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Ventilation rate in modern flats

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The air change between a room and its environment, also known as air renewal or ventilation (stated as the volume per unit of time), is of great importance hygienically. The reason for this is that the air change removes airborne pollutants which collect in any room due to the emission of gases, vapours and particles of building materials, furniture, textiles and so on as well as to the occupants and their activities. If these pollutants are not removed, the quality of the air is lowered causing danger to the health (and incovenience) of the occupants of the room.

Knowledge of the size of the ventilation rate in Danish flats is, however, very limited. The last major investigation carried out in 1959 (5) focussed attention on the ventilation arrangements in kitchens, bathrooms and WCs. An investigation was carried out in 1974 into the natural ventilation of 25 nurseries in newly built flats ready for occupation. The average air change was 0.8/hour ranging from 0.1 to 4.6 air changes/hour (2). A large number of investigations of the air-tightness of the flats was carried out with open doors and do not therefore allow calculation of the natural air change in the individual rooms. Neither was the inconvenience to the occupants investigated (7).

To save energy, attempts have been made to reduce the natural ventilation rate not only in new buildings but also by modernising older flats. The aim of the present work has been to make a hygienic appraisal of these modifications based on measurements of the size of the ventilation rate in a number of new flats. The measurements of the amount of gases, vapours and dust in the same flats are described in a previous article (13).

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OWN INVESTIGATIONS

Field of study

39 flats were studied chosen from among 412 new housing projects which had been previously well described as regards standards relating to building technology and health (4).

The criterion for selection in these investigations was that the mother should be working at home, since the measurements, which lasted for about five hours, required the presence of an adult.

The buildings were all flat dwellings situated in the Århus area and erected in accordance with the provisions of the building regulations from 1961 to 1976. Buildings in this category can be described as being built to a good technical standard with radiators in every room, double glazing or thermoglass window panes as well as outside wall insulation corresponding to a heat transfer coefficient k < 1 W/m^{2} °C. The buildings were erected from 1959 to 1973 (Table 1). There were one three-roomed, twelve four-roomed and three five-roomed flats. The number of occupants varied from three to five with an average of 3.5. The air-tightness of the flats varied between 0.8 and 1.5 with an average of 1.1. None of the flats was overcrowded in accordance with the housing ministry directive on building inspection (12), since in no case did the air-tightness of the flat exceed that required for two people over two years of age per room.

The average size of living room in which the measurements were made was 25 m^{2} ranging from 16 to 38 m^{2}. The floor area of the nurseries in the flats varied from 7 to 15 m^{2} with an average of 12 m^{2}. The ceiling height was 2.5 m in all the flats, resulting in a room volume of 17 to 37 m^{3} in the nurseries and 40 to 95 m^{3} in the large living rooms. The flats investigated were built as precast concrete structures or as brick-built flat dwellings equally distributed over the area of the property. None of the flats was provided with mechanical ventilation plant, but the statutory requirements for ventilation of kitchens and toilets were met. These rooms are therefore usually at a lower pressure than the remaining rooms in the flat which assists the natural ventilation in the latter.

The measurements were carried out between February and May 1976.

Method

The air change measurements were always carried out in the living room, i.e. in a room with a volume of 40 - 95 m^3. The measurements were made using freon 12 (CCl_2F_2) as a tracer gas for elimination measurements. The gas was dosed from a 1 litre pressurised gas bottle, measurement of the tracer gas flow being made at the same time using a flow meter until the concentration was of the order of 1000 parts per million (ppm). A dosage of about 90 l of freon was used in an average size room of 62 m^3, a certain quantity of gas having to be dosed to compensate for the elimination which occurred during the dosing period which lasted about 15 minutes. A propellor fan in the middle of the room provided uniform mixing of the tracer gas with the room air during dosage and measurement. Samples of air for subsequent gas analysis were also taken in the middle of the room with gas pipettes (9). Each ventilation rate determination was based on six concentration measurements at intervals of 20 minutes since observation over the total period of elimination of about $1\frac{1}{2}$ to 2 hours was necessary for optimum accuracy of measurement of the air changes in the specified interval of from 0.5 to 1.5 timess per hour. The collected samples of air were analysed by means of a mass spectroscope.

Windows and doors were closed during the measurements. In a good $\frac{1}{3}$ of the rooms the occupants had removed the doors to the adjoining rooms so as to create a larger unit. These rooms are separately indicated in table I. Measurements of
** air temperature and humidity were made with a psychrometer and the outdoor wind speed was measured with a cup anemometer.

