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Improved performance of ventilation system components

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IMPROVED PERFORMANCE OF VENTILATION SYSTEM COMPONENTS

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Introduction

A substantial flow of outdoor air must be supplied to a room to enable acceptable air quality to be maintained. In the most favourable case, when the emission of pollutants from the building material, the interior fittings and various machines is negligible, the necessary supply of outdoor air can be determined on the basis of only the pollutants emitted by the occupants themselves, i.e. principally carbon dioxide and odours. This has long been the basis for the minimum permissible outdoor air flows specified in building standards and other regulations.

Much evidence is currently available to support the view that the outdoor air flows supplied to most premises may have to be increased in order to reduce the content of pollutants in the indoor air, including those emitted by the building materials (1). An inevitable consequence is that the demand for higher rates of air flow will also impose stricter demands on the ventilation systems and their components. It can be assumed that the demand will then principally be for components that are energy-efficient and generate a low level of sound. As a general rule, the strict demands on the quality of the indoor air should obviously lead to endeavours to limit the pollutants that may possibly be emitted by various components of the ventilation systems.

Component improvements are thus important both to the quality of the indoor air and to the opportunities available for limiting the consumption of heat and electrical energy. However, strict demands can often be met even by the standard components available today. But this presupposes that the components are installed in ventilation systems that are correctly rated and well adjusted, and that maintenance work is carried out in accordance with the instructions. It would be basically desirable to develop components that have a high level of tolerance in all of these respects.

The most important task of a ventilation system is to restrict the pollutants in the indoor air, and it is therefore justifiable to make particularly strict demands that the ventilation system itself and its components should not contribute towards increasing the contents of pollutants. The objective should be that ventilation will continue to be regarded as a solution to environmental problems indoors - instead of being a problem itself. It is vitally important that consideration always be given to this objective, both in component development and in the project design of ventilation systems.

This article discusses the opportunities available for achieving improved performance of the components normally included in modern ventilation systems. The components discussed include fans, heat exchangers, filters, supply air devices, humidifiers, cooling towers, silencers and ducts. Particular attention is devoted to the air quality aspects when assessing how the various components and their technical design affect the indoor conditions.

Energy-efficient Components

If the energy consumption for ventilating a building can be minimised by utilising energy-efficient components in the ventilation systems, relatively high rates of outdoor air flow can be supplied without the operating costs being excessive. This, in turn, enables a relatively high standard of air quality to be maintained in the premises. When the components that are to be included in the ventilation system are sized, it is important to bear in mind this relationship between energy consumption and air quality. Minimised energy consumption for heating, cooling and distributing the ventilation air is also of importance to the outdoor environment.

The Distribution of Energy Consumption

In cold climates, a large proportion of the energy consumption in buildings was previously employed for heating the ventilation air. This is still true of many industrial buildings, although the current pattern in modern, non-industrial buildings is that a significant proportion of the energy supplied is used for distributing and cooling the ventilation air. The consumption of electrical energy has therefore increased substantially in recent years; in office buildings, for instance (2).

Table 1 shows a calculation of the energy consumption in a modern office building which has a floor area of 910 m^2 and is sited in a climatic region corresponding to that of Stockholm, Sweden. Three different ventilation systems are compared, one of which has airborne cooling and Constant Air Volume (CAV system), the second has airborne cooling and Variable Air Volume (VAV system), and the third has water-based cooling and fan coil units (FC system). The assumptions made in the calculations are that 30% of the workplaces are equipped with PC terminals and that the room temperature in all cases should be between 20 and 24^{o}C. Other assumptions are that the heat recovery system has a temperature efficiency of 60, 70 or 80%, and that the electrical energy consumption for lighting amounts to 22 530 kWh. The pre-treated air supplied to the FC system is assumed to be at a temperature of 15^{o}C downstream of the fan, whereas the corresponding temperature of the air in the CAV and VAV systems is 15^{o}C at outdoor temperatures down to +10^{o}C and then increases linearly to 17^{o}C at an outdoor temperature of -20^{o}C. The temperature rise in the ducts has been assumed to be 1^{o}C.

Table 1. Energy consumption in an office building with a floor area of 910 m^2, according to calculations with the VENTAC computer program (with climate data for Stockholm).

