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VENTILATION EFFECTIVENESS AND PURGING FLOW RATE - A REVIEW

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ABSTRACT

In the past, when designing a general ventilation system, the main concern was comfort. However, a system should be designed to be both an efficient ventilation system and at the same time meet the comfort requirements. The two are in fact closely related, a system that does not meet the comfort requirements can later give rise to indoor air quality problems.

Contaminant exposure is dependent on the contaminant, its properties and how it is spread, the amount of air supplied and the distribution of ventilation air within a room. This paper deals with the methods used to describe and quantify the above. The various elements in the concept Ventilation Efficiency, as defined and applied in Scandinavia, are introduced and their usefulness is illustrated from case studies. Furthermore the aim of General Ventilation is discussed.

KEYWORDS

Ventilation, Ventilation effectiveness, Contaminants, Age distribution, General ventilation systems.

INTRODUCTION

The air quality in a room can be controlled by either control of contaminant sources or by a ventilation system.

The best way of controlling air quality is of course to entirely avoid harmful contaminants by proper source control. This can be achieved by selecting "clean" or low-emitting building materials, furnishings and decorations, not allowing smoking etc.

Two types of ventilation are employed:

- Local exhaust ventilation
- Supply of air that dilutes and transport away the contaminant

The latter type of ventilation is frequently called General Ventilation.

Concentration levels from sources that cannot be avoided (in general contaminants caused by people and their activity) are controlled by dilution with outdoor or other uncontaminated air. The supply of air is provided by general ventilation systems. This paper deals with how to describe the performance of general ventilation systems. The paper focus on the concepts that are in use in Scandinavia.

THE AIM OF GENERAL VENTILATION SYSTEMS

One can define the *aim of ventilation* as follows:

- Remove contaminants as quickly as possible from the ventilated space

Side condition: (Comfort constraint)

- The ventilation shall, be arranged in combination with heating or cooling systems, such that the comfort conditions are met

Contaminants shall in this context be interpreted to also include excess heat. The above definition may at first glance seem very trivial. However, two decades of experience at the Institute carrying out full scale tests of ventilation systems for various clients has shown that they rarely ask about the performance of a ventilation system as a ventilation system. Instead the ventilation is usually regarded as a potential source of draught. A typical question from a client is; what velocities does this system give rise to at the design flow rates? The requirements concerning the flow rate were usually taken from the building regulations.

The focus on comfort and in particular draft is easy to understand because a human's reaction to draught is immediate. A system that gives rise to draught is a severely malfunctioning and can by no means be accepted. If the situation is not improved, people start to manipulate the ventilation system by blocking the supply air terminals, increasing the supply air temperature etc. These alterations may later lead to air quality related problems. However, the reaction time to bad air quality is longer and the symptoms are more elusive. Symptoms common experienced are headaches tiredness, nasal irritation, dry eyes, smells etc.

The whole matter is also complicated by the fact that the sense of smell is subject to rapid adaption. The reason for considering heat as a contaminant is natural. In many cases ventilation is used for temperature control. Therefore the goal is analogue to that for a contaminant i.e. to keep the "contaminant" indoor temperature at a low and acceptable level. The ventilation requirements for temperature control frequently dictate the required flow rates necessary for adequate air quality according to current standards. The best way of controlling the "heat" environment is source control. Therefore low heat emitting office electronics should be selected. To control the temperature by introducing large quantities of air may easily create opposing flows where the air stream from the supply air terminal and natural convection currents from the heat sources are in opposite direction. Opposing flows will often cause draught problems. As described above draught problems may later, after manipulation of the system, lead to air quality problems.

The challenge for the designer is to create systems that provide a proper air quality and at the same time meet the comfort constraints.

WHY DO WE NEED THE CONCEPT VENTILATION EFFECTIVENESS?

The primary ventilation related air quality parameter is the amount of outdoor air supplied to the room. In principle one can satisfy any requirements (subjective or objective) of air quality by supplying a sufficient amount of air. If all general ventilation systems behave with regard to their ability to transport and dilute contaminants, then there would be no need for a concept such as Ventilation Effectiveness. The only concern would be to arrange the ventilation such that draught due to moving air is avoided. However, systems are not alike. The performance is dependent on the layout of the ventilation system and the operating conditions.

THE VENTILATION PROCESS

Air quality in terms of concentration of contaminants depends on a number of factors, see Figure 1 and Figure 2.

- The amount of air supplied, q_v, and the distribution of air within the room
- The amount of contaminant, $\dot{m}_s$, released and the spread of contaminant within the room.

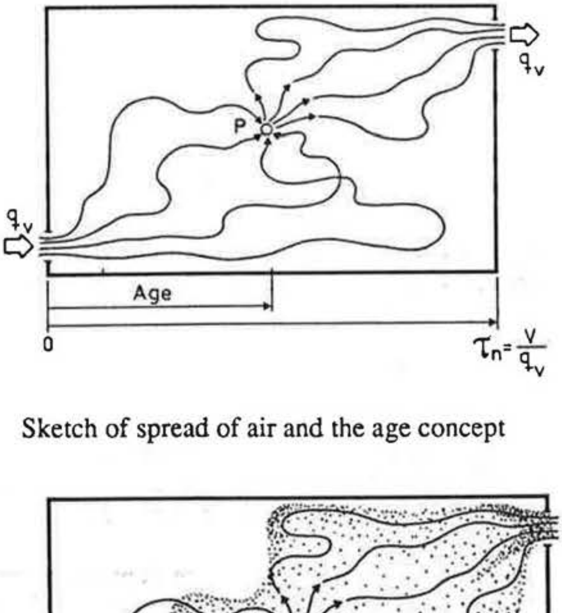


FIGURE 1 Sketch of spread of air and the age concept

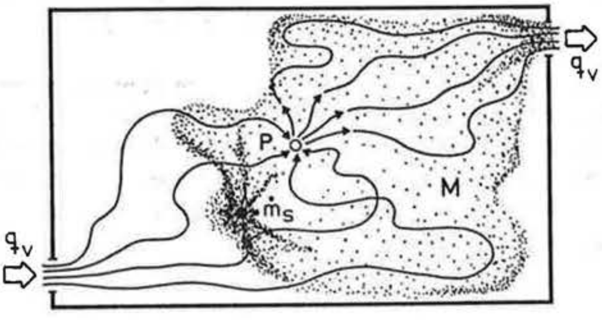


FIGURE 2 Sketch of spread of contaminant due to a release $\dot{m}_s$. M is the total amount (hold up) of contaminant in the room