Results

The total number of flats investigated was ~~30~~ 31, but due to technical errors, measurements of the ventilation rate in four flats were omitted, so that data exists for a total of 35 flats. These results are given in table I arranged in accordance with the year in which the property was built. The ventilation rates measured ranged from 0.3 to 2.9 changes per hour, the average being ~~1.4~~ 1.3 changes per hour. By multiplying these values by the volume of the room, a replacement air volume of 19 to 175 m^3/hour was obtained in the living room with an average value of 80 m^3/hour. Windows and doors were always closed during the measurements, but in the cass of 15 of the total of 35 measurements, a door between the living room and the adjoining

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** Translator's note: Psychrometer is of course a wet and dry bulb thermometer.

room had been removed by the occupants in order to create an "open plan" flat and provide freer passage for the occupants. The average rate of ventilation in the open rooms was 0.7 changes per hour which was higher than in the closed rooms which had an average of 1.0 ± 0.4 changes per hour. The distribution of air changes and air volumes is illustrated in figures 1 and 2 respectively, and figure 4 shows the room volumes and air changes.

The average wind speeds were 3.5 m/s with a standard deviation of 1.9 m/s, while the average temperature difference between the inside and outside was 13° C with a standard deviation of 5° C. In order to make a mutual comparison of the measured ventilation rates, these were corrected for identical climatic conditions. The following expression was chosen for this correction calculation (7):

$$n_k = \frac{1 + 0.05 \times 17 + 0.3 \times 4.6}{1 + 0.05 \times \Delta t + 0.3 \times v} = \frac{3.23}{1 + 0.05\,\Delta t + 0.3v}$$

where the wind speed under normal conditions is taken to be 4.6 m/s corresponding to the average value (1) of the reference year reduced by 10 % corresponding to a wind speed reduction in the vicinity of the buildings, and a temperature difference of 17° corresponding to an outside temperature of +4° C (average outside temperature in the heating season) and an inside temperature of 21° C.

As can be seen from the penultimate column (a) of table I, this correction is tantamount to increasing the measured ventilation rate in 26 cases, i.e. the vast majority, while in five cases, the ventilation rate is reduced and in two cases it is not corrected. In two cases climatic data are missing. The average ventilation rate in these cases was increased from 1.3 to 1,7 changes per hour. For measurements in the closed rooms this means an increase of from 1.0 ± 0.4 to 1.3 ± 0.7, and for measurements in the open rooms, from 1.7 ± 0.7 to 2.1 ± 1.0 changes per hour. Variations in the natural ventilation rate due to different outdoor weather conditions are therefore very important. An investigation was therefore also made to find out by how much the natural ventilation rate will decrease under climatic conditions which bring about a minimum ventilation rate (table I, last column (b)). A low wind speed of 1 m/s and a low temperature difference of 10° C between outside and inside were chosen as basic conditions corresponding to an outside temperature normally requiring continuous heating of the buildings, open windows not being used for ventilati

It is evident from table I that the average values for the measured ventilation rates are in this way reduced from 1.3 ± 0.65 to 0.9 ± 0.5 for the 33 measurements where both climatic observations and ventilation rate measurements are available. In the closed room group, the average ventilation rate then becomes 0.75 ± 0.4 and in the open room group 1.2 ± 0.5.

DISCUSSION

The most striking result of the investigation is the very considerable scatter of the ventilation rates found in these flats which were all built to a high technical standard after 1960 and provided with heat insulation and double glazed windows in accordance with the first building regulations covering the whole country. All the buildings were designed and built before energy saving measures came to be discussed and for this reason no special action was taken to make them air-tight. There was no tendency for the ventilation rate to be lower in the newer buildings than in the older ones. For the building as a whole, i.e. when measurements were taken with open doors in all the rooms, such a trend is detectable (7).

The scatter of ventilation rates includes variation from flat to flat, variation of weather conditions and, finally, a variation in the construction and use of the flat. This means that it is virtually meaningless to state ventilation rates for a flat without at the same time giving full details of the conditions to which they apply.

