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QUALITY OF AIR AND THE AMOUNT OF FRESH AIR IN CLASSROOMS

Ove Nielsen
Danish Building Research Institute

Abstract

This paper describes the results of a study of the indoor climate at 11 Danish schools. The investigation shows how the pupils themselves experience the indoor climate and indicates, for example, the relationship between the volume of outdoor air supplied per pupil and the pupils' evaluation of the quality of the air in the classroom.

Introduction

The purpose of this experimental study was to investigate the relationship between the physical indoor climate in classrooms in mechanically ventilated schools and the pupils' subjective evaluation of this. The principal question was the relationship between the volume of outdoor air supplied and the pupils' evaluation of the quality of the air, but the pupils' sensation of the temperature and the humidity can also be deduced from the study.

The reason for the study was that the Danish Building Research Institute's mobile indoor climate laboratory, had measured very large differences in the volume of outdoor air supplied per pupil in several investigations of the indoor climate carried out over a period of about 10 years. Too little outdoor air per pupil can result in an uncomfortable indoor climate, whereas too much outdoor air per pupil probably not necessay will indicate a more comfortable indoor climate. When the quantity of air per pupil exceeds a certain limit, the result will at any rate be an uncalled-for increase in energy consumption to treat the air supplied without a corresponding increase in comfort.

Most countries have mainly based their directions and norms for outdoor air requirements on studies performed by Yaglou (1) in 1935.

There thus seems to be a great need for investigations with the aim outlined above as a basis for determining how mechanical ventilation plants should be designed and operated in schools.

Scope of the Field Study

The study was carried out in the period March 1982 to April 1983. Measurements were only taken during the heating season. The study covered 11 schools, at each of which measurements were taken in two classrooms for three consecutive days. The age of the pupils varied from about 13 to about 16 years. The schools and the classrooms were selected completely at random. The only requirement to the school was mechanical ventilation in home classrooms. The data from the 11 schools are shown in Table 1.

School No.	Class-Room	Max. no. of pupils in class-room during measurements	Location of supply air inlets	Method of heating	Possibility of return air	Volume of class-room m^3
1	7a	20	At top of rear wall	With ventilation	yes	202
	8a	18				202
2	8a	19	Down along window	With ventilation	yes	219
	9b	19				219
3	6a	23	In floor under windows	Radiators	no	180
	7b	14				180
4	8a	19	In ceiling	With ventilation	yes	156
	8b	18				191
5	6a	18	At top of rear wall	Radiators	yes	180
	7a	15				180
6	8g	18	In ceiling	Radiators	no	154
	9y	15				154
7	8z	19	At top of rear wall	Radiators	no	213
	8y	17				213
8	7a	18	In floor along cross-wall	Radiators	yes	245
	7b	19	At top along cross-wall			245
9	7a	17	At top of rear wall	With ventilation	yes	199
	7b	16				199
10	8a	15	At top of rear wall	Radiators	yes	188
	8b	16				177
11	6b	21	In window frame up along window	Radiators	yes	167
	7b	17				167

Table 1. Data for schools and classrooms

Method of Investigation

The teachers and pupils at the selected schools were informed about the investigation, and only when they had all agreed to cooperate were the measurements taken. A questionnaire was distributed to each pupil in the two classes in question on Tuesday, Wednesday and Thursday morning in the week of the investigation. The questionnaire contained four questions which the pupils were required to answer at the end of each hour in the home classroom. The time spent in special classrooms was thus excluded.

The four questions and the reply options were as follows:

1. How does the indoor climate feel at the moment:
   (a) Comfortable? (b) Uncomfortable?

2. Do you find the quality of the air (a) fresh, (b) satisfactory, (c) unsatisfactory?

3. Do you find the air in the classroom (a) hot, (b) warm, (c) slightly warm, (d) neutral, (e) slightly cool, (f) cool, (g) cold?