System/eff. of heat exchanger	Terminal unit coil output			Central air handling		Heating plant input	Cooling plant input	Fans input
	Heating		Cooling	Heating	Cooling			
	Norm.running kWh	Night/H.running kWh	kWh	kWh	kWh	kWh	kWh	kWh
CAV/60 %	30 497	33 698	0	6 889	14 910	71 084	4 970	26 263
CAV/70 %	30 497	33 698	0	885	14 910	65 050	4 970	26 263
CAV/80 %	30 497	33 698	0	0	14 910	64 195	4 970	26 263
VAV/60 %	12 585	31 477	0	1 996	9 972	46 057	3 324	7 707
VAV/70 %	12 585	31 477	0	221	9 972	44 282	3 324	7 707
VAV/80 %	12 585	31 477	0	0	9 972	44 061	3 324	7 707
FC/60 %	11 233	25 099	21 165	998	3 090	37 330	8 085	19 153
FC/70 %	11 233	25 099	21 165	50	3 090	36 382	8 085	19 153
FC/80 %	11 233	25 099	21 165	0	3 090	36 332	8 085	19 153

As shown in Table 1, the energy demand over the year for heating the ventilation air is very low in all three systems, provided that the heat recovery system has an efficiency of 70% or better. The total energy supplied for cooling is lowest in the VAV system (3324 kWh if the refrigeration unit has a coefficient of performance of 3.0), since outdoor air in this case accounts for a relatively large proportion of the cooling. The energy demand for driving the fans is also lowest in the VAV system.

Efficiencies and Pressure Drops

As mentioned above, the energy consumption for distributing the ventilation air in a building may represent a large proportion of the total energy consumption for air handling. It is therefore vitally important to install high-efficiency supply and exhaust air fans, and also to limit the pressure drops across various components. In many ventilation systems, it may be economically justifiable to select larger component sizes in order to reduce the pressure drops and thus cut down the energy consumption.

The efficiencies of ventilation fans have been improved in recent years, due to factors such as the introduction of more rational manufacturing methods, which has allowed for improvements to the aerodynamic design. Moreover, the scatter in the performance has been reduced by more effective quality control. However, what is even more important to energy saving is probably that the fans are now being connected to an increasing extent in such a manner that the aerodynamic performance will not be jeopardised (3).

The fan type employed also affects the energy consumption for ventilating the building. The efficiency of a centrifugal fan with forward-curved blades is typically 65 - 70%, whereas that of a centrifugal fan with backward-curved blades may very well exceed 80%. The somewhat higher capital cost of a centrifugal fan with backward-curved blades can thus quickly be recovered.

The required air flow and pressure rise can usually be achieved by several sizes of a given fan type. It is then usually profitable from the operating cost aspect to select a relatively large fan, so that its operating range for optimum efficiency will be utilised, and the flow velocity at its connections will simultaneously be reduced. This is illustrated in Table 2. The task here is to select a double-inlet centrifugal fan for the following conditions: Air flow of 16 m^3/s, static pressure rise of 900 Pa, operating time of 8760 h/year and electrical energy cost of 0.35 SEK/kWh.

A type GFAB-5 fan (from Fläkt AB) has been selected for the calculation. In addition, it is assumed that the fan is installed with open suction and open discharge. Table 2 shows that, due to the lower operating costs, the higher investment cost, even of the largest fan in the table (size 125), will quickly be recovered.

Table 2. Comparison between different sizes of centrifugal fan (type GFAB-5).

		GFAB-5 size		
		100	112	125
Fan efficiency	%	79	83	85
Sound power level	dB	100	98	96
Total power demand	kW	28	24	22
Standard motor	kW	30	30	22
Energy cost/year	SEK	85 800	73 600	67 400
Saving/year	SEK		12 200	18 400
Capital cost increase	SEK		5 000	2 000
Pay-off time relative to size 100	year		0.4	0.1

Sizing is also very important for the heat exchangers used for heat recovery in heating or cooling. The demand that the heat exchangers must be compact leads to high pressure drops if high efficiencies are required. A tendency in recent years has been to increase the efficiencies of various types of heat exchangers by inducing increased turbulence. This has enabled the areas of the heat transfer surfaces to be reduced, which has also reduced the material consumption. Since the generation of turbulence also increases the pressure drop across the heat exchanger, the operating costs must also be taken into account in the design of heat exchangers. The price relationship between thermal energy and electrical energy will then be of major importance in this respect.