The natural ventilation rate of a flat depends on the temperature difference between outside and inside air and on the wind speed. That part of the natural ventilation which is due to buoyancy in the buildings varies in proportion to the temperature difference between the warmer air inside and the cooler air outside. The transverse air stream in a building is impelled primarily by the action of the wind outside due to the pressure difference between the windward side and the lee side. In this way, the room air is continuously replaced by outside air. Figure 3 illustrates the variation in room ventilation rate (ordinates) as a function of wind speed (abscissae) and of the temperature difference between the inside and the outside (Δt). The curves are based on an average of the measurements in different types of flat (7). Starting from a ventilation rate measured when the wind speed is 4.6 m/s it will be seen that when it is calm and the temperature difference (Δt) is 17° C (i.e. outside temperature +4° C and room temperature 21° C), the ventilation rate falls to 60 % of the original value of the ventilation rate. If there is no difference between the outside and inside temperature, the ventilation rate falls further to 30 % of the original value. This last mentioned situation is of no great practical significance however, since a satisfactory ventilation rate can be achieved by opening one or more windows.

The investigation also shows how modifications in a flat can affect the natural ventilation rate. In the flats where the doors to the adjoining rooms were removed, the average ventilation rate was 1.7 changes per hour, while in the flats which had not been modified in this way, it was on average lower than 1.0 changes per hour. When the doors were removed, the resistance to air flow from one side to the other was reduced, partly due to wind pressure and partly because the additional number of doors and windows in the larger room relieves the air exchange with the surroundings. It can therefore be expected that measurements of the ventilation rate of the flat as a whole, i.e. under conditions where all doors are open, will produce values which are considerably higher than those applying to conditions of use where the doors to the various rooms are more often than not closed. From the hygienic point of view, it must be possible for every room to support human life even when doors and windows are closed, so that a more accurate measurement of ventilation rate will be achieved if each room is measured individually. It is therefore recommended that room ventilation rate is measured in preference to flat ventilation rate. A living room usually has doors to several rooms which causes it to have a higher ventilation rate than for instance a bedroom or a nursery which usually only has a single door. In nurseries in buildings of the same age as existing, ventilation rates of 0.8 changes per hour were measured (2) and in entirely new flats an average of 0.3 changes per hour (3).

Measurement of the ventilation rate of a flat is of great importance technically since it has a considerable bearing on the economics of energy saving and heating. Every increase of 0.1 air change per hour in the average flat means an additional 160 000 tons of oil per year over the whole country or about 3 % of the approximately 5 million tons oil equivalent of energy which is consumed annually to heat flats in Denmark (8). Improved insulation of flats will eventually result in the heat loss in the ventilation air being of relatively greater significance, but at present any appreciable heat savings from air tightness measures can only be achieved when they reach a maximum. Today this corresponds to a ventilation rate of from 0.05 to 0.2 per hour.

At a meeting held in 1977 concerning the establishment of joint Nordic Standards for air quality (6), it was agreed to aim at a limit for the ventilation rate in new flats of 0.5 changes per hour until more accurate information is available about the health hazards of a low degree of ventilation. The relationship of the measured air changes, room volumes and corresponding ventilation rates is shown in figure 4, while figure 5 shows the equivalent values after making a corrective calculation for the lower ventilation rate in calm conditions (wind speed 1 m/s) and limited temperature difference between the inside and outside air ($\Delta t = 10^{o}$ C). It is evident from the graphs that this low rate of ventilation lies outside any experience which can be derived from existing modern buildings both from the technical and health points of view. The effects of this technical proposal are therefore difficult to estimate. Instead, it is recommended that ventilation rate is related to the rate of emission of pollutants in the various rooms, i.e. background pollution and pollutants from the occupants and their activities.

This means that the ventilation rate may be low when a room is unoccupied. The ventilation rate must simply be capable of removing pollutants such as radon, formaldehyde and so on from the room, its furniture and other effects so as to prevent any health risks (or inconvenience) to the occupants coming into the room. By limiting the emission of pollutants from building materials and furniture, the ventilation rate under these conditions can be kept to very low values. As soon as a room is occupied, the air supply needs to be increased since body odours, water vapour, particles etc given off by the occupants must be removed.

In this respect, bedrooms and nurseries are particularly critical rooms due to their usually being of quite small cubic capacity. Odours from the occupants will usually be the decisive factor governing ventilation rate. The air supply necessary for this is not known since no effective dosage graphs have been drawn up on the subject. The knowledge in this field is essentially based on investigations since the middle of the 1930's into odours given off by people and which were carried out under uncontrolled conditions without using objective methods of measurement (14). It is clearly absurd to build a modern social energy policy on such a weak foundation.

