AIR RECIRCULATION PRACTICES AND RESEARCH IN SWEDEN

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Abstract

The current Swedish practices on air recirculation are based partly on regulations for office buildings and partly on old regulations for hazardous industrial dusts. There are no general regulations for industrial air recirculation. The Department of Occupational Health (corresponding approximately to NIOSH) of the Swedish National Board of Occupational Safety and Health (corresponding approximately to OSHA) is investigating what factors to be considered when writing such regulations.

The influence of different parameters on contaminant concentrations has been studied in an analytical model. The model includes airflow rates, contaminant generation rates (or measured contaminant concentrations), hood capture efficiencies, and air cleaner efficiencies. Methods have also been designed, tested, and used for measuring hood capture efficiencies and for measuring air cleaner efficiencies for some industrial dusts.

I would like to thank the National Institute for Occupational Safety and Health for the invitation to speak here on Swedish practices and research on air recirculation. My intention to attend this symposium was not primarily to speak but to listen. The reason is that, outside Sweden, I have found no country other than the United States, except perhaps Western Germany, where work on the problems involved with air recirculation in industry is going on.

The National Board of Occupational Safety and Health is the central Swedish authority for implementing the occupational safety and health legislation. On the regional level there is a Labour Inspectorate in several districts, with supervisory and advisory duties. One department of the National Board is the Department of Occupational Health, which has approximately the same functions as NIOSH. A subdivision of this department is the Ventilation Section. One of our main interests, currently, is the problems associated with general regulations for recirculation of industrial exhaust air.

The existing regulations that apply to air recirculation in Sweden are found in two official documents. One is the Swedish Building Code from 1975 (ref. 1), which applies mainly to new office, school, hospital buildings, etc.; the

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parts that are valid for industrial buildings state that recirculation is allowed if the following requirements are fulfilled.

1. It must be possible to shut off the recirculation systems.
2. Minimum outdoor airflow (supply air) rates must be supplied.
3. The highest design contaminant concentration for all inlet air should be less than 5 percent of actual threshold limit values (TLVs).

Moreover, there is a paragraph in the Swedish Building Code stating that an air conditioning system should include a heat recovery system, if the total enthalpy difference between outlet air and outdoor air is more than 50 MWh per year (170 M Btu's per year). Assuming an 8-month heating period, and mean outlet and outdoor air temperatures of 25° C and 3° C, respectively, which are normal values in Sweden, the building code calls for a heat recovery system if the airflow is more than approximately 5,400 m^3/h (1.5 m^3/s or 3,200 ft^3/min). This provision in the code leads, in most cases, to recirculation being profitable, since one must otherwise install heat exchangers.

The other document is a regulation from the National Board of Occupational Safety and Health from 1972 (ref. 2). In this document there is a paragraph stating that recirculation is not allowed if silica, asbestos, or lead dusts are present. If there are other hazardous or annoying contaminants in the air, it is the individual labour inspector who decides if recirculation is allowed.

Naturally the TLVs (ref. 3) always apply. There are also some separate regulations for specific branches, e.g., industrial vacuum cleaners for asbestos dust must have a minimum filtering efficiency.

In practice these regulations have led to central air recirculation, i.e., recirculation with outdoor air dilution generally being allowed for office buildings, business buildings, etc., and for industrial buildings without hazardous or irritating contaminants. For other industrial buildings, recirculation may be allowed, depending on how the individual labour inspector interprets the regulations, his knowledge of the properties of the contaminants and of air conditioning systems, etc. The interpretation and knowledge naturally vary among different districts and individuals. The same confusing conditions also exist when local air recirculation (i.e., recirculation without outdoor air dilution) is wanted. In the regulations there exists no clear definition of air recirculation, which has had the result that in some labour inspectorate districts, local recirculation is defined as not being recirculation!

The current stand of the National Board (Supervision Department) is not clear, but it seems that the following requirements are normally imposed on central air recirculation systems.

1. No recirculation is allowed if a process contaminant is a carcinogen (suspected or identified) or has a "Skin" notation or a ceiling value.
2. The contaminant concentration in any air inlet diffuser must be lower than 5 percent of the actual TLV.