A contaminant is not usually spread in the same way as supply air because it has a different point of release. The air is "released" at the supply air terminal whereas the contaminant is released within the room. Furthermore a contaminant may have another density, frequently caused by temperature differences, than the ambient and can therefore set up its own motion.

The concept of Ventilation Efficiency comprises of several other concepts which evaluate the spread of both contaminant and air.

The problem of quantifying the performance of a general ventilation systems raises the question of what terms one should express the following factors in:

1. The *distribution of the ventilation air* in the room.

- Where does the ventilation air go and how fast?
- How much ventilation air passes a given point?
- What time does it take to replace (exchange) the air present in a room?

The *answer* to the *first question* is given by the Age Distribution of the air within the room (Sandberg and Sjöberg (1983)). The age concept is in use in chemical reactor engineering (Nauman (1981). Within chemical reactor engineering one is only interested in the relation between input and output and not of the behaviour at a specific point within the reactor. When the air enters the room its age is zero, see Figure 1. The Age Distribution at a point, p, is given by its statistical distribution. Only the mean value of the statistical distribution, i.e. the local mean age, $\bar{\tau}_p$, has any physical interpretation.

The mean age of the air when it leaves the room is *always* equal to the Nominal Time Constant, τ_n, of the ventilated space, which is defined as the net volume ventilated, V, divided by the ventilation flow rate, q_v:

$$\tau_n = \frac{V}{q_v} \qquad \text{[Time]} \qquad (1)$$

The Nominal Time Constant, τ_n, is essential for determining whether or not we have stationary conditions. If the duration of the contaminant release is much longer than the nominal time constant then the equilibrium concentration will be attained.

The *answer* to the *second question* is the net flow rate of ventilation air or the purging flow rate, U_p (Zvirin and Shinnar (1976),Sandberg and Sjöberg (1983)) . The purging flow rate is of course always less than the ventilation air flow rate. The local flow rate of air is dependent on the volume we are considering (whole room volume or fraction of room volume). The properties of the purging flow rate have some similarities with the scale for Ventilation Efficiency based on the mean radius of contaminant diffusion used by Kato and Murakami (1988).

Finally the *answer* to the *third question* is given by the mean age of all air *present* in the room, $\langle\bar{\tau}\rangle$. The time it takes on average to replace the air present in the room, τ_r, is equal to twice the mean age of all air present in the room.

$$\bar{\tau}_r = 2\langle\bar{\tau}\rangle \tag{2}$$

By knowing the local mean age of air, $\bar{\tau}_p$, the magnitude of the purging flow rate can be assessed, Sandberg and Sjöberg (1983):

$$U_p < \frac{\tau_n}{\bar{\tau}_p} q_v \qquad (\text{When } \bar{\tau}_p > \tau_n) \tag{3}$$

2. The *distribution of the contaminants* and *dilution.*

The distribution of the contaminant within the room, due to a continuous release, $\dot{m}_s$, at a source point s is quantified by

- The local flow rate of contaminant, $\dot{m}_p$, at an arbitrary point, p, within the room
- The age distribution of the contaminat at the same point

The equilibrium concentration, C_p, attained at a point is expressed in the terms given above as:

$$C_P = \frac{\dot{m}_p}{U_p} \tag{4}$$

This is the *fundamental dilution equation* for a contaminant.

In the extract the purging flow rate is equal to the ventilation air flow rate. All contaminant generated passes the extract so the equilibrium concentration, C_e, in the extract becomes:

$$C_e = \frac{\dot{m}_s}{q_v} \tag{5}$$

Definition of complete mixing

Ideal or complete mixing is often referred to, however the definition of the concept complete mixing as presented in the literature is often very vague. Complete mixing means that in some sense we have uniform conditions throughout the whole space. With the aid of the concepts introduced earlier we can give a precise meaning to the complete mixing.

One starting point is to take the time it takes to for the air to arrive at different points and another is to take the local flow rates (purging flow rates):

Definition 1

Complete mixing is a condition where the *local mean age of air* everywhere is the same and equal to the Nominal Time Constant.

Definition 2

Complete mixing is a condition where the *local flow rate* (purging flow rate) everywhere is the same and equal to the ventilation flow rate.

When the second definition is fulfilled the first definition is also satisfied, however the reverse is not true.

Complete mixing according to definition two implies that, independently of where a release of contaminant occurs in the room, the concentration at the source becomes the same as the concentration in the extract, i.e. maximal dilution (see the dilution equation). However, condition 2 is impossible to fulfill in practice because it requires infinitely large secondary air flows in a room. This kind of mixing could perhaps therefore be called complete and instantaneous mixing. To fulfill the first definition is easier, it requires only that the amount of air that arrives to a given volume is proportional to the the volume in question. Experience shows that mixing according to the first condition is relatively easy to attain.

A practical definition of complete mixing in terms of contaminant concentrations could be stated as follows:

- Complete mixing is a condition where the concentration outside the source region is uniform and equal to the concentration in the extract duct.