Finally it must be mentioned that various activities such as cigarette smoking will increase the ventilation requirement. Large quantities of air - of the order of 50 m^3 of fresh air per cigarette (10) - are needed to remove the fumes and pollutants created by one cigarette.

To ensure that the quality of the air is satisfactory hygienically, the flats should therefore be arranged so that the ventilation rate can be adjusted to the degree of pollution of the inside air rather than simply fixing the ventilation rate. From the hygienic point of view it is unimportant whether the necessary volume of fresh air is provided by natural ventilation, by improved methods of ventilation, by mechanical ventilation or by a combination of all three. The choice between them has to be based on both technical and economic grounds. It must however ensure that the system chosen is reliable, flexible and does not cause inconvenience such as noise or draught and it must be made clear what risks and disadvantages the system may involve in emergencies, for instance with prolonged power failure.

Summary

Measurements of natural ventilation rates were carried out in the living rooms of 39 flats built during the last 20 years. The method used was to measure the elimination of the tracer gas freon 12. Windows and doors were closed during the measurements.

Ventilation rates were from 0,3 to 2.9 changes per hour, the average being 1.3 changes per hour. Correction for the average outdoor climate conditions in the heating season increases the average from 1.3 to 1.7 changes per hour, and correction for outdoor climate conditions resulting in a minimal ventilation decreases the average from 1.3 to 0.9 changes per hour. The natural ventilation rate depends on the wind velocity, the indoor/outdoor temperature difference and the construction and use of the flat. It is therefore meaningless to state the ventilation rate of a flat without at the same time defining the conditions which apply. A joint Nordic proposal for a ventilation rate of 0.5 changes per hour lies outside the experience gained both technically and from the health angle, from buildings erected during the last 20 years. In order to achieve satisfactory conditions for health, the ventilation rate of a flat should be adjusted to the rate of emission of pollutants from building materials, from furniture and from the occupants and their activities.

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** Translator's note: I am uncertain of the meaning of the abbreviation "VVS", but assume it has to do with ventilation

*** ASHVE = Ammerican Society of Heating and Ventilating Engineers.

Table I. Age of the flats, measured air changes per hour and corresponding air volumes, together with conditions having special significance for natural ventilation.

Flat No.	Year of building	Measured air changes h^{-1}	Cor. air vol. m^3/h	Condition closed/ open room	Wind speed m/s	Temp. diff. inside/ outside °C	Corrected air changes	
							a)	b)
01	1959-60	1,3	76	closed	2	12	1,9	1,1
02	61-65	1,1	51	open	2	1	2,1	1,2
03	—	1,7	99	closed	3	15	2,1	1,1
04	—	0,7	64	open	0	22	1,1	0,6
05	—	—	—	closed	5	16	—	—
06	—	0,9	45	open	4	7	1,1	0,6
07	—	0,7	36	closed	1	13	1,1	0,6
08	—	2,7	175	open	3	8	3,7	2,1
09	—	1,2	51	open	2	10	1,8	1,0
10	66-68	2,6	146	open	7	4	1,7	1,0
11	68-69	1,3	85	open	—	—	—	—
12	—	0,3	19	closed	2	12	0,4	0,3
13	—	1,2	71	closed	4	12	1,4	0,8
14	65-70	1,5	60	closed	6	18	1,3	0,7
15	—	—	—	closed	—	—	—	—
16	—	1,0	68	closed	2	16	1,3	0,7
17	—	0,55	36	closed	2	23	0,7	0,4
18	—	—	—	—	—	—	—	—
19	—	1,2	67	open	2	20	1,5	0,8
20	—	2,0	93	closed	1	13	3,2	1,8
21	—	1,5	88	open	7	15	1,3	0,7
22	—	0,6	39	closed	5	17	0,6	0,3
23	—	1,6	83	open	2	15	2,2	1,2
24	—	2,5	119	open	2	13	3,5	2,0
25	—	2,9	165	open	4	4	3,9	2,1
26	—	—	—	closed	—	—	—	—
27	—	1,1	61	closed	4	0	1,6	0,9
28	68-70	1,2	104	closed	2	22	1,4	0,8
29	—	2,3	163	open	1,5	23	2,8	1,6
30	—	0,8	66	closed	5	13	0,8	0,5
31	—	1,3	118	open	7	14	1,1	0,6
32	—	0,8	70	closed	4	17	0,9	0,5
33	—	0,9	60	closed	2	9	1,4	0,8
34	—	1,2	88	closed	0	12	2,4	1,3
35	71-72	1,3	80	open	8	18	1,0	0,6
36	72-74	0,7	47	closed	4	11	0,8	0,5
37	—	0,6	30	closed	—	—	—	—
38	73-75	1,5	88	closed	3	10	2,0	1,1
39	—	1,0	59	closed	0	9	2,2	1,2
Average number		1,3	80		3,5	13	1,7	0,9
Scatter		±0,65	±38		±1,9	±5	±0,9	±0,5

a) Correction for winter conditions (mean wind speed and mean outside temperature in the heating season).