3. At least 33 percent of the airflow to a workroom must be outdoor air.
4. It must be possible to shut off air recirculation systems.

Sometimes point 2. is extended and also involves a requirement of continuous monitoring.

In order to provide the basis for new, uniform regulations from the National Board of Occupational Safety and Health, we started looking into the problem some years ago. To obtain an understanding of different parameters' influences on contaminant concentrations, we have made an analytical model (refs. 4 and 5). And now we regard model making as a necessary tool and also a necessary condition for creating new regulations for air recirculation.

The model includes airflow rates, contaminant generation rates (or measured contaminant concentrations), hood capture efficiencies, and air cleaner efficiencies. For local exhaust recirculation, our model (see fig. 1) is similar to the model Astleford (ref. 6) designed, but we have used it in another way.

The model is found by setting a mass balance for a room with complete mixing, and solving the obtained differential equation. The solution is

$$C = \left[\frac{\dot{m} \cdot (1 - \alpha \cdot \eta)}{q_{out} \cdot (1 + \kappa \cdot \eta)} + \frac{C_{in}}{(1 + \kappa \cdot \eta)}\right] \left[1 - e^{-(1 + \kappa \cdot \eta) \cdot \frac{t}{T}}\right]$$

In this equation and in the figure the following symbols are used:

C = Contaminant concentration in the room with recirculation,
C_{in} = Contaminant concentration in supply air (not recirculated),
C_{out} = Contaminant concentration in exhaust air (not recirculated), identical with C,
q_{in} = Supply airflow (not recirculated),
q_{out} = Exhaust airflow (not recirculated),
q_{rec} = Recirculated airflow,
V = Volume of the room,
T = Time constant for the room, identical with V/q_{out},
η = Air cleaner efficiency,
$\dot{m}$ = Contaminant generation rate,
α = Hood capture efficiency,
κ = Air recirculation degree, that is $\kappa = q_{rec}/q_{out}$.

Assuming steady state, which is allowable when comparing systems, the time term disappears. Moreover, for many systems the concentration in the supply airflow is negligible and the second term in the first parentheses also disappears.

