THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

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FIRST-PHASE OCCUPANT REACTION TO WELL-SEALED INDOOR ENVIRONMENTS.

M.IVERSEN[1], E.BACH[2], G.R.LUNDQVIST[1]

1) Institute of Hygiene
Building 180
University of Aarhus, DK-8000 Århus, Denmark.

2) The Danish Institute for Clinical Epidemiology
Svanemøllevej 25, DK-2100 Copenhagen, Denmark.

ABSTRACT

Possible health effects and changes in sensation of comfort among tenants after replacement of single glass windows in leaky frames with double glass windows in airtight frames have been studied. The study design was observational, and included a study group and a corresponding control group. The results indicate essential improvements of the indoor climate and of the health status of the tenants after replacement of the windows (i.e. positive effects on temperature conditions, lowering of noise, fewer symptoms related to mucosal surfaces, fewer rheumatic symptoms, and possibly fewer headaches). Significant changes in complaints or health effects which could be related to reduced air quality caused by the airtightening were not found. This study cannot give any evidence of inconveniences that may occur later if the apartments become too airtight.

INTRODUCTION

Increased energy costs have brought efforts to reduce ventilation and infiltration in indoor spaces.

The air quality in an indoor space, and more specifically the concentration of a given inhaled pollutant indoors, depends on the outdoor air quality, on the presence and strength of emissions from indoor sources, on the ventilation rate and ventilation efficiency, and the presence and effectiveness of other elimination procedures such as adsorption, sedimentation, or neutralization.

The pollutants to be considered will generally be tobacco smoke (passive smoking), NO_2, CO_2, CO (from combustion), formaldehyde, asbestos, mineral fibres, organics, and radon (from materials and consumer products), odours, moisture, and microorganisms (from occupancy). Some pollutants can more specifically be listed as allergens.

It has been realized that the knowledge of exposure effect relationship, especially with regard to delayed effects of chronic exposure is inadequate, while the knowledge of complaints on acute discomfort by occupants in some buildings is well established (1).

The aim of this study was to measure the possible health effects among tenants after certain energy conservation measures had been taken in their dwellings i.e. replacement of windows in leaky frames with double glass windows in airtight frames.

In addition to health effects, changes in sensation of comfort/-discomfort related to indoor climate, including the thermal and acoustic environment, were also included.

The study has been designed as an observational study with two groups; a study group and a corresponding control group not exposed to environmental changes in their homes.

MATERIALS AND METHODS

The majority of apartment houses in central urban areas, which have been weatherproofed in recent years, are owned by building societies. Thirty-three of the largest building societies in Denmark were invited to participate in the study. Twenty-four building societies accepted, and 8 of these owned apartment houses that fulfilled the criteria for participation:

Study group: Houses 2-5 stories high, with untight windows having one layer of glass. Windows were replaced during the period from September 1981 to November 1981.

Control group: Houses 2-5 stories high with untight windows that were not replaced in the study period.

Personal data (name, address, age and sex) were collected from the Central Person Register using the addresses supplied by the building societies.

All residents over 18 years of age received a questionnaire in August 1981 before replacement (if any) of windows. The persons who answered the questionnaire and thereby indicated that they were willing to participate in the study received new questionnaires in December, January and February. In the study group the replacement of windows took place in the period between the first and the second questionnaire. The winter period was chosen because changes in indoor climate are maximal at this time of year (Korsgaard, 2).

Questionnaires were each month sent to all persons who had answered the previous questionnaire. The response rates are given in Table 1, i.e. the number of valid answers in percent of the number of distributed questionnaires, but corrected for the number of persons who had moved.

Table 1 shows that a large number did not respond in August. This number was smaller in December and very small in January and February , thus indicating that the group of persons that participated in the study gradually stabilized.

The persons who had answered all four times and whose apartments fit the criteria for participation are included in the analysis of data.

This group consists of 641 persons, where 106 are in the study group and 535 are in the control group, see table 2. The reduction from 1013 to 641 was caused by the building societies' change of plans for the replacement of windows.

The age distribution in the group of persons who were invited to participate in the study was: 28% 18-40 years, 51% 41-70 years and 21% over 70 years. The age distribution in the group of persons who responded was, 30% 18-40 years, 52% 41-70 years and 18% over 70 years. Women constituted 59% of the original group and 60% of the group of responders. Thus, the response rate was not related to age or sex.

The questionnaires consisted of the same questions on all four occasions, except the questions regarding the characteristics of the apartment (number of rooms etc.) which were only included in the first questionnaire.