Classification of air flow conditions

The air flow conditions in a room can be classified into the following ideal forms. (Table 1)

TABLE 1 Air flow conditions and air quality

Air flow pattern	Air quality	Air exchange efficiency	Air exchange time ($\bar{\tau}_r$)
Unidirectional flow	Supply air conditions		
Displacement ventilation	Supply air conditions in the lower part of the room	<100 % and >50 %	$<2\cdot\tau_n$ and $>\tau_n$
Complete mixing	Extract air conditions	50 %	$2\tau_n$
Short circuiting	Worse than extract air conditions in the lower part of the room	<50 %	$>2\tau_n$

The relation between type of air flow pattern and age distribution is not unique, so the reverse is not always valid. For example, an Air-exchange efficiency of 50 % does not automatically imply that we have complete mixing.

With unidirectional flow the air flows in one direction only. With mixing flow there is a strong recirculation of air. In shortcircuiting flow a large proportion of the supply air flows directly to the extract air device without passing the occupied zone. In practice different air flow patterns may occur in different parts of a room. For example ventilation by displacement gives rise to two zones, a lower zone with unidirectional flow and an upper zone with recirculation.

THE ELEMENTS IN THE CONCEPT VENTILATION EFFICIENCY

Within the Nordic countries a number of terms (Sandberg and Skåret (1988)) have been proposed for use in describing the performance of ventilation systems with regard their ability to distribute the air and how efficiently they remove contaminants. In brief the concepts are as follows:

Concepts related to the ventilation air

Specific flow rate. The Specific Air Flow Rate is defined as the supply of "clean air" (outdoor air) in relation to the total ventilated volume. The Specific Air Flow Rate is designated n and is defined as:

$$n = \frac{q_v}{V} \qquad (6)$$

Note the physical dimension - this is flow per unit volume. The units must not be abbreviated to (1/h). The specific flow rate is often called the "air change rate". The unit is then stated as "changes/hour". This is however misleading since it gives the impression that the air in the room is changed a given number of times during one hour.

Air exchange efficiency. The Air Exchange Time is τ_r which is related to the mean age of all air present in the room as given by equation. The theoretically shortest change time for the air in the room is the same as the nominal time constant τ_n. It easy to see that the pure unidirectional flow ("piston flow") gives a change time which is the same as τ_n. This flow represents a special case, in reality the Air Exchange Time is longer.

The Air Exchange Efficiency, ε_a, is defined as:

$$\varepsilon_a = \frac{\tau_n}{2\langle\tau\rangle} \times 100 = \frac{\tau_n}{\tau_r} \times 100 \qquad (\%) \qquad (7)$$

The upper limit to the air exchange efficiency is 100 %.

Table 1 provides a summary of the Air Exchange Efficiency for different air flow conditions.

Concepts related to contaminants

Average Ventilation Effectiveness. As a reference point the conditions in the extract, C_e, are taken. The Average Ventilation Effectiveness is defined as the ratio between the concentration in the extract and the average concentration in the room, $<\bar{C}>$:

$$<\varepsilon> = \frac{C_e}{<\bar{C}>} \times 100 \qquad (\%) \qquad (8a)$$

This agrees with the classical definition of ventilation effectiveness by Yaglou and Witheridge (1937) in USA and Rydberg and Kulmar (1947) in Sweden. The Average Ventilation Effectiveness can be expressed in terms of the age of contaminant (Sandberg & Sjöberg (1983)).

At steady state the total amount of contaminant (hold up) M in the room is equal to

$$M = m_s \cdot \bar{\tau}_e^c \qquad (9)$$

where $\bar{\tau}_e^c$ is the mean age of contaminant in the extract. Inserting (5) and (9) into (8a) gives

$$<\varepsilon> = \frac{\tau_n}{\bar{\tau}_e^c} \cdot 100 \qquad (\%) \qquad (8b)$$

Local Ventilation Index. When considering local concentration levels the Local Ventilation Index, ε_p, for an arbitrary point is used

$$\varepsilon_p = \frac{C_e}{C_p} \text{ X } 100 \qquad (\%) \qquad (9)$$

Where C_p is the equilibrium concentration at point p. The magnitude of the Local Ventilation Index depends significantly of course on the location of the measurement point. With a measurement point near the supply air device it can in theory be infinite irrespective of the type of system. This is why it is called a ventilation index.

EXAMPLE OF RECORDED AIR EXCHANGE EFFICIENCY

In general the magnitude of the air exchange-efficiency is determined by the following factors

- Direct loss of the supplied air
- Air flow pattern in the room

Direct loss of ventilation air

Direct loss of the ventilation air occurs when the air issuing from the supply device travels only a short distance before it arrives to the extract point. Due to the short distance relatively small quantities of air has been entrained into the jet and a relatively large quantity of the supplied air is caught by the extract air device. Figure 3 shows the performance of three systems. The supply and extract air device is located at the same level (Ceiling-Ceiling system). Supply air temperature is the same as the room air temperature and the flow rate is the same in all cases.

