Environment International, Vol. 12, pp. 161–166, 1986

0160-4120/86 $3.00 + .00

HEALTH AND COMFORT CHANGES AMONG TENANTS AFTER RETROFITTING OF THEIR HOUSING

Martin Iversen, Elsa Bach, and Gunnar R. Lundqvist
Institute of Hygiene, University of Århus, and Danish Institute of Clinical Epidemiology, Hellerup, Denmark

(Received 1 June 1985; Accepted 3 October 1985)

The aim of this study has been to follow apartment residents' evaluation of their health status and indoor climate perception related to the implementation of energy conservation measures in Danish housing. The study was designed as a prospective study including a study group and a control group. In the study group an intervention took place, as windows were replaced in the follow-up period. The control group did not have any changes carried out in their homes. The study has demonstrated the benefits of a less drafty dwelling, especially for the elderly who spend most of their time at home. The disadvantages of reduced natural ventilation on indoor air quality could not be demonstrated, because it is less pronounced in old buildings where off-gassing from materials are neglible. In addition the households were usually small and did not include overpopulated dwellings. The size of the population in the study was not large enough to include at random a sufficient number of subjects suffering from allergic diseases. Those individuals should be first to respond on changes in indoor allergens favoured by increased air humidity after sealing of the houses. It is therefore concluded that requirements to the ventilation rates after retrofitting of the dwellings should still be considered from a health point of view.

Introduction

The aim of this study has been to follow apartment residents' evaluation of their health status and indoor climate perception related to the implementation of energy conservation measures in Danish housing, which are carried out in the nation's effort to save energy.

Denmark has about 2,000,000 habitat units with an estimated 200 million m^2 floor area and a corresponding 500 million m^3 space volume. The air change rate in multistory buildings with leaky window frames has been found to vary between 0.3–2.9 with an average of 1.3 air changes per hour (ach) under varying measuring conditions and 1.7 (ach) under standard reference conditions (Møller *et al.*, 1979). Modern window constructions has reduced air infiltration rates to less than 0.5 ach, and retrofitting has reduced the variation of infiltrating air caused by wind pressure and temperature differences (Harrje and Mills, 1980). The use of double glass instead of single glass improves the thermal insulation to a *k*-value better than 2.9 W/m^2 C.

For this reason, a Danish Governmental Notice has been supporting the replacement of windows in leaky frames with double glass windows in airtight frames. This study of the acute health consequences of the related indoor environmental changes has been undertaken while the process of building changes still has been in continuation nationwide (Iversen *et al.*, 1982).

Material and Methods

The habitat units included in the study were chosen among Danish building areas in the capital of Copenhagen, and in the major provincial cities of Aalborg, Esbjerg, Herning, and Vejle. The participants were invited to join the study on a nonindividual identification basis; the benefit offered was a free copy of the results.

The study was designed as a prospective study including a study group and a control group. The study was observational but had similarities to an experimental study. In the study group an intervention took place, as windows were replaced in the follow-up period. The control group did not have any changes done in their homes. The housing areas in which the study took place could all be classified as "good" areas.

The dwelling types were medium-rise flats; all were central heated. No homes had air treatment units installed, as such units do not exist in private homes in Denmark. The tenants were of medium social class and included pensioners.

Questionnaires were sent to residents in apartment buildings 2–5 stories high in August and December 1981, and January and February 1982. In the study group windows were replaced during the period between the first and the second questionnaire. The winter period was chosen because airing by opening of windows in Danish dwellings are minimal at this time of year (Korsgaard, 1983a).

In August, 3,309 residents over 18 yr of age received a questionnaire. The persons who answered the questionnaire, thereby indicating that they were willing to participate in the study, received new questionnaires in the following months. The response rate was 54%. A total of 1,013 persons answered all four times. A subtotal of 641 were included in the analysis, apportioned with 106 in the study group and 535 in the control group. This reduction and the small number in the study group was caused by the building societies' change of plans for the replacement of windows.

