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CHANGES IN INDOOR CLIMATE AFTER TIGHTENING OF APARTMENTS

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The effect of reduced air infiltration rate caused by energy-saving measures has been studied by comparing the indoor climate in 25 sealed apartments with the conditions in 25 unsealed apartments in four seasonal periods. The indoor temperature in bedrooms during February and March was 19.3 °C in sealed apartments and 17.8 °C in unsealed apartments, and the occupants in the sealed apartments correspondingly complained less frequently of draught problems during the winter. When the frequency of window opening was at its minimum (February–March), there was a higher indoor humidity in sealed compared with unsealed apartments, and this probably accounts for an increased occurrence of house-dust mites in dust from the sealed apartments during the winter. Also in February–March there was a slight increase in the concentration of suspended particulate matter in sealed apartments. Considering health effects of a reduced air infiltration rate, it can be predicted that the increased indoor air humidity will indirectly increase the frequency and severity of house-dust mite allergy in the population.

Introduction

To improve heat economy, leaky single-glass windows are being widely replaced with new, double-glass windows in tight frames. Such measures will reduce energy consumption for heating through a lowering of the air infiltration rate, and through an increase in insulation. The present results describe changes in the indoor climate which follow from such draughtproofing of dwellings. Korsgaard (1981) gives a full account of all results obtained in the investigation.

Material and Methods

The present report studied two groups of 25 homes, one group with and one without sealing measures during four seasonal periods: November–December 1979, and February–March, June–July, and September–October 1980. Each of the four sampling periods lasted 5 weeks. The windows in the sealed apartments were double-glass windows in tight plastic frames, and they were installed during the winter of 1978/1979. The windows in the unsealed apartments were single-glass in old and leaky wooden frames. The two groups were in similar locations in the town of Aarhus, and followed identical construction principles and materials. The size of individual apartments was the same, and type of heating system was identical. Both groups were three-story brick buildings built between 1945 and 1950, that is, before the first Danish building code in 1961; therefore, they were built virtually without any of the present energy-saving measures.

The apartments were selected so that the age of the oldest resident, the family size, and the number of persons per room were similar for the two groups. The mean family size was 1.8 persons (sealed) and 2.0 persons (unsealed), and the number of persons per m^2 apartment area ($\times 10^{-2}$) was 2.9 (sealed) and 2.6 (unsealed).

At each visit to the apartments, members of the family were interviewed about their experience of the indoor climate: they were asked about their living habits in the apartment with respect to frequency of window opening, smoking, and cleaning frequency. Information on the energy consumption for heating for each individual apartment was obtained from the cooperative housing society.

Temperature and humidity were measured by placing a thermometer (accuracy at 20 °C = ±0.1 °C) and a hygrometer (accuracy = ±3%) in each bedroom to be read by the residents themselves in the morning and evening for the 7 days following each visit.

To establish the occurrence of house-dust mites (*Dermatophagoides* spp.), dust samples were collected with a vacuum cleaner from mattress surfaces and floor carpets of the sleeping and living rooms. Within 5 h the samples were processed in the laboratory: A subsample (0.1 g) of dust was mixed with 10 ml 90% lactic acid in a 10-cm Petri dish, and a few crystals of the dye Lignin Pink were added; after stirring, the suspension was incubated for 2 days at 55 °C. House-dust mites were found in a stereomicroscope at ×25 (Korsgaard, 1979).

The concentrations of suspended particulate matter (s.p.m.) in the indoor air of bedrooms was measured with a Sartorius Gravikon (High Volume Sampling) using Sartorius fiberglass filters (SM 134 00). The sampling time was 45–60 min. The sampling conditions were standardized by closing all windows and doors in the bedrooms during sampling, and no activity took place in the bedrooms during sampling.

Results

Experience of the indoor climate

No difference was found between the two groups concerning their experience of the indoor temperature, indoor air humidity, frequency of eye and throat irritations, and complaints of static electricity. When asked about draught problems during the winter, members of 19 families in the unsealed apartments said they had problems, while no members of the 25 families in the sealed apartments experienced draught problems. When assigned to a nine-step ordinal scale, on which only the extremes were given, less draught was experienced in sealed than in unsealed apartments during the winter and spring, while no difference was found in the summer period (Fig. 1).

Extent of window opening

The residents were asked how long they had the kitchen, living room, and bedroom windows open on the average during the 3 months preceding each visit. As could be expected, great seasonal variation was found (Fig. 2). In winter the living room window was open for 0.3 h (median) every day in both groups, while in summer it was open for 4 (sealed) and 10 (unsealed) h every day, respectively. During the winter the living room window was never opened in 8 apartments (5 sealed and 3 unsealed), and the bedroom window was never opened in 6 apartments (2 sealed and 4 unsealed).

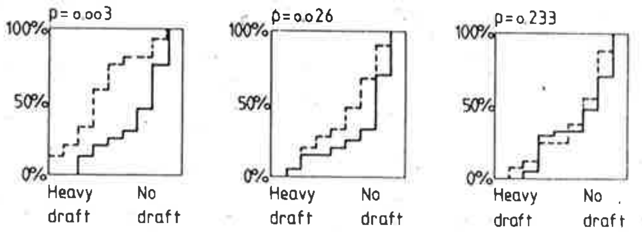

Fig. 1. Family members' experiences of draft in unsealed (broken line) and sealed apartments voted on a nine-step ordinal scale in three seasonal periods.

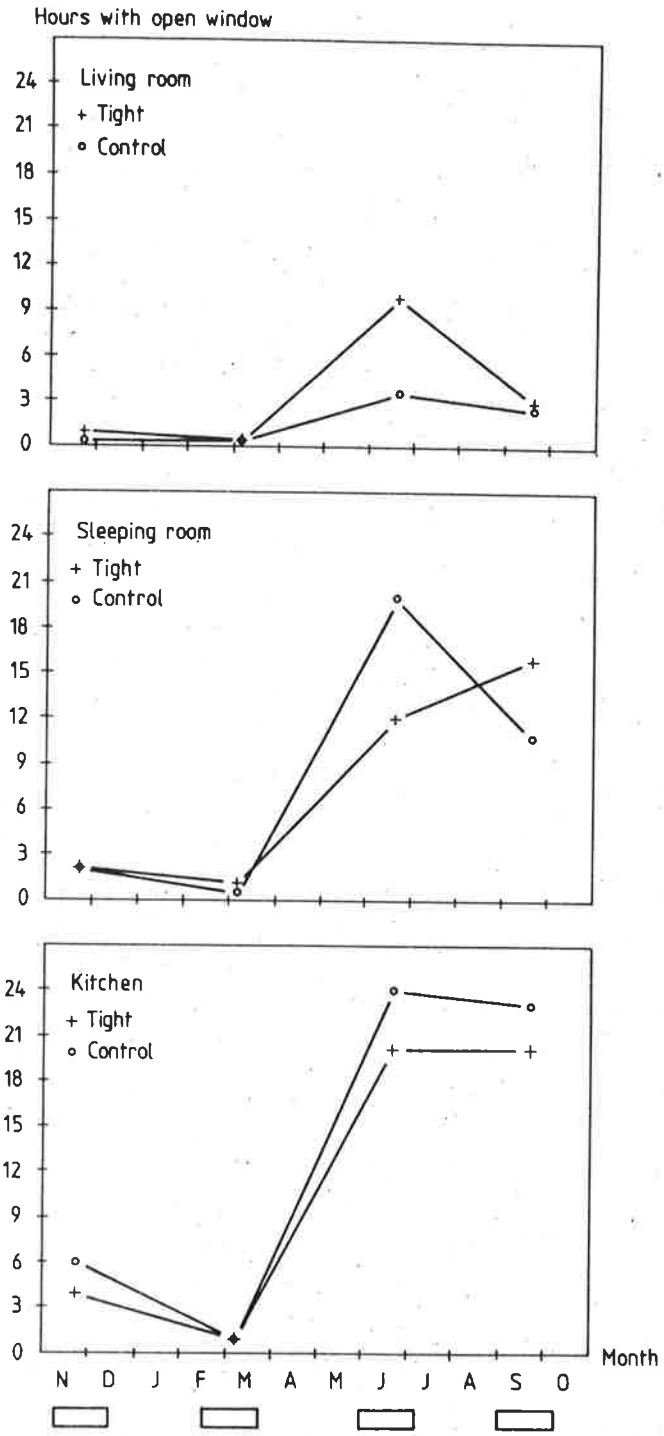

Fig. 2. Number of hours (median) with open window in living room, sleeping room, and kitchen in tight (sealed) and control apartments through four seasonal periods.

Heat consumption

When comparing the heat consumption for the winter of 1977/1978 and the winter of 1979/1980, a

Table 1. Indoor air temperature (°C) in sealed and unsealed apartments during four seasonal periods. The measurements were made by the family members in the bedrooms (morning readings).

	November–December 1979 median (n)	February–March 1980 median (n)	June–July 1980 median (n)	September–October 1980 median (n)
Sealed	19.5 (25)	19.3 (24)	21.9 (21)	20.9 (21)
Unsealed	17.7 (25)	17.8 (24)	22.1 (19)	20.9 (24)
p^a	0.0014	0.014	n.s.	n.s.

[a]Mann–Whitney *U* test.

14% decrease (95% limits = 6%–18%) was found in the sealed apartments, while no significant difference was found for the unsealed apartments. The number of degree days was higher in 1979/1980 than in 1977/1978. There was no significant difference in the hot water consumption between 1977/1978 and 1979/1980 in either of the two groups.

Temperature and humidity

As appears from Table 1, the indoor air temperatures was 1.5–2 °C higher in sealed than in unsealed apartments in winter. In the June–July and September–October periods, the indoor temperature was 21–22 °C with no difference between sealed and unsealed apartments.

In the February–March period the absolute humidity was 0.9 g/kg higher in the sealed apartments (Table 2 and Fig. 3). This means that the contribution of water vapor to the indoor air from internal processes in the apartments (indoor minus outdoor) increased by 30%, when sealed and unsealed apartments are compared. No difference was found in the absolute humidity between the two groups by the measurements in the summer period (Fig. 3). When the outdoor temperature was below 15 °C, the indoor absolute humidity increased above the outdoor level (Fig. 3), an indication of the increased contribution of indoor water vapor sources to the resultant indoor level of humidity.

House-dust mites

Products from house-dust mites are a major cause of the human allergic diseases asthma and allergic rhinitis. Several investigations (Spieksma, 1967; Portus and Blasco, 1977; Korsgaard, 1979) have shown that a relatively high absolute humidity in the indoor air causes relatively high concentrations of mites in house dust. As mentioned above, the indoor air humidity was higher in the sealed apartments, and, as a consequence, concentrations of house-dust mites were higher (p = 0.012, Mann-Whitney U test) in dust from bedroom floors (February–March) in sealed apartments (median = 1.5 mites/0.10 g dust); in unsealed apartments, the median was 0 mites/0.10 g dust. In the June–July period, dust from mattresses showed a similar tendency.

Suspended particulate matter

In the February–March period, higher (p = 0.057, Mann-Whitney U test) concentrations of s.p.m. were found in the sealed apartments (median = 48.5 $\mu g/m^3$) than in the unsealed apartments (median = 42 $\mu g/m^3$). There was no difference in smoking habits between the two groups of families. Not surprisingly, the amount of smoking in the apartments had a strong effect on the amount of s.p.m. in the indoor air. In apartments where more than 10 cigarettes were smoked daily, the concentration of s.p.m. was 63 $\mu g/m^3$ (median) compared with 38 $\mu g/m^3$ in apartments without regular smoking. This result confirms the conclusions of earlier investigations (Biersteker *et al.*, 1965; Lefcoe and Inculet, 1971; Binder *et al.*, 1976; Spengler *et al.*, 1981) on the relationship between smoking and the level of s.p.m. in indoor air.

Discussion

The results of the present investigation shows that an increase in airtightness and insulation properties of the building envelope has a significant influence on the indoor thermal and atmospheric conditions. A considerable reduction in the complaints of draft from the

Table 2. Indoor air humidity (g/kg) in sealed and unsealed apartments during four seasonal periods. The measurements were made by the family members in the bedrooms (morning readings).

	November–December 1979 median (n)	February–March 1980 median (n)	June–July 1980 median (n)	September–October 1980 median (n)
Sealed	7.6 (25)	7.4 (24)	9.8 (21)	9.3 (21)
Unsealed	7.1 (25)	6.5 (24)	9.4 (19)	9.4 (24)
p^a	0.052	0.026	n.s.	n.s.

[a]Mann–Whitney *U* test.

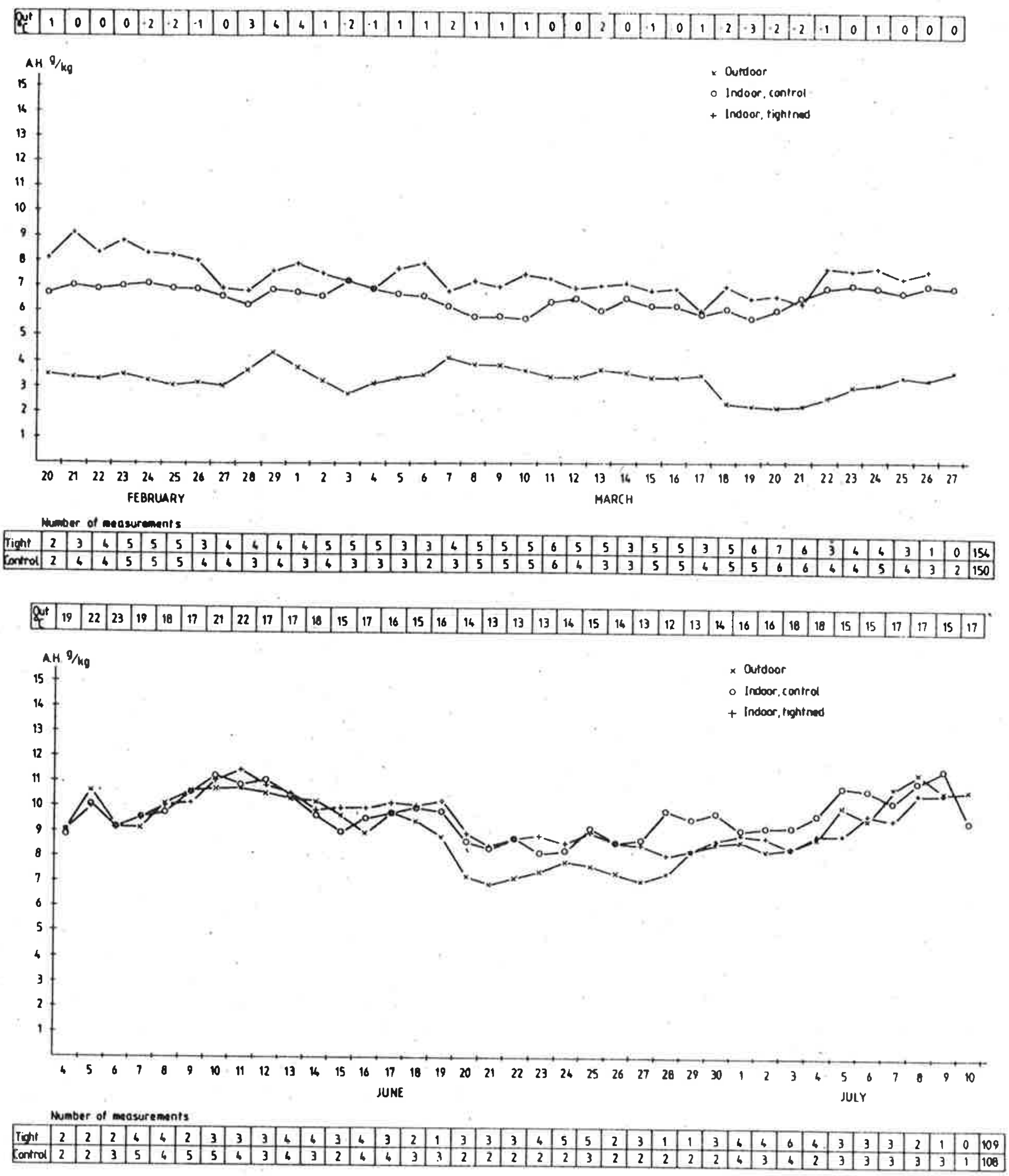

Fig. 3. The absolute humidity of the indoor air as the mean humidity in different sealed and unsealed apartments every day, winter and summer. In each apartment the measurements were made by the family members themselves in the bedroom for 7 days or less.

occupants in the winter period in the sealed apartments indicates that a higher thermal comfort has been obtained through energy-saving measures.

The measured indoor winter temperature in sealed apartments (1.5–2.0 °C higher than unsealed apartments) confirms the experience of a higher thermal comfort in the sealed apartments, since the indoor temperature in the unsealed apartments was as low as 18 °C in winter. In spite of this increase in indoor temperature, which in itself implicates an increase in energy consumption of about 10%, there was an actual decrease in the energy consumption of 14%, when comparing the heating seasons immediately before and immediately after the change of windows in the sealed apartments.

Previous works (Korsgaard, 1977; Budnitz *et al.*, 1979; Lippmann, 1979; Korsgaard, 1982a) on the indoor climate have emphasized that the reduction in the air infiltration rate brought about by energy-saving measures might have a negative health effect on the occupants. The present results show that a decrease in the air infiltration rate will increase the absolute humidity and the concentration of s.p.m. in the indoor air in those seasons in which window opening is less frequent. House-dust mites are known to produce substances which cause chronic asthma and allergic rhinitis in sensitive persons. In Denmark it is estimated that at least 1% of the population suffers from house-dust mite allergy, since the 1-yr prevalence of asthma is 3.8% in Denmark (Weeke *et al.*, 1980) and one-third of all Danish patients with allergy and positive skin reactions have positive skin tests to house-dust mites (Østerballe *et al.*, 1981).

The occurrence of house-dust mites in the home environment has been mentioned in several systematic studies which have shown that bad housing conditions, i.e., high indoor humidity, is responsible for the development or aggravation of chronic human disease (Maunsell, 1952; Voorhorst *et al.*, 1969; Ishii *et al.*, 1979). In agreement with the higher indoor humidity in sealed apartments, more house-dust mites were found there than in the unsealed apartments. The population exposure to house-dust mites in the home environment will increase as a result of the decreased air infiltration rate, and this will again lead to an increase in the frequency of house-dust mite allergy; it is estimated that at least 15% of the population has an inherent ability to develop some kind of allergy (Arbeiter, 1967; Tennenbaum, 1970; Warwick, 1971).

Recent studies have shown that one characteristic of house-dust mite sensitive patients is that they more often live in new and presumably more airtight homes than the average Danish population (Korsgaard, 1982b), and that avoidance measures in case of house-dust mite allergy is probably more a question of changing construction principles (i.e., increasing the air infiltration rate) rather than changing the living habits of the family members (Korsgaard, 1983).

Thus, everything indicates that energy-saving measures stressing a reduced air infiltration rate must be seen as contributing to the development of allergy. With the information now available, this is a problem that by no means can be neglected.

Conclusions

1. Energy-saving measures consisting of replacing leaky single-glass windows with tight double-glass windows will reduce the energy consumption by 14%.

2. The frequency of complaints of draft is considerably reduced in sealed apartments compared with unsealed apartments.

3. Family members in the sealed apartments also benefitted from greater indoor thermal comfort as the indoor temperature was 1.5–2 °C higher in sealed than in unsealed apartments in winter.

4. There is reason to believe that the reduced air renewal rate in sealed apartments will raise the concentrations of all indoor air contaminants produced in the house. In case of increased indoor air humidity, this will indirectly increase the frequency and severity of house-dust mite allergy.

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