# Ventilation and Body Odor

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## INTRODUCTION

Body odor is the major pollutant in many spaces in practice. Such spaces comprise lecture halls, class rooms, theatres, and meeting rooms where smoking is prohibited. The spaces are often ventilated constantly corresponding to maximum occupancy. When such a space is unoccupied or lightly occupied the room is overventilated and energy is wasted. Other and more energy conserving ventilation strategies should be considered to optimize the energy utilization. It seems rational to ventilate a space to maintain the body odor intensity at a given maximum permissible level. This raises two questions: how can body odor be quantified and measured, and what is an acceptable odor level? The aim of this paper is to answer these questions.

## BODY ODOR

Body odor originates from sweat and sebaceous secretions from the skin, foul breath, and gases from the digestive tract. Body odor is a mixture of odors from a wide range of organic gases in small concentrations, difficult to measure. Since man is exhaling carbon dioxide in large quantities, $CO_2$ may be a useful index of human occupancy and of body odor intensity. The odor emission from the body shows large individual differences and depends on diet, activity, and personal hygiene, i.e. bathing habits, frequency of clothing change, etc.

People vary also in their response to body odor. Some do not seem to object while others find it most objectionable. During the 19th century a common belief existed that the human body emitted a poisonous substance (anthropotoxin) that caused a threat to man's health in densely occupied spaces. This theory was disproved early this century. The malaise frequently occurring in crowded assembly halls was shown to be attributable to warmth alone.

Although not poisonous, body odor may evoke a feeling of nausea and loss of appetite in some people [1]. But the main objection to body odor is the subjective discomfort. In general, people find strong body odor unpleasant, and it is the aim of ventilation in densely occupied spaces to dilute the odor intensity to a level where it is acceptable to most people. Body odor is especially noticeable by persons entering a space (visitors). The sense of smell is quickly fatigued or adapted, and on that account which is readily noticeable, or even unpleasant to a newcomer, may be unnoticed by occupants who have been exposed to it for a few minutes. The quick adaptation may also explain why man is less bothered by his own body odor. He is exposed to it for long periods by inhaling air contaminated by odor from his own body.

Corresponding to the quick adaptation of the sense of smell there occurs a quick restoration when exposed to clean air. An occupant adapted to a strong body odor in a space will, when reentering after having left the space for a few minutes, feel the same strong odor as a visitor. This is one reason why it has been common practice to design ventilation systems which provide body odor levels acceptable for visitors rather than just for occupants.

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The conclusions of Yaglou [2,3] from his studies 1936-37 have had a dominating influence on ventilating engineering. During 45 years standards and handbook recommendations in many parts of the world have been based on his work.

Yaglou's studies took place in a 40 $m^3$ experimental chamber where temperature, humidity and ventilation rate could be controlled. The chamber was occupied for 3½ hours by 3, 7 or 14 occupants at each ventilation rate. Every hour the odor intensity in the chamber was estimated by judges who, one at a time, visited the chamber for a few moments. A 6-point psycho-physical scale was used by the judges to quantify the odor intensity: 0(None), 1(Definite), 2(Moderate), 3(Strong), 4(Very Strong), 5(Overpowering). The major group of occupants studied consisted of 177 sedentary men and women of average socio-economic status including students, office workers and housewives, who had their last bath at an average of 2.2 days before the experiment.

Yaglou decided arbitrarily to use the mean vote 2, i.e., 'moderate' odor, as an acceptable odor intensity. Fig. 1 shows the corresponding required ventilation rate derived from his data. The curve represented Yaglou's first surprising conclusion. It showed that a much higher ventilation rate (per person) was required when the chamber was densely occupied than when it was sparsely occupied. A doubling of the number of persons in a space required nearly a quadruplication of the outdoor supply air.

Yaglou [2] reports another surprising observation. When the occupants left the chamber and the ventilation was turned off, the odor intensity fell dramatically from 'strong' to 'moderate' in a few minutes. Yaglou named this observation 'spontaneous disappearance of body odor'. He claimed that body odor is very instable, and he suggested this instability as an explanation to the effect of occupant density on required ventilation rate.