4. Does the air feel (a) dry, (b) nothing noticeable, (c) humid?

The following parameters were measured:

Temperature of the air, relative humidity of the air, temperature of supplied air, volume-flow supplied and exhausted, CO_2-concentration of the classroom air, CO_2-concentration of the air exhausted, quantity of dust in the classroom air, size of dust particles and man-made mineral fibres contained in the normal dust. In addition, the ability of the ventilation system to ventilate the occupied zone of the classroom was measured. The dimensions of the classrooms were measured. The building materials used were recorded, and an estimation was made of the surface area of mineral-wool products in direct contact with the air in the ventilation system, such as acoustic dampers, ceiling insulation and ducts. The cleaning procedure was recorded.

Measurements were not taken of acoustic or lighting parameters, content of organic solvents and organic dust in the classroom air, static electricity, or ion balance. These unmeasured parameters presumably also have a varying effect on the pupils' degree of comfort in the climate of the classroom. In addition, it should be noted that in some of the schools in the study, the pupils hung their outdoor clothes in the classroom itself. These factors, too, must be expected to influence the pupils' evaluation of the quality of the classroom air.

The pupils had been asked to complete the questionnaire independently and not to use window ventilation or open any door from the classroom to the outside during the 3-day test period. On each of the three test days at each school, the test engineers changed the volume of outdoor air supplied with the aim of achieving between approx. 3 l/sec. per person and approx. 10 l/sec. per person. The actual form of operation of the heating and ventilation systems was only changed when obvious faults were ascertained.

Results

Table 2 shows the average values, the dispersion, the maximum values and the minimum values measured for air temperature, relative humidity, CO_2-concentration in the classroom, volume of outdoor air supplied per person, total volume of air supplied, and the dust content of the classroom air.

	Air temperature °C	Relative humidity %	CO_2 %	Volume of outdoor air supplied l/s • p	Volume of air supplied l/s	Volume of dust mg/m^3
Average	22.1	37	0.10	6.4	166	0.13
Dispersion	1.25	8.4	0.02	2.79	65.6	0.09
Max value	25.0	55	0.15	15.4	306	0.32
Min value	18.5	25	0.05	1.8	72	0.01

Table 2. Values of physical parameters

A statistical analysis of the physical parameters against the replies to the four questions was performed using the SAS (Statistical Analysis System)-program "Stepwise backward elimination linear regression procedure". This made it possible to see how each class, taken together, replied to the four questions each hour, and which parameters who have statistically significant influence on these answers. The physical parameters comprised both measured values: air temperature, relative humidity, CO_2-concentration, quantity of dust, the total volume of air supplied, and calculated values: volume of outdoor air supplied per person; volume of space per person; relative humidity divided into three categories: RH < 30 per cent, 30 per cent < RH < 45 percent, RH > 45 per cent; the numerical value of the deviation of the temperature of the air from 21°C; and the hour of the day. The school in question was introduced as a dummy variable to take into account the differences in replies due to other parameters than those measured.

For example, the following relationships are obtained:

1. How does the indoor climate feel at the moment?

Comfortable = 0, Uncomfortable = 1

With R^2 (correlation coefficient) = 0.53, the following relationship is obtained:

$$Y = 0.267 - 2.239\ C - 0.051\ k + 0.2495\ F + 0.87\ s + 0.04\ h,$$

where

K = outdoor air l/sec. person

h = hour of the day

F = category of
RH = 1 for RF > 45%
= 2 for 30% < RH < 45%
= 3 for RH < 30%

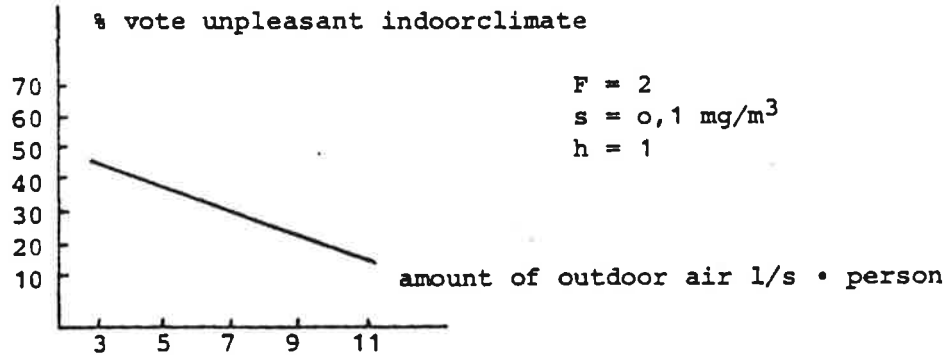
s = volume of dust mg/m^3

C = CO_2-concentration %

and the following relationship $C = 0.14 \times e^{-0.05 \cdot k}$ was found in this investigation.