A typical plate heat exchanger with highly optimised efficiency, pressure drop and material utilisation is shown in Fig. 1. The heat exchanger plates have a surface with a fine structure designed to increase the turbulence and also to increase the stiffness of the plates. The measured efficiencies and pressure drops on this heat exchanger at equal supply and exhaust air flows are shown in Fig. 2.

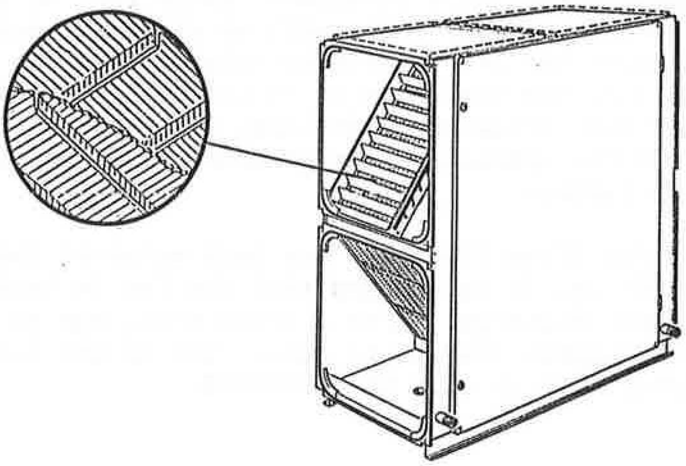


Fig.1. Cross-flow plate heat exchanger incorporating plates with fine corrugations.

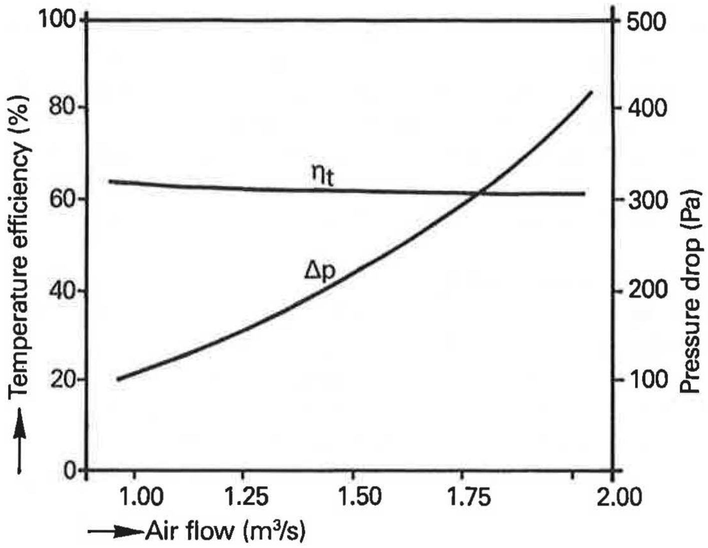


Fig. 2. Measured efficiencies and pressure drops on the plate heat exchanger shown in Fig. 1.

Control of Air Flows

The benefit of a Variable Air Volume (VAV) ventilation system is that it can maintain good average air quality throughout the year, even though the energy consumption for the handling and distribution of the ventilation air is comparatively moderate. The air flow in such systems is usually controlled by the cooling requirements in the building. The energy-efficiency of a VAV system is conditional on scope being available for effective variation of the air flows in the system. Supply air devices that can achieve effective ventilation of the premises at varying air flows must also be available.

The most common methods for controlling the ventilation air flows are as follows:

1. damper control in the duct system
2. guide vane control of centrifugal fans
3. blade pitch control of axial-flow fans
4. speed control of axial-flow and centrifugal fans

In the above control methods, damper control involves the lowest capital cost but also incurs the highest operating cost. The method is therefore recommended only for fairly low rates of air flow. On the other hand, guide vane control of centrifugal fans and blade pitch control of axial-flow fans are very energy-efficient methods.

Electrical methods are usually employed for controlling the fan speed, principally by varying the frequency or voltage. Frequency control is very efficient, but has gained only limited application in VAV systems, since it has proved difficult to master the problem of disturbing sound generated in the motor due to transients in the a.c. current supplied by the frequency converter. On the other hand, voltage control on fan motors causes high losses and is best suited for relatively low ratings.

Lower Sound Levels

Too high sound levels are a frequent source of complaint in ventilated premises. It is important to meet the provisions of the relevant standards, and to do this with a certain margin, bearing in mind the increasingly strict demands currently made. Due to the increasing air flow rates in ventilation systems, sound problems must be given even more attention than in the past, both in the selection of components, and in the project design and adjustments after installation.

Problems are most frequently caused by the sound generated in fans, supply and exhaust air devices, terminal units, dampers and flow controllers. Vibrations originating from fans, the entire air handling unit and the duct system must also be taken into account. The way in which the various components are installed in the systems is of major importance in this respect. The opportunities available for reducing the duct-borne sound by means of silencers must also be taken into account in the project design of ventilation systems.

The sound generated in centrifugal fans is usually lower than that generated in axial-flow fans. In a given type of fan, there is often a distinct relationship between sound generation and efficiency, whereby the sound generated in a high-efficiency fan is usually comparatively low. The efficiency improvements achieved in recent years due, in part, to improved manufacturing methods have also resulted in improved acoustic data. Sound generation can probably be reduced by a few dB by special design of the fans, although it is doubtful whether this is economically justifiable as compared to improving the sound attenuation in the ventilation system.

The choice of fan size is also of major importance in restricting the sound level in a ventilation system. This is clearly illustrated by the example given in Table 2 above. The sound power level of the smaller size (size 100) of this particular centrifugal fan is 100 dB, whereas the sound power level of size 125 at the same air flow rate is 96 dB.

The problem of low-frequency sound has come to the fore to an increasing extent in recent years. This applies particularly to the infrasound range between 2 and 20 Hz. However, the sound generated by a fan within this frequency range does not differ significantly from the levels generated by the same fan within the audible range.

Measurements of the infrasound generated by fans have shown that centrifugal fans with backward-curved blades give a lower level of infrasound than fans with forward-curved blades, and that a higher rate of air flow also causes higher generation of infrasound. On the other hand, the dimensions of a fan appear to have a limited influence on the amount of infrasound it generates (4). Fig. 3 shows measured infrasound levels at different air flow rates generated by centrifugal fans with forward-curved and backward-curved blades. These measurements have been carried out in a reverberation room.

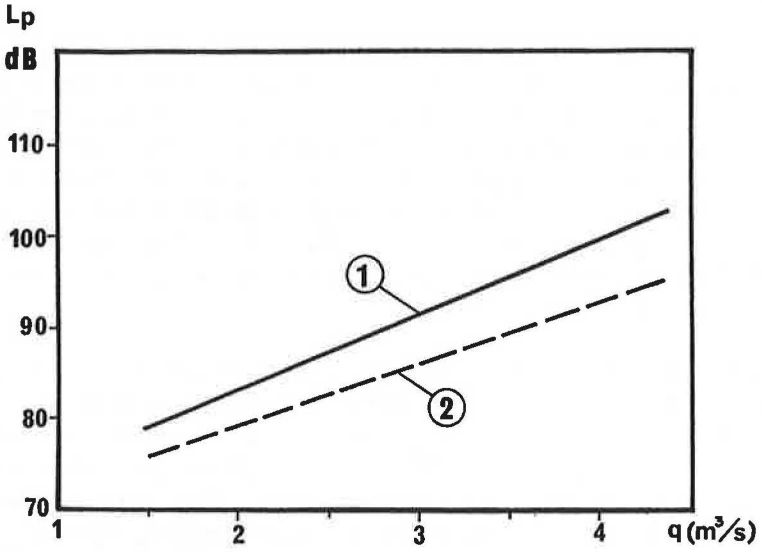


Fig. 3. Measured infrasound levels (2 - 20 Hz) generated by centrifugal fans with 1) forward-curved blades and 2) backward-curved blades measured in a reverberation room.

The design of the duct system is also an important factor in attempts to reduce the infrasound level in a building. Circular ventilation ducts provide much better isolation than rectangular ducts. However, the isolation provided by rectangular ducts can be improved substantially by suitable staying. In most cases, infrasound levels in a ventilated room can be restricted to levels far below the relevant limit values (5).

Reduced Emission of Pollutants

As mentioned in the introduction, it is important to restrict the emission of pollutants from the components of a ventilation system. It is normally assumed that the pollutant emission is negligible and that ventilation systems have no negative effect whatever on the quality of the indoor air. Much attention was therefore attracted when the ventilation systems themselves were found to emit pollutants.

Principal pollutants emitted by various ventilation components include fibres, bacteria and odours. The emission of bacteria in particular has led to serious health consequences in certain cases. However, problems can often be avoided by the adoption of relatively simple measures.

In ventilation systems in which part of the exhaust air consists of process air with high contents of pollutants, it is important to prevent the leakage of exhaust air into the supply air side. To achieve this, the dampers included in most air handling units must be very tight and reliable. Practical experience in this respect is far from satisfactory, and component improvement would appear to be an urgent matter (6).

Particles and Fibres

Particulate pollutants are generally easy to separate from the ventilation air by means of filters that have long been available. But significant advances have been made in recent years, particularly on filters that have very high collecting efficiencies and that are principally intended for application in industrial clean rooms. However, a trend towards filters with increasingly high efficiencies is discernible for most types of buildings. This is caused by factors such as the growing frequency of allergy problems that are often related to high contents of particles in the indoor air (7).

As an example, if a fine filter with a high collecting efficiency, such as class F85 or F95 (EU7 or EU8), is installed in an office building, a large proportion of the pollen, spores and bacteria present in outdoor air can be collected (see Fig. 4). Fine filters can also be installed downstream of ventilation system components that can be expected to emit particles, which is already applied to ventilation systems for operating theatres, for instance. But a high degree of filtration of the ventilation air will also reduce the need for cleaning the duct system and various components, such as heating and cooling coils.

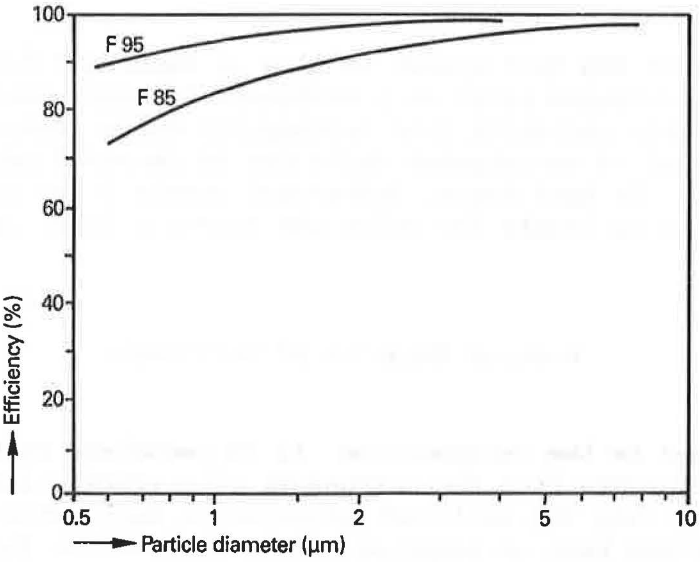


Fig. 4. Measured particle-collection efficiency of class F85 and F95 fine filters.

Airborne particles in fibre form must receive special attention (8). Up to the mid-1970s, it was not uncommon for asbestos to be used even in supply air systems. The hygienic limit value for asbestos fibres has been substantially reduced since that time (Table 3). Components containing asbestos are no longer installed in ventilation systems.

Health aspects must also be taken into account if glass fibre is used. A hygienic limit value for glass fibre has been specified in the directives issued by the Swedish Board of Occupational Safety and Health back in 1984 (9). Hygienic limit values can also be expected to be introduced for other fibre materials used for replacing asbestos.

Table 3. Hygienic limit values for asbestos (without crocidolite)

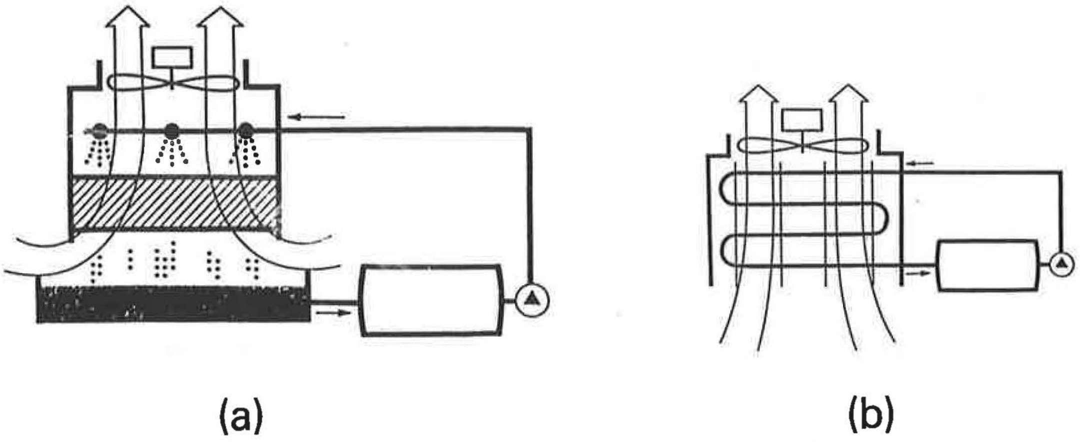
Year	Regulation/Code of Statutes of National Swedish Board of Occupational Safety and Health	Hygienic limit value (fibre/ml)
1974	Regulation No. 100	2
1978	Regulation No. 100, rev. edition	1
1984	AFS 1984:5	0.5
1987	AFS 1987:12	0.2

In view of the restrictions applicable to the use of glass fibre material, surfaces which are in contact with the ventilation air, such as in ducts, silencers and terminal units, should be protected so that the air will not entrain fibres. This can be done by providing the glass fibre material with a surface coating. Glass fibre insulating material in sheet form is now often provided with a protective film of this nature. However, it is important that machined surfaces of this material be coated with some protective film after machining.

Microorganisms

Some microorganisms occur in most environments, both indoors and outdoors. In most cases, these microorganisms are harmless to humans. Only in special circumstances will the microorganisms that are present in the indoor environment give rise to hygienic problems.

It would appear that the most serious health problem in this respect is that of the spreading of bacteria from cooling towers. The temperature of the water in cooling towers included in the cooling system of a building is often within the range of 35 - 40°C, which is an ideal temperature for the propagation of Legionella bacteria. If the cooling tower is located close to open windows or ventilation air intakes, the bacteria can easily spread to the indoor air and cause Legionnaires' disease (10, 11, 12). Another spreading path for this type of bacteria in buildings is through the hot water system.



(a) (b)

Fig. 5. Diagrammatic arrangement of: a) cooling tower and b) closed-circuit cooler.

In order to minimise the risk of the spreading of bacteria, cooling towers should be provided with effective droplet eliminators. If possible, the cooling tower should also be located well away from the air intake of the building. In addition, the growth of bacteria in the cooling tower can be substantially reduced by regular cleaning. To eliminate the problem entirely, cooling towers can be replaced by closed-circuit coolers (see Fig. 5). This approach involves increased capital cost and operating costs, but it is still recommended for hospital buildings and other buildings occupied by particularly infection-sensitive people.

Growth of bacteria in humidifiers may also give rise to hygienic problems. The humidifiers used in ventilation systems are generally spray-type humidifiers, evaporative humidifiers or steam humidifiers. The first two of these (see Fig. 6) use recirculated water from a water tray in which bacteria can easily grow. Since the content of water droplets downstream of evaporative humidifiers is very low, or practically negligible, the bacteria count entrained by the air is also very low (13). In spray-type humidifiers, the emission of droplets and thus the transfer of bacteria is appreciably higher than in evaporative humidifiers, but the droplet content can be substantially reduced by means of droplet eliminators.

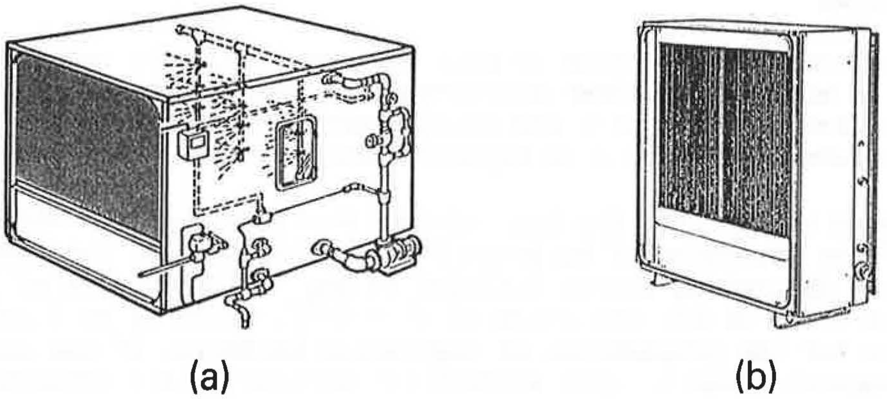

(a) (b)

Fig. 6. Schematic arrangement of air humidifier: a) spray-type and b) evaporative type.

The bacteria emission from an air humidifier can be determined by adding known contents of bacteria or known contents of solid particles to the humidifier water, and the bacteria emission can then be specified as the carry-over factor (14). Fig. 7 shows the results obtained on a spray-type humidifier and an evaporative humidifier. This figure illustrates that particularly low bacteria emissions have been recorded on a modified evaporative humidifier.

The hygienic effects reported in conjunction with the emission of bacteria from air humidifiers consisted of fever reactions of short duration (15). In virtually all cases reported, the offending humidifier was of a type that emits water in droplet form. However, problems originating from an evaporative humidifier with insufficient water supply have also been reported in one case (16).

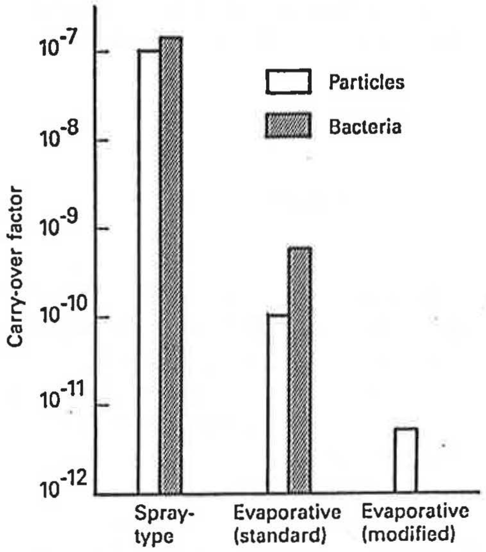


Fig. 7. Carry-over factors for particles and bacteria measured during air humidifier tests.

Apart from cooling towers and humidifiers, surfaces in other parts of the ventilation system can also emit microorganisms, if these surfaces are in humid condition over an extended period of time. Cooling coils and heat exchangers, for instance, must therefore be provided with drainage. In addition, the duct system must be designed so that condensate precipitation will be avoided. Moreover, the connection of the duct system to the outdoor air intake must be arranged in such a manner that rain and snow will not give rise to humid conditions that promote the growth of microorganisms.

Odours

Keen attention has been focused in recent years on the odour problems that may occur in buildings (17, 18). Some of these problems have been related to ventilation systems, and others to the activities pursued in the premises and to the building materials. The contributions of various components of the ventilation systems have also been investigated in this respect (19).

The components that have been shown by these investigations to contribute most to the problems are filters, heat exchangers and air humidifiers. The dust collected can be expected to be part of the explanation for the odours emitted from filters and heat exchangers. Immediately after these components have been taken into operation, certain substances may possibly originate from adhesives and sealing compounds or, in the case of filters, from the filter material itself.

In the case of air humidifiers, the odour problems can be expected to originate largely from the growth of microorganisms. If the humidifiers are cleaned and maintained as specified, the problems can generally be eliminated. Filtration of the air supplied to a humidifier will also substantially reduce the growth of microorganisms.

Dust collected in supply air ducts may also be part of the explanation for odours being emitted from a ventilation system. In some buildings, this may justify cleaning or replacement of the ducts after a long period of service. The duct system should therefore be designed to facilitate such work.

Conclusions

Most of the components used in modern ventilation systems are well suited for the demands made so far. But new conditions, principally stricter demands on the air quality, may make it necessary to modify and improve these components. Consideration must then also be given to the substantial increase in the thermal loads that have occurred in recent years in non-industrial buildings.

Components in the form of compact units have long been in demand, since such components promote a reduction in the capital costs. But at the same time, they cause an increase in operating costs due to the increased pressure drops. In order to minimise the electrical energy consumption for the ventilation of buildings, it is desirable to give more detailed consideration to the overall cost during the entire service life of the component. This usually leads to the conclusion that it is favourable to specify more energy-efficient components.

Restricting the pollutants emitted by certain components in a ventilation system is a particularly important issue. The objective should be to reduce the emission of fibres, bacteria, odours, etc. to negligible values. This should often be attainable at reasonable cost by selecting suitable components. The sound levels that are normally common today in ventilated premises can generally be reduced without any major increase in cost.

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SUMMARY

This article discusses the opportunities available for improving the performance of the components of modern ventilation systems. It is mainly the growing demands on the quality of the indoor air that justify improvements to most of these components. The increased thermal loads and the higher consumption of electrical energy in many buildings also justify modifications to certain components of ventilation systems. Components with improved performance, particularly as regards reduced energy consumption, lower sound generation and reduced emission of pollutants, are expected to be in demand in the future. Fortunately, most of the component improvements related to sound generation and emission of pollutants can be implemented without significant increase in the total capital cost of the ventilation system.