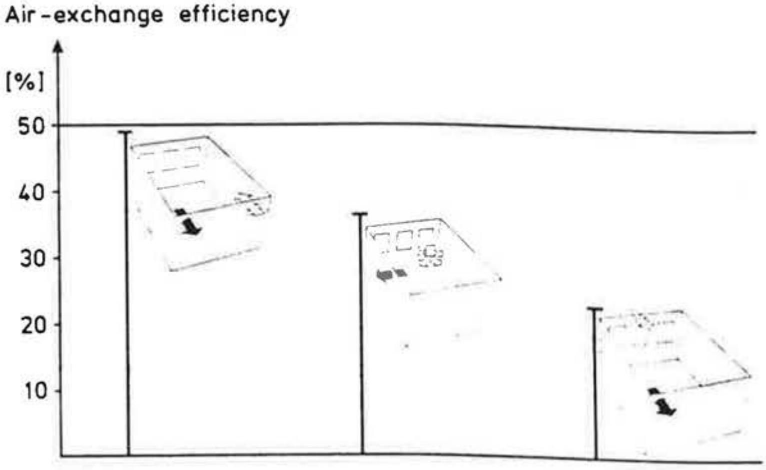


FIGURE 3 Air-exchange efficiency. Isothermal conditions. Sandberg (1985)

In the first system the air-exchange efficiency in near equal to the maximum attainable for a Ceiling-Ceiling system. In this case the jet travels all along the whole perimeter of the room before it reaches the extract device. The next system is provided with a radial supply. Therefore a fraction of the supply air flows directly towards the extract. The last system gives rise to a dramatic reduction of the air-exchange efficiency. This is a consequence of that now the whole air flow supply is directed towards the extract air device.

Air-flow pattern in the room

The air flow pattern in the room depends on the following factors: Mutual location of the supply and extract air devices, momentum of the jet (flow rate), load in the room (magnitude and location), supply of positively - or negatively buoyant air, discharge Archimedes number (relation between buoyancy and inertia).

Figure 4 show three different ventilation schemes in the same room. Tests were carried out at both heating - and cooling of the ventilation air (Sandberg (1985).

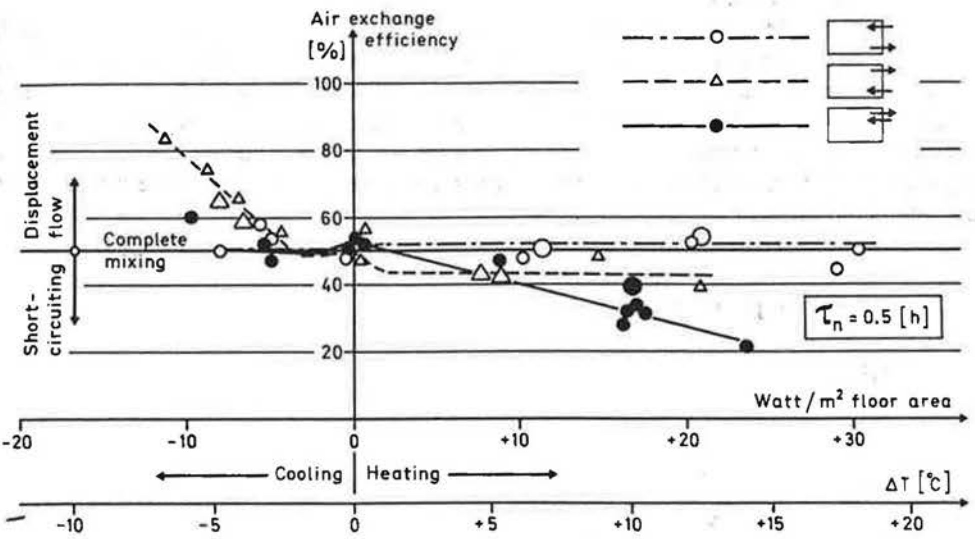


FIGURE 4 Air-exchange efficiency
ΔT denotes the temperature difference between supply and extract
o Ceiling-Floor system, Δ Floor-Ceiling, o Ceiling-Ceiling

When used for heating the Ceiling-Ceiling system exhibits a pronounced short circuiting. This is due to that the buoyant jet, due to the opposing buoyancy force is hindered from to flow along the hole perimeter of the room. In the Ceiling-Floor system the meter of the room. In the Ceiling-Floor system the air is forced to pass the whole room. At cooling the Floor-Ceiling system (provide with a low-velocity device) works as a displacement system and gives rise to a high air-exchange efficiency.

RELATION BETWEEN THE AIR EXCHANGE EFFICIENCY AND THE EXPOSURE TO CONTAMINANTS

We will consider the ceiling-ceiling and the floor-ceiling system. Contaminants with both greater, less and approximately the same density as air were released. In Figure 5 the vertical axis gives the concentration in the extract, C_e, divided by the average concentration in the occupied zone, $\langle C \rangle_o$. The horizontal axis gives the Air Exchange Efficiency.