b) Correction for possible low values (low wind speed and high outside temperature in the heating season)

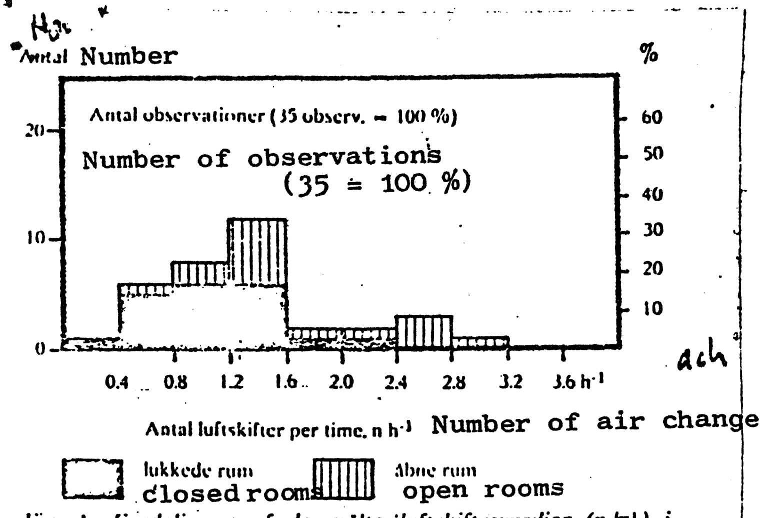

Fig. 1. *Fordelingen af de målte luftskifteværdier ($n\ h^{-1}$) i lukkede rum.*

Figure 1: Distribution of measured air changes ($n\ h^{-1}$) in closed rooms

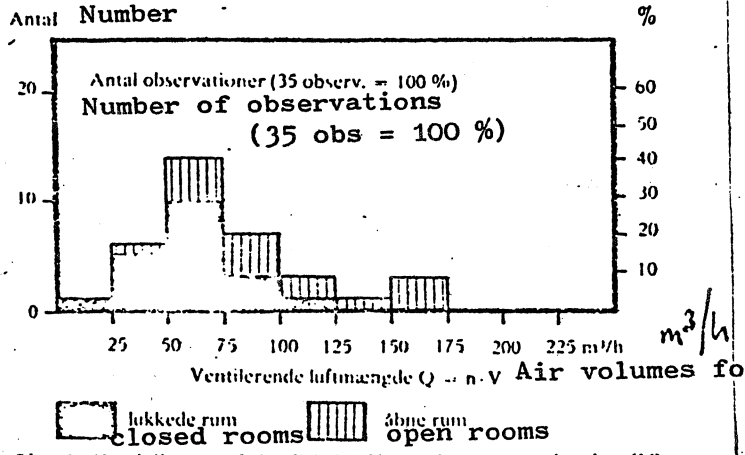

Fig. 2. *Fordelingen af de til luftskiftet (n) og rumvolumina (V) svarende ventilerende luftmængder (Q m³/h) i lukkede og åbne rum.*

Figure 2: Distribution of the air volume for ventilation (Q m^3/h) corresponding to the air change (n) and room volume (V).