A third conclusion of Yaglou was that carbon dioxide exhaled by occupants proved to be an unreliable index of body odor.

The present experiments were planned to check Yaglou's conclusions and to establish a rational basis for ventilation of spaces where body odor is the major pollutant.

## METHOD

The experiments took place in two identical auditoria at the Technical University of Denmark (12 years old). The auditoria were modified to be suited for experiments. The ventilation system was changed so the outdoor air flow rate could be maintained at any level up to 4700 $m^3/h$. The supply air was discharged through ceiling diffusers and the return inlets were situated in the floor under the chairs. Equipment and instrumentation were installed to measure air change, carbon dioxide, temperature, and humidity in the space. Each auditorium was designed for 172 occupants and had a volume of 850 $m^3$. The experiments took place during normal lessons where the experimental auditoria were occupied by 41-216 male engineering students, who had had their last bath at an average of 0.7 days before the experiment. During all the experiments more than one thousand persons served as occupants. Ten minutes before the end of each 35-min lecture period ten judges entered the space and were questioned concerning their acceptance of body odor (see Fig. 2). Furthermore, they were asked to evaluate the odor intensity on the scale shown in Fig. 3. Both responses were based on the immediate impression of each judge when entering the space. The judges comprised 48 male and 41 female students. On average each judge participated in 22 experiments.

A total of 200 experiments were performed at ventilation rates of 0.4-26 l/s·person, with an air space per occupants of 4-21 $m^3$ and with air temperatures of 17-26°C.

## RESULTS

Preliminary results for 95 experiments at moderate air temperatures (17-22°C) are reported in this paper. Fig. 4 shows the odor intensity judged by the visitors as a function of the carbon dioxide concentration. There was no significant influence of air space per occupant on the odor intensity. Yaglou did not report the carbon dioxide concentrations but they can be estimated, and Fig. 4 shows how the odor intensity would be predicted based on Yaglou's data. There is an obvious large difference compared to the rather close odor/$CO_2$ relation established in the present study.

Fig. 5 shows the relation between the percentage of dissatisfied, i.e., those visitors who judged the odor to be unacceptable, and the odor intensity. It is obvious that there is a close relationship between the two subjective judgments.

Fig. 6 shows the percentage of dissatisfied as a function of the $CO_2$ concentration. For comparison is shown a line based on an analysis of the results of Cain et al. [4], who recently studied body odor in a 27 $m^3$ experimental chamber occupied by 4, 8 or 12 subjects and ventilated at four different rates. During 47 one-hour experiments the odor was judged every 15 minutes by judges at a sniffing station outside the chamber. The dotted line in Fig. 6 is based on the reported acceptances during Cain's experiments at low humidity, and calculated $CO_2$ concentrations, assuming a $CO_2$ production of 16 l/h·person.

## DISCUSSION

Neither of Yaglou's three conclusions could be confirmed in the present experiments. No significant influence of crowding (space volume per occupant) on the required ventilation rate was found (Fig. 4). This agrees with results by Cain et al. [4].

How could it then be explained that Yaglou found a crowding effect (Fig. 1)? The most likely explanation may be the infiltration of air to his small experimental chamber caused by the numerous door openings, when his judges, one at a time, were visiting the chamber. The decreased ventilation efficiency at increased ventilation rate may also contribute to the explanation.

The instability of body odor was disproven by Yaglou's own data [3]. If body odor should disappear spontaneously (in a few menutes) the logical consequence is that a steady-state level of odor should also occur spontaneously (in a few minutes). But Yaglou claims that it took at least one hour before steady-state conditions were reached, and this agrees with the data by Cain et al. [4]. Body odor seems to be rather stable. This is also indicated by the relationship established in the present study between the stable gas, carbon dioxide, and the odor intensity (Fig. 4).

Carbon dioxide seems to be a reasonable index of body odor emitted by the occupants investigated (Fig. 4). For other groups of occupants of another age, sex, national geographic origin, diet, hygienic standard, and at other activities and temperatures there may be other relations between body odor intensity and $CO_2$ concentrations.

