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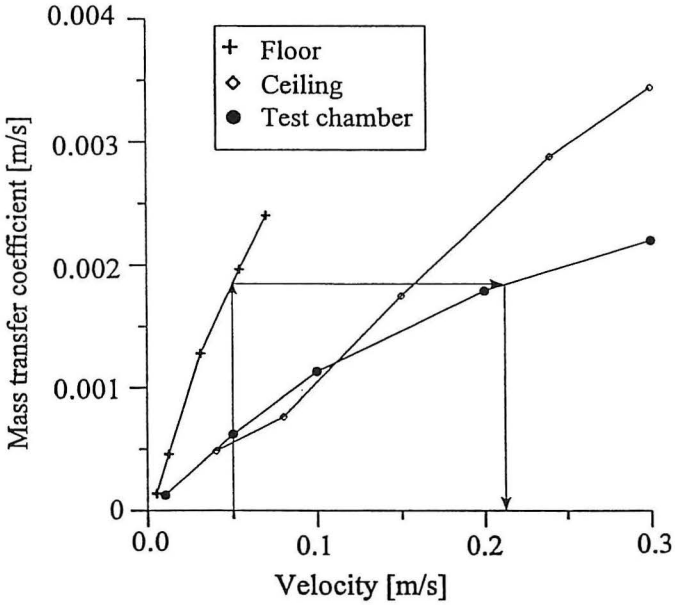



**INDOOR ENVIRONMENTAL TECHNOLOGY**
**PAPER NO. 50**

**Presented at Healthy Buildings '95**
**Milano, Italy, September 1995**



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# TRANSFER OF EMISSION TEST DATA FROM SMALL SCALE TO FULL SCALE

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## INTRODUCTION

Emission testing of building materials is often carried out in small-scale test chamber. A method to transfer results from these tests to full scale is presented. A difference in scale can lead to a difference between the emission rate of a given pollutant measured in a small-scale test chamber and the one that is found in a full-scale ventilated room. The discrepancy is noticeable when the emission is dependent on environmental parameters such as room temperature, pollutant concentration, humidity and air flow pattern. Testing conditions are usually chosen to reflect the situation experienced in full scale, i.e. Test conditions such as temperature, relative humidity, and air velocities are chosen within the range that are found in ventilated rooms. However, the difference in scale can lead to some problems and misconception of the size of the actual emission rate for a building material. This paper highlights some of these problems and introduce an approach on how to overcome them and produce useful results. The paper concentrates on describing situations where the air velocity field near the source influence the emission rate.

Emission of volatile organic compounds (VOC) from drying paint can be regarded as limited by diffusion through the boundary layer (Kornum, 1980). Emission of VOC can then be described by Fick's law

$$E = - D \frac{\partial c}{\partial y}$$

where E[mg/m$^2$s] is the emission rate, D[m$^2$/s] is the molecular diffusion coefficient, c[mg/m$^3$] is the concentration and y[m] is distance. The emission rate can also be described in terms of a mass transfer coefficient $k_c$[m/s].

$$E = - k_c \, (c - c_s)$$

where $k_c$ is the ratio ($D/\delta$), $\delta$[m] is the boundary layer thickness (Figure 1) and $c_s$ is the vapour pressure at the surface expressed as concentration.

The boundary layer thickness is dependant on flow near the source, and the influence of turbulence is very important. Some models of emission in test chambers include the effect of the air flow field near the emitting surface. This is done by including the boundary layer thickness as a parameter in the calculation of the emission (Tichenor et al., 1993). The next step is to link these models to full scale conditions. In this paper, a method is introduced which can handle turbulent and laminar flow, and varying boundary layer thickness. The method can be used both to decide under which conditions test chamber tests should be done, and to decide the emission rate in a given case.

## METHODS

Room air flows are often simulated by using a k-ε turbulence model, where k is turbulent kinetic energy and ε is energy dissipation. The k-ε model is based on the assumption that the flow is fully turbulent, this is not true in the near wall region where a laminar layer persists. Turbulent boundary layer flows have a laminar sublayer adjacent to the wall, where there is a linear relation between the velocity and the distance from the wall (Figure 1). At some distance from the wall we have fully turbulent flow, between the two layers there is a buffer zone. Near the wall velocity fluctuations are damped and the molecular viscosity is dominating.

