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DESIGN OF LOCAL VENTILATION BY FULL-SCALE AND SCALE MODELLING TECHNIQUES

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INTRODUCTION

The ventilation of a working place in an industrial environment is often established by a combination of a general and a local ventilation system. The general ventilation ensures the air quality and comfort far away from the contaminant sources, while the local ventilation - often as exhaust hoods - ensures the contaminant transport close to the emission sources and the people working there. The general ventilation system will control the air distribution and the contaminant distribution in the whole space, but the system cannot control the contaminant transport close to the sources and the people working in the surroundings of the sources. Therefore, it is necessary to have a local ventilation system, and it is very important that this system is efficient as contaminant control system because it represents one of the first elements in the chain process that will bring the contaminant out into the room. A well-designed local ventilation system will also lower the energy consumption of the total system because it is energy efficient to remove the airborne pollution as close to the emission source as possible.

This paper will show the experiments with local ventilation of a filling machine from the paint industry, local ventilation of a film developing machine, experiments with a vortex exhaust opening and local heating of a checkout assistant's working place.

MODEL EXPERIMENTS AND GOVERNING PARAMETERS

Field measurements are used to identify the problems in connection with a specific local ventilation system. The equipment is rebuilt in the laboratory on the scale of 1:1 (1:2 for the vortex exhaust opening), and the general air movement and the local ventilation are established.

The conditions of model experiments with the rebuilt equipment can be formulated from the governing equations of the flow, Nielsen (1993). An experiment on the scale of 1:1 or on any other scale is identical to the real situation if:

- the dimensionless boundary conditions, including geometry, are identical,
- the dimensionless numbers, Archimedes number, *Ar*, Reynolds number, *Re*, and Prandtl number, *Pr*, are the same for both model and real situations.

Using the correct Archimedes number in an experiment is always necessary. This may cause problems if the experiments are made on a reduced scale (e.g. if the scale is reduced by a factor of two, then the temperature difference has to increase by a factor of eight to maintain the level of the Archimedes number and the Reynolds number). The Prandtl number, on the other hand, is unchanged when air is used as fluid in the model experiments.

In practice the problem can be overcome if the Reynolds number is high and the flow pattern is governed mainly by fully developed turbulence. It is possible to ignore the Reynolds number and the Prandtl number because the structure of the turbulence, and the flow pattern at a sufficiently high level of velocity, will be similar at different supply velocities and, therefore, independent of the Reynolds number. The transport of thermal energy by turbulent eddies will likewise dominate the molecular diffusion and will, therefore, also be independent of the Reynolds number.

Figure 1 shows as an example how the dimensionless maximum velocity in a room u_{rm}/u_o is constant at different supply velocities u_o for Reynolds numbers larger than 45000 (*Re* based on diffuser geometry and inlet velocity).

Figure 2 shows an enclosure with an emission source *S* and a laboratory set-up with a model source S_t. The dimensionless concentration c/c_R is identical with c_t/c_{Rt} in the laboratory model at the corresponding location if the Archimedes numbers are identical in full scale and in model, and if the Reynolds numbers are identical or above the critical value for a fully turbulent flow in both cases.

The concentration at a given position close to an emission source can be calculated from

$$c = c_t \frac{c_R}{c_{Rt}} \qquad (1)$$

where c_t, c_{Rt} and c_R are tracer gas concentration at the corresponding position in the laboratory model, tracer gas concentration in the reference point in the laboratory model (return opening), and contaminant concentration in the reference point, respectively.

The concentration can also be found from

$$c = c_t \frac{S}{S_t} \frac{q_{ot}}{q_o} \qquad (2)$$

where q_o and q_{ot} are flow rate around the contaminant source and flow rate in the laboratory model, respectively.

All the experiments in this paper are made under isothermal conditions ($Ar = 0$). Most of the experiments are made on the scale of 1:1, which makes it easy to obtain identical Reynolds numbers in full scale and in laboratory tests.

LABORATORY EXPERIMENTS

This chapter will show the experiments with different equipment from the industry and the optimization which can be obtained by the experimental method.