The variables are written by turns of effect on the independent variable. The p-factor are 0,0001 for K, h, F and 0,0002 for s and 0,0461 for C.

Example:



2. Do you think the quality of the air is

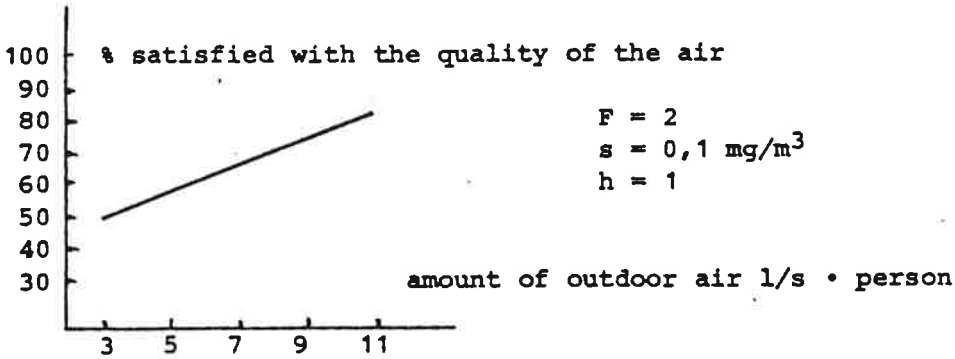
Fresh or satisfactory = 1, Unsatisfactory = 0

With $R^2 = 0.50$, the following relationship is obtained:

$Y = 1.014 + 0.037\ k - 0.236\ F - 0.77\ s - 0.04\ h$

In this connection the p-factor are 0,0001 for K, h, F and 0,0007 for s.

Example:



Discussion

C.P. Yaglou carried out a series of laboratory tests with adults in 1936 (1). On the basis of odour criteria, he found a relationship to the need for outdoor air. Yaglou also found that the volume of space per person was involved as a parameter. The outdoor-air requirement that

produced the evaluation "moderate odour" varied from about 4 l/sec. x person to about 10 l/sec. x person. In 1981, W.S. Cain (2) published results from a similar laboratory investigation. He found no relationship with volume of space, but that a volume of outdoor air of 2.5 to 5 l/sec. x person satisfied about 90 per cent of persons staying in a climate chamber for a prolonged period and about 75 per cent of persons staying in the chamber for a short period. Other investigations, too, have shown that persons entering a room from outside need larger quantities of outdoor air in order to regard the quality of the air in the room as satisfactory, as those persons staying in the room.

The study described in this report shows that for 80 per cent of the pupils in a classroom to describe the quality of the air as satisfactory, it is necessary to supply the room with about 10 l/sec. per person of outdoor air.

In the classes participating in the study, extensive use was made of teaching methods involving some activity outside the normal classroom during the periods (group work in the school hall, visit to the school library, etc.). That means that some of the pupils must have evaluated the climate in the classroom on the basis of the "guest criterion".

Conclusion

This investigation have shown, that the most statistically significant variables to the pupils' subjective evaluation of quality of the air, are the amount of outdoor air, the hour of the day, the humiditycategory and the content of dust in the air.

Afterword

The statistical treatment of the results was carried out by Mogens Weinreich of the Danish National Institute of Social Research.

The analysis of the dust measurements (weighing and counting mineralwool fibres) was carried out by Thomas Schneider of the Danish National Institute of Occupational Health (3).

References

(1) Yaglou, C.P. et al., "Ventilation Requirements", ASHVE Trans. 42, 133, 1936.

(2) Cain, W.S. et al., "Ventilation requirements for control of occupancy odour and tobacco smoke odour. Laboratory studies". John B. Pearce Foundation Laboratory, New Haven, Connecticut, April 1981.

(3) Schneider, Th., "Man-made mineral fibres (MMMF) and other fibres in the air and in settled dust. This conference.