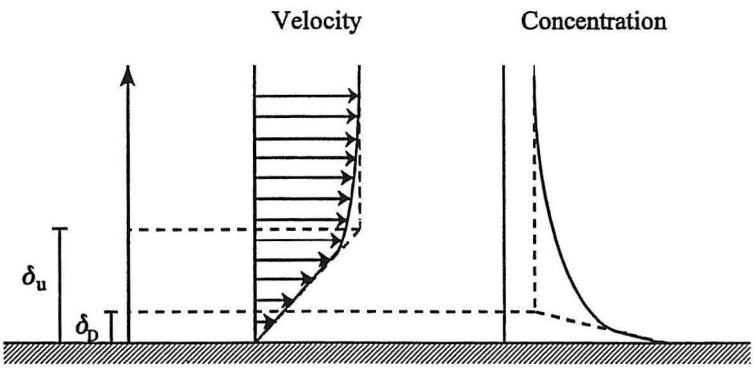


**Figure 1:** Velocity and concentration profiles for fully turbulent boundary layer flow near a wall. $\delta_u$ is the velocity boundary layer thickness and $\delta_D$ is the diffusion boundary layer thickness.

Traditionally the problem with low Reynolds numbers in the near wall region has been handled by applying the so-called universal law-of-the-wall. For solving practical engineering problems the method is very useful, but it has some shortcomings for example if the flow is not fully turbulent, if free convection is present or if wall jets are present.

Many problems in modelling flows in ventilated room are due to Low Reynolds Number (LRN) effects. To simulate this, LRN versions of the k-ε model have been developed. These models account for LRN effects by damping the turbulence near the wall. Patel et al. (1985) reviewed a number of LRN-models and found that the Launder-Sharma model (Launder and Sharma, 1974) was one of the better ones. In this study the Launder-Sharma model is used to overcome scaling problems, which occur when small scale test chamber emission data is transferred to full scale. An example on how to deal with the

transfer of emission data is demonstrated. A typical test chamber and a typical full-scale room are chosen. LRN-models are expensive in terms of computer time, because a high resolution of the boundary layer is needed. To reduce usage of computer time all simulations are done in two dimensions.

The geometry of the full-scale room is chosen similar to the room used in the IEA annex 20 programme, (Figure 2). The geometry is well-tested both in terms of measurements and simulations (Nielsen, 1990 and IEA, 1991).

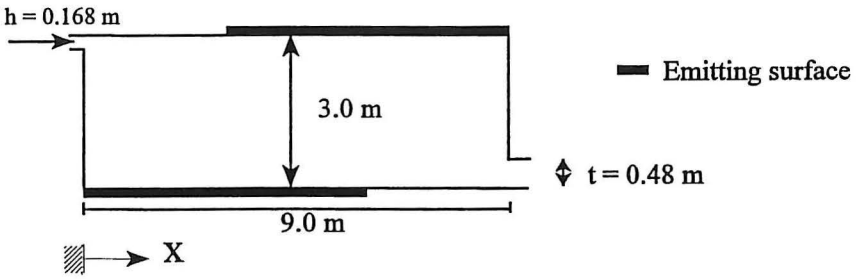


**Figure 2.** Dimensions of the two dimensional full scale room (IEA, annex 20, Nielsen 1990).

Emissions from ceiling and floor are tested. An area 3 m from the inlet at the ceiling and 3 m from the outlet are not emitting because local conditions influence the emission in these regions. The emission is simulated for air exchange rates from 1 to 10 $h^{-1}$.

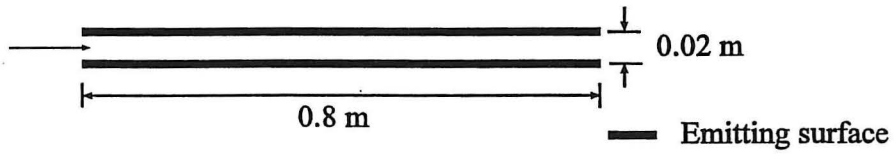


**Figure 3.** Dimensions of the test chamber

The test chamber is chosen as two emitting surfaces with the length 0.8 m in the direction of the flow and a spacing between the plates of 0.02 m (Figure 3).
In both cases a hypothetical set of agent and material is used. The surface concentration is set at $c_s$ = 1000 mg/m$^3$ and the diffusion coefficient of D= 1.51· $10^{-5}$ m$^2$/s.

