as shown in figure 5B which indicates a high "self exposure". The inhaled concentration will increase with increasing air velocity and a decrease will only take place at a velocity larger than 0.4 m/s. Other body positions relative to the air velocity will give a low inhaled concentration. The bioeffluents and water vapour are contained in the thermal plume which rises from the body.

CONCLUSIONS

The emission from building materials can either be diffusion controlled or evaporation controlled. The emission rate is dependent on the boundary layer in the latter case and, in this situation, it is therefore necessary to have a procedure which can be used for transformation of small scale test results to full scale.

The VOCs in a room are not fully mixed in practice and the real distribution can be found by Computational Fluid Dynamics. Predictions show that the concentration level is dependent on many parameters including the heat load, the layout of the ventilation system and the location of the emission sources.

The concentration distribution will be influenced locally by the presence of a person. It is necessary to take this effect into consideration when the exposure is predicted in a given situation.

Humans act as emission sources. Experiments show that the influence of expiration on inhaled air is very small in normal situations. To some extent "Self exposure" takes place in connection with emission of bioeffluents from the body surface. This situation is especially pronounced in situations with quiet air surroundings, displacement ventilation and horizontal air movement directed towards the back of the body.

ACKNOWLEDGEMENT

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