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INDOOR AIR QUALITY AND AIR EXCHANGE IN BEDROOMS

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SYNOPSIS

Measurements of natural ventilation rates in bedrooms during nighttime has been carried out in retrofitted apartments as part of a study investigating environmental data in relation to the results of preceeding epidemiological studies.

The meaurements indicate clearly that indoor air quality in bedrooms may be unacceptable in dwellings with a energy-efficient minimal ventilation rate. The air supply rates may be as low as 1 l/s/person in the median case of bedroom size, ventilation rate and two occupants. The carbon dioxide concentration will reach a level of 4000-4500 ppm in the morning depending on the length of the sleeping time in a closed room. The air humidity will be increased too, but depending on the accumulation and condensation of moisture in the room. However, users habits of living and housekeeping can increase ventilation rates in practice. The need of public information about indoor air quality and ventilation practice is therefore underlined.

INTRODUCTION

Regulatory requirements to thermal insulation in new buildings has been in force in Denmark since 1960, when specifications on maximal allowable k-values were given. These values have later on been upgraded, and the current demand is a k-value between 0.2 - 0.4 W/m^2 $^\circ$C for various components of the building envelope.Windows have to be thermal windows and the total area of glass may not exceed 15 percent of the gross area of the building[1]. Airtightness standards similar to those in other IEA/AIC affiliated countries as reviewed by Jackman[2], have not yet been introduced in Denmark.

However new airtight window types, caulking and other measures designed to reduce heat loss by natural infiltration have besides been introduced in both existing and the new buildings, but normally without attention to ensure any lower health ventilation safe limit to be maintained. A safe limit is not only a minimal supply of oxygen for breathing, but a sufficient ventilation rate for dilution of airborne contaminants of any short-term or long-term significance to health and well-being.

A decription of the adverse health effects which can be associated with indoor non-occupational exposure are recently listed with reference to combustion sources and indoor air quality by the U.S. Department of Energy[3]. The knowledge available is based on clinical as well as epidemiological research.

The aim of the present study has been to investigate if such lower limits are violated in bedrooms in dwellings after change to tight thermal windows and retrofitting was carried out. The bedroom in the dwellings was chosen for field measurements and parametric calculations because this room is considered to be the most loaded indoor space with regard to continuous occupancy time and minimal volume ratio per person compared to the living rooms. Railio[4] has described this in particular as "the bedroom problem".

The exhalation of carbon dioxide and water vapour has been used as an indicator of human load of the indoor environment. This means that ventilation requirements to airborne contaminants from materials, household products, tobacco smoking, gas burning devices, cooking and unvented space heaters was not considered primarily.

MATERIAL AND METHODS

The measurements took place in the winter 1984-1985 in apartments which previously had been included in the study group of a prospective epidemiological study of the health and comfort changes among tenants after change to new airtight thermal windows and retrofitting of their apartments[5]. The changes to the new windows of PVC-frames had been executed in the fall of 1981. The ventilation rate in the dwellings before that time is not known, as environmental measurements were not performed in the buildings before the energy conservation measures took place.

The building types were medium rise brick buildings 3-4 storeys high built about 1950. All apartments were central heated and had a good maintenance standard. The kitchens had electric cooking, and laundry was supposed to take place in a separate common facility. Kitchens and bathrooms had openings to a passive exhaust ventilation stack to the roof. No homes had air conditioning units installed, as such units do not exist in private homes in Denmark. Living rooms and bedrooms were supplied with windows which could be opened for escape in case of fire and for airing. All measurements were performed with closed windows and doors in order to have the most reproducable condition and the worst condition in a contaminant build-up situation.

Outdoor weather conditions in terms of air temperature, humidity, wind velocity and wind direction were recorded from the meteorological station of Aalborg airport, located in a about 10 km distance from the housing areas.

The 29 investigated dwellings were of medium size, having separate kitchen and wc, one larger living room and one or two smaller bedrooms. The bedrooms were mostly used by 1 or 2 persons, but by three persons in a few cases. The size of the bedrooms was between 18-43 m^3 with a median value of 32 m^3 (IQR 28-34).

Ventilation rates were determined with carbon dioxide as a tracer gas, and the decay from a initial level of 6-8000 ppm was measured continuously with a Leybold Heraeus/Binos 1 infrared gas analyzer. Uniform mixing was obtained by a table ventilator.

