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Investigation of Ventilation Conditions in Naturally Ventilated Single Family Houses

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Synopsis
The reason for the present project is the need for more reliable information about the actual ventilation conditions in naturally ventilated, detached houses. The aim has been to quantify the ventilation and humidity conditions and to establish a better basis for elaborating directions and guidelines on proper ventilation of detached houses.

A national questionnaire survey covering more than 2100 households has been carried out, together with detailed investigations in about 150 houses. The investigations comprised measurements of the average outdoor air supply and the average relative humidity. The main bedroom was investigated separately. The measurements were performed during the heating period. Passive measurement techniques were used.

Results show that the air change rate on average is about 0.35 h^{-1}. In more than 80 per cent of the houses the air change rate is lower than the recommended rate of 0.5 h^{-1}. The relative humidity is on average 0.45 in the living-room and 0.53 in the bedroom.

1. Introduction

In detached houses, the ventilation is often based on natural ventilation. The principle is that air is removed from the house through vertical air ducts in the kitchen and bathroom/toilet, while replacement air - outdoor air - is supplied to the other rooms in the house through open windows and/or outdoor air inlets and random leaks in the building envelope.

Natural ventilation systems are often evaluated on the basis of theoretical considerations. The function of the system is based primarily on the difference between the temperature of the room air and that of the outdoor air, but is also affected by wind. Consequently, the effectiveness of the system is more dependent than other ventilation systems on the outdoor climate. Also the behaviour of the occupants affects the performance of the system. Therefore, natural ventilation systems should be evaluated, instead, on practical experience and results obtained by measurements - preferably long-term measurements - in occupied houses.

Results of earlier field investigations [1] [2] have indicated that the air change rate is low in naturally ventilated, detached houses compared to traditional views on appropriate ventilation. However, the material was too limited to allow any reliable conclusions to be drawn on causal relationships. Aiming at procuring more reliable information about the actual ventilation conditions in naturally ventilated houses a national questionnaire survey covering more than 2100 households has been carried out and detailed measurements have been performed in about 150 houses. In connection with the measurements the occupants completed a supplementary interview form. This paper deals with the results of the measurements.

2. Procedures and measurement techniques

From the Ministry of Housing's Register of Buildings and Houses, BBR, about 2100 addresses of detached houses built since 1982 were selected. The addresses were selected at random, however, the geographical distribution of the houses was representative with respect to the total number of detached houses built in Denmark between 1982 and 1989. In addition to the addresses BBR reported various design data for the houses.

A questionnaire was sent to the householders. The questionnaire dealt primarily with questions concerning the household and its use of the house and questions concerning ventilation arrangements installed in the house. About 1400 householders, corresponding to 67 per cent, returned usable replies. Based on these replies 150 houses were selected for closer examination.

Ventilation and humidity measurements were carried out. The ventilation measurements were performed using a passive multiple tracer gas method, the PFT-method [3] [4], and the relative humidity was measured using moisture-calibrated beechwood blocks [5]. The measuring period in each house lasted about two weeks. In connection with the placing of the passive measuring equipment in the houses, the room air temperature was measured both in the living-room and in the main bedroom, and the occupants completed a supplement interview form.

3. Results

In about 150 naturally ventilated, detached houses measurements have been performed of the average total outdoor air supply and of the average outdoor air supply to the main bedroom. Also the average relative humidity in the living-room and in the bedroom have been measured together with the room air temperature in the rooms mentioned. Through simultaneous use of two different tracer gases, the air exchange between the bedroom and the rest of the house has been determined. The air change rate of the house has been calculated as the ratio between the average total outdoor air supply and the net volume of the house. Table 1 shows some characteristics of the houses investigated and table 2 shows the main results of the measurements.

Table 1. Some characteristics of the houses.

	Average
Net floor area of house	115.6 m^2
Area of main bedroom	15.1 m^2
Occupants per house	3.3 persons
Adults (≥ 16 yrs) per house	2.2 persons
Children (< 16 yrs) per house	1.1 persons
Living area per person	38.5 m^2/pers.

Table 2. Main results of the measurements.