Filling machine

The contaminant source considered in this section is a wood preservation filling machine. Figure 3A shows the machine with a filling tube (to the left in the figure) and equipment for closing of cans (to the right in the figure). The machine was originally delivered without exhaust equipment, but an exhaust opening has been mounted behind the filling tube. Measurements at the working place show an exhaust flow rate of 180 m^3/h and an acceptable air quality in the operator's breathing zone.

Figure 3B shows a full-scale model of the machine. Many details and surfaces are made in the correct size and location to achieve a reproduction of the actual capturing zone. The capture efficiency α is used for the evaluation of the system, and it is defined as the ratio between the flow rate of the contaminant S_E directly captured from the process, and the total flow rate of the contaminant S released from the process.

$$\alpha = \frac{S_E}{S} \tag{3}$$

Figure 4 shows the capture efficiency as a function of the exhaust flow rate q_E both with the emission source at the "filling position" and with the emission source at the "closing position". The last position shows the lowest values in capture efficiency due to the distance to the exhaust opening. The shaded area in the figure corresponds to the position between the filling and the closing of the cans.

The exhaust air represents a high energy consumption and it is, therefore, important to have a design with a high capture efficiency at low flow rates. Figure 5 shows a new design of the exhaust opening where parts of the machine are integrated into the opening and in this way act as flanges for the flow. It is shown in figure 4 that this solution makes it possible to decrease the flow substantially (65%) and still keep the high capture efficiency. The experiments have been further discussed by Nielsen et al. (1991).

Generally it must be concluded that the exhaust openings should always be an integrated part of the machine or the equipment to obtain an optimal solution.

Film developing machine

Figure 6 shows a film developing machine and the corresponding full-scale model for laboratory experiments. The machine consists of two sections, a developing section in the lower part and an air drying section in the upper part. The new-developed films leave the air drying section through the opening shown in the upper part of the figure. Air is supplied to the drying section from ventilators, and it is blown out into the surroundings through the opening for the films and, consequently, it causes low air quality in the room.

The initial solution of this problem was to install an exhaust channel on the opening for the films, see figure 6. Laboratory experiments show that the principle is inexpedient, and it is only possible to obtain a capture efficiency of 70% at a flow rate of 100 m^3/h. There is also an additional problem because the operator of the developing machine will be highly exposed when he stands in front of the machine and changes the films.

The experiments show that it is impossible to make a simple design of the opening which can improve the air quality in the room. A proper solution should have been chosen in the design phase of the machine. It would for example be obvious to reverse the direction of the air flow and extract the air from the room through the machine.

Vortex exhaust

The vortex exhaust has a geometry which generates a rotating flow (vortex, tornado or cyclone) behind the opening. It is suitable for installation in a narrow space, and it is traditionally used with hand-held equipment which generates jets of air and particles.

Figure 7A shows a vortex exhaust used to capture concrete dust from a hand-held grinding machine, and figures 7B and 7C show two laboratory models. Both models are made on a scale of 1:2, and the first model (figure 7B) is identical with the real opening (figure 7A), while the other model has simplified geometry.

A reduced scale of the model requires an increased velocity level in the experiments to obtain the correct Reynolds number. The influence of the turbulence level is shown in figure 8. A velocity u is measured at a location in front of the opening, and it is divided by the exhaust flow rate q_E in order to obtain a normalized velocity. Figure 8 shows that the normalized velocity is constant for Reynolds numbers larger than 10,000, which means that the flow has a fully developed turbulent structure at that velocity level. The flow may be described as a potential flow with a constant normalized velocity independent of the exhaust flow rate at large distances from the exhaust opening - and far away from surfaces. The experiment can be made at any velocity level above the critical Reynolds number if the flow is fully turbulent in the real situation at the working place.

Comparisons between measurements on the two geometries, figures 7B and 7C, show that a rotating flow will be generated in both cases. The T-shaped exhaust opening in the middle of the rotating flow in the original design is not the only part which generates the vortex, the asymmetry must also be important. The T-connection will smooth the capture velocity in the horizontal direction compared with the velocity distribution obtained in the simplified design.

It is important that the vortex exhaust has a high capture efficiency in connection with blasts from high-pressure air cleaning equipment. The geometry is designed to capture jets from different directions, and experiments with two versions (figure 7B and figure 7C) indicate that both versions have high capture efficiency of concentrated jets.

The T-connection in the original vortex exhaust will increase the pressure loss and increase the consumption of energy. Measurements of the pressure difference in the two versions show a seven times higher pressure difference in the original version (figure 7B) compared with the pressure difference in the

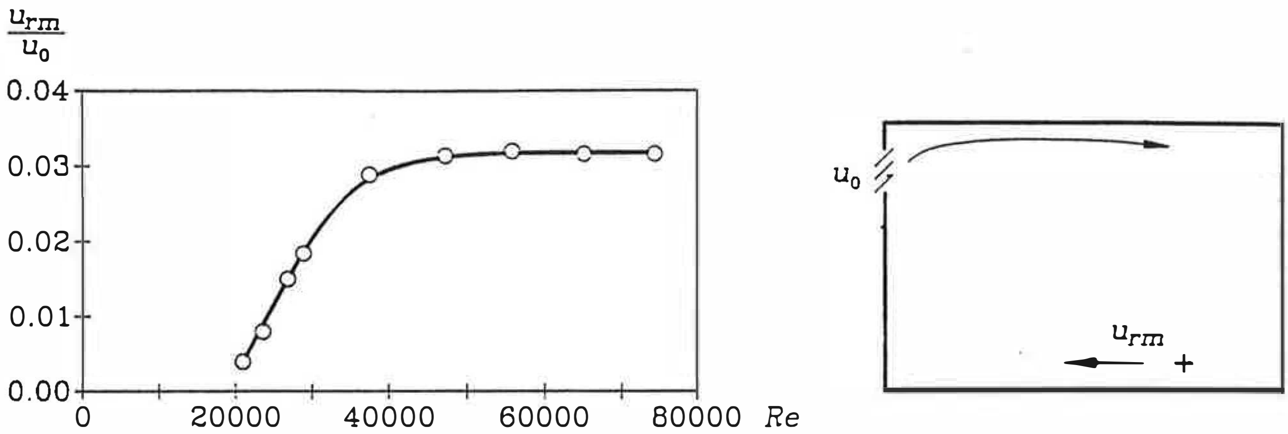


Figure 1. Normalized velocity versus Reynolds number in a ventilated room, see Nielsen (1993).

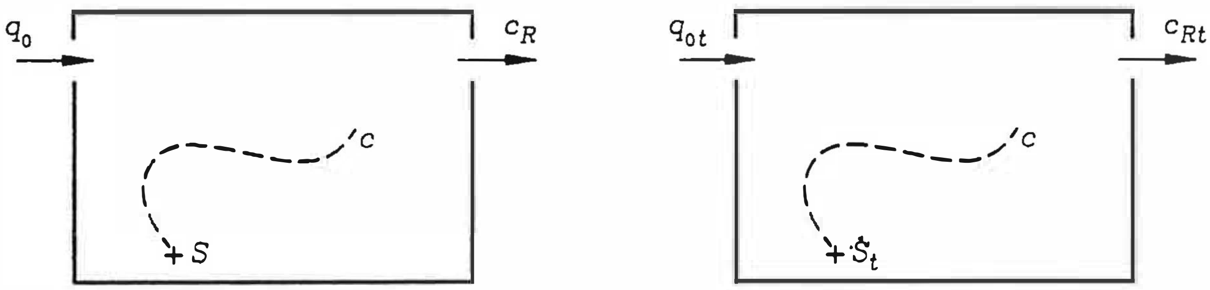
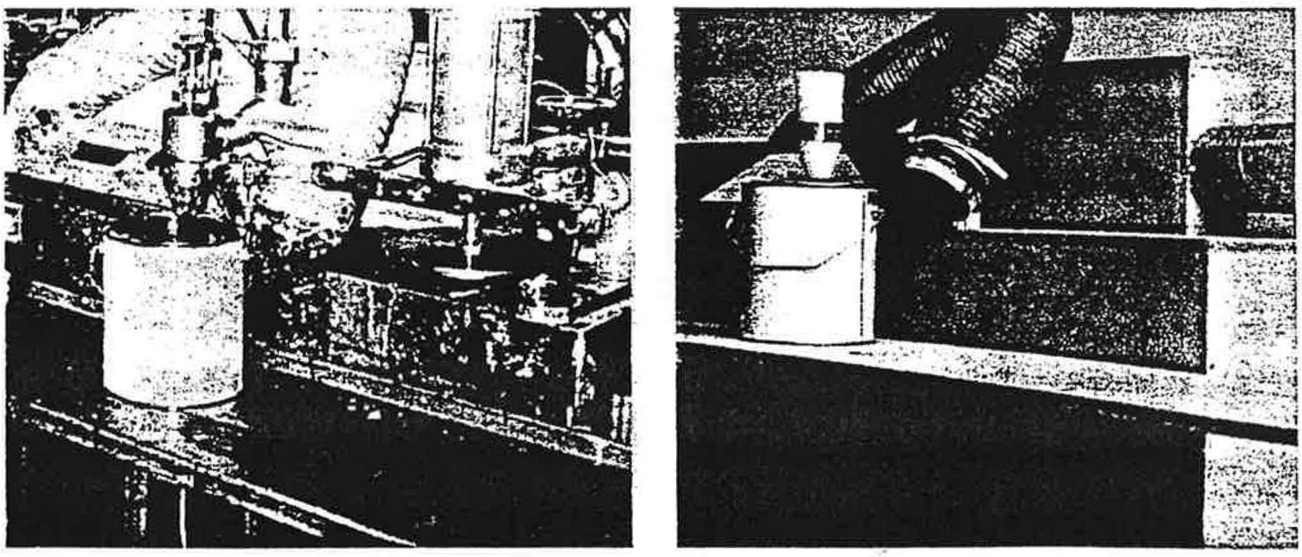


Figure 2. Enclosure with contaminant source S and a laboratory model with model source.



A B

Figure 3. A: filling machine from the paint industry and B: full-scale model of the machine.

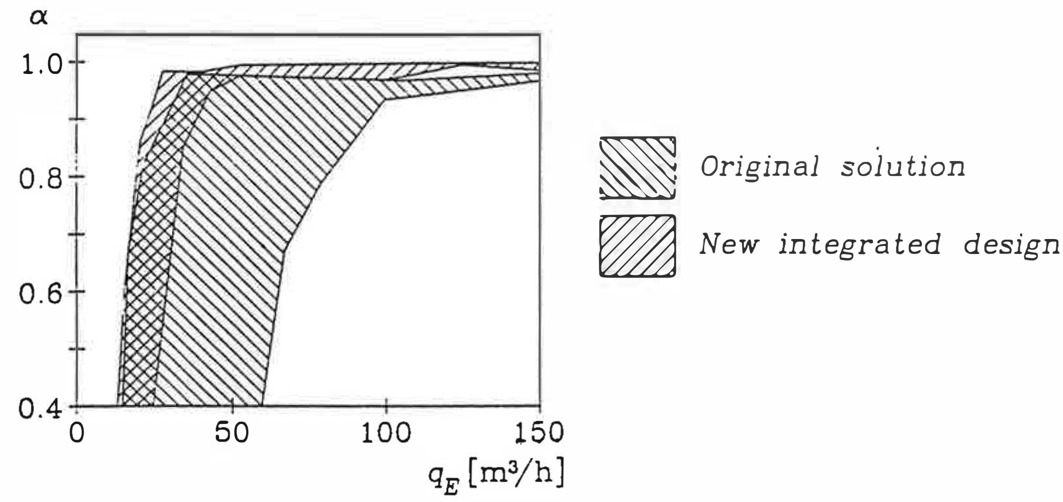


Figure 4. Capture efficiency versus exhaust flow rate for the original solution and for the new integrated design.