The questionnaire included questions about number of rooms, number of persons under and over 18 years in the household, number of smokers in the household and type of windows.

In addition to the questions related to the characteristics of the apartment, the questionnaire included a number of questions concerning the person's wellbeing and health status. There were questions about the number of days with inconvenience in the previous month (0, 1-2, 3-8 and more than 8 days per month).

The questions related to well-being and inconvenience could be divided into five groups: Temperature, Noise, Symptoms related to mucosal surfaces, Rheumatic symptoms, and General symptoms.

The study was carried out in a period with temperatures below normal. The average temperature in December 1981 was -4,3^{o}C - the lowest average temperature in Denmark ever measured.

STATISTICAL METHODS

In the statistical analysis was used contingency tables. Correlation between retrofitting and symptoms was expressed with odds-ratios.

Example, odds-ratios in August:

Study group: a persons with symptom X in August
b persons without symptom X in August

Odds for X in the study group: a/b

Control group: c persons with symptom X in August
d persons without symptom X in August

Odds for X in the control group: c/d

$$\text{Odds-ratio for X} = \frac{a/b}{c/d} = \frac{a \cdot d}{b \cdot c}$$

Odds-ratios were calculated separately for each month and normalized with respect to August (odds-ratio for August = 1). The odds-ratios for December, January and February were thus compared with the odds-ratios for August. A x^2-test in a log-linear model is used for significance testing. The p-values indicate the probabilities that the odds-ratios in August, December, January and February are equal.

RESULTS

Apart from the replacement of the windows, there exist certain background variables which affect the registered inconveniencies, e.g. the time per day spent in the apartment and the participants' age.

About 40% of the residents either live by her/himself , or only one person from the apartment answered. This applies to the study group as well as to the control group.

The persons in the control group tend to be away from the apartment for a longer time than the persons in the study group. This is related to the fact that there are more persons over 60 years in the study group: 56% in the control group and 41% in the study group. Smoking habits are similar in the two groups, see table 2.

The questions related to well-being and inconvenience were originally divided into four categories. However, the results show that the answers were concentrated in category 1 (0 days per month) and category 4 (more than 8 days per month). Taking this into account, the categories were combined so that only two categories of answers are considered: 0-2 days and more than two days per month. It was tested for all results whether age had any effect on the results. Results on symptoms on which age had effect are described in the text. The frequency of symptoms was not observed to be related to the person's sex.

Information related to temperature is collected from four questions. The questions concerned draught, cold floor, too low temperatures and too high temperatures, see Fig. 1. In August, 22% of the participants in the control group and 33% in the study group reported that they experienced inconvenience from draught in the apartments. In all three months during the winter season more participants in the control group and less in the study group reported draught inconvenience. The same pattern was observed with regard to cold floor, which bothered 20% of the participants in August and with regard to low temperature which bothered 10% of the participants in August.

Table 3 shows the results of the normalized odds-ratios on temperature. The effects of weatherproofing on draught, cold floor, and low temperature are significant ($p = 0.000$, $p = 0.000$ and $p = 0.007$ respectively). Weatherproofing had no effect on inconveniences from high temperatures.

Almost 40% of the participants were bothered by outdoor noise and about 20% of the participants were bothered by noise originating from inside the building, see Fig 1. The frequency of noise nuisance is apparently constant in the following months in the control group, whereas there is a dramatic drop in the study group. Outdoor noise almost disappears after weather proofing ($p = 0.000$) but with regard to the noise from the building the effect is less pronounced ($p = 0.06$), see Table 3.

Smarting or irritation of the eyes is reported by more than 10% of the residents in August, but the frequency of disturbances drops dramatically in the following months in both groups, see Fig. 2. Throat complaints were reported by 8% of the participants in August, see Fig. 2. In the following months throat complaints were reported by 20% of the participants in the control group and by 10-15% in the

study group. For both of these symptoms related to mucosal surfaces it is noted that the tendencies towards improvements in the study group observed in Fig. 2 are not significant ($p = 0.2$ and $p = 0.4$, respectively).

Further analysis of the impact of flu and cold, age and smoking habits showed that correction for these background variables did not change the calculated odds-ratios substantially.

Rheumatic symptoms are included in questions concerning knee and hip joints, pains in the neck and upper part of the back and intake of analgesics for each of these two conditions (salicylic acid and like substances). The frequency of pains are seen in Fig 2.

The calculation of odds-ratios for rheumatic symptoms shows that weatherproofing had a pronounced effect. However, this effect is not manifest until January and February. The effect on joint pains and neck/back pains is significant ($p = 0.04$ and $p = 0.000$). The effects on intake of analgesics are also significant ($p = 0.02$ and $p = 0.001$), see Table 3.

The rheumatic symptoms mentioned previously increase in frequency with age, especially for persons over 60. The results were therefore divided into two age groups: less than 60 years/over 60 years.

This analysis showed that the effect on joint pains was most pronounced for persons over 60 years. The neck and back pains were affected in both age groups but the effect was most pronounced in the age group over 60 years. The same tendencies were observed for the intake of analgesics for both age groups for joint pains and neck and back pains, respectively.

Fig. 2 indicates that weather proofing apparently had a positive effect on the frequency of headaches and the frequency of the intake of analgesics for headaches. However, this effect is not significant ($p = 0.5$).

Apparently there was a minor effect of weatherproofing on the symptoms "one's head feels heavy". However, this effect was not significant ($p = 0.096$).

Additional analyses were carried out for these symptoms in order to make corrections for age and sex, but these corrections had only minor influence on p-values and odds-ratios.

Cases of flu and cold had also a very limited influence on the frequency of symptoms.

Habits with regard to airing were investigated in order to test any relationship to weatherproofing and age. However, there was not found any relationship between these two variables. Smoking was the only variable which had pronounced effect on airing: smokers aired more than non-smokers.

In addition, it was investigated whether mould growth and damages due to moisture in the apartment were related to airing habits and drying of clothes in the apartment. Only drying of clothes was found to be related to signs of mould.

DISCUSSION

The response rate from the first questionnaire was 54% which might seem low. The persons who participate in an epidemiological study like this will not benefit directly or personally. Thus they are not greatly motivated 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 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 (Capital, Provincial towns). 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 due to loss of participants only, but is mainly the result of the building societies' change of plans for the replacement of windows.

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

Furthermore, it should be emphasized that all the measured effects are acute or subacute effects. This study cannot give any evidence of inconveniences that may occur later if the apartments become too airtight.

The dramatic improvement in the indoor climate with regard to temperature and noise may have influenced the answers to the questions about symptoms, which are not directly related to low temperatures and draught.

The results of this study therefore show that it would be desirable to conduct similar studies under different climatic conditions and for other types of buildings, but with the same methodology so that the studies would be comparable.

This study has been part of a number of projects, which the Department of Energy, Copenhagen has given the Institute of Hygiene, University of Aarhus, comprising indoor pollutant source control (3) as well as changes in housedust mite populations related to moisture changes in retrofitted dwellings (2,4).

The concept of combining different methodological studies like this is based on the experience from other fields of environmental health studies in that they generally should include both field measurements and observational health studies, as well as controlled exposure studies, to be conclusive.

The conclusion so far has been that insulation and retrofitting in flats seems to have predominantly positive acute effects regarding to votes on comfort and well-being. Possible long term consequenses, of a very low ventilation rate, with negative health effects cannot be excluded from this study and will have to be observed in the future.

The environmental changes which took place in the buildings concerned in this study were not physically monitored. This has to be done in studies in continuation.

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Table 1 Number of reponses and response rates

	August	December	January	February
Number of distributed questionnaires	3309	1739	1268	1112
Number of answered questionnaires	1922	1306	1148	1043
Number of valid answers	1739	1268	1112	1013
Response rate	53.6	73.9	88.5	92.8

Table 2 Follow-up group: Distribution of background variables in percent

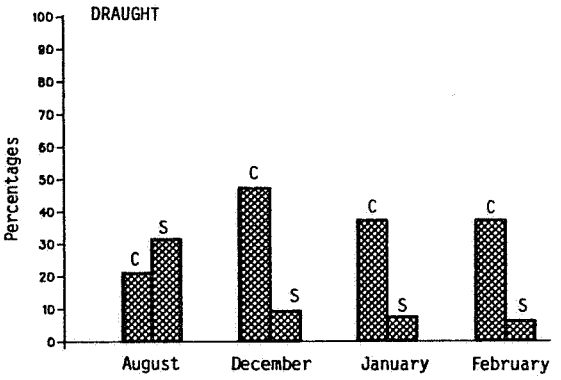
		August	December	January	February
Periods away from apartment $\leq$ 4 hours	control group	18.3	57.1	61.5	57.5
	study group	24.2	69.5	67.9	67.0
Smokers	control group	51.8	52.0	51.1	51.7
	study group	51.7	51.8	53.6	54.1
Total number of answers	control group	535	535	535	535
	study group	141	141	141	141

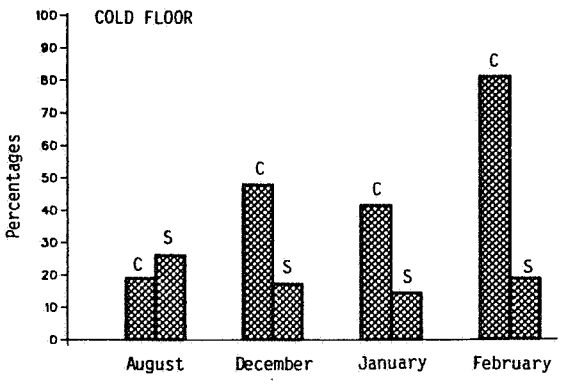
Table 3. Normalized odds-ratios for disturbances and symptoms

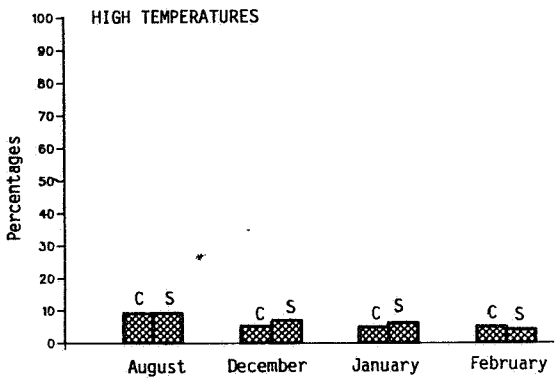
	August	December	January	February
Temperature				
Draught	1	0.07	0.08	0.06
Cold floor	1	0.15	0.16	0.18
High temperatures	1	1.32	1.22	0.79
Low temperatures	1	0.15	0.14	0.17
Noise				
Outdoor noise	1	0.04	0.02	0.03
Noise from the building	1	0.33	0.26	0.35
Symptoms related to mucosal surfaces				
Smarting 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

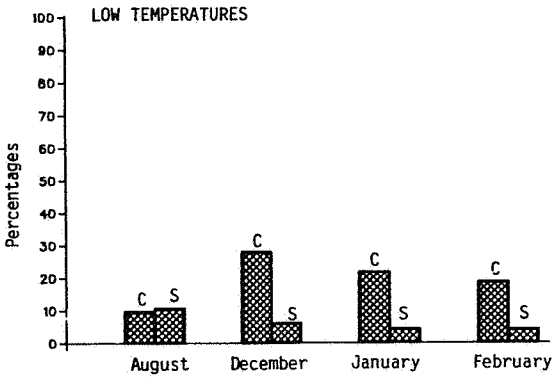
Fig. 1 Frequencies of disturbances

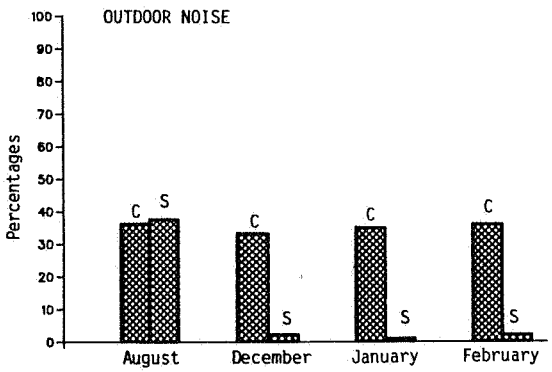
C = control group
S = study group











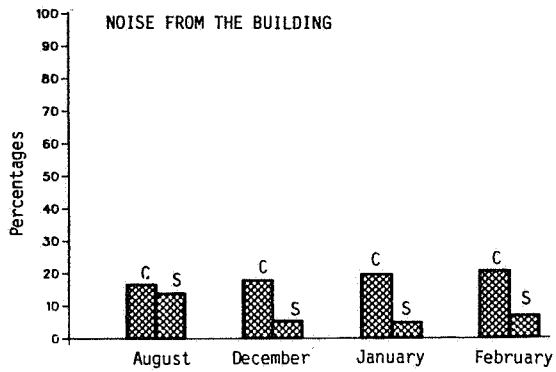


Fig. 2 Frequencies of symptoms

C = control group
S = study group