	Average ± Standard Error	
Whole house		
Outdoor air supply	25.5 ± 0.9	l/s
Outdoor air supply per m^2	0.22 ± 0.01	l/s per m^2
Outdoor air supply per pers.	8.36 ± 0.30	l/s per pers
Air change rate	0.35 ± 0.01	h^{-1}
Living-room		
Relative humidity	0.45 ± 0.01	
Room air temperature	21.2 ± 0.1	°C
Main bedroom		
Outdoor air supply	4.5 ± 0.2	l/s
Outdoor air supply per m^2	0.31 ± 0.02	l/s per m^2
Relative humidity	0.53 ± 0.01	
Room air temperature	20.9 ± 0.2	°C

Figure 1 shows the results of the measurements of the total outdoor air supply, l/s, and the calculated air change rate, h^{-1}. The curves show the percentage of the houses in which the total air supply and the air change rate, respectively, is lower than the values shown on the abscissa.

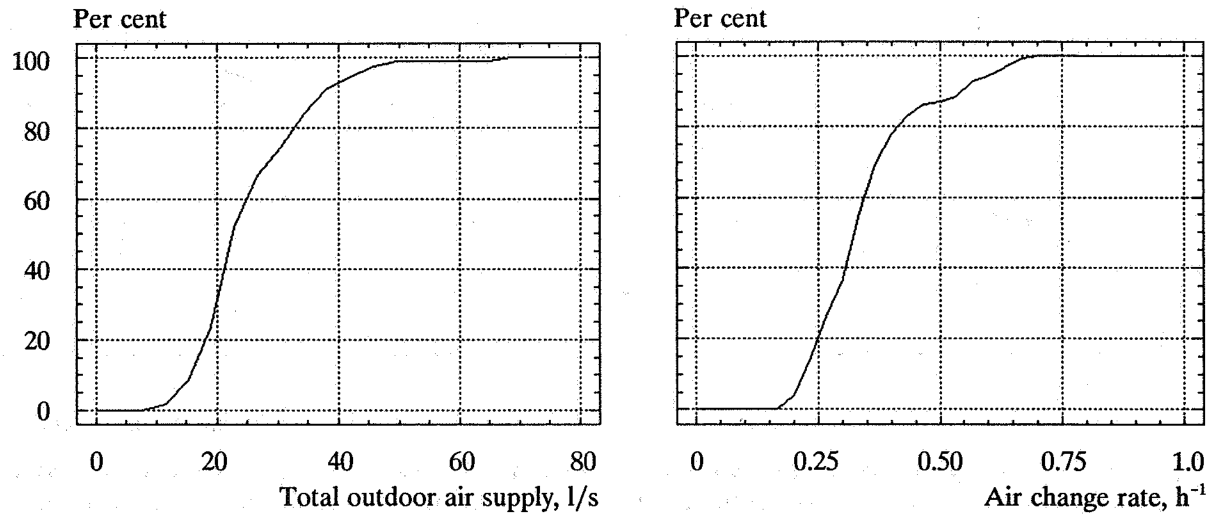

Figure 1. Cumulative, relative frequency of the total outdoor air supply, l/s and of the air change rate, h^{-1}.

Figure 2 shows the measured airflows *from* the bedroom *to* the rest of the house and *from* the rest of the house *to* the bedroom. The difference between the two airflows is denoted the net transference of air. Acceptable results exist from measurements in 102 houses. The measurement results have been numbered from number 1 to number 102, sorted according to increasing net transference of air and displayed on the abscissa on figure 2.