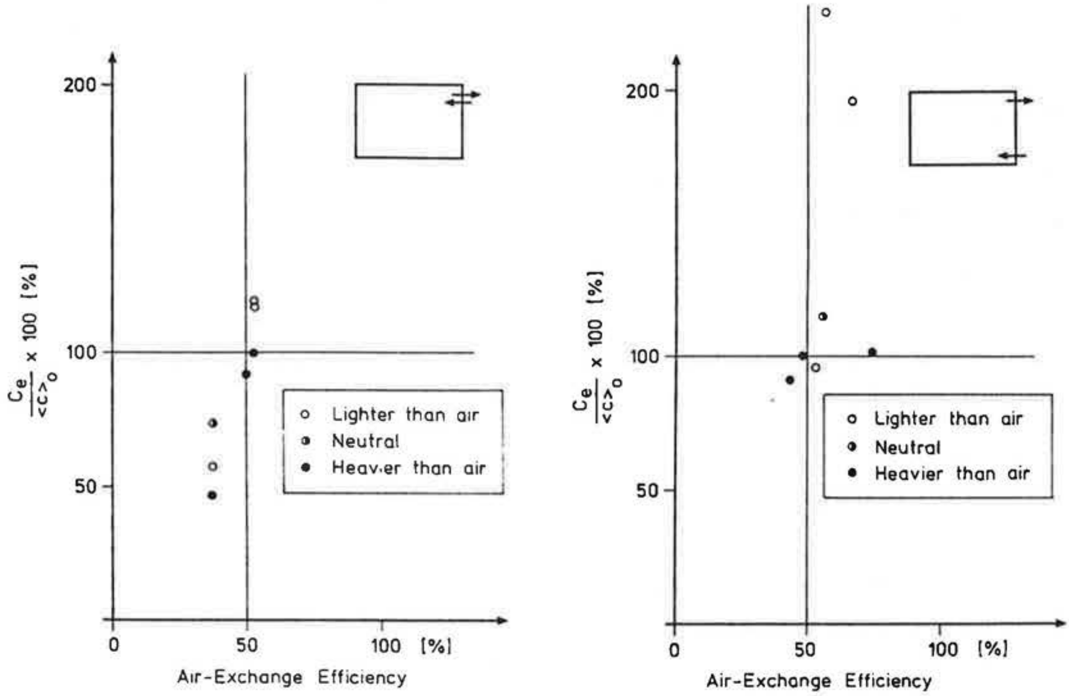


FIGURE 5 Exposure in the occupied zone versus the air-exchange efficiency. Ceiling-Ceiling system and Floor-ceiling system

We see that two types of results are obtained: When the Air Exchange Efficiency is greater than 50 % the average exposure in the occupied zone becomes less than the concentration in the extract. On the other hand when the Air Exchange Efficiency becomes less than 50 % the contaminant concentration in the occupied space increases and becomes greater than that in the extract. One can therefore conclude that in this case the Air Exchange Efficiency provides correct qualitative information regarding the concentration exposures. Therefore, if a system attains a high Air Exchange Efficiency then in all likelihood the system will efficiently remove contaminants. This does not mean, however, that a system with an Air Exchange Efficiency less than 50 % is necessarily poor. It is possible that both the air and the contaminant are shortcircuited, i.e. the contaminant goes directly from the source towards the extract point (Skåret (1984)). This situation will give rise to good air quality despite the fact that the air is shortcircuited. Measurements of the actual concentrations are of course more informative than recording the Air Exchange Efficiency. However, in many situations one does not know in advance what contaminants a system is going to remove. The Air Exchange Efficiency is useful is for trouble shooting when a system does not work properly. The course of the malfunctioning may be bad distribution of room air and this may be revealed by recording the Air Exchange Efficiency.

MIXING VENTILATION VERSUS VENTILATION BY DISPLACEMENT

Ventilation by displacement is a type of ventilation where the buoyancy forces (induced by heat sources) govern the flow in the room. Because the air flow is thermally driven this type of ventilation can only be used when there is a heat load in the room. Air with lower temperature than the room temperature is supplied at floor level, while the air is extracted at the ceiling level. By this arrangement one obtains a vertical temperature gradient. In terms of the flow pattern the room becomes divided into two zones. One lower zone with unidirectional flow and one upper recirculation zone. The two zones are separated to by an interface. This interface between the zones are located at the height where the flow rate in the natural convection currents in the room is equal to the ventilation flow rate. At this interface the velocity outside the plumes are horizontal. The plume flows starting from heat sources make "holes" in this interface. With regard to the air quality the aim of this ventilation principle is to create supply conditions in the occupied zone. This is in contrast to traditional mixing ventilation, where the aim is to obtain extract air conditions in the whole space.

The net effect of the pure horizontal flow at the interface and the density stratification caused by the increasing temperature with height is that the transport of contaminants from the upper zone to the lower zone is hindered. This is shown in Figure 6 (Stymne et al (1991)). Tracer gas was emitted into the boundary layer flow from one of the heated dummies. The tracer is directly and completely transported upwards to the mixing zone. The two zones appear clearly, within the lower zone there are no contaminants.

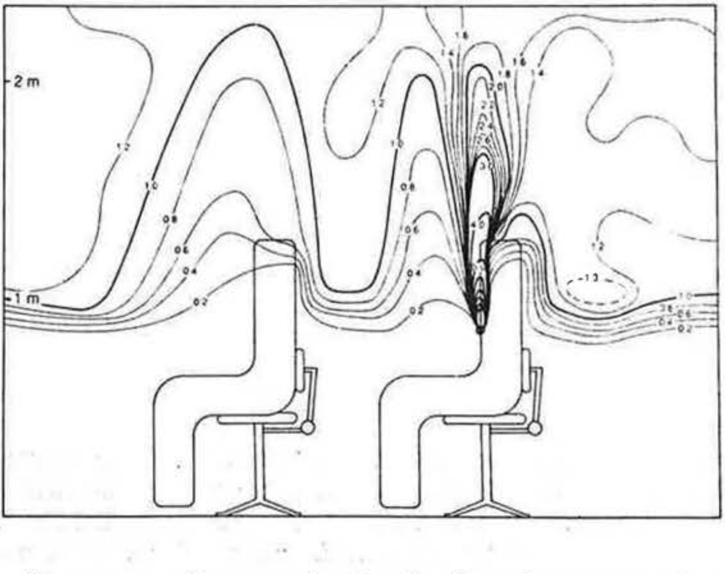


FIGURE 6 Iso-concentration map showing the dispersion pattern of a tracer gas emitted close to one of the two heated dummies. Concentrations are given relative to that in the extract (concentration in the extract = 1)

Figure 6 shows that the interface between the lower clan zone and the upper contaminated zone is locally displaced upwards around the heated dummies. This is an effect of the plume flow around the bodies. The plume flow dilutes the air around the body.

Tests were also carried out with the ventilation arranged as a mixing ventilation system. The plume flows were unaffected by the change of system. This was evident from the locally higher than ambient concentrations in the plume above the dummy provided with the tracer gas source. Outside this plume, however, the tracer concentration was uniform and close to the concentration in the extract. This shows that we do not obtain complete mixing in terms of the purging flow rate being everywhere equal to the supply flow rate.

A nice example of the recorded concentration distribution in mixing ventilation is shown in Heilselberg(1991).