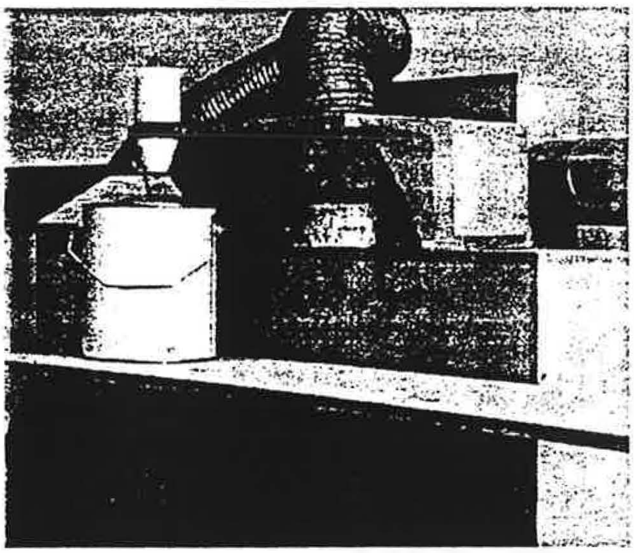


Figure 5. New design of an exhaust opening integrated into the can filling machine.

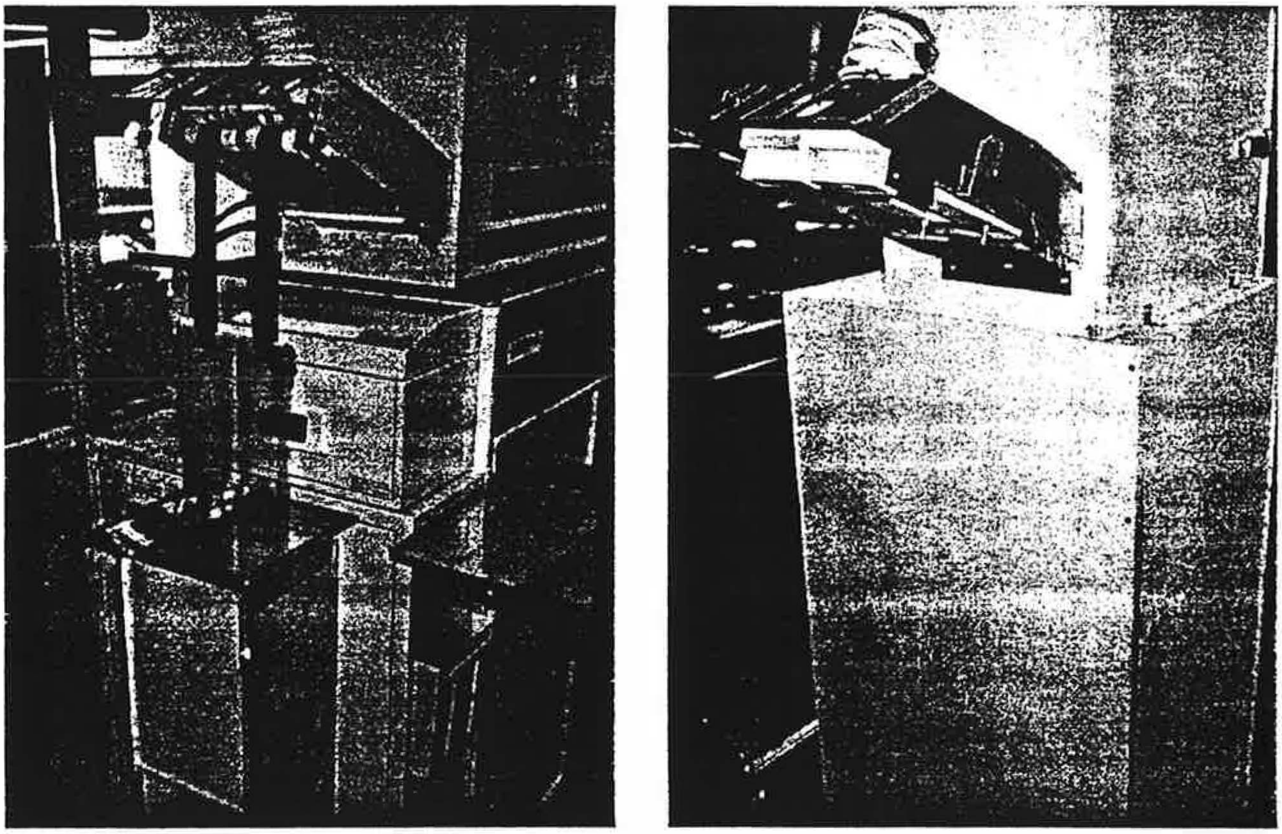
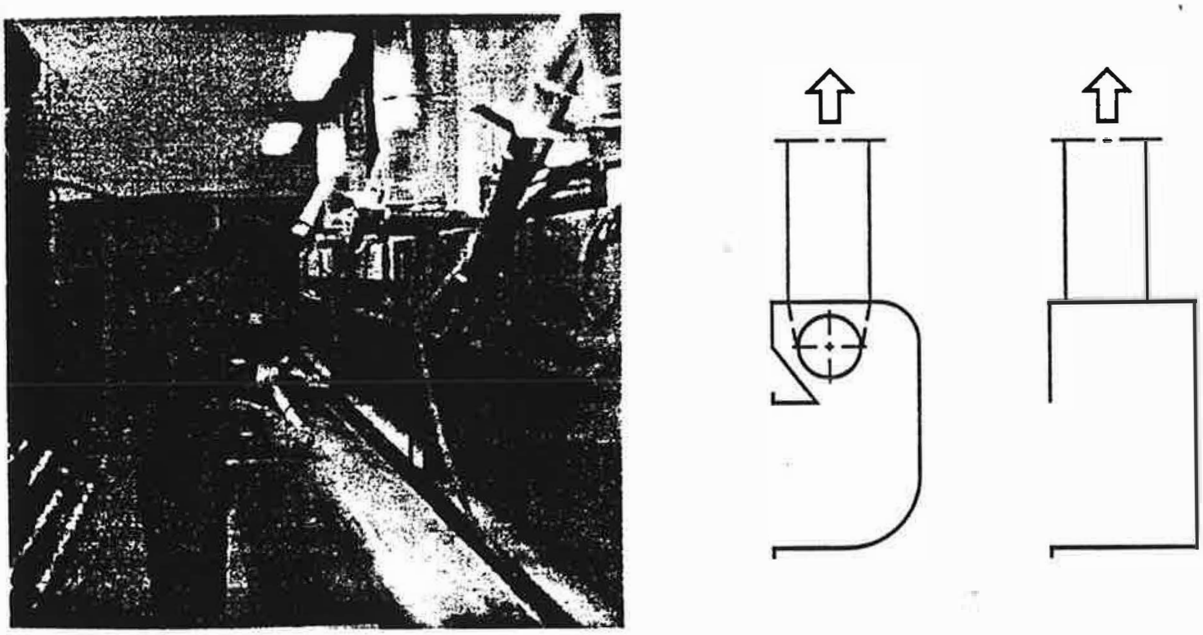


