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Comfort criteria related to ventilation of spaces

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COMFORT CRITERIA RELATED TO VENTILATION OF SPACES

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Abstract

Human comfort in a ventilated space depends on the perceived air quality, on the general thermal sensation of the occupants and on the risk of draft. Each of these aspects are discussed separately. The perceived air quality is expressed in decipol. The general thermal sensation is expressed by the PMV/PPD indices. The perception of draft is expressed by the new model of draft risk. Indoor air quality is mediocre and causes complaints in many buildings. The reason for this is often hidden pollution sources in the building, hitherto ignored in existing ventilation standards. To determine the required ventilation, a new method is prescribed acknowledging <u>all</u> pollution sources in the building, expressed in olfs. The method is based on the desired air quality in the space, the available quality of the outdoor air and on the total pollution load in the space.

Introduction

Spaces for human occupancy are ventilated or air conditioned for two reasons: (i) to provide a good air quality in the breathing zone of the space; (ii) to provide a comfortable temperature field in the occupied zone of the space. It is the challenge of the engineer to design a system which meets these two requirements without causing any significant risk of draft for the occupants.

The thermal capacity of the system should be designed to provide the required temperature level in the space. Well-known methods for the thermal design are available. The system should also be designed to supply the outdoor air required to obtain a desired level of air quality in the space. A new method to calculate the required ventilation is presented in this paper. But although the right level of temperature and air quality is provided, there may be large differences from place to place in the occupied zone. This non-uniformity is caused by the air distribution system and the location of heat and pollution sources. Ways of expressing the non-uniformity of the thermal environment, of the air quality and of the draft risk in the occupied zone are also described in the paper.

Indoor Air Quality and Ventilation

Ventilation is supply of air to a space to improve the indoor air quality. The idea is to dilute pollutants emitted in the space to a desired, acceptable level. Since Pettenkofer (1) and Yaglou (2) ventilation standards have assumed that the occupants are the dominating or exclusive polluters. Unfortunately, compliance with the existing standards have not prevented widespread complaints on indoor air quality in many buildings. Recent studies have identified that materials in the building often are more important polluters than the occupants and contribute significantly to the complaints (3,4,5). In the present paper a new method of determining the required ventilation is prescribed. By this method all pollution sources are considered. This means, that use of low-polluting materials in a building is rewarded by a low required ventilation, while the use of high-polluting materials is penalised by a high required ventilation.

In contrast to existing standards this paper does not just prescribe a given quantity of outdoor air to be supplied to a space. It begins with a decision on the level of air quality aimed at in the ventilated space. A high, a standard or a minimum air quality may be desired. The available quality of the outdoor air is also considered. A high outdoor air quality requires a lower ventilation rate than a moderate outdoor air quality. The required ventilation can then be calculated based on the total pollution load, the desired indoor air quality, the outdoor air quality available and the ventilation effectiveness of the ventilated space. The occupants in a space have two requirements to the air they are breathing in a space. First the air should be perceived fresh and comfortable rather than stale, stuffy and irritating. Furthermore, the health risk of breathing the air should be negligible.

There are large individual differences in the human requirements. Some persons are very sensitive and have high requirements to the air they are breathing. Other persons are rather insensitive and have low requirements to the air. The quality of the indoor air may be expressed as the extent to which human requirements are met. The air quality is high if there are few dissatisfied, while many dissatisfied persons means a low air quality. People may be dissatisfied because they perceive the air as stale, stuffy or irritating. Or they may be dissatisfied due to a possible health risk. The ventilation required to obtain a certain perceived air quality is discussed in this paper. It is usually much larger than required from the point of view of health.

Perceived Air Quality

Man perceives the air by two senses. The olfactory sense is situated in the nasal cavity and is sensitive to several hundred thousand odorants in the air. The general chemical sense is situated all over the mucous membranes in the nose and the eyes and is sensitive to a similarly large number of irritants in the air. It is the combined response of these two senses that determines whether the air is perceived fresh and pleasant or stale, stuffy and irritating.

Perceived air quality is expressed in decipol (6). One decipol is the perceived air quality in a space with a pollution strength of one olf, ventilated by 10 l/s of clean air, i.e. 1 decipol = 0.1 olf/(l/s). One olf is defined as the pollution from a standard person (6). Any pollution source can be expressed in olfs, i.e. the number of standard persons required to make the air equally annoying as the actual pollution source. Fig. 1 shows the percentage of dissatisfied, i.e. those persons who perceive the air to be unacceptable just after entering a space, as a function of the ventilation rate per olf. Fig. 2 shows the corresponding relation between perceived air quality in decipol and the percentage of dissatisfied.