The first questionnaire included questions about the number of rooms, the number of persons, and the number of smokers in the household. In addition to health effects, changes in sensation of comfort/discomfort related to indoor climate were also included, i.e., the number of days with inconvenience. The following questionnaires were identical to the first questionnaire, but did not include the questions related to the characteristics of the apartment.

Correlations between retrofitting and symptoms were measured by odds-ratios. The odds-ratios were calculated for each month (odds for symptoms in the study group divided by odds in the control group), and normalized with respect to August.

Nonrespondents were not different from respondents with regard to age, sex, and location in the country (capital of Copenhagen versus major provincial cities). The participant in the control group tended to be away from the apartments for a longer time than the persons in the study group. This was closely related to the fact that there were more older people in the study group. The smoking habits were similar in the study and the control group. Additional analyses were carried out for potential confounders, but the confounders had only minor effect.

Results

The questionnaire included questions of five groups of symptoms. For all questions the normalized odds-ratios were calculated.

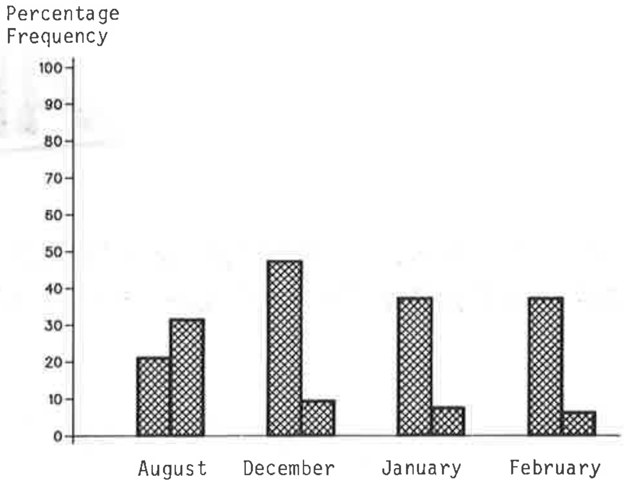

Fig. 1. Symptoms related to thermal conditions. Inconvenience from draught in the apartments. Left columns: control group; right columns: study group.

Symptoms related to thermal conditions

In August, 33% in the study group and 22% in the control group reported inconvenience from draught in the apartments. During the winter period these inconveniences bothered 40%–50% of the participants in the control group and less than 10% in the study group. Similar effects were seen with inconveniences from cold floors and low temperatures.

All the results were significant on a 0.1% to 1% level. A control question on high temperatures was not different from 1.0. The percentage frequencies are depicted in Fig. 1 and 2, the normalized odds-ratios in Table 1.

Noise

Nearly 40% of the participants felt inconvenience from outdoor noise. As for thermal conditions a dra-

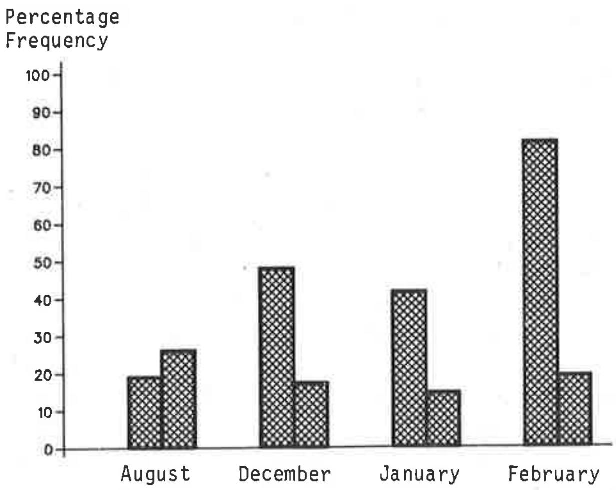

Fig. 2. Symptoms related to thermal conditions. Inconvenience from cold floors. Left columns: control group; right columns: study group.

