CAN WE MEET THE VENTILATION REQUIRED IN INTERNATIONAL STANDARDS IN AN ENERGY EFFICIENT WAY?

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ABSTRACT

Today an acceptable indoor air quality is mainly defined by specifying the required level of ventilation in air changes per hour or the outside air supply rate. This would be equivalent to defining the requirements for thermal comfort by specifying the level of heating or cooling in Watts. The increasing societal need for energy efficiency will often result in very tight buildings. This means that the amount of outside air supplied by infiltration is not enough to provide the required ventilation. In some standards the required ventilation is based on adapted people (occupants) while other standards refer to un-adapted persons, who have just entered a room. Which approach is correct? Or should it depend on the type of space or occupancy? Furthermore, the level of ventilation will depend on the criteria for acceptability, like health, comfort (perceived air quality) or occupant performance. The required outside air supply rate will be the same or higher than the required ventilation rate depending on the ventilation effectiveness. Existing standards do not or only in a limited way acknowledge the use of air cleaning as substitute for outside air. Furthermore the concept of demand controlled ventilation is in many cases not taken into account.

The present paper provides an overview and discusses the criteria used for specifying required ventilation rates, and suggest ways of meeting the criteria in a more energy efficient way by means of improved ventilation effectiveness, use of air cleaning and by means of demand controlled ventilation

KEYWORDS

Ventilation, energy, indoor environment, air purification, ventilation effectiveness,

INTRODUCTION

All over the world there is today a lot of focus on energy conservation in buildings, possible use of renewable energy sources and search for new energy sources. It is very important to realize that the reason for building buildings and install heating, cooling and ventilation systems is to provide a healthy and comfortable indoor environment that does not impair the productivity of the occupants. Therefore the research trends have been to find energy efficient measures and technologies that will provide an acceptable indoor environment.

In many cases it is possible to improve the indoor environment and at the same time reduce energy consumption. An example is the increase in better insulation of windows and external walls that result in a more uniform indoor thermal environment with less risk of radiant asymmetry, risk of draught and vertical air temperature differences. Unfortunately the tighter buildings have often resulted in too low ventilation rates in many residential buildings. Recent studies [1] have found that it is quite acceptable to provide a drifting temperature during the day, which can result in reduction of energy consumption and peak loads.

Finally many research projects are studying new technologies like personalized HVAC systems, use of air cleaning technologies to substitute for fresh outside air, use of low emitting building materials, and improved control systems. These technologies will in most cases provide an acceptable indoor environment with reduced energy consumption.

REQUIRED VENTILATION RATES IN INTERNATIONAL STANDARDS

The requirements to an acceptable indoor air quality is in most cases specifyed as a required level of ventilation, assuming that the outside air is fresh clean). The required rates depends on the type of building and space.

Non-residential buildings

Originally, most standards and guidelines for required ventilation rates were given as the required outdoor air supply rate per person. Laboratory and field studies have subsequently shown[4] that people and their activity (smoking, activity level), building and furnishing (floor covering, paint, furniture, cleaning, electronic equipment, etc.) and ventilation systems (filters, humidifiers, ducts etc.) may also contribute to indoor pollution. Even the outside air may be a source of poor indoor air quality.

Both people and building-related sources of pollution are taken into account in newer standards for the required ventilation rates in buildings, which include ASHRAE 62.1 [2], and EN15251 [3]. In all of the standards more than one procedure is specified. They all include a prescriptive method, where the minimum ventilation rates can be found in a table listing values for different types of space, as well as an analytical procedure for calculating the required ventilation rate. By means of the analytical procedure, the required minimum ventilation rates can be calculated on the basis of type of pollutant, emission rates and acceptable concentration. All of the proposed standards deal with the health issue and as well as the comfort issue.

Prescriptive procedure

For the prescriptive method, a minimum ventilation rate per person and a minimum ventilation rate per square metre floor area are required. The two ventilation rates are then added. The person-related ventilation rate should take care of pollution emitted from the person (odour and other bioeffluents) and the ventilation rate based on the person's activity and the floor area should cover emissions from the building, furnishing, HVAC system, etc.

The design outdoor airflow required in the breathing zone of the occupied space or spaces in a zone, i.e., the breathing zone outdoor airflow (V_{bz}), is determined in accordance with the equation:

$$V_{bz} = R_p P_z + R_a A_z \qquad (1)$$

Where:

A_z = Zone floor area: the net occupied floor area of the zone m^2,

P_z = Zone population: the greatest number of people expected to occupy the zone during typical usage.

R_p = Outdoor airflow rate required per person: these values are based on adapted occupants in EN15251 and un-adapted in ASHRAE-62.1.

R_a = Outdoor airflow rate required per unit area.

In the standards different methods for calculating the recommended ventilation rate are included. As a minimum it must be ventilated to dilute the bioeffluents from the occupants (people component, R_p, see table 1). These rates are in EN15251 specified for three categories of indoor air quality, based on the prediction that a certain percentage of visitors will find the air quality unacceptable (see Table 1). The design levels are thus adequate for people who walk into a space. It is debatable if this should always be the case. People adapt very quickly to the odour (bioeffluents) in a space while there is less adaption to emissions from building materials and tobacco smoke (odour and irritants, [5]). To provide an acceptable perceived air quality for occupants (who have adapted to the air quality for at least 15 min.) it is estimated that one third of the ventilation rate is sufficient i.e. for category II 2, 5 instead of 7 l/s per person. The ASHRAE Standard 62.1 for ventilation and indoor air quality defines ventilation levels for adapted persons (occupants).

In addition, the minimum recommended ventilation is increased with a building-related ventilation rate, in order to take into account the emissions from the building and its systems (see Table 1). There is, however no general agreement on whether the contribution from the building should be added in full. Several studies indicate this is the best approximation, but it may not be valid for all types of pollutants. Here it is the contribution to the odour and irritation (perceived air quality) which must be taken into account. So it can be argued they all influence one organ (the nose) and so should be added. When the health risk is considered a simple addition can only be made for the same chemical component. Therefore in some countries it is recommended that the minimum ventilation rate should be specified as a value between the minimum level for people (bioeffluents) and the higher rate that takes account of both occupant and building emissions.

Category	Expected Percentage Dissatisfied	People component l/s person	Building component		
			Very low polluting l/s m²	Low polluting l/s m²	Not Low polluting l/s m²
I	15	1O	0,5	1,0	2,0
II	20	7	0,35	0,7	1,4
III	30	4	0,2	0,4	0,8

Table 1. Basic required ventilation rates for diluting emissions (bio effluents) from people and three types of buildings for different categories of indoor environmental quality

Criteria for the ventilation rate may also be expressed as total rates per m^2 floor area (l/s per m^2) or per occupant (l/s per occupant). By expressing it as a people part and as a building part it becomes easier to calculate required ventilation rates for non-typical levels of occupancy. One issue is the rate for the building component for different types of buildings. For new buildings (Wargocki-2004 [6]), where attention has been paid to the selection of building materials, no smoking etc., lower levels corresponding to 0,14 l/s per m^2 can be obtained. A very-low polluting building is therefore included in Table 1 and 2. There is, however, a need to establish procedures and test methods for materials on the basis of which the type of building pollution level can be determined. In the annex to the standard some suggested criteria have been included.

Table 2 shows the required ventilation rates from standard EN15251 compared to ASHRAE 62.1. There are quite big differences between the European recommendations and those listed by ASHRAE. One major reason is that ASHRAE requirements are minimum code requirements, where the basis for design is adapted people, while the European recommendations are for un-adapted people (visitors).

Ventilation effectiveness

The ventilation rates specified in the standards (Table 2) are the required rates at breathing level in the occupied zone. The required ventilation rate at the room supply diffusers are calculated as:

$$\text{Total ventilation rate V} = V_{bz} / \varepsilon_v \qquad (2)$$

Where :

V_{bz} = *breathing zone ventilation*

$$\varepsilon_v = \frac{C_e - C_s}{C_i - C_s} \qquad (3)$$

Where:

ε_v = Ventilation effectiveness

C_e = Pollutant concentration in extract air

C_s = Pollutant concentration in supply air

C_i = Pollutant concentration at breathing level

The ventilation effectiveness depends on the air distribution efficiency and the type and position of the pollution source(s), so this value is not only a system characteristic. In most cases it is assumed that the pollutant emission is uniform, so the ventilation effectiveness is the same as the air distribution effectiveness. For a fully-mixed ventilation system the value is 1 and the ventilation rates in Table 2 can be used for the design of the supply grills. The ventilation effectiveness or air distribution efficiency is a function of the position and type of supply and return grills, and depends on the difference between supply and room temperature and on the total amount of airflow through the supply grill. The air distribution effectiveness can be calculated numerically or measured experimentally. Typical examples of ventilation effectiveness/air distribution effectiveness are shown in Figure 1 [7].

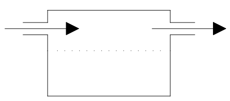
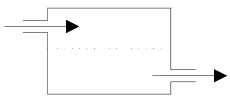
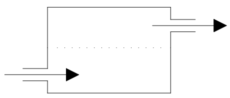
Mixing ventilation		Mixing ventilation		Displacement ventilation		Personalized ventilation	
							
T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T room °C	Vent. effect. -
< 0	0,9 - 1,0	< -5	0,9	<0	1,2 - 1,4	-6	1,2 - 2,2
0 - 2	0,9	-5 - 0	0,9 - 1,0	0-2	0,7 - 0,9	-3	1,3 - 2,3
2 - 5	0,8	> 0	1	>2	0,2 - 0,7	0	1,6 - 3,5
> 5	0,4 - 0,7						

Figure 1. Typical examples of ventilation/air distribution effectiveness [8]

The air distribution effectiveness takes into account the air distribution in a space, but does not take into account how effectively the outside air is transported through the ducts to the space. If the system has any air leakage, the amount of ventilation air must be increased. This is not dealt with in en15251, but is mentioned in ASHRAE 62.1.

Analytical procedure

All of the listed standards specify an analytical procedure, either in the standard text or in an informative appendix. In this procedure the required ventilation rate is calculated on a comfort basis (perceived odour and/or irritation) as well as on a health basis. The highest calculated value, which in most cases will be the comfort value, is then used as the required minimum ventilation rate. The basis for the calculation is in all standards based on a mass balance calculation.

The required ventilation rate is calculated as:

$$Q = \frac{G}{(C_i - C_o) \cdot E_v} \qquad \mathrm{l\ s^{-1}} \qquad (4)$$

where G = Total emission rate mg s^{-1}
C_i = Concentration limit mg l^{-1}
C_o = Concentration in outside air mg l^{-1}
E_v = Ventilation effectiveness

Type of building space	Occupancy person/m^2	Category CEN	Minimum ventilation rate, i.e. for occupants only l/s person		Additional ventilation for building (add only one) l/s·m^2				Total l/s·m^2	
			ASHRAE R_p	CEN	CEN Very low-pollut.	CEN Low-pollut.	CEN *Not* low-pollut.	ASHRAE R_a	CEN Low Pol.	ASHRAE
Single office (cellular office)	0,1	I	2,5	10	10	1,0	2,0	0,3	2	0,55
		II		7	7	0,7	1,4		1,4	
		III		4	4	0,4	0,8		0,8	
Land-scaped office	0,07	I	2,5	10	10	1,0	2,0	0,3	1,7	0,48
		II		7	7	0,7	1,4		1,2	
		III		4	4	0,4	0,8		0,7	
Confe-rence room	0,5	I	2,5	10	10	1,0	2,0	0,3	6	1,55
		II		7	7	0,7	1,4		4,2	
		III		4	4	0,4	0,8		2,4	
Audito-rium	1,5	I	3,8	10	10	1,0	2,0	0,3	16	6
		II		7	7	0,7	1,4		11,2	
		III		4	4	0,4	0,8		6,4	
Class-room	0,5	I	3,8	10	10	1,0	2,0	0,3	6	2,2
		II		7	7	0,7	1,4		4,2	
		III		4	4	0,4	0,8		2,4	
Kinder-garten	0,5	I	5,0	12	12	1,0	2,0	0,9	7	3,4
		II		8,4	8,4	0,7	1,4		4,9	
		III		4,8	4,8	0,4	0,8		2,8	
Depart-ment store	0,15	I	3,8	14,7	14,7	2,0	3,0	0,6	4,1	1,17
		II		10	10	1,4	2,1		2,9	
		III		6	6	0,8	1,2		1,7	

Table 2 Smoking free spaces in commercial buildings according to ASHRAE 62.1[3] and EN15251 [4]

In all of the standards, however, knowledge concerning emission rates (G) and concentration limits (C_i) that safeguard health, is very limited. Within the next few years, knowledge will increase and data will be available from ongoing research projects and from testing by manufacturers of building materials and furnishing.

Residential buildings

In residential buildings the requirements are often expressed as required air change per hour, ach and additional required exhaust in kitchen, bathrooms and toilets. (Table2).

Category	Air change rate 1)		Living room and bedrooms, mainly outdoor air flow		Exhaust air flow, l/s		
	l/s,m^2 (1)	ach	l/s, pers 2) (2)	l/s/m^2 (3)	Kitchen (4a)	Bathrooms (4b)	Toilets (4)
I	0,49	0,7	10	1,4	28	20	14
II	0,42	0,6	7	1,0	20	15	10
III	0,35	0,5	4	0,6	14	10	7

1) The air change rates expressed in l/sm^2 and ach correspond to each other when the ceiling height is 2,5 m
2) The number of occupants in a residence can be estimated from the number of bedrooms. The assumptions made at national level have to be used when existing, they may vary for energy and for IAQ calculations.
Table 2 Ventilation rates for residential buildings with mechanical ventilation. Continuous operation of ventilation during occupied hours. Complete mixing. EN15251:

In ASHRAE 62.2 [5] the requirements are specifyed as a basic mechanical ventilation of:

$$0.05l/s*FloorArea+3.5l/s*number\ of\ persons \qquad (4)$$

where it is assume that the number of people=1+number of bedrooms
It is also assumed that you get 10 L/s per 100 m^2 of floor area of extra ventilation from infiltration. For a US sized house this leads to a total of about 0.35 ACH half of which is coming from infiltration and half from the mechanical system. This corresponds to category III in EN15251.

TECHNOLOGIES AND METHODS TO IMPROVE INDOOR AIR QUALITY

Removal of Sources
The most efficient way of reducing energy consumption for ventilation and increase the indoor environmental quality is reducing the sources of emissions in buildings. There is an urgent need for better certification and labeling of the materials used in buildings and the ventilation standards must include methods that favor the manufacturers of “good” (low polluting) materials. A start has been made by defining three types of buildings in EN15251, but the method for evaluating to which type an existing or projected building should belong is not good enough.
In many countries a material labelling system and certification of emissions from material have been introduced ; but without any direct link to the influence on required ventilation in a space.
Increased ventilation effectiveness
In most cases it is assumed that the pollutant emission is uniform, so the ventilation effectiveness is the same as the air distribution effectiveness. The air distribution efficiency is a function of the position and type of supply and return grills, and depends on the difference

between supply and room temperature and on the total amount of airflow through the supply grill [7]. The air distribution effectiveness can be calculated numerically or measured experimentally.
To use ventilation effectiveness can be one way of taking into account personalized ventilation; but we need also to look at issues like acceptance of higher air velocities and less strict requirements to the general environment if the person is equipped with a personal system.

Demand controlled ventilation
A well known method to reduce energy use for ventilation is only to ventilate when occupants are present. As also the number of occupnats are the source strength that varies the most in a building the level of ventilation should preferably corresponds to the number of occupants. This is basiccally what demand controlled ventilation (DCV) is about.
In residential buildings DCV can be controlled by time schedule (occupation of the house), humidity or CO_2 sensors. As some of the major sources in residential buildings may not be people a CO_2 sensor is not always the best choise. There has been for many years an interest in developping sensors, which reponses to many polutants, like a human nose ; but until now it has been very difficult to find a good sensor. As there is a significant background level of pollutant in a residential building the onset of ventilation must be before the occupants arrive, which makes it even more difficult. Some countries require a ventilation rate of 0.5 ach in every room all the time. It would be more energy efficient if this requirement was only valid when the room is occupied. This would then also open up for the possibility to vary the ventilation rate from room to room i.e.ventilate in kitchen living room during day and evening and bedrooms during the night.
In commercial buildings DCV could first of all be based on a schedule for working hours, secondly it could be based on a person detector and finally what is becoming more common on a CO_2 sensor. In commercial buildings a CO_2 sensor is normally a good choise as the dominant source is people.

Air cleaning
Gaseous air cleaning is not taken into account at all in EN15251, while ASHRAE 62.1 by using the analytical procedure can allow some credits for air cleaning. There is an increased interest in the development of air purification equipment. This may be an acceptable way of reducing the amount of outside air, saving energy and still having an acceptable indoor air quality. However, better test methods for air cleaners are required, because at present the test is usually based on chemical measurements and the resulting effect on odour or perceived air quality is not taken into account [8,9]. It is also very important to specify which kind of "pollutants" should be used when testing. Some air purification systems may work well on VOC's (emission from materials) but have zero or even a negative effect if the source is people (bio effluents).

Adapted or Non-adapted
Who should we ventilate for? For people just entering the room (un-adapted) or for people already occupying a room (adapted)? Here the philosophy adopted by ASHRAE 62.1 and EN15251 differs. But should it really be one or the other? In a conference room, auditorium or lecture room most people enter at the same time. It then takes some time before the odour level has reached an unacceptable level and meanwhile people adapt. In this case it may be appropriate to require a ventilation rate based on adapted persons. There may be other spaces where you would design for un-adapted people, e.g. in a first class restaurant, offices, and department stores. It seems logical that more differentiated criteria could be used.

Occupant behaviour

A factor that can influence the energy consumption by ventilation significantly is the occupant behaviour. How often do they open windows? Why do they open windows, bad air quality or feeling too warm? Do they block the supply grills because of draught? Or do they shut off the fans because of noise? This factor is often the reason why predicted energy consumption does not match with measured energy consumption. Here the control of the ventilation, feed-back to the occupants and a guide for operation of the ventilation can in most cases significantly improve the energy efficiency by ventilation and at the same time guarantee an acceptable indoor air quality.

DISCUSSIONS

Even if we today have standards and guidelines for estimating the required minimum ventilation rate, they are fare form being complete. The goal is of course to be able to calculate the required ventilation rate as straightforwardly as in cooling load calculations. We need to know the requirements for acceptable indoor air quality based on health, comfort and performance and we need to know the emission rates from all the sources. Unfortunately, this is not as easy as in cooling load calculations, where room and outside temperature (^oC), energy emission (watts), heat storage, solar radiation (watts) are all evaluated with similar units and all affect the same parameter of the human body (heat balance). For indoor air quality, we have thousand of substances that are emitted from people, furnishing, systems, from outside etc., each of which may affect one or more organs of the body.

We have good knowledge about the required ventilation for the “people” component, while the “building” component is not very well documented. There is an urgent need for better certification and labeling of the materials used in buildings and we must also develop ventilation standards that favour the manufacturers of “good” (low polluting) materials

The rates given in the Tables are based on full mixing and in practice the ventilation effectiveness is very seldom taken into account. One complication is that some systems may have a different ventilation effectiveness summer and winter. If the supply temperature is lower than room temperature the ventilation effectiveness is normally 1 or higher, but if the ventilation system is used for heating in winter the ventilation effectiveness could be as low as 0.5, and the ventilation rates should really be doubled. More information and a greater emphasis on this factor is required.

Better test methods for gaseous air cleaners are required, because at present the test is usually based on chemical measurements and the resulting effect on odour or perceived air quality is not taken into account

One serious problem is how to ventilate if a building is located in an area with poor outside air quality or if there is a time of the day (e.g. rush hour) when the outside air quality is unacceptable. In some cases it might even be better to reduce ventilation under these circumstances, and the use of air cleaning technologies can be a better solution.

CONCLUSION

Recent research has resulted in improved personalized ventilation and conditioning systems, which can improve the indoor environment at a work place in an energy efficient way.

The results of research on improved air distribution in spaces demand control ventilation and the use of air cleaning will be future technologies that reduce energy consumption and may improve comfort.

Occupant behaviour is a major factor for the energy performance of a building.

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