Fig. 6 shows the percentage of dissatisfied as a function of $CO_2$. The term 'percentage of dissatisfied' has been used by Fanger in several earlier studies [5,6] to express thermal discomfort. It has proven to be a rational and easily understandable way of expressing the impact of an environmental factor on man. For practical applications any percentage of dissatisfied may be selected according to the economy. Fig. 6 will then provide the corresponding $CO_2$% which may be used for the design of the ventilation system and for setting up a strategy to ventilate the space during the day. The ventilation system may also be controlled to maintain a constant $CO_2$ percent in the space.

The present results (Fig. 6) show that a substantial part of the population is quite sensitive to body odor, and high ventilation rates are required to satisfy this group. This agrees well with the results of Cain et al. [4]. ASHRAE's new ventilation standard [7] defines acceptable air quality as a condition where the air quality is accepted by at least 80% of the population (20% dissatisfied). The present results show (Fig. 6) that 20% dissatisfied correspond to a $CO_2$ concentration of 0.10% and a required steady-state ventilation rate of 7 l/s·person. This is nearly three times higher than the ventilation rate of 2.5 l/s·person in the ASHRAE standard. Fig. 6 predicts as many as 50% dissatisfied at a ventilation rate of 2.5 l/s·person. It is obvious from the present study that much higher ventilation rates than recently recommended will be required to satisfy visitors.

The curve in Fig. 6 has a low slope, i.e., it is difficult and expensive to satisfy the most sensitive. Some complaints of unacceptable odor intensity may therefore be expected in practice even at rather high ventilation rates.

Yaglou selected arbitrarily a limit on the odor intensity scale of 2 corresponding to 'moderate'. This would create as many as 32% dissatisfied among our judges according to Fig. 5. Yalou's ambition for air quality was obviously rather low. Still his criterion caused rather high recommended ventilation rates due to the lower hygienic standard of his occupants.

The present study was performed at an outdoor $CO_2$ level of 0.035%. At a higher level of outdoor carbon dioxide, all $CO_2$ percentages in Figs. 4 and 6 should be elevated correspondingly.

CONCLUSIONS

- The carbon dioxide concentration may be used as an index of the body odor intensity experienced by visitors entering a space with occupants at a given activity and temperature.

- No significant influence of space volume per occupant on body odor intensity or steady-state ventilation requirement was found.

- A relationship between percentage of dissatisfied visitors and $CO_2$ concentration has been established for sedentary male occupants.

ACKNOWLEDGEMENTS

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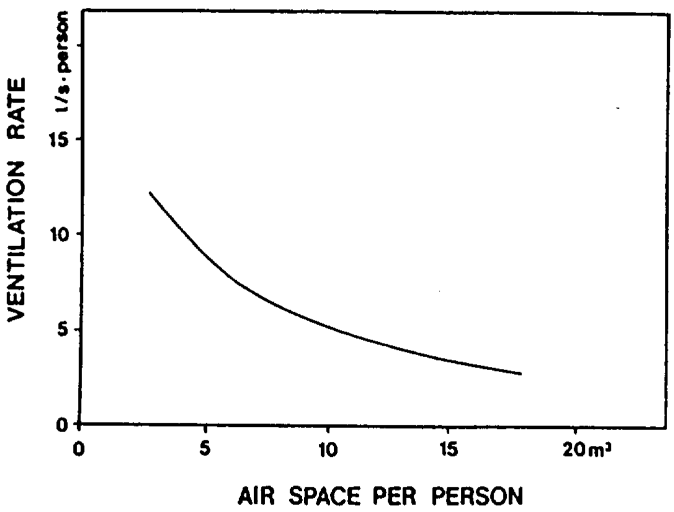


*Figure 1. Yaglou's [2] required ventilation rate as a function of air space volume per person. The curve was claimed to correspond to a constant body odor intensity of 2 ('moderate') experienced by visitors*

*Imagine that you during your daily work should enter this auditorium frequently. Would you judge the odor in the auditorium as acceptable?*

*acceptable* ☐

*not acceptable* ☐

*Figure 2. Question on odor acceptance*

*How strong is the odor in the auditorium? Please mark on the scale.*

- *No odor*
- *Slight odor*
- *Moderate odor*
- *Strong odor*
- *Very strong odor*
- *Overpowering odor*