## RESULTS

The computer simulations were performed for the two geometries mentioned above. Figure 4 shows velocity profiles near the ceiling and the floor. At the floor the velocity boundary layer was thicker than at the ceiling. To compare the variation of emission rate with velocity a reference velocity is needed. For the full-scale room the local maximum velocity parellel to the surface $u_m$ is used (Figure 4).

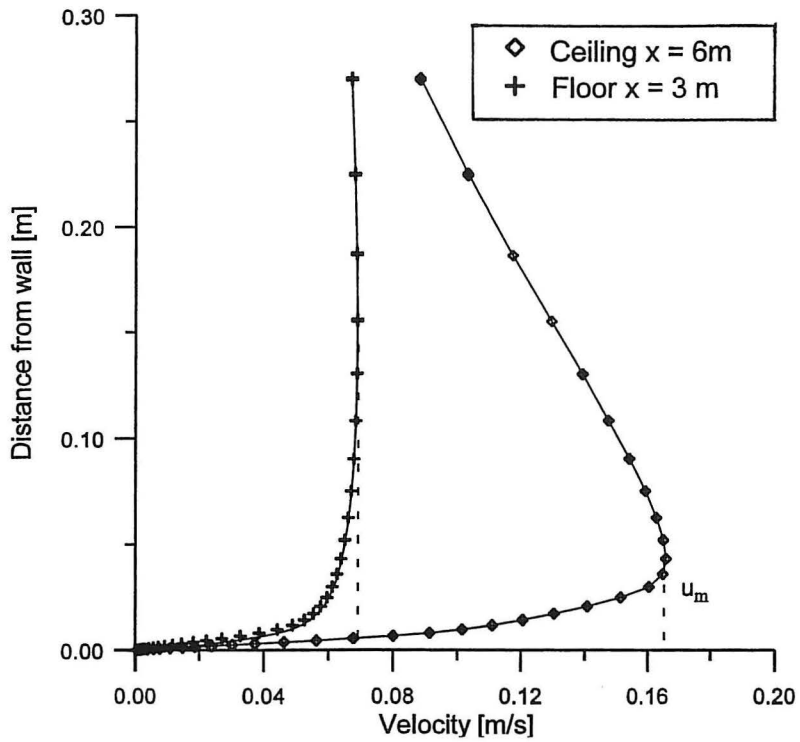


**Figure 4**. Velocity profiles corresponding to an air exchange rate of 10 $h^{-1}$.

In the laminar layer near the wall, molecular diffusion is dominating, and the concentration gradient is controlling the mass transport. Two typical profiles are shown in figure 5. The high velocities at the ceiling result in a high concentration gradient.