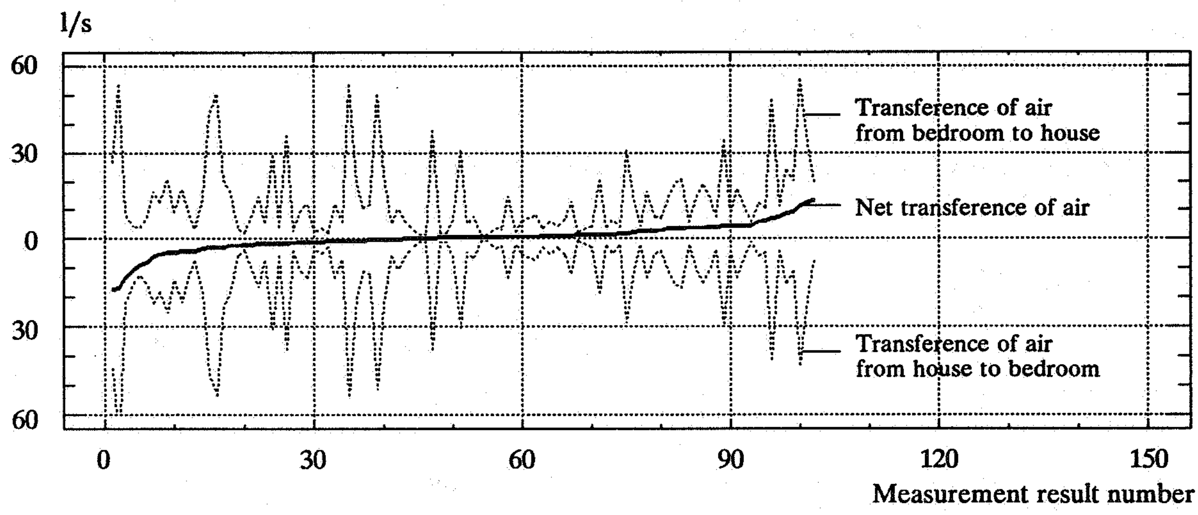

Figure 2. Internal air exchange between bedroom and the rest of the house. Airflow displayed above the horizontal 0-line indicates transference of air from bedroom to the rest of the house. Airflow displayed below the 0-line indicates transference of air in the opposite direction, i.e. from the house to the bedroom. The net transference of air is the difference between the two airflows. The abscissa is a numbering of 102 measurement results sorted according to increasing net transference of air.

Figure 3 shows the regression for the relation between the relative humidity of the room air and the outdoor temperature. Regressions for the living-room and the bedroom are shown.

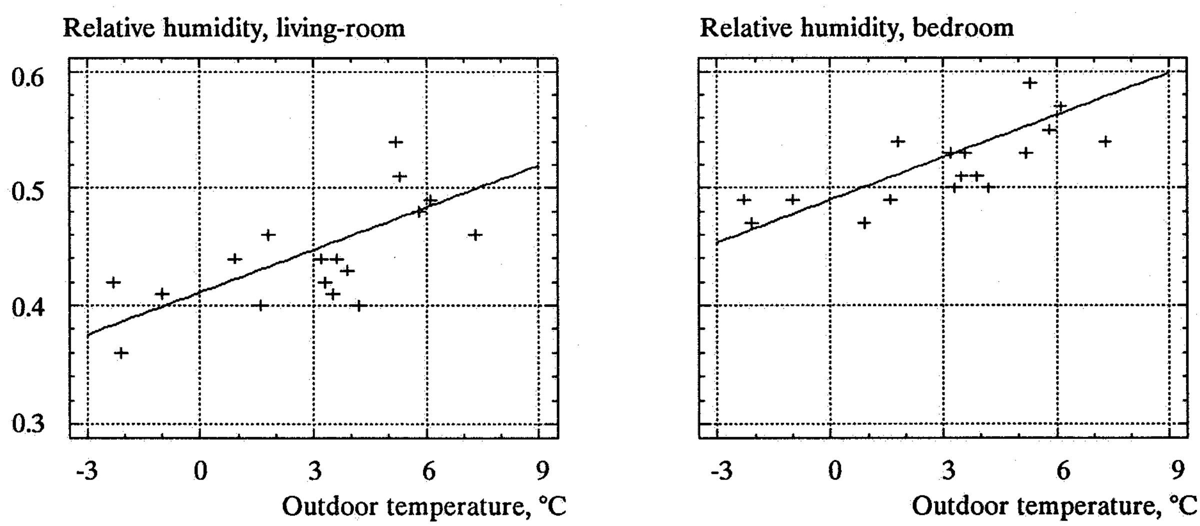

Figure 3. Regression of the measured relative humidity in the living-room and in the bedroom, respectively and the outdoor temperature. Each point represents the average of a number of measurement results measured simultaneously and at the outdoor temperature in question. The regressions have been calculated on the basis of the individual results, i.e. not only on the average values.

Figure 4 shows the cumulative, relative distributions of the measured relative humidity of the room air.