*Figure 3. Yaglou's psycho-physical scale for the subjective judgment of odor intensity (slightly modified). For data analysis these numbers were assigned to the scale: 0 - no odor, 1 - slight odor, 2 - moderate odor, 3 - strong odor, 4 - very strong odor, 5 - overpowering odor*

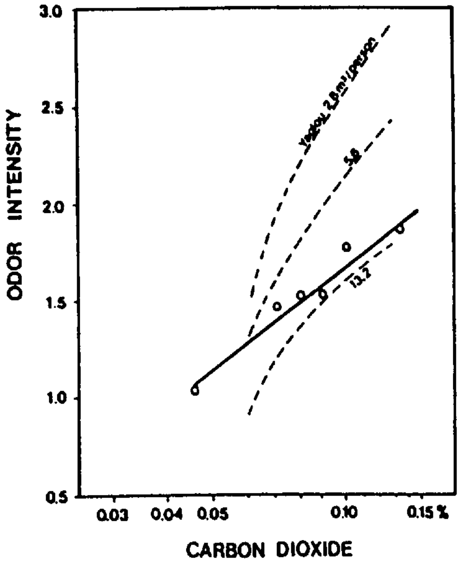


*Figure 4.* Odor intensity as a function of the carbon dioxide concentration. The points and the regression line are based on the present experiments. For comparison predictions of body odor from a reanalysis of Yaglou's data with estimated $CO_2$ concentrations are shown. The present experiments showed no significant effect of space volume per person, while Yaglou claimed a strong effect of this factor as indicated by the three dotted curves

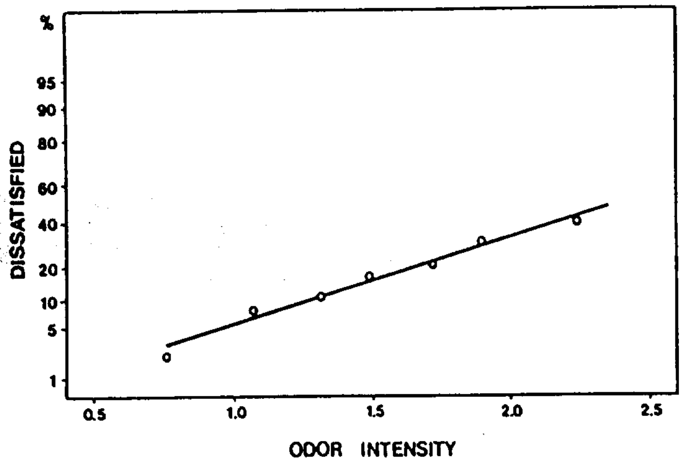


*Figure 5.* Percentage of dissatisfied as a function of the mean odor intensity

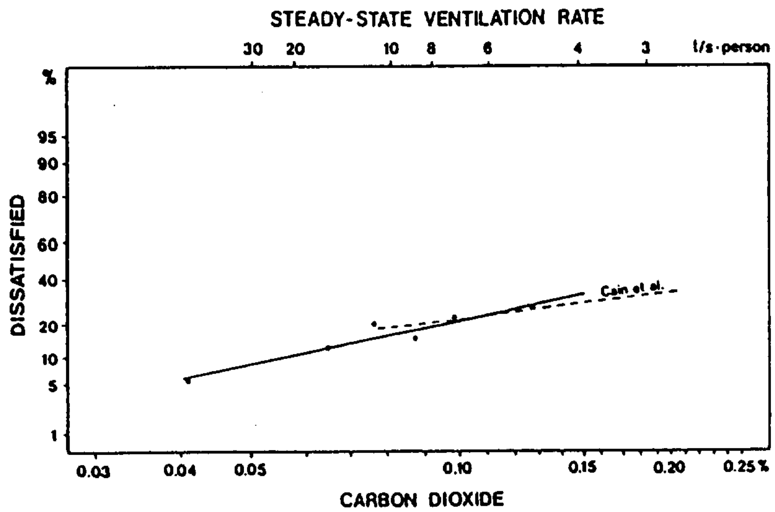


*Figure 6.* Percentage of dissatisfied as a function of the carbon dioxide concentration