Figure 6. Film developing machine and laboratory model.



A B C

Figure 7. A: vortex exhaust on a concrete element factory, B: laboratory model of the vortex exhaust and C: simplified model of the exhaust.

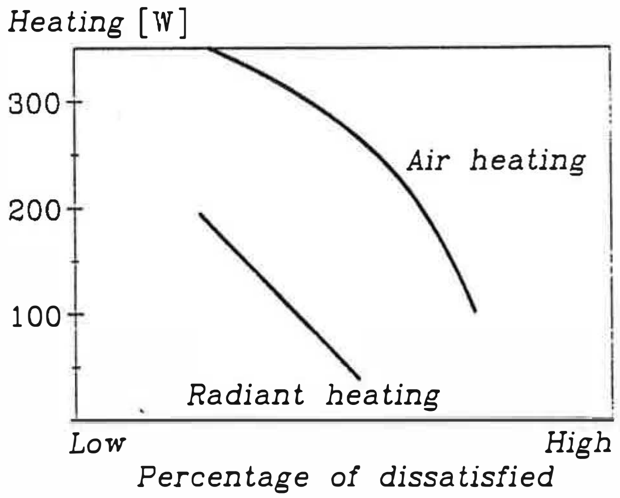


Figure 10. Heat consumption versus predicted percentage of dissatisfied for a checkout assistant.