Table 1. Normalized odds-ratios for disturbances and symptoms.

	August	December	January	February
Temperature				
Draught	1	0.07	0.08	0.06
Cold floor	1	0.15	0.16	0.18
High temperatures	1	1.32	1.22	0.79
Low temperatures	1	0.15	0.14	0.17
Noise				
Outdoor noise	1	0.04	0.02	0.03
Noise from the building	1	0.33	0.26	0.35
Symptoms related to mucosal surfaces				
Smarting or irritation of the eyes	1	0.33	0.00	0.00
Dryness of the throat	1	0.44	0.52	0.67
Rheumatic symptoms				
Joint pains	1	0.79	0.41	0.28
Analgesics for joint pains	1	1.30	0.37	0.32
Neck/back pains	1	0.38	0.11	0.18
Analgesics for back pains	1	0.73	0.11	0.19
General symptoms				
Heaviness of the head	1	0.64	0.25	0.35
Headache	1	0.45	0.63	0.72

matic effect was found. After retrofitting, complaints from outdoor noise almost disappeared. Retrofitting had a moderate effect on noise from inside the building.

The percentage frequencies in Fig. 3 and normalized odds-ratios are shown in Table 1. The odds-ratios for noise from the outside are significantly lower than 1 (0.1% level) and odds-ratios for noise from inside the building are significantly lower than 1 (5% level).

Symptoms related to mucous membranes

These symptoms consist of stinging and irritation of the eyes and dryness of the throat. These symptoms were only reported by few persons and the frequency decreased in the winter months in both the study and the control group.

There was a tendency for less symptoms in the study group, but the normalized odds-ratios were not significantly different from 1.0. Odds-ratios were adjusted for age, smoking habits, and colds, but this did not change the odds-ratios significantly (Fig. 4 and Table 1).

Rheumatic symptoms

Questions on rheumatic symptoms and consumption of analgesics for these were included, because an

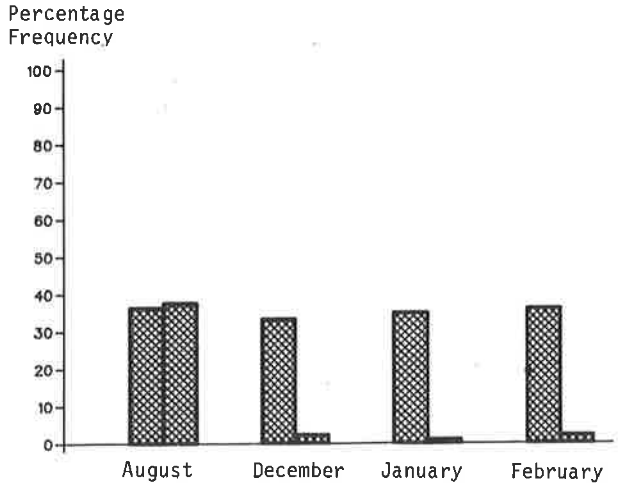

Fig. 3. Complaints on exposure to noise in the apartment. Left columns: control group; right columns: study group.

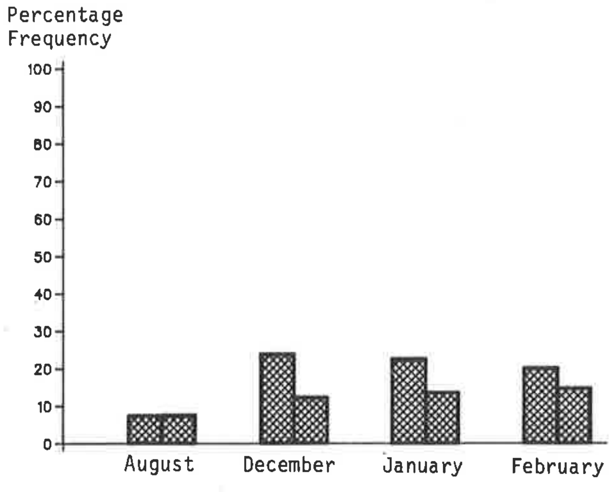

Fig. 4. Symptoms related to mucous membranes. Dryness of the throat. Left columns: control group; right columns: study group.

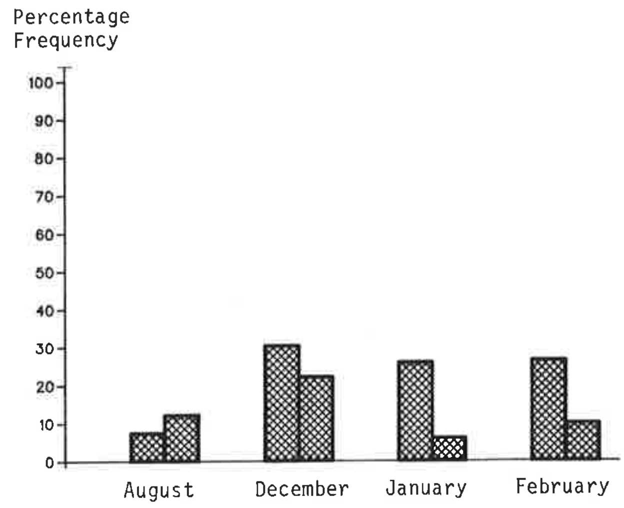

Fig. 5. Rheumatic symptoms. Muscular pains in the back neck. Left columns: control group; right columns: study group.

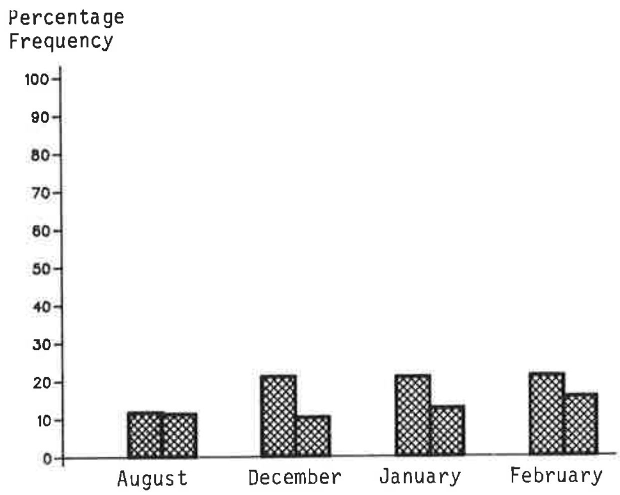

Fig. 6. General symptoms. Headache and sensation of heaviness of the head. Left columns: control group; right columns: study group.

improvement in thermal conditions might influence pain due to rheumatic diseases. Symptoms were divided between joint pains, thought to be characteristic of osteoarthritis in the elderly and muscular pains in the back or neck.

Retrofitting caused a decrease of symptoms and a corresponding decrease in consumption of analgesics; for both there was a latency period of one month. Not all normalized odds-ratios were significant but the above mentioned pattern emerged clearly (Fig. 5, Table 1).

The symptoms were standardized to age (below/above 60 yr). The pattern was the same as for the unstandardized odds-ratios but the effect of retrofitting was most pronounced in persons above 60 years.

General symptoms

These symptoms included headache and sensation of heaviness of the head. These symptoms were reported by only 10%–20% of the participants. The symptoms were found to decrease in the study group after retrofitting. Only one of the normalized odds-ratios was significant at a 5% level, but all odds-ratios were between 0.25 and 0.72 (Fig. 6, Table 5). A stratification with respect to age, sex, flu, and colds were undertaken without any change in the tendency.

Discussion

Generally, the relationship between housing and health is described as extremely complex. Health disorders may be the combined outcome of exposure at work, breathing polluted outdoor air, smoking, and poor housing. Also, those in better housing may be suffering the health consequences of living a longer time in very much worse conditions (McCarthy *et al.*, 1985). The elderly as a risk group, in particular in improperly heated houses, has been described earlier (Collins *et al.*, 1977).

The description of health effects which can be associated with indoor nonoccupational exposure are recently listed with reference to combustion sources and indoor air quality (U.S. Department of Energy, 1985). The knowledge available is based on clinical as well as epidemiological research.

However, such symptoms as headache, smarting or irritation of the eyes, dryness of the throat, and joint pains are not specific for indoor climate exposure. An estimate of the occurrence of headache and mucous membrane irritation in a representative group of Danish citizens at home and at work has been made by interviews among a representative sample size of 2060 Danish adult citizens (Valbjørn and Kousgaard, 1984).

For January 1983, the frequencies of headache and dryness or irritation in mucous membranes once a week or more was reported from about 7%–8% of adults in dwellings and between 12%–16% at work. Several variables such as type of dwelling, inhabitants per room, male or female, age, occupation, smoking habits, and location of dwelling in humid or moldy areas was found to have significant influence on the frequency.

Much higher numbers were found in a self-administered Work Environment Survey questionnaire designed to collect perceptions of environmental conditions and prevalence of building illness symptoms. The questionnaire was administered to 1106 office workers in New York City. Thirty-seven percent of office workers reported headaches, 52% reported fatigue, while 32% reported nasal irritation and 37% reported eye irritation more than once a week. Twenty-one percent of respondents reported sore throat or headcold symptoms once a week or more (Sterling, 1984).

The prevalence of reported health effects in such questionnaire surveys should be supported by either environmental measurements or a clinical examination of each individual. This has been done in population studies of relationship between indoor air pollution sources and chronic obstructive respiratory disease. But even here results may be confounded by selective underreporting of personal exposure such as active smoking (Tashkin *et al.*, 1984). We have therefore decided to focus only on the relative differences between the two groups, and within each group to follow random fluctuations and seasonal changes.

The response rate from the first questionnaire was 54%; this might seem low, but response rates in questionnaire studies may be as low as 25% in "healthy" buildings and 40% in "sick" buildings (Stolwijk, 1984). The persons who participate in an epidemiological study like this will not benefit directly or personally. The nonrespondents may not be motivated enough to participate.

In addition, we assume that the low response rate to some extent is due to the fact that the questionnaire had a rather computer-like design in order to facilitate analysis of data. Furthermore, the participants may have felt obliged to answer the following three questionnaires if they had answered the first one.

The only information available for all participating persons included sex, age, and address. There was apparently no selection with regard to these three factors.

Originally the study group was supposed to be as large as the control group. The observed reduction is not only due to loss of participants, but is as mentioned before mainly the result of the building societies' change of plans for the replacements of windows.

The results of the study are rather clear-cut, even though the reduction in participants was large. The nonparticipants had to be different from the participants to influence the results in an opposite direction. The effects are registered for the same participants before and after the intervention took place, i.e., the results are intrapersonnel variations. We conclude, therefore, that the magnitude of the effects must be interpreted with some caution, whereas the trends are clear.

Most public housing policies tend to give priority for transfers to better housing to the ill who are living in poor housing. An alternative strategy might be the improvement of the existing housing by building renovation. This can be done as an integrated part of energy conservation policy. This has the advantage of improvements for the entire risk population which can be defined in the older housing sector, and not only those already ill.

This study has demonstrated the benefits of a less drafty dwelling to the elderly, who spend most of their time at home. The disadvantages of reduced natural ventilation on indoor air quality could not be demonstrated, because it is less pronounced in old buildings where off-gassing from materials are 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 2 yr per room.

The size of the population in the study was not large enough to include at random 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, 1983a, 1983b).