The room was unoccupied under the measurement, and the carbon dioxide concentrations in adjacent rooms were measured as well. The decreasing tracer concentration was measured within a 90 minutes period in order to obtain a 95% confidence level in the slope determination of the ventilation rate as stated by Kronvall[6].

The total ventilation rate of the dwelling as well as the room-to-room air transfer within the dwelling was measured in some cases.

Build-up of carbon dioxide and water vapour per kg dry air in the bedrooms during the nighttime has been calculated based on the values of air change rates and corresponding volume flow of outdoor air determined. The findings in field measurements will be described later on.

RESULTS

The ventilation rates in the 29 bedrooms were found to vary between 0.1-0.5 ach having a distribution with a a median value of 0.23 (IQR 0.17-0.31) and an arithmetic mean value of 0.25 ach (SD= 0.1). The related air volumes supplied from the outside depended on the room volume in each case and were found to vary between 1,0-3,7 liters/second, with a median value of 2.0 (IQR 1.5-2.8) l/s.

The distribution of air change rates and air supply rates is shown in table 1.

Outdoor temperatures were between 1.5 to 9.8 C with a median value of 5.0 C (IQR 3.4-7.6) and the wind velocities between 1.6-7.8 m/s with a median value of 6.2 m/s (IQR 2.6-8.2) on the days when measurements took place. Indoor temperatures varied between 16-22 C. Multiple linear regression analysis did not show any significant correlation between air change rates, wind velocity and temperature, certainly because air infiltration through the new window constructions are not that much influenced by outdoor weather conditions (Harrje and Mills[7]).

Analysis of means and moments of air change rate and air volume flows shows a tendency to a positively skewed distribution with respective skewness coefficients of 1.05 and 0.57. The difference between the two ventilation parameters is because of the tendency to a lower air change rate in the larger bedrooms and a relatively higher air change rate in the smaller bedrooms.

Assuming an 8 hour continuous occupation of the bedroom of two resting persons exhaling 30 liters of carbon dioxide per hour, carbon dioxide concentrations in the morning are calculated in table 2 for the lowest, the mean and the highest air supply rates measured. The steady state concentrations of which 95% is reached within 6-30 hours at ventilation rates between 0.1-0.5 ach are shown as well.

These concentrations will exceed the recommended values of limits for carbon dioxide exposure in non-occupational environments which vary between 1000-2500 ppm (WHO Meeting Report[8]). The Threshold Limit Value of 5000 ppm for occupational exposure may even be exceeded in the worst cases.

The corresponding increase in indoor air humidity will depend on the adsorption of water vapour in the bedroom interior materials. The required volume of ventilating air to keep the air humidity below a certain level will, moreover, vary according to the humidity in the outdoor air, and therefore depend on the climatic conditions of the year round.

DISCUSSION

Apartment residents' evaluation of their health status and indoor climate perception related to the implementation of energy conservation measures in Danish housing has previously been described[5].

This showed the benefits of better insulation and a less draughty dwelling especially to the elderly, spending most of their time at home. Any immediate disadvantages of reduced natural ventilation on indoor air quality could not be demonstrated. This might be because it is less pronounced in 30-40 year old buildings where off-gassing from materials is neglible. In addition the households were usually small and did not include overpopulated dwellings, which in Denmark is stipulated to be more than two individuals older than two years per room.

The size of the population in the study was in addition not large enough to at random include a sufficient number of subjects suffering from allergic diseases. Those individuals should be first to respond on changes in indoor allergens caused by house dust mites, favoured by increased air humidity after sealing of the houses (Korsgaard[9,10]).

Therefore requirements for ventilation rates after retrofitting of the dwellings should still be considered from a health point of view. It is most obvious to propose that the ventilation rates should fulfil the existing building code for new houses. This specifies an air change rate of 0.5 per hour to be obtained by the presence of a user-operable fresh air valve in each room with a 30 cm^2 free square [1]. Even better would be to agree with The Guidelines for Nordic building regulations regarding indoor air which has specified a fresh air supply of 4 l/s per person in bedrooms[11]. This equals a 0.9 ach in a average bedroom of 30-35 m^3 occupied by two persons, which is almost twice the prescribed value of 0.5 ach.

The present study has shown, that the air supply rates may be as low as 1 l/s/person in the median case of bedroom size, ventilation rate and two occupants. The carbon dioxide concentration will reach a level of 4000-4500 ppm in the morning depending on the length of the sleeping time. The air humidity will be increased too, but depend on the accumulation and condensation of moisture in the room. Becker[12] has described the problem of invisible condensation and mould growth in particular for housing in areas with high temperature differences between minimum night temperature and maximum day temperature with related variations in air humidity.

It is obvious that the user-operated ventilation is a most important parameter in practice. It has recently been shown by continuous measurement of ventilation rates in occupied homes, that the basic ventilation rate may be increased with a factor of 3-4 at the average (Kvisgaard, Collet and Kure[13]). The need for user active ventilation precautions has to be underlined in the case of bedrooms in energy efficient tightened building envelopes without controlled mechanical ventilation systems by public information. Field measurements in continuation including epidemiological studies can emphasize this need in further detail.

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REFERENCES

1. BYGNINGSREGLEMENT BR 82
   The Danish Building Regulations BR 82. Ministry of Housing, Copenhagen, 1982.

2. JACKMAN, P.J.
   Review of building airtightness and ventilation standards.
   Proc.5th AIC Conference, Reno, U.S.A.,1-4 October 1984.

3. INDOOR AIR QUALITY.
   Environmental Information Handbook: Combustion Sources.
   U.S. Department of Energy. Washington 1985.

4. RAILIO, J.
   Better airtightness: Better or worse ventilation
   Proc.5th AIC Conference, Reno, U.S.A.,1-4 October 1984.

5. IVERSEN M., BACH,E. and LUNDQVIST,G.R.
   First-phase Occupant Reaction to well-sealed Indoor Environments.
   Proc.5th AIC Conference, Reno, U.S.A.,1-4 October 1984.

6. KRONVALL, JOHNNY
   Airtightness-measurements and measurement methods.
   Swedish Conuncil for Building Research. Stockholm 1980.

7. HARRJE,D.T. and MILLS,T.A.
   Air Infiltration Reduction Through Retrofitting.In:Building Air Change Rate and Infiltration Measurements.
   ASTM STP 719 C.M.Hunt, King,J.C. and Trechsel,H.(Eds.) 1980 pp.89-104.

8. INDOOR AIR POLLUTANTS: EXPOSURE AND HEALTH EFFECTS
   Report on a WHO meeting. EURO Reports and Studies 78.1983.

9. KORSGAARD,J.
   Changes in indoor climate after tightening of apartments.
   Environment International, 1983, 3:195-200.

10. KORSGAARD,J.
    Mite-asthma and residency - a case-control study on the impact of exposure to house-dust mites in dwellings.
    Am.Rev.Resp.Dis. 1983,128:231-235.

11. SUNDELL,J.
    Guidelines for Nordic building regulations regarding indoor air quality.
    Environment International;1982,8:17-20.

12. BECKER, R.
    Condensation and Mould Growth in Dwellings- Parametric and

Field Study.
Bldg.Envir.19,1984,pp. 243-250.

13. KVISGAARD,B. COLLET, P.F. and KURE, J.
Research report on fresh air change rate:1.
Teknologisk institut, Taastrup,(Denmark), 1985.

TABLES

Table 1. Air change rates (h^{-1}) in bedrooms and corresponding air supply rates (l/s) according to room volume (m^3).

air change rate	number of dwellings	(%)	range of room Volumes	range of air supply rates
0 - 0,1	0	0%	-	-
0,1- 0,2	8	28%	33-37	1,0-1,7
0,2- 0,3	15	52%	21-43	1,3-2,7
0,3- 0,4	4	14%	18-33	1,8-3,1
0,4- 0,5	2	6%	27-28	3,1-3,7
0,5	0	0%	-	-

Table 2. Carbon dioxide concentration levels in bedrooms at air supply rates as measured. Background 350 ppm.

air supply l/s & p interval	number of cases	carbondioxide concentration levels ppm after 8 hours occupation	steady-state
0,5-1,0	15	5500-4300	8700-4500
1,0-1,5	10	4300-2900	4500-3100
1,5-2,0	4	2900-2400	3100-2400