EXAMPLE OF DETERMINATION OF THE PURGING FLOW RATE

Figure 7 (Sandberg and Stymne (1990) or Stymne et al(1991)) shows 5 office rooms connected to a common corridor. To each room there is an individual supply of air. The extract point is located at the end of the corridor and from each room the extracted air flows via an overflow device to the corridor. Within the whole area a total amount 240 m^3/h of outdoor air is circulating. The question is how this air is distributed among the rooms?

In order to explore this distribution the purging flow rate was recorded by placing a tracer gas source in each individual room, one at a time, and recording the equilibrium concentration simultaneously in many points. The first inset in Figure 7 shows the situation when all doors are closed whereas the second inset shows the case when all internal doors are open.

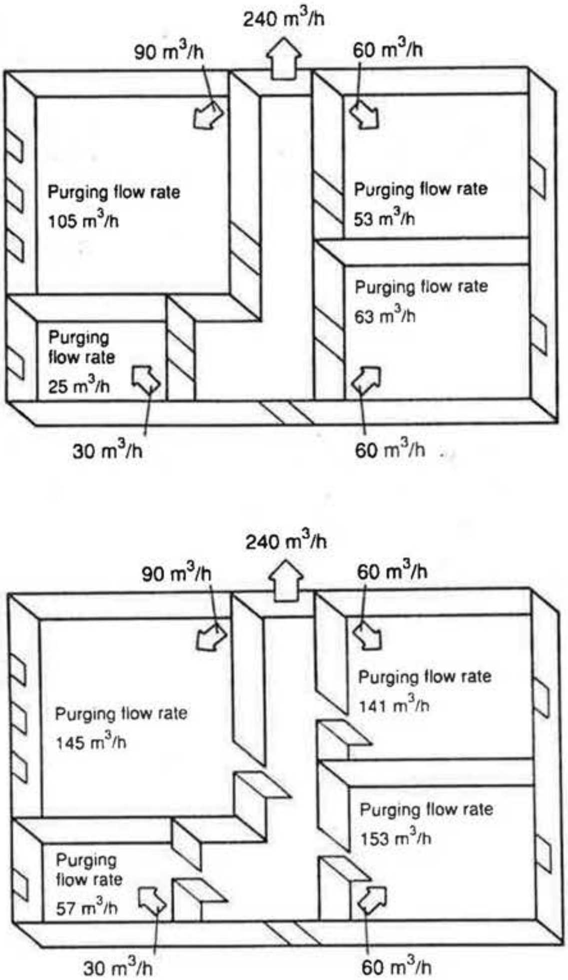


FIGURE 7 Office rooms connected to a common corridor.
Above: All internal doors closed
Below: All internal doors opened

We see that when all doors are closed the purging flow rate in each individual room is close to the supplied flow rate.

When the doors are opened the purging flow rate increases in each room and becomes greater than the direct supply of air to a room. This is a because by opening the doors each room get access to a larger flow rate of air. Therefore the concentrations generated by a contaminant now become lower than when the door are closed. However, this advantage is gained at the expense of other rooms. Contaminant released in one room is spread to all other rooms.

The local purging flow rates can be determined by using numerical simulation models for flows and contaminat transport in rooms. Figure 8 which is from Davidsson and Olsson (1987).

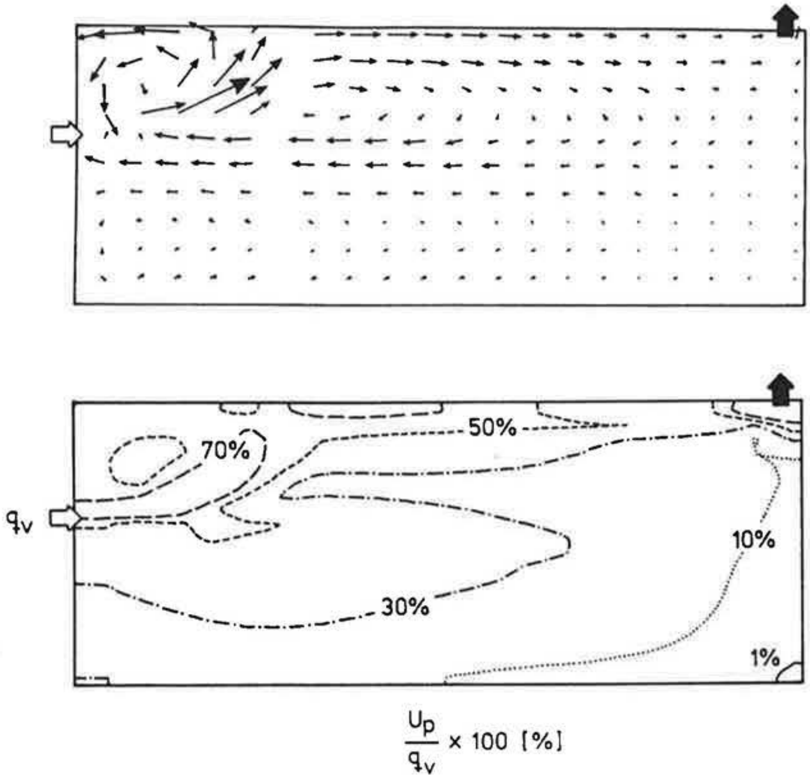


FIGURE 8 Above: Velocity field
Below: Purging flowrate divided by the ventilation air flow rate

At present we do not possess any practical method for determing the local purging flow rate. However, work is going on at the institute to develop methods (Sandberg and Stymne (1992)). A local control volume is created by mounting 40 passive samplers in a circle (diameter 120 mm) around a tracer gas source. The tracer gas source consists of a glass vial provided with a capillary tube with an inner diameter of 0.02 mm. The whole device is rotating around a vertical axis at a rate 1 rpm.

