

The 3-year follow-up study in a block of flats – experiences in the use of the Finnish indoor climate classification

Abstract Indoor climate of two new blocks of flats was investigated. The case building was built for people with respiratory diseases by following the instructions of the Finnish Classification of Indoor Climate, Construction and Finishing Materials, while the control building was built using conventional building technology. The main indoor air parameters (temperature, relative humidity and levels of CO, CO₂, ammonia, total volatile organic compounds, total suspended particles, fungal spores, bacteria and cat, dog and house dust mite allergens) were measured in six apartments of both the buildings on five occasions during the 3-year occupancy. In addition, a questionnaire to evaluate symptoms of the occupants and their satisfaction with their home environment was conducted in connection with indoor air quality (IAQ) measurements. The levels of indoor air pollutants in the case building were, in general, lower than those in the control building. In addition, the asthmatic occupants informed that their symptoms had decreased during the occupancy in the case building. This case study showed that high IAQ is possible to reach by careful design, proper materials and equipment and on high-quality construction with reasonable additional costs. In addition, the study indicated that good IAQ can also be maintained during the occupancy, if sufficient information on factors affecting IAQ and guidance on proper use and care of equipment are available for occupants.

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Practical Implications

National and international guidelines and labelling systems have been developed during the last decade in order to control and improve indoor air quality (IAQ) in buildings, to promote the development and use of low-emitting building materials, and to establish quality-controlled building practices for the construction phases. The present study shows that the case building designed and built according to the Finnish Classification achieved the higher IAQ and had more satisfied occupants than the control building constructed by a conventional way. This was possible by high motivation and commitment of all the partners (owner, builder, planners, constructors and workers) to a shared and clear target in the project. The target, high IAQ in the case building, was reached with low additional costs. In addition, IAQ in the case building could be maintained at a high level by distribution of information and instructions on the care of the buildings to the occupants and service staff.

Introduction

Good indoor air quality (IAQ) in the home environment is essential for the general comfort of occupants, and it is a key factor for the well-being of people with respiratory diseases (Jones, 1999, 2000; Platts-Mills, 1994; Platts-Mills et al., 2000; Tovey and Marks, 1999). Therefore, good indoor climate should be a central target when constructing a building. Several factors, such as the surrounding area and outdoor climate, as well as the design, choice of building

materials and equipment [heating, ventilating, and air-conditioning (HVAC), and central cleaning system], the quality of construction work, and the use and maintenance of the building, have an impact on indoor climate. Therefore, aspects of indoor climate should be taken into consideration at all stages of the lifespan of the building.

Since 1995 the voluntary Classification of Indoor Climate, Construction and Finishing Materials (Seppänen et al., 1995), later called the Finnish Classification, has been available for clients, designers,

builders, and manufacturers of equipment and materials in Finland. The classification includes the target and design values for essential indoor climate parameters (S), principles and procedures for construction works (P), and the limit values of emission rates for building and finishing materials (M). The most demanding categories (S1, P1, and M1) ensuring an indoor climate of high quality are recommended to be used for special needs, e.g. for people with allergies and respiratory diseases. The Finnish Classification has been used in real building processes with promising experiences (Ruotsalainen, 2000; Saarela et al., 1999, 2000; Tuomainen et al., 2001). Till now, the M1 label has been granted to more than 400 building products, e.g. paints, fillers, wallpapers, floorings, building boards, mineral wools in Finland (Neuvonen, 2000). The classification was updated in 2000, and also the English version is available (Seppänen and Säteri, 2001).

Similar processes to improve IAQ in buildings are ongoing also in other countries. In Denmark, Germany and USA, labeling systems for building materials and products and other guidelines (Indoor Climate Labelling, GuT, GEV-Emicode, RAL UZ 38, Green-guardTM, ASHRAE guideline for HVAC work) have been established (ASHRAE, 1999; Danish Society of Indoor Climate, 2001; Jann et al., 2000; Maroni and Lundