VENTILATION, ENERGY AND INDOOR AIR QUALITY

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ABSTRACT

As ventilation is a significant consumer of energy the rates of ventilation have often been minimised, particularly after the energy crisis in the early 70's, in order to reduce equipment and energy costs. Buildings, particularly those in cold climates, have also become more airtight a factor which has reduced ventilation airflow through the building envelope. This has caused in many countries indoor air quality problems. It has been shown that ventilation rates have adverse effects on communicable respiratory illnesses; on sick building syndrome symptoms; on productivity and perceived air quality. In many studies, the prevalence of sick building syndrome symptoms has also been associated with the characteristics of ventilation systems. Often the prevalence of SBS symptoms is higher in air-conditioned buildings than in naturally ventilated buildings. The evidence suggests that improvements in the hygiene, commissioning, operation and maintenance of air handling systems may be particularly important for reducing the negative effects of air conditioning systems.

INDEX TERMS

Ventilation, air conditioning, energy efficiency, indoor air quality, health effects

INTRODUCTION

Ventilation rates have an important role on efficiency of buildings and in respect of good indoor air quality and climate. Residential and service buildings use between 39% (Orme 1998) and 42% (COM 226, 2001) of primary energy. Its breakdown by end use in the residential sector of EU countries is: space heating 57%, water heating 25%, cooking 7% and electrical appliances 11%. In the service buildings 52% is for space heating, 9% for water heating, 14% for lighting, 5% for cooking, 4% for cooling and 16% for other use. The proportion of the heated ventilation air derived from the energy delivered for space conditioning of residential and service buildings is roughly 33%.

Ventilation air efficiently transfers the indoor pollutants from a building or dilutes the concentration to an acceptable level. Without proper design and engineering the measures to save energy by reduced ventilation may degrade indoor air quality. The expense of deteriorated indoor climate is not recognised as easily as wasteful energy consumption, but it may be equal to or more than the cost of heating and cooling the same building. Poor indoor air quality incurs costs to the economy through increased illnesses and sick leave, decreased productivity, and heavy medical care expenses. Calculations (Fisk and Rosenfeld 1997, Seppänen 1999), have shown that the order of magnitude of energy costs for space conditioning and for inferior indoor climate is the same. Thus, from an economic point of view, energy and health aspects are equally important, **and energy ought not be saved if indoor air deteriorates significantly at the same time**. The requirements for good indoor air quality and energy efficiency have often been seen to conflict with each other, yet buildings with low energy consumption may also show a lower rate of building related symptoms if the ventilation system is properly designed, constructed and operated. Many technologies are available which meet both of the goals: good energy efficiency and indoor quality (Seppänen 1998).

VENTILATION AND ENERGY

Factors affecting energy consumption

Ventilation consumes energy primarily because the ventilation air is thermally conditioned, i.e., heated, cooled, and either dehumidified or humidified. The energy consumption of ventilation is calculated from the following expression

$$E = q\Delta hT \tag{1}$$

where q is ventilation air flow, Δh is enthalpy difference between outdoor and indoor air, T is operation time of the ventilation.

The relation shows that the energy consumption for conditioning the air does not depend on ventilation system at all, but simply on **the ventilation rate, the operation time and the difference between the condition outdoors and indoors**. However, the ventilation system affects the energy consumption by how the air is moved around in the building. In mechanical systems electricity for fans increases the energy consumption compared to natural or passive stack ventilation with the same airflow. Mechanical ventilation, however, is more stable in respect of airflow and independent on weather conditions. It also allows moreover greater freedom for the building design and better control over the indoor climate.

An important factor in energy efficiency is the enthalpy difference between outdoors and indoors. It should be kept as small as possible within the range favourable to comfort and health. This means in practice keeping low indoor temperature and humidity during the heating season, and high humidity and high room temperature during the cooling period to avoid unnecessary energy use in conditioning the air. Low enthalpy of the air is also beneficial for the perceived air quality.

VENTILATION RATES AND ENERGY CONSUMPTION

The primary energy consumption attributable to the ventilation of all buildings is estimated to reach 9% of the total primary energy consumption in major industrialised countries (Orme 1998). Climate has a great influence on the energy required to thermally condition ventilation air. In a cold climate, most of this energy is used for heating the ventilation air. In a warm climate significant energy is used for both heating and cooling. In a humid climate most of the energy (Miami 86%) is used to remove moisture from the ventilation air.

A recent simulation study of the energy performance of ventilation in typical European buildings placed in Sweden Belgium and Portugal shows the significant influence of ventilation rates on energy consumption. In the cold climate of Sweden heating energy consumption increases with ventilation while in the warm Portugese climate energy consumption for cooling increases with ventilation (TIP-VENT 2000). However, the study also shows that best system performance in respect of energy efficiency compared with common used systems can allow an energy saving of between 60 and 70% in all climatic conditions by applying the control of ventilation rates, free cooling, heat recovery and energy efficient air-moving design.

In residential buildings in a cold climate the ventilation rate has a major effect on energy consumption (TIP-VENT 2000). The proportion of ventilation may reach 77% of the total heating energy demand of a residential building in cold climate. However, this can be easily reduced by 50% with heat recovery. In the buildings with natural ventilation the tightness of a building has a dramatic influence on ventilation rates, indoor air quality and energy consumption (TIP-VENT 2000). With a tight building envelope the ventilation rate becomes easily too small in respect of air quality, and with a leaky building envelope the energy consumption for heating the excess infiltration air becomes easily unacceptable high.

Depending on the system design the outdoor air used for ventilation can also be used for the conditioning of the building. This technology known as economizer cycle or free cooling, is a widely used control principle in the design of air conditioning systems. In large office buildings with a proper control system the effect of the ventilation rate is small. Eto and Meyer (1988) estimated the impact of increased outdoor air supply rate on the total energy cost in an office building with a variable air volume system with an economizer – by the DOE-2 simulation programme. They showed that increasing the outdoor air supply rate from 2.5 to 10 L/s per person would increase energy costs by less than 5%.

In American-style commercial buildings ventilation systems with air recirculation, the ventilation rate often has a negligible influence on the energy consumption of fans in the ventilation system. In European-style ventilation systems without air recirculation, both fan energy and energy for thermal conditioning are affected by the ventilation rate, but the common use of heat recovery from the ventilation air decreases the influence of ventilation rate on building energy consumption.

VENTILATION RATES IN STANDARDS

Ventilation rates are specified in many national building codes and standards. European draft standard has derived ventilation rates (Table 1) in for four indoor air classes based on the technical report (CEN 1996). In American standard (ASHRAE 62 2001) the ventilation rate per person is 10 per person in office. It the proposed addendum (ASHRAE 62n 2001) the rates are in most cases lower than in the standard; 8.5 L/s for offices.

Table 1 Air quality and ventilation rates (outdoor air) in European draft standard CEN 2002) in buildings with non- or low-polluting building materials.

Category	IAQ	ΔCO_2	PAQ/ dp	L/s per person No smoking	L/s per person Smoking allow
IDA 1	High	≤400	1.0	>15	>30
IDA 2	Medium	400-600	1-1.4	10-15	20-30
IDA 3	Acceptable	600-1000	1.4-2.5	6-10	12-20
IDA 4	Low	>1000	>2.5	<6	<12

VENTILATION RATES IN PRACTICE

In practice the choice of airflow in ventilation has mainly been based on the floor area or on the number of people in the room. The design values of ventilation in office buildings based on area vary typically from 1 to 5 L/sm^2 depending on the designer. The airflow determined per person vary from 4 to 25 L/s per person. These values are typically higher than the minimum values specified in standards. In the European Audit Project, the average ventilation rate was 1.8 L/sm^2 or 25 L/s per occupant (Bluyssen et al. 1996, Roulet et al. 1995). A recent review of ventilation rates and human responses (Seppänen et al. 1999) showed a wide spread of mechanical ventilation rates from almost zero up to 60 L/s per person.

VENTILATION RATES AND INDOOR AIR QUALITY

Rationale

Previously it had been assumed that the only pollution sources in buildings are the occupants and their activities. It has been shown that chemical and sensory emissions of building materials, ventilation systems and HVAC-components are also significant and play a major role in the indoor air quality of a space (Fanger et al. 1988). A recent study (Wargocki et al. 2002a) has shown a slighly lower but still significant pollution load from building sources including the air handling systems (0.04 – 0.27 olf /m^2). The practice is, however, gradually changing. The latest guidelines and draft standards include a method of ventilation design in which airflow is calculated from the pollution load of the room, (CEN 1996, CEN 2002).

$$q_h = \frac{G_h}{C_{h,i} - C_{h,o}} \cdot \frac{1}{\varepsilon_v} \qquad (2)$$

where q_h = the airflow needed for selected air quality in respect to any contaminant in the air,
G_h = the generation of chemical contaminant,
$C_{h,i}$ = acceptable contaminant concentration in indoor air,
$C_{h,o}$= the contaminant concentration of intake air,
ε_v = the ventilation efficiency, ($\varepsilon_v = 1$ for complete mixing to $\varepsilon_v = 2$ for piston flow)

When used, equation 2 means that the ventilation airflows in buildings are rationally selected and distributed to all rooms depending on the pollution loads. At the same time air quality is improved and energy consumption decreased. Introducing the proposed method requires, however, a great amount of work in order to identify the sources of emissions, and to effectuate a change in design practice.

A two-component approach, aiming at a similar goal was introduced in the recent Addendum 62n (ASHRAE 62n, 2001) to ASHRAE standard Ventilation for Acceptable Indoor Air Quality. The strength of the sources associated with occupants is taken proportional to the number of occupants, while the source strength of building materials plus furnishings is taken proportional to the room size, which is defined by the floor area.

VENTILATION RATES AND HUMAN RESPONSES

Ventilation rates and SBS-symptoms

Recent reviews (Seppänen et al. 1999, Wargocki et al. 2002b) on the association of ventilation rates and human responses show that ventilation rates below 10 L/s per person are associated with a significantly inferior prevalence or value of one or more health or perceived air quality outcomes. Most studies indicated a significant association with ventilation rate. Available studies further show that increases in ventilation rates above 10 L/s per person, up to approximately 20 – 25 L/s per person, are associated with a significant decrease in the prevalence of SBS symptoms, or with improvements in perceived air quality. The less consistent findings for relationships in the range above 10 L/s per person are compatible with the prediction that benefits per unit increase in ventilation would be likely to diminish at higher ventilation rates and, thus, be more difficult to detect epidemiologically.

VENTILATION AND HEALTH EFFECTS

The review of ventilation rates and human responses (Seppänen et al. 1999) summarises the results of four studies available at that time on the health effects of ventilation rates. These were performed in a jail, barracks, a home for the elderly and offices. All of them reported significant association between low ventilation rates and increase in health problems: pneumonia, upper respiratory illnesses, influenza and short term sick leave respectively. Even though the ventilation rates were estimated and not measured, the consistent findings are a strong indication of the association of ventilation rates with health effects.

The strongest evidence is provided by the most recent study of these (Milton et al. 2000). The association with sick leave was analysed for 3720 employees in 40 buildings using 115 independently ventilated ventilation areas. Among office workers, the relative risk for short term sick-leave was 1.53 (1.22 – 1.92 c.i.) with the estimated ventilation of 12 L/s per person compared with a ventilation rate of 24 L/s per person.

Ventilation and productivity

The effect of ventilation on productivity was demonstrated by Wargocki et al. (2000) in a simulated office environment. Here they exposed five groups of six female subjects to three ventilation rates (3, 10, and 30 l/s per person), one group and one ventilation rate at a time. The performance of four simulated office tasks improved monotonically with increasing ventilation rates, and the effect reached significance in the case of text typing. For each twofold increase in ventilation rate, performance improved on average by 1.7%. The study indicates the benefits of ventilation at rates well above the minimum levels prescribed in existing standards and guidelines.

DISTRIBUTION OF THE VENTILATION AIR

Pollutant removal efficiency

Task ventilation has been commonly used in industry for years, and various applications have been presented in several guidebooks for industrial ventilation. Task ventilation is one method to extract pollutants at source and to supply clean conditioned air directly to the occupied zone or work station. In that way, conditioning and ventilating a large space to the same level as a work station becomes unnecessary as long as the work stations are well conditioned. One residential application of local ventilation is the commonly-used range hoods in kitchens. They improve air quality by preventing the pollutants from spreading to living areas. The same principle can be applied in other pollution sources too.

During the past few years increasing attention has been paid to air distribution systems that condition the immediate environment of office workers and their work stations. A comprehensive guide to task ambient systems has been written by Bauman and Arens (1996). The major advantages of the task conditioning system are:

1. It offers occupants the possibility of controlling their environment individually
2. The task/ambient system saves heating, cooling and fan energy if properly designed and used.
3. Task/ambient systems have been reported to improve working efficiency and alleviate the SBS symptoms.

VENTILATION EFFICIENCY

The importance of ventilation efficiency has been widely recognised, and is now proposed to be included in the ventilation standards (ASHRAE 62n, 2001, CEN 1996). Poor room air distribution can significantly reduce the air quality in a room, if the supply airflow spreads the pollutants generated in a room to the breathing zone, or if the supply air flows directly towards the return air openings (short-circuiting flow). According to the original definition, the air change efficiency for complete mixing is 50%. In the draft standards, complete mixing was taken as a reference and the value 1 given to effectiveness of ventilation. Accordingly the values for the other flow patterns are given in Table 2.

Table 2. Values of ventilation effectiveness for various flow patterns.

Flow pattern	Air change efficiency %	Zone air distribution effectiveness (ASHRAE 62n) Ventilation efficiency (CEN 1996) ε_v (equation 2)
complete mixing	50	1
piston flow	100	2
displacement flow	50-100	1-2
short circuiting flow	< 50	0-1

When these numbers are applied to the air flow calculations in Equation 2, it can be seen that the same air quality can be achieved in the best cases with half the air flow, or contamination concentration can be reduced to half with the same air flow by improving the ventilation efficiency.

One way to improve the effectiveness of ventilation is the displacement or low velocity air distribution system. The displacement air distribution system is widely used in North European countries, and recommended also all over Europe (REHVA 2002). Detailed measurements and CFD simulations have shown that the benefits of displacement ventilation can be even greater than evaluated, just by using air change efficiency. Several research groups have shown that the convective plume created by warm human bodies improves the air quality in the displacement system, because it draws clean air to the breathing zone from the clean lower zone of a room. Brohus and Nielsen (1996) have even introduced two new quantities to evaluate personal exposure: (1) the personal exposure index and (2) the effectiveness of entrainment in the human boundary layer.

A system efficiency has been introduced in the addendum (ASHRAE 62n 2001) for the Ashrae ventilation standard 62. The system efficiency accounts for the overall efficiency of the distribution of outdoor air from the intake to the occupants. It integrates distribution of air through the system, movement of air between spaces and the distribution within the room. The system efficiency is particularly important in systems using recirculation of the air.

DISTRIBUTION OF AIR FLOWS IN THE BUILDING

Ventilation rates per person or floor area vary a lot in office buildings. In the European Audit Project the outdoor airflow rate per floor area varied from almost zero to more than 5 L/sm^2.In naturally ventilated buildings, the outdoor airflow rate was below 1 L/sm^2 in 80% of cases. In the mechanically ventilated buildings it was much higher, more than 1 L/sm^2 in 80% of cases. The average value for the outdoor airflow rate was 25 L/s per person (Roulet et al. 1995). Even if the average outdoor airflow is correct in a building, the outdoor air is often unevenly distributed due to improper balancing of airflow or recirculation of return air.

In the Helsinki Office Environment and Health Survey, ventilation rates were measured in 1,782 occupants working rooms in 33 randomly-selected buildings. The airflow rate was 17.2 L/s per person on average, which clearly exceeds the Finnish code value of 10 L/s per person. The variation of airflow rates between different buildings, and within buildings, was considerable. The standard deviation of all airflow rates was 11.6 L/s per person (Teijonsalo et al. 1996). In ten buildings, the standard deviation of the air flows was higher than half of the mean value of the air flows, in which case the balancing of ventilation can be considered insufficient.

An imbalance in outdoor air flows leads to high energy consumption in the rooms with high outdoor rates, and degrades air quality in the rooms with low outdoor air flow rates. This is particularly the case in the ventilation systems without air circulation. By balancing the air flows the average air quality in a building can be enhanced and energy efficiency improved.

Control of ventilation rates

Ventilation systems without the economizer often run with constant outdoor airflow throughout all operational hours. Airflows are not altered by any change in the use of a room. The present condition of ventilation design would equate with a heating system in which constant heating power is supplied into each room regardless of the room temperature or the heating requirements. Usually the ventilation loads of the interior spaces vary with time, and the ventilation rates should be adjusted to the loads.

Demand controlled ventilation (DCV) is a ventilation system where airflows in the rooms are controlled according to the contaminant loads. The use of DCV is based on temporarily varying contaminant sources, and on actual need of ventilation when the system of constant airflow ventilation wastes energy; whereas a system with varying air flows saves energy but does not degrade indoor air quality.

Contaminants originate from building and decoration materials, furniture, people and their activities, and intake air. With respect of DCV, the most important indoor air contaminants to be measured are carbon dioxide, emissions from building and decoration materials (volatile organic compounds), tobacco smoke, and moisture. For DCV, proper air quality sensors are needed. The room sensor can be such as carbon dioxide, mixed-gas, attendance, combined CO_2/mixed-gas or combined CO_2/CO etc. Progress has been made also in developing *artificial noses* to measure objectively the perceived air quality.

Significant savings of energy have been achieved with demand controlled systems when compared to the constant airflow system. Typical applications of demand-controlled ventilation systems with consequent energy savings in ventilation vary in levels between 20 to 70% depending on the type of the application and on the use of space. The pay-back time of demand controlled ventilation is shorter, having higher air flow rates and operation hours. If the energy saving in ventilation is 40%, the pay-back time will be two years with a system air flow of 1 m^3/s (Meier 1998).

Type of ventilation system

Recent summaries (Seppänen and Fisk 2002, Wargocki et al. 2002) showed that most studies on the association of ventilation systems and human responses indicate that relative to natural ventilation, air conditioning (with or without humidification) was consistently associated with a statistically significant increase in the prevalence by approximately 30% to 200% of one or more SBS symptoms. In two of three analyses from a single study (assessments), symptom prevalence was also significantly higher in air-conditioned buildings than in buildings with simple mechanical ventilation and no humidification. The available data also suggest, with less consistency, an increase in the risk of symptoms with simple mechanical ventilation relative to natural ventilation. The statistically significant association of mechanical ventilation and air conditioning with SBS symptoms are much more frequent than expected by chance and moreover not likely to be a consequence of being confounded by several potential personal, job, or building-related confounders. A group of European scientists (Euroven group) elaborated and tested several hypothesis on the reasons for improper performance of mechanical systems but was able to find support to some of the hypotheses only. The group concluded that potential causes of adverse health effects due to HVAC systems comprise: poor maintenance and hygiene in the HVAC systems; intermittent operation of the HVAC systems, and lack of moisture control; lack of control of HVAC system materials and loaded filters (Wargocki et al. 2002c).

Cleanliness of Ventilation System

The European audit project on indoor air quality (Bluyssen et al. 1996), the European Data Base Project on Air Pollution Sources and the European Airless (Bluyssen et al. 2001), project have shown that the perceived quality of supply air is not always the best possible, and is often even worse than the perceived quality of outdoor air quality. The perceived air quality of the air supplied to the rooms, however, was usually not as bad as it was immediately after passing through a filter. This may be due to absorption in duct systems or chemical reactions in the air.

Severe problems are created also with condensation if the components are not properly maintained, drained and cleaned. Improperly maintained condensing cooling coils may be a major source of microbial pollution in buildings. Several studies and guidelines (e.g. Flannigan and Morey 1996) have pointed out the importance of the cleanliness of cooling coils. For example a study in Southern California discovered that one third of the cooling coils in the large air handling units and two thirds in the small ones were contaminated in the United States (Byrd 1996).

The importance of the cleanliness of air handling systems has been already recognised in the national guidelines and standards in many countries (CEN 2002, FiSIAQ 2001, ASHRAE 2001, VDI 6022 1997). A labelling system for clean air handling components have been developed in Finland as a part of the Finnish Classification of Indoor Climate (FiSIAQ 2001, Bjorkroth et al. 2002a,b). The general criteria for the cleanliness are the following:

1. A labelled component should not increase the concentration of pollutants harmful to health or comfort in the air-handling system.
2. A labelled component should not produce odours or gaseous or particulate pollutants that degrade the quality of supply air.
3. A labelled component should be easy to clean.

The specific criteria for the cleanliness of (metal) ducts and accessories are shown in Table 3.

Table 3. The cleanliness classification for metal ducts and accessories (FiSIAQ 2001).

Pollutant	*Criterion*
Surface density of oil in ducts	0.05 g/m^2
Surface density of oil in accessories, terminal units, and air and fire dampers	
Parts manufactured by cutting, bending or jointing	0.05 g/m^2
Parts manufactured from deep-drawn sheet metal, processes requiring oil	0.3 g/m^2
Mineral fibres released into air flow (MMMF)	10^4 fibres/m^3
Amount of surface dust (after manufacture)	<0.5 g/m^2

The labelling system includes also specific requirements concerning the hygiene of other components used in the air handling system. In order to receive a cleanliness label, each component must fulfil both the general requirements and specific requirements for the component group presented in the testing protocol.

Heat recovery

In many buildings, heat recovery from ventilation air is the most important single means of energy conservation. The same level of indoor air quality is achieved with lower energy consumption if the heat recovery units are properly designed, installed and maintained. Good indoor air quality and energy efficiency for houses in cold climates can be achieved only with balanced ventilation systems with heat recovery.

Heat recovery is common in new buildings in Nordic countries, even houses have often a balanced supply exhaust ventilation system with heat recovery. The performance of heat recovery depends on the type of system (Table 4).

Table 4. Typical efficiencies of the heat recovery systems (Irving 1994):

Heat recovery type	Efficiency, %
Run-around coils	50-65
Small recuperative heat exchangers, (plate heat exchanger)	40-60
Large recuperative heat exchangers, (plate heat exchanger)	50-70
Regenerative heat exchangers, (thermal wheel)	60-85
Air-to-air heat pumps,(calculated from the temperatures)	>100

The typical payback time for heat recovery from exhaust air is within the range of one to five years. The payback time becomes shorter with larger systems, long operating hours and colder climates. The energy economy of heat recovery requires a tight building envelope. Energy cannot be recovered from the ventilation air through exfiltration but only from air exhausted through ducted system.

Improper operation of heat recovery systems can also degrade the supply air quality. The exhaust air should not leak into the ventilation air. The heat exchanger should be air tight or the pressure of the supply air should be higher than the exhaust air. Moisture might condense from exhaust air and even freeze and block the air flow. Proper drainage of condensed water and defrosting of accumulated ice should be arranged, to prevent the adverse effects from possible microbial growth.

Regenerative heat exchangers (heat wheels) pose a specific problem if used with dirty exhaust air. They may transfer pollutants from exhaust air to supply air. This is particularly a problem with water soluble chemicals in the air and mixtures of gases and droplets such as environmental tobacco smoke.

Heat exchangers to recover heat increase the pressure drop of the air handling system, and increase the power demand of the fans. This is, however, typically only 5-10% of the recovered energy. Energy recovery from ventilation air may also reduce the total heating or cooling demand (peak) of the building and result in significant savings in the first cost of the heating or cooling plant.

Commissioning, Operation and Maintenance

In the Swedish mandatory program for the testing and examination of ventilation systems, only 34% of the 5,625 systems evaluated passed the test criteria, which were mainly based on regulations that applied when the system was brought into operation (Engdahl 1998). Systems without satisfactory operational and maintenance instructions had 50% more faults in performance compared with those with satisfactory instructions. This points up the importance of the proper commissioning and maintenance of air handling systems. Guidelines for such commissioning have been published in the USA by ASHRAE, and, in Europe by CEN and in several languages by REHVA.

The proper operation of a ventilation system is of great importance. This has been stressed in many national standards. The operation schedule for ventilation should take into the account the hours of occupation of the various spaces. Since contaminant concentration increases when ventilation is not operating, there should always be efficient ventilation before the room is occupied. It has been suggested to start ventilation well before the room is occupied (ASHRAE 62 2001, FiSIAQ 2001). Buildings should also be ventilated more when they are new or have gone through major renovations to flush out the pollutants as fast as possible. The operation hours of ventilation might be reduced when the emissions from building materials have levelled off.

Buildings tend to get ever more technically complicated, and moreover require more skilful labour to operate them. Unfortunately, the building operators are not always trained properly to perform their tasks, which may lead to poor operation of the building and a deteriorated indoor climate. A typical mistake in operation, for example, is saving heating costs by reducing ventilation rates or the operation hours of ventilation. This may result in serious indoor climate and moisture problems in the long term. Requirements for training of the facility management is outlined in the German guidelines (VDI 6022 1997).

Poor maintenance may result in serious failures in the operation of a ventilation system, which again may lead to the problem of deteriorated indoor air quality. Good maintenance improves the air quality and user satisfaction (Dorgan et al. 1999). Advanced requirements for the maintenance of air handling systems are given in the German guidelines (VDI 6022 1997). These give recommendations for the maintenance schedule for air handling systems providing good indoor air quality, and set the requirements for the training in building hygiene of a facility manager and service personnel.

SUMMARY

Ventilation rates and systems have an important role on efficiency of buildings and in respect of good indoor air quality and climate. The requirements for good indoor air quality and energy efficiency have often been considered to conflict with each other. However, buildings with low energy consumption seem also to have a lower rate of building related symptoms. Several strategies for ventilation have been described by which at the same level of energy consumption, indoor air quality is improved; or at the same level of indoor air quality, energy consumption is reduced. Or in the best case both objectives are achieved simultaneously.

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