Therefore requirements to the ventilation rates after retrofitting of the dwellings should still be considered from a health point of view. The ventilation rates should fulfil the existing building code for new houses. These specify an air change rate of 0.5 per hour and the presence of a user operable fresh air valve in each room with a free square of 30 cm^2 (Danish Building Code, 1982). 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/sec per person in bedrooms (Sundell, 1982). This equals 0.9 ach in an average bedroom of 30–35 m^3, which is almost twice the prescribed value of 0.5 ach.

Epidemiological studies in continuation including environmental measurements should emphasize this need in further detail.

Acknowledgements—The authors appreciate the advices of Dr. Johs. Ipsen, Institute of Social Medicine, University of Århus. The study has been part of a number of projects, which the Department of Energy, Copenhagen, Denmark, has given to the Institute of Hygiene, University of Århus, comprising indoor pollutant source control and indoor climate changes in energy-efficient housing.

References

Collins, K., Dore, D., Exton-Smith, A., Fox, R., MacDonald, I., and Woodward, P. (1977) Accidential hypothermia and impaired temperature homoeostasis in the elderly, *Brit. Med. J.* **1**, 353–356.

Harrje, D. T. and Mills, T. A. (1980) Air infiltration reduction through retrofitting. In building air change rate and infiltration measurements. ASTM STP 719 C. M. Hunt, J. C. King, and H. Trechsel, eds., pp. 89–104.

Iversen, M., Lundqvist, G. R., and Bach, E. (1982) En prospektiv undersøgelse af beboernes sundhedstilstand i boliger før og efter udførelsen af energibesparende foranstaltninger. (In Danish with an English summary.) Hygiejnemeddelelser 2, Sundhedsstyrelsen, National Board of Health, Copenhagen.

Korsgaard, J. (1983a) Changes in indoor climate after tightening of apartments, *Environ. Int.* **3**, 195–200.

Korsgaard, J. (1983b) Mite-asthma and residency—A case-control study on the impact of exposure to house-dust mites in dwellings, *Am. Rev. Resp. Dis.* **128**, 231–235.

McCarthy, P., Byrne, D., Harrison, S., and Keithley, J. (1985) Respiratory conditions: Effect of housing and other factors, *Epidemiol. Commun. Health.* **39**, 15–19.

Møller, J., Lundqvist, G. R., Mølhave, L., Andersen, I. (1979) Luftskiftet i nyere boliger, *Ugeskr. Laeg.* **141,** 961–966.

Sterling, T. D. (1984) Effects of restricting and prohibiting smoking in office environments on reactions of office personnel to environmental health and stress factors, in *Indoor Air,* B. Berglund, T. Lindvall, and J. Sundell, eds., vol. 2, pp. 329–334. Swedish Council for Building Research, Stockholm.

Stolwijk, J. (1984) The "sick building" syndrome, in *Indoor Air,* B. Berglund, T. Lindvall, and J. Sundell, eds., vol. 1, pp. 23–30. Swedish Council for Building Research, Stockholm.

Sundell, J. (1982) Guidelines for Nordic building regulations regarding indoor air quality, *Environ. Int.* **8,** 17–20.

Tashkin, D. P., Clark, V., Simmons, M., Reems, C., Coulson, A., Bourque, L., Sayre, J., Detels, R., and Rokaw, S. (1984) The UCLA population studies of chronic obstructive respiratory disease. VII. Relationship between parental smoking and children's lung function, *Am. Rev. Resp. Dis.* **129,** 891–897.

U.S. Department of Energy (1985) Indoor Air Quality. Environmental Information Handbook: Combustion Sources. U.S. DOE/EV/10450-1, Washington, DC.

Valbjørn O. and Kousgaard N. (1984) Headache and mucus membrane irritation. An epidemiological study, in *Indoor Air,* B. Berglund, T. Lindvall, and J. Sundell, eds., vol. 2, pp. 249–254. Swedish Council for Building Research, Stockholm.