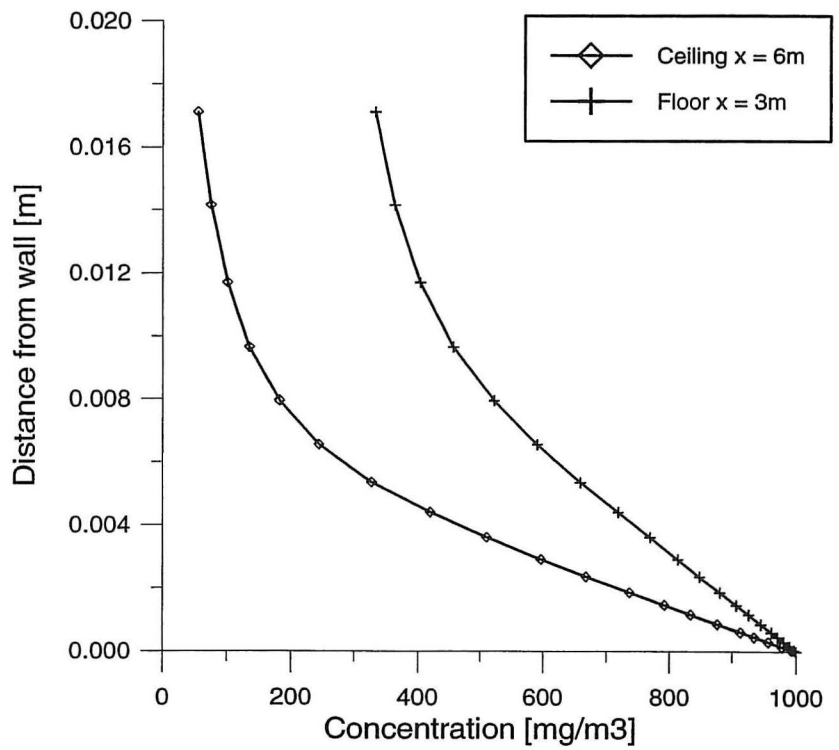


**Figure 5**. Concentration profiles for the air exchange rate equal to 10 $h^{-1}$ .

Figure 6 shows how the mass transfer coefficient $k_c$ varies as a function of the velocity. For the test chamber the average velocity of a cross section is used as the reference velocity.

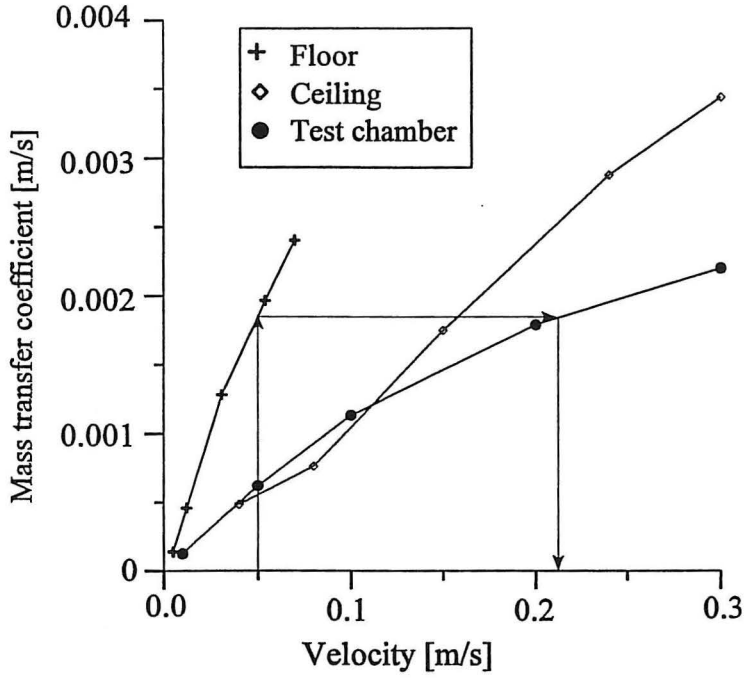


**Figure 6.** Mass transfer coefficient in full scale and test chamber.

The figure can be used to transfer the emission test data obtained in a small test chamber to full-scale conditions. For example: $u_m = 0.05$ m/s is expected at the floor. Then the mass transfer coefficient found from experiment at 0.21 m/s should be used in predicting the emission to the room air. Curves that are made by using a hypothetical agent can be used for other agents which have similar diffusion coefficients.

## DISCUSSION

The results serve as an example on how to use the method. They show that similar velocities can give large differences in emission rates for different geometries. Factors such as the turbulence intensity and the velocity profile near the source are important. Because of the differences, the 'translation' of results is important. The method also provides us with a tool to compare emission test data from different test chamber designs.

It must be noted that for all simulations it is assumed that the emission is controlled by diffusion through a boundary layer near the surface. But the method is general applicable to the study of other limiting processes and environmental parameters influencing the emission rate. To use the method, processes of interest must be included in the simulations, ie. If diffusion within the source material is limiting for the emission, mass transfer within the material must be included in the model.

Next step in developing the method will be to validate with experiments. And possible to improve the turbulence model, because it must be recognised that the LRN-model is based on empirical data, and that some flow phenomena are not accounted for.

## ACKNOWLEDGEMENT

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