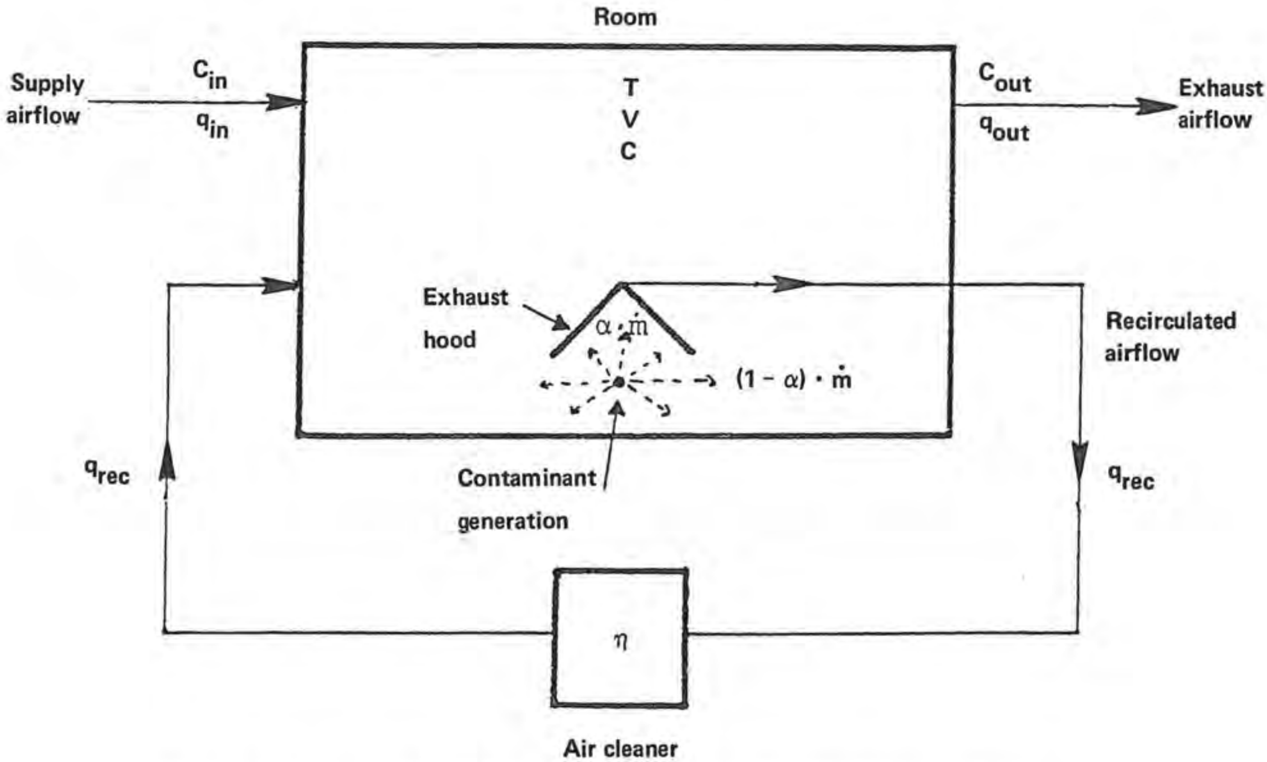

Figure 1. Model for local exhaust recirculation system.

We can then define a concentration, C_o, by dividing contaminant generation rate, $\dot{m}$, with the outlet airflow, q_{out}. This concentration, C_o, it appears, is the same concentration that will be found in the room if we do not have any recirculation. We have thus simplified the first equation to the following form:

$$C/C_o = \frac{1 - \alpha \cdot \eta}{1 + \kappa \cdot \eta} \qquad (1)$$

With this equation it is possible to calculate the concentration reduction in a workroom when a recirculation system is introduced, if we know hood capture efficiency, air cleaner efficiency, and the airflows (i.e., relation between outlet airflow and recirculated airflow). It is also possible to calculate contaminant concentration in the recirculated air and the influence of changes in different parameters.

I will here demonstrate one example of the kind of considerations the model makes possible. Suppose that you install a recirculation system for which the hood capture efficiency is 90 percent and the recirculated airflow is 10 percent of the outlet airflow. What filter efficiency should you choose in this case?