Figure 9 shows examples of recorded concentrations in two cases with this device. In both cases the flow rate is the same. The concentration is given as the average concentration divided by concentration in the extract.

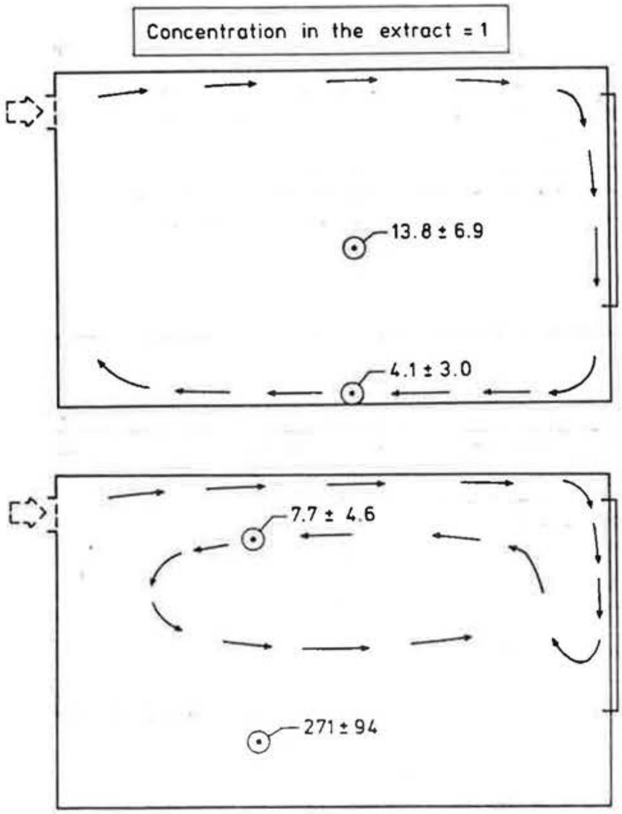


FIGURE 9 Average concentration around a local point source
Above: Isothermal conditions
Below: Supply of heated air

MEASURING TECHNIQUES

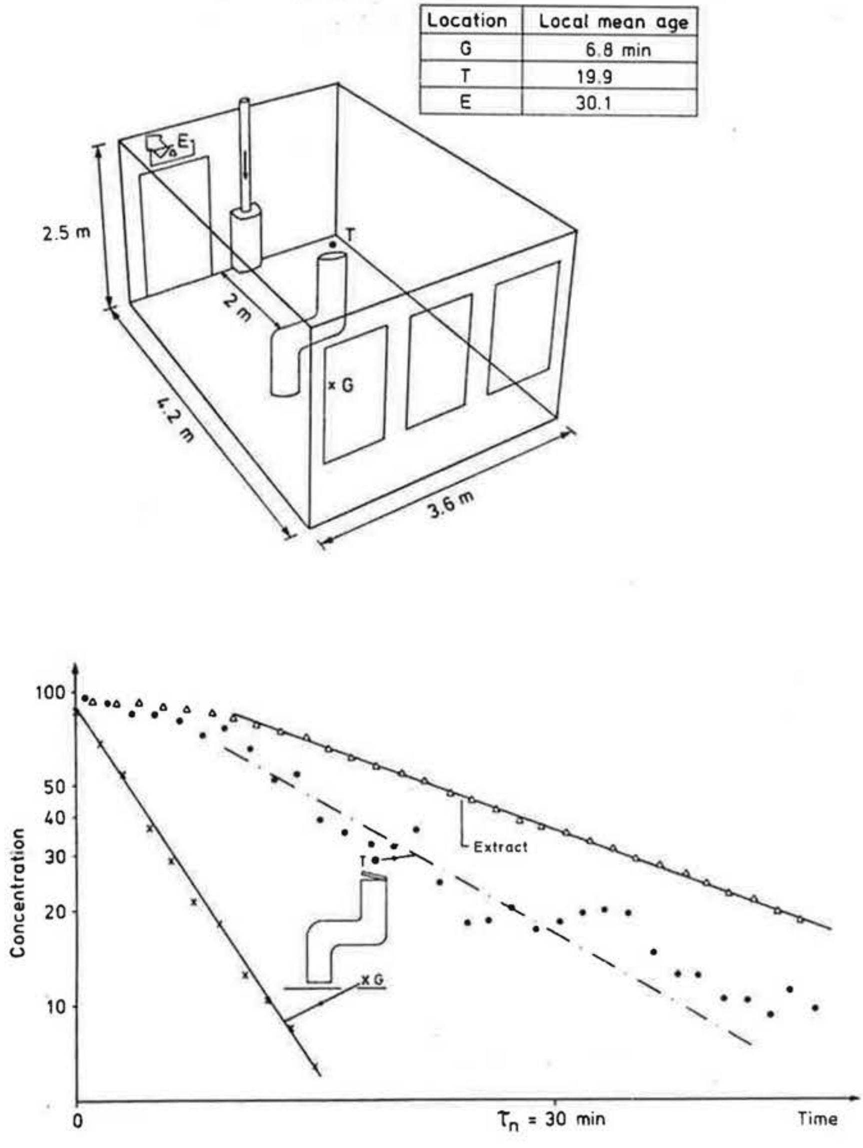
For measuring the age distribution and thereby determining the air-exchange efficiency tracer gas technique is employed. Most commonly used methods are the "Step down (decay)" and "Step up" method. They are theoretically equivalent in tight buildings. However in real buildings they are not equivalent. Their properties are summarized in Table 2.

TABLE 2 Tracer gas methods for determining the age distribution

Method	Injection method	Advantage	Disadvantage
Step up	Continuous injection into the ventilation system's supply	No artificial mixing necessary	Only air coming from ventilation system is labelled
Step down	Initial short term release of tracer and mixing	All air in the room labelled	Initial artificial mixing necessary

In case the extract points are well defined the mean-age of all air present in the room can be determined from the concentration readings in the extract. Figure 10 shows an example of the use of the step down method in a room ventilated by a displacement ventilation system.