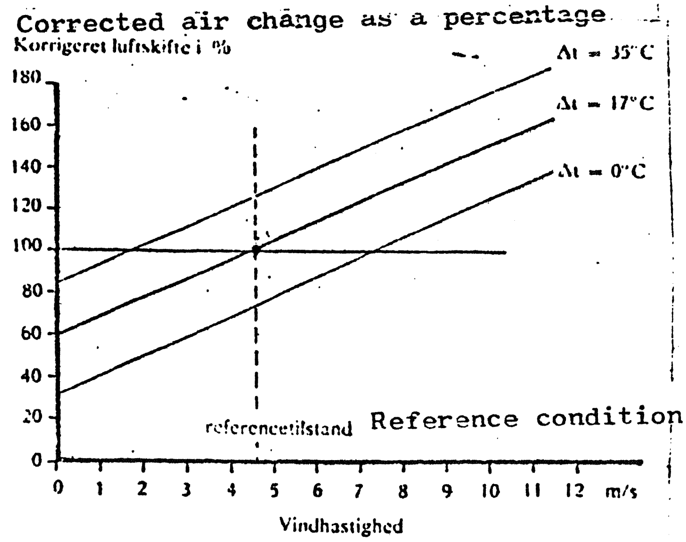

Fig. 3: *Et rums luftskifte ved forskellige omstændigheder af vindhastighed (m/s) og temperaturforskel (Δt) mellem inde- og udeluft på 0°C, 17°C og 35°C. Referencetilstanden svarer til en måling af luftskiftet ved 4.6 m/s og Δt = 17°C.*

Figure 3: Air change in a room under different conditions of wind speed (m/s) and temperature difference (Δt) between inside and outside air of 0° C, 17° C and 35° C. The reference condition corresponds to air change measurement at 4.6 m/s and t = Δ 17° C.

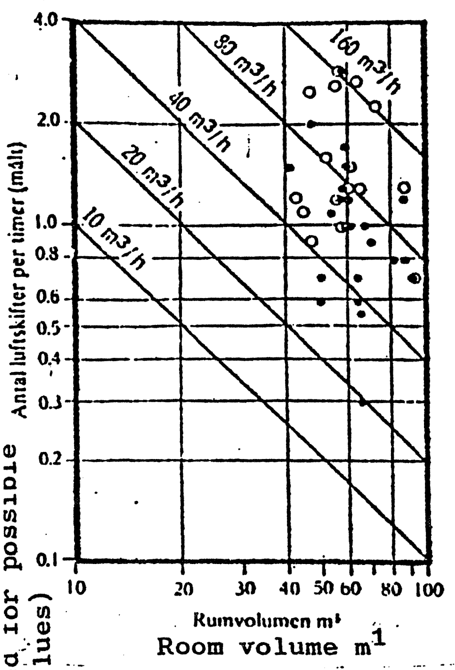

Fig. 4. *Målte værdier af rumvolumen og luftskifte i lukkede rum (●) og åbne rum (O). De skrå linjer afbilder den hertil svarende luftmængde i m³/h.*

Figure 4: Measured values of room volume and ventilation rates in closed rooms (●) and open rooms (O). The sloping lines represent the corresponding air volumes in m^3/h.

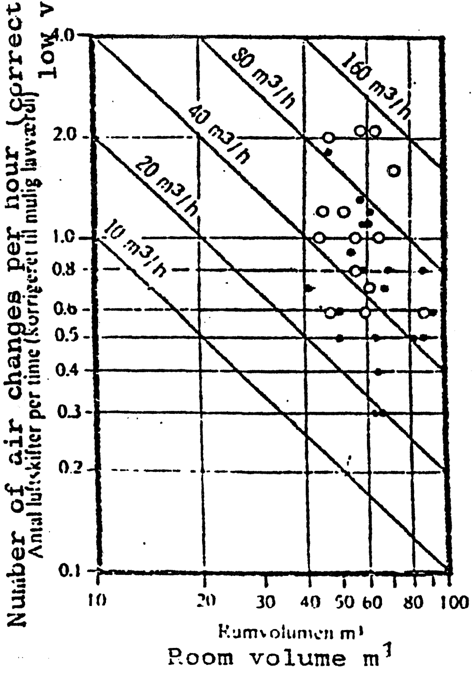

Fig. 5. *Beregningsmæssig korrektion af de på Fig. 4 afsatte værdier til mulig lavværdi ved lav vindhastighed (1 m/s) og temperaturforskel inde/ude = 10°C. Det fremgår, at de pågældende værdier for langt de flestes vedkommende stadig er beliggende over lavventilationskravene svarende til $n = 0.3\ h^{-1}$ eller $n = 0.5\ h^{-1}$.*

Figure 5: Values plotted in figure 4 are shown after correction calculation for possible low values when the wind speed is low (1 m/s) and the temperature difference between the inside and outside = 10° C. It is evident that in the majority of cases they lie above the requirements of low ventilation rate corresponding to

$n = 0.3\ h^{-1}$

or $n = 0.5\ h^{-1}$