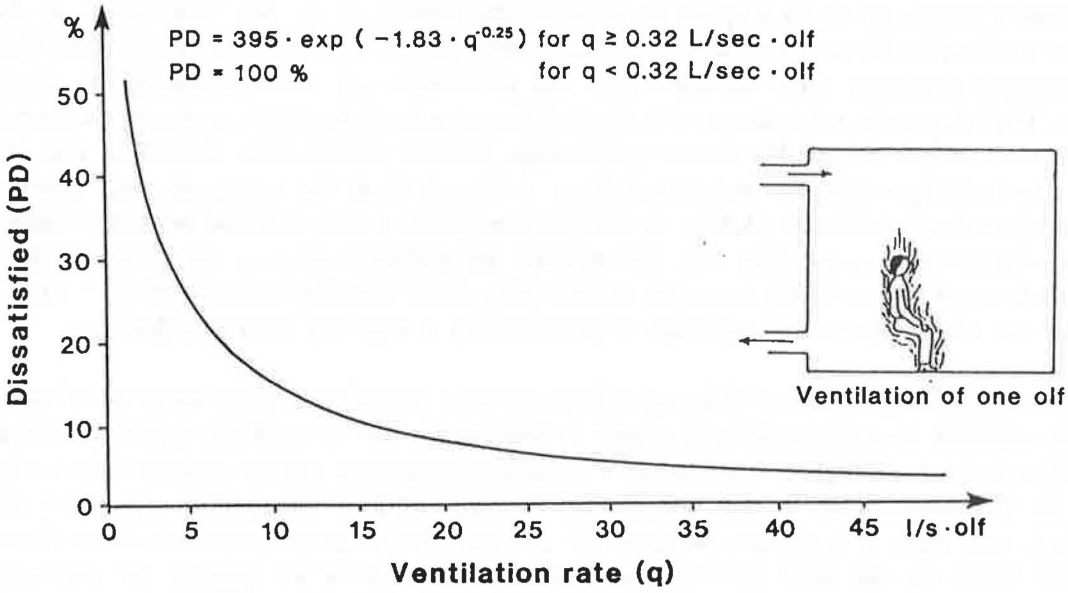

Fig. 1. Dissatisfaction caused by one olf at different ventilation rates (6). The curve is based on studies where 168 European subjects judged air polluted by bioeffluents from more than one thousand sedentary men and women. Similar studies in North America (7) and Japan (8) show close agreement with the present European data.

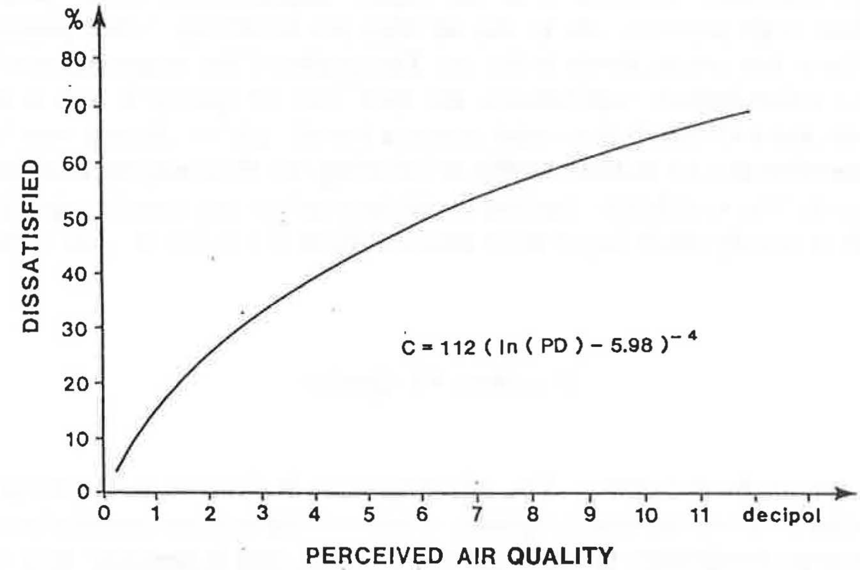

Fig. 2. Perceived air quality in decipol as a function of the percentage of dissatisfied (6).

To determine the required ventilation it is essential to consider the level of indoor air quality to be desired. In some spaces it may be sufficient to provide a **minimum** air quality. In many spaces a **standard** air quality would be required, while in other spaces a **high** air quality may be desired. These three suggested levels of comfort are given in Table 1 as percent dissatisfied and in decipol. The decision on the desired level of air quality in a space depends mainly on economical considerations and on the application of the space.

Table 1. Three levels of perceived indoor air quality

	% dissatisfied	perceived air quality decipol	required ventilation rate * l/s·olf
High indoor air quality	10	0.6	16
Standard indoor air quality	20	1.4	7
Minimum indoor air quality	30	2.5	4

* Assuming clean outdoor air and a ventilation effectiveness of one

The perceived air quality in Table 1 refers to peoples' initial judgement when entering a space. The first impression is essential, i.e. it is important that the air immediately is perceived acceptable. However, some adaptation do take place during the first 15 minutes of occupancy. Considerable adaptation takes place in air polluted by human bioeffluents, some adaptation occurs in tobacco smoke (at moderate levels), while little adaptation may take place in air polluted by building materials etc. (9).

Air Pollution Sources

The purpose of ventilation is to dilute the pollution emitted in a space. The pollution sources comprise the occupants and their possible smoking. Furthermore, materials in the building, including furnishing, carpets and the ventilation system may contribute significantly to the pollution. Some materials pollute a lot, some a little, but they all contribute to degrade the indoor air quality. Many sources emit hundreds or thousands of chemicals but usually in small quantities. The source strength can be expressed by the olf unit which integrates the effect of the many chemicals as perceived by human beings (6).

A pollution source strength is not always a constant. It may change with temperature, humidity, age and pollution level in the space.

Olf Load

The total olf load in a space is found by adding the olf values of the different pollution sources in the space. The pollution sources comprise the occupants and the building, including furnishing, carpeting and ventilation system.

The occupants emit bioeffluents and some produce tobacco smoke. A standard sedentary person produces 1 olf, while an average smoker produces 6 olf. Table 2 lists the olf load from occupants at different activities with no smoking and with different percentages of smokers among the occupants (6,7).

The source strength of the building may be found by adding the olf values of all materials present. But information on olf per m² is only available for few individual materials yet. A more feasible approach at this present time is to estimate the olf load per m² floor caused by the building, including furnishing, carpeting and ventilation system. Such data have been measured in different existing buildings (3,4,5). Table 3 comprises data from the measured olf loads in different types of existing buildings. The olf load caused by the building is often high and varies widely from building to building. It is essential that new buildings be designed as low olf-olf buildings. This requires a systematic selection of low-polluting materials for the building including furnishing, carpets and ventilation system. Many existing buildings need to be redecorated to reduce the olf load.

Table 2. Olf load caused by the occupants

SEDENTARY, 1-1.2 met*	olf/occupant
0% smokers	1
20% smokers**	2
40% smokers**	3
100% smokers**	6
PHYSICAL EXERCISE	
Low level, 3 met	4
Medium level, 6 met	10
High level (athletes), 10 met	20

* 1 met is the metabolic rate of a resting sedentary person (1 met = 58W/m² skin area)

** average smoking rate around 1 g tobacco/hour per smoker, i.e. typically around 1.2 cigarettes/hour in Europe and 2 cigarettes/hour in North America

Table 3. Olf load caused by the building, including furnishing, carpets and ventilation system

	olf load olf/(m² floor)	
EXISTING BUILDINGS	mean	range
Offices*	0.3	0.02-0.95
Schools (class rooms)**	0.3	0.12-0.54
Assembly halls***	0.5	0.13-1.32
LOW-OLF BUILDINGS	0.05-0.1	

* Data for 24 mechanically ventilated office buildings (3,4,5)
** Data for 6 mechanically ventilated schools (5)
*** Data for 5 mechanically ventilated assembly halls (3)

It is here recommended to calculate the total olf load in a space by simple addition of the olf values of the individual pollution sources in a space. This has been shown to provide a reasonable first approximate method of combining many pollution sources (10,11). But simple addition is not a prerequisite for the present method. Future studies may show that some materials, when occurring in the same space, provide a stronger or weaker total source strength than predicted by simple addition of the individual olf values.

Outdoor Air Quality

The required ventilation depends also on the quality of the outdoor air. If the outdoor air has a high quality, less ventilation is required than if the outdoor air has a low quality. Table 4 lists characteristic levels of outdoor perceived air quality.

The World Health Organization has published "Air Quality Guidelines for Europe" (12), where guideline values for certain individual substances in the outdoor air are given. If the outdoor air quality is poor, it may be required to clean the air before it is suitable for ventilation.

Table 4. Typical outdoor levels of perceived air quality

	decipol
In mountains, at sea	0
In towns, high air quality	< 0.1
In towns, medium air quality	0.2
In towns, low air quality	> 0.5

Required Ventilation

The required ventilation rate to obtain the perceived air quality desired indoors is calculated from this equation (13):

$$Q_c = 10 \cdot \frac{G}{C_i - C_o} \cdot \frac{1}{\epsilon_v} \qquad [1]$$

where

Q_c = ventilation rate required for comfort (l/s)

G = total pollution load (olf)

C_i = perceived indoor air quality, desired (decipol)

C_o = perceived outdoor air quality (decipol)

ϵ_v = ventilation effectiveness

The ventilation effectiveness is the relation between the air pollution concentration in the return air and in the breathing zone. It is important to select an air distribution system which provides a high ventilation effectiveness. The location of the pollution sources in the space as well as the air distribution system influence the ventilation effectiveness (14,15).

Eq. [1] applies to steady-state conditions. Adsorption and desorption of air pollutants at surfaces in the space may prolong significantly the period it takes to obtain steady-state air quality.

Non-Uniformity of Air Quality

The required ventilation has been calculated to provide a certain air quality in the breathing zone. Still there may be large differences inside the space depending upon the selected air distribution system and the location of the pollution sources. The non-uniformity of the perceived air quality may be calculated and expressed by drawing iso-decipol curves at the breathing level inside the occupied zone.

Thermal Environment

The thermal sensation of the occupants in a ventilated space may be predicted by the PMV index (16). The Predicted Mean Vote is a function of the clothing and activity of the ocupants and of the thermal parameters: air temperature, mean radiant temperature, air velocity and humidity. The activity and clothing may be estimated according to the application of the space and the season. The PMV may then be calculated throughout the occupied zone. The PPD (Predicted Percentage of Dissatisfied) is a function of PMV and may also be calculated. The thermal non-uniformity in the occupied zone may be expressed by iso-PMV or iso-PPD curves. The international standard (16) recommends as a comfort limit that PMV be within ±0.5. This corresponds to less than 10% dissatisfied.

Risk of Draft

Draft is an unwanted local cooling of the human body due to air movement. In ventilated spaces it is one of the most common causes of complaint. There are large individual differences in the sensitivity to draft. Some people are extremely sensitive while others are rather insensitive to air movement. The risk of draft may be expressed as the percentage of people predicted to be dissatisfied due to air movement. The risk of draft may be calculated by the model of draft risk (17) shown in Fig. 3. The risk of draft depends on the air temperature, the mean velocity and the turbulence intensity. The risk of draft may be predicted by the model for any point in the occupied zone and the average risk may be estimated. Iso-draft-risk curves may also be drawn in the occupied zone. The comfort limit used for design may be a draft risk less than 10, 15 or 20%.

MODEL OF DRAFT RISK

$$PD = (34 - t_a)(\bar{v} - 0.05)^{0.62}(0.37\ \bar{v}\ Tu + 3.14)$$

for $\bar{v} < 0.05$ m/s insert $\bar{v} = 0.05$ m/s, for PD > 100% use PD = 100%

where PD = Percentage Dissatisfied people due to draft (%)

t_a = air temperature (C)

$\bar{v}$ = mean air velocity (m/s)

Tu = turbulence intensity (%)

Fig. 3 The model of draft risk (17) predicts the percent of dissatisfied people caused by draft as a function of air temperature, mean air velocity and turbulence intensity (= standard deviation divided by mean velocity). The model applies for sedentary persons.

Conclusions

- Human comfort in a ventilated space depends on the perceived air quality, on the general thermal sensation and on the risk of draft.
- A new method is presented for obtaining a desired air quality in a ventilated space.
- The new method calculates the ventilation required to handle all pollution sources in the space.
- The non-uniformity of the perceived air quality may be expressed by iso-decipol curves in the breathing zone of the space.
- The non-uniformity of the thermal field may be expressed by iso-PMV or iso-PPD curves in the occupied zone.
- The average draft risk may be predicted in a space and iso-draft-risk curves be drawn in the occupied zone.

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