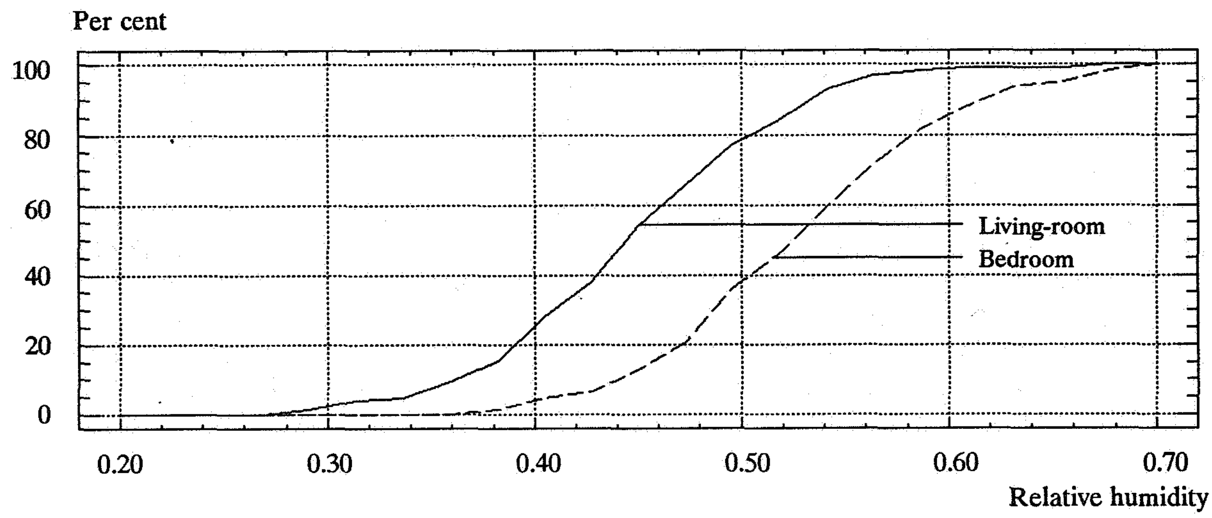

Figure 4. Cumulative, relative frequency of the relative humidity of the room air. The curves show the percentage of the houses in which the relative humidity is measured to be lower than the values shown on the abscissa.

On the basis of the measured room air temperatures and relative humidity the vapour pressure and the vapour content of the room air can be calculated. The vapour content of the room air is governed by the vapour content of the outdoor air supplied, together with the supply from moisture producing sources such as persons, cooking, washing and house cleaning. Providing stationary conditions the relative supply from moisture producing sources to the vapour content of the room air mainly depends on the ventilation. Table 3 shows the difference between the vapour content of the room air and that of the outdoor air, together with the calculated average moisture supply for the whole house as well as for the bedroom alone. The calculations for the whole house are based on the measurements of the relative humidity in the living-room and on the measurements of the total outdoor air supply to the house including the bedroom.

Table 3. Difference in vapour content indoor/outdoor, g H_2O/kg air, and the calculated average moisture supply, kg H_2O/day and kg H_2O/day per person.

	Average ± Standard Error
Difference in vapour content indoor/outdoor	
Living-room	3.2 ± 0.1 g H_2O/kg air
Bedroom	4.3 ± 0.1 g H_2O/kg air
Moisture supply	
Whole house	8.2 ± 0.3 kg H_2O/day
Whole house per person	2.7 ± 0.1 kg H_2O/day per person
Bedroom	2.0 ± 0.1 kg H_2O/day

4. Discussion

From table 2 it can be seen that the average air change rate is measured to be 0.35 h^{-1}, and figure 1 shows that the air change rate is 0.5 h^{-1} or lower in about 85 per cent of the houses investigated. The Danish Building Code states as a general rule concerning the basic ventilation of houses, that the ventilation of a house should enable an air change rate of at least 0.5 h^{-1}.

A frequently stated value for the necessary basic ventilation in houses is 0.35 l/s per m^2 net floor area. In houses with normal room height, that corresponds to an hourly supply of outdoor air equal to about half the net volume of the house, i.e. an air change rate of 0.5 h^{-1}. It will be seen from table 2 that the supply of outdoor air per m^2 net floor area in the houses investigated averaged 0.22 l/s per m^2.

The purpose of ventilating a dwelling is, in addition to satisfying people's needs for acceptable indoor air quality from the point of view of hygiene and comfort, to control the humidity conditions in the rooms. The direct moisture emission from one person is in the order of 50 g vapour per hour corresponding to about 1 kg per day. However, the total moisture supply from people and processes in a household is considerably larger. As a key figure it is often assumed that a family of four supply about 10 kg water per day to the room air. From table 3 it can be seen that in this study it has been found that the average moisture supply is 8.2 kg water per day. On average the size of a household in this study is 3.3 persons. Calculations of the average moisture supply per person show that one person supplies 2.7 kg water per day. The results of the measurements thus substantiate the key figure. Table 3 also shows that on average the bedrooms are supplied 2.0 kg water per day. It must be noted that normally the bedrooms are only used part of the day and the bedrooms are used by 1-2 persons.