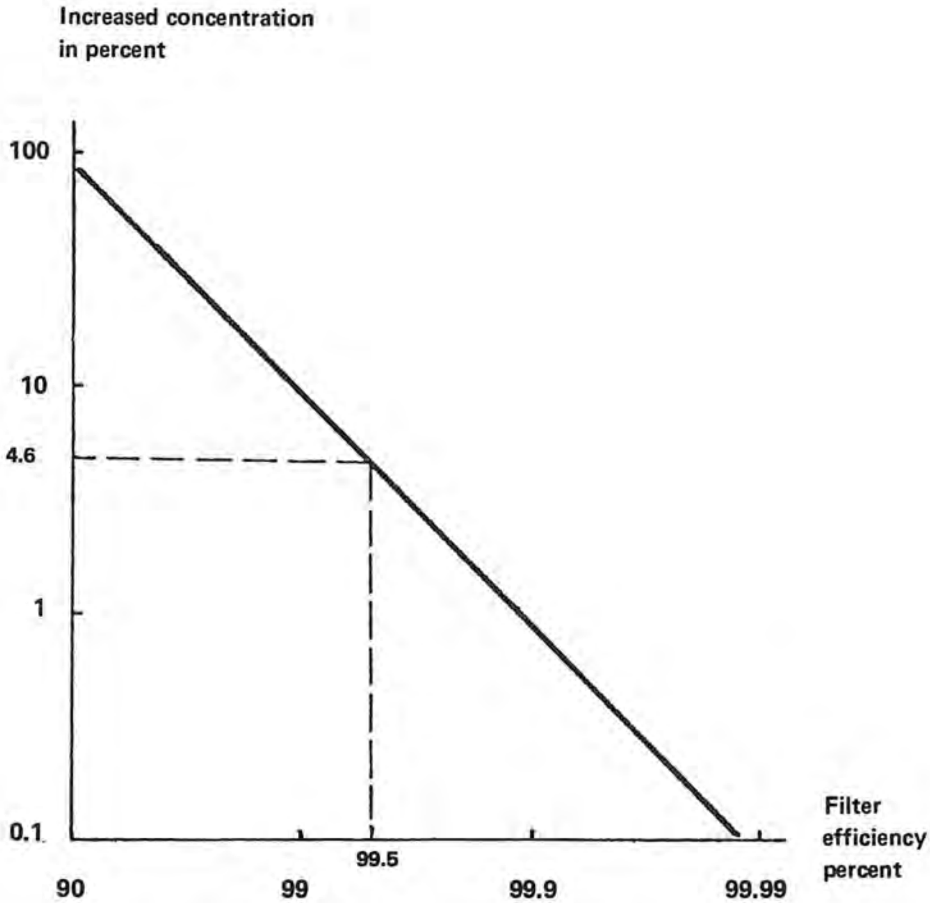

Figure 2. Increase of concentration (in percent) depending on filter efficiency, compared with concentration with 100 percent filter efficiency.

To answer the question we use equation (1) above and compare with a filter efficiency of 100 percent. The relation between concentration difference and filter efficiency is illustrated in figure 2.

From this figure we can see that a filter efficiency of 90 percent will give a concentration approximately 100 percent higher than if the filter efficiency is 100 percent (i.e., no contaminant penetrates or all air is directed outwards). If we take a filter with 99.5 percent efficiency we will get a concentration that is less than 5 percent higher than if no contaminant penetrates the filter. A concentration difference of 5 percent in an industry is neither measurable nor observable. And thus we can see that it would be meaningless in this case to use a filter with a higher efficiency than 99.5 percent.

Naturally, we can use the model to calculate wanted recirculated airflow or outlet airflow or hood capture efficiency if the other parameters are known.

The model also shows that the mentioned practice in Sweden only to demand a contaminant concentration less than 5 percent of the TLV makes it advantageous to have a poor hood capture efficiency. This is one reason for me to think that this practice should be abandoned. The other reason is the great difficulties that will arise if such low concentrations are to be measured continuously.

Of the parameters in the model, the airflow rates and contaminant concentrations are measurable with known methods. Filter efficiencies are normally measured for some standard aerosols, which do not ordinarily exist at workplaces. Since the filter efficiency depends on a number of variables, it is not possible today to predict filter efficiencies for industrial dusts from these standard tests. We have therefore studied and developed measurement methods for determining efficiencies of filters for oil mist, welding fumes, and respirable silica dust. We intend to look at the possibilities of relating standard test efficiencies to efficiencies for industrial dusts.

The hood capture efficiency is a parameter that is not normally known, since most hoods are designed with the help of capture velocities (ref. 7). However, we have designed a method for determination of hood capture efficiency of low volume/high velocity exhaust systems and we have measured capture efficiencies of systems for portable grinding and polishing machines and for a hammer drill (ref. 8). We have also measured capture efficiencies of a number of exhaust hoods for welding fumes.

Thus, we have for some common industrial operations obtained preliminary numerical values of all parameters in the recirculation model.

However, differences always exist between a theoretical model and reality, and one of the problems when using recirculation in new buildings, sometimes also in old ones, is to predict the contaminant transport in a room. We are trying to use tracer-gas to measure the efficiency of the dilution ventilation in a room, but it is an approach that involves great difficulties. I know that you here in the United States use an empirical factor, K, when designing air conditioning systems (ref. 7). At the Royal Institute of Technology, Sweden, two research projects are being carried out whose main purpose is to investigate the relationship between different air currents and the relative movements of different industrial aerosols. In these projects, some of the results imply that air contaminants may concentrate in the center of macroscopic vortices in rooms.

Another problem is the possibility of a failure of an air cleaner. The only certain way of controlling air cleaner efficiencies is to use continuous contaminant measurements. There are, however, a lot of problems connected with continuous measurement of the low concentrations after air cleaners, but in the last few years some new instruments have been developed that may be usable. In Sweden there is one project going on aimed at constructing a relatively cheap aerosol monitor intended for use in recirculation systems.