Occupancy was simulated by a heated dummy.



Location	Local mean age
G	6.8 min
T	19.9
E	30.1

FIGURE 10 Step down method. Tracer gas histories

Large buildings pose special problems (Raatschen & Walker (1991)). When using the step down method it may be difficult to achieve a homogeneous mixture of tracer gas. On the other hand the use of the step up method gives rise to other problems, the infiltration is not accounted for.

In order to overcome the difficulties, a new method based or constant emission of tracer gas has been developed by Stymne et al (1992). The space is sub-divided into smaller zones, in each of which tracer gas in injected at a rate proportional to the zone-volume. The local mean age of air in each zone is evaluated from the steady state concentrations.

THE HUMAN FACTOR

A human creates air motion in two ways; As a source of heat (buoyancy source) and due to body movement. Both factors will enhance mixing. Furthermore a human is a contaminat source producing carbondioxide.

The natural convection around a human body caused by metabolic heat plays an important role in the ventilation process as has been pointed out by Kim and Homma (1992). Figure 11 shows one such example. The results are from a room ventilated by displacement ventilation. In the room a heated dummy was placed to simulate occupancy. The concentrations were recorded in two points at head height, one point located on the dummy (•) and the other in the ambient (X) outside the natural convection flow outside the dummy.

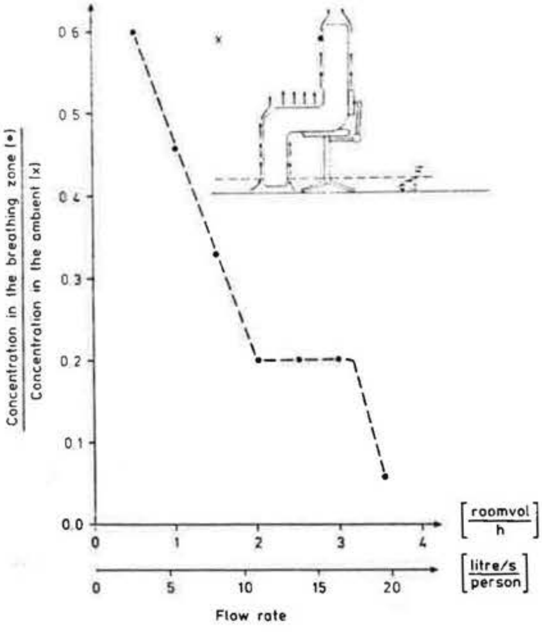


FIGURE 11 Ventilation by displacement. Concentration in the breathing zone (•) in relation to the concentration in the ambient at the same height (X)

We see that even at low flow rates , when the level of the interface between the upper polluted and the lower "clean" zone is well below head height, the concentration in the breathing zone is higher than that in the ambient. This is a result of the purging effect created by the flow around the body.

In order to explore the effect of body movements on a displacement ventilation system tests were carried out in a model with water as operating fluid (Sandberg and Mattsson (1992)). The layout of the "ventilation" was that of a displacement system with supply at floor level and extract at ceiling level. A man was simulated by using a heated cylinder that could be moved back and fourth on a conveyor belt. Figure 12 below shows a visualization of a typical test.

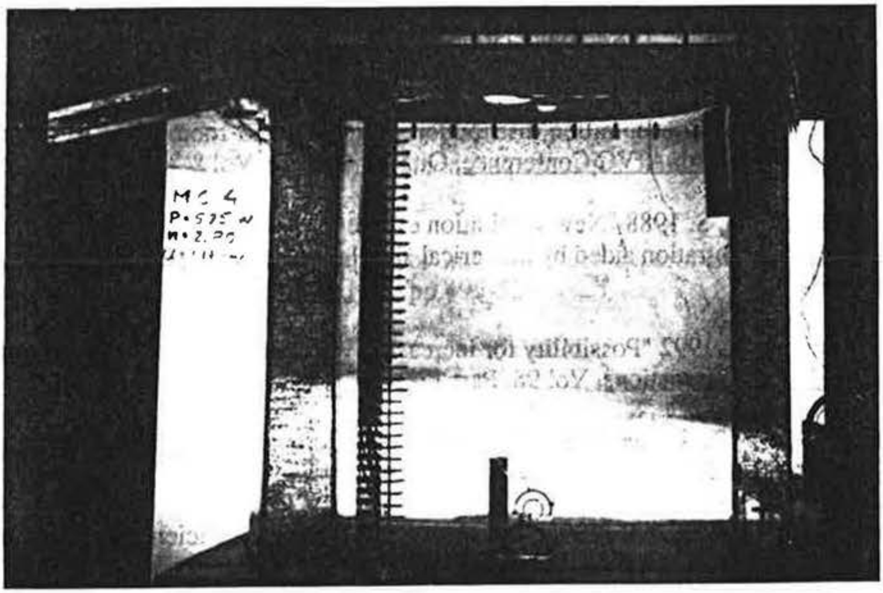


FIGURE 12 Visualization of a test with a moving heat source

We see that although the source is located below the interface its movements affect the interface. The interface oscillates and the height of the interface is lowered.

CONCLUSIONS

The concept *ventilation effectiveness* does not constitute a single element, but consists of a number of elements that reflect the efficiency of the different parts of the ventilation process. These concepts can be used as:

- Diagnostic tool for the detection of malfunctioning
- Tool for development of systems

Proper *source control* of both contaminants and excess heat from apparatus is important in order to obtain efficient and cost-effective general ventilation systems. The task of a ventilation system must be limited to only removing contaminants generated by people and their activities. Generally speaking, it is not the task of a general ventilation system to remove contaminants generated by people and their activities.

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