Two different viewpoints can be put forth to form basis for recommendations to the maximum acceptable level of the humidity of the room air in residential buildings. One viewpoint is that the vapour content of the room air must be so low that the number of house dust mites are reduced to none or just a few per gramme house dust. Another viewpoint is that the humidity must be kept at a level where condensation on the windows will not occur.

Regarding the first viewpoint, the vapour content of the room air ought to be lower than 7 g water per kg air, corresponding to a relative humidity of about 0.45 at 20-22 °C, a couple of months in the winter period. From figure 4 it can be seen that at the time the measurements were performed the average relative humidity in the living-room was more than 0.45 in about half of the houses investigated. In the bedrooms the relative humidity was on average lower than 0.45 in about 10 per cent of the houses. In practice, the risk of an elevated humidity level leading to moisture problems can be most distinct in bedrooms, as the moisture production often will take place while the ventilation is low.

Regarding the second viewpoint, where condensation on the windows must be prevented, a difference in vapour content between indoor and outdoor air of 2.5-3.0 g water per kg air will usually not result in condensation problems. A difference of 4.0-5.0 g water per kg air may cause problems in connection with double glazing, when the temperature is lowered and curtains are drawn. Table 3 shows that the average difference in vapour content between indoor and outdoor is 3.2 g water per kg air in the living-room and 4.3 g water per kg air in the main bedroom.

Approximately two thirds of the measurements were performed in January and February and one third of the measurements were performed in October and November. Examination of the results of the measurements of the relative humidity with respect to the measurement period show that the relative humidity on average is significantly higher in the autumn/winter period than in the winter/spring period. The results reflect known variations in the humidity of the outdoor air. Variations in the humidity of the room air are to some extent subdued because of moisture accumulation in building materials and furniture. However, the results support the theory that the moisture accumulated will be released when the temperature falls, i.e. at the beginning of the heating season.

The average outdoor air supply to the bedrooms have been measured to be 4.5 l/s, cf table 2. The generally accepted minimum outdoor air supply to a bedroom from the point of view of hygiene and comfort is 4 l/s per person. If the bedrooms on average are used by 1.5-2 persons, the ventilation in the bedrooms thus appears to be lower than desirable. However, the results of the measurements of internal air movements show that there is an air transfer of at least 5-10 l/s from the rest of the house to the bedroom. Assuming that this air transfer acts to some extent as a supplement to the ventilation, it can be concluded that the bedrooms are satisfactory ventilated.

Natural ventilation systems are based on thermal buoyancy in the ducts. The driving forces originate in the temperature difference between indoor and outdoor, and the effect is therefore dependent on the outdoor climate. In addition, the efficiency of the system is dependent on the vertical height of the duct. In low houses the conditions for obtaining sufficient height and with that reliable performance are unfavourable, especially if the inclination of the roof is small. In this study about 90 per cent of the houses were one-storeyed. Furthermore, the system is susceptible to influence from wind just as the internal distribution of the outdoor air supplied is exposed to the action of the wind. The performance of the natural ventilation system is also influenced by the tightness of the building envelope. Theoretically, the performance will be reduced concurrently with increasing tightness. However, a tight building envelope will, together with correct placing and proper construction and use of outdoor air inlets, be able to improve the possibilities for providing appropriate internal air distribution in the house.

5. Conclusion

In defiance of the fact that natural ventilation systems now and then are considered obsolete there is no proof that the system is so unsuitable that the use should be dissuaded. The ventilation installations can only provide the possibility for the users to ventilate properly. The attitude and the behaviour of the occupants are determining for the actual ventilation conditions in dwellings is. From the national questionnaire survey it was found that in spite of the low ventilation rates about 97 per cent of the households judged the air quality in their house as "fresh" or "ordinary" and only a few per cent judged the air quality as "poor".

It has not been possible in this study to identify structural or design factors with such a crucial effect on the ventilation and humidity conditions that changes would definitely be regarded as likely to improve matters. The ventilation problems encountered in lowering room temperatures and tightening buildings in order to reduce energy consumption are presumably not only technical but also a question of proper information.

6. References

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