I believe that air recirculation will be allowed in Sweden to a greater extent in the future. I would like to see the following distinctions and general requirements made concerning central and local systems.

For central air recirculation systems:

1. These systems must be designed by air conditioning engineers in cooperation with professionals of industrial hygiene.
2. No limit should exist for the proportion of recirculated air in relation to supply air. There should only exist a minimum supply of outdoor airflow depending on the number of working persons.
3. The contaminant concentration in the recirculated air must be lower than, for example, 50 percent of the actual TLV.
4. The contaminant concentration must be monitored continuously, either in the recirculated air or in the air at the workplaces.
5. The systems must have either a bypass to outdoor air or a shutoff.
6. A list must specify for which contaminants air recirculation is allowed (or not allowed).

For local air recirculation systems:

1. A representative example of each system must have been tested and approved by the National Board of Occupational Safety and Health. The test should include measurements of filter efficiency and hood capture efficiency.
2. There must be instructions for use and maintenance on every system.
3. The total recirculated airflow must be limited compared with the nonrecirculated airflow.
4. As for central systems, a list must specify for which contaminants air recirculation is allowed (or not allowed).

Our work on air recirculation systems can thus be summarized as follows. The engineers who design air conditioning systems can reduce heat consumption and minimize costs either by using heat exchangers or by recirculating air. The existing regulations applying to the use of heat exchangers are sufficient for making it possible to calculate, in advance, the investment costs, yearly costs, and returns. These calculations are not possible for air recirculation, because the regulations are partly nonexistent and partly nonuniform and confusing. We intend to write as soon as possible a uniform regulation proposal for air recirculating systems, which will make it possible to compare economically heat exchanger systems with air recirculation systems already on the drawing-board. With this proposal we hope that the industry, the trade unions, the labour inspectors and the regulation department people will be content, since all of them for years have been wanting clear, uniform regulations for air recirculation systems.

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DISCUSSION

MR. GEORGE HAMA (Consultant, Huntington Woods, Michigan): I don't feel that that model is practical to work with in industry because it uses hood capture efficiencies. In this country, as far as I know, in the ventilation field there are actually no data on what capture efficiencies are. I'm not saying you can't get laboratory study capture efficiencies, although it's quite an involved study to get them; however, when you do get them, if you apply them to actual industrial operations, you may have to modify them to fit the hoods located in machines and special working conditions. There will be likely variance in cross-draft velocities that will change the efficiencies. As far as I can see I don't think we can approach this thing practically using hood efficiencies. For example, you might get a hood efficiency in the laboratory for welding, but I doubt that it would meet all the variable conditions you encounter, such as distance from hood or from source of contaminant and cross-drafts.

PROFESSOR OLANDER: I'm quite sure that most people in Sweden also agree with you. We don't have the resources you have here in the United States, and as I said my intention was to learn. When I wrote this 3 months ago we were approximately at the same level as you were 2 years ago on the work on recirculation. On your remark I want to state that we have used the model to get an understanding of the sizes of different parameters' influence. And when comparing an exhaust system without recirculation with the same system with recirculation (equation 1), we naturally assume that the hood capture efficiency is the same, that is, it has the same variations or the same constant value. I agree with you regarding the problems if the hood capture efficiency should be used for determining the concentrations.

CHAIRMAN HUGHES: Your equation also uses the mass generation. What type of information do you have on mass generation process?

PROFESSOR OLANDER: We have made measurements for different welding operations, for different grinding operations, and for different drilling operations. I can't tell you if and where they are going to be publicized, but we have the measurements made, and everyone who tried to make that kind of measurements knew there were great problems in making them. We have not determined the connection between hood capture efficiency and different mass generations. Instead we have measured the hood capture efficiencies for the highest possible mass generation rate for each operation. For example, the hoods for welding fume have been measured for continuous welding with different sizes of welding rods. In reality, there is no welder who welds continuously.

CHAIRMAN HUGHES: In the regulations that you have, or would propose, you would probably tend more to look at the type of model that we have developed?

PROFESSOR OLANDER: We do not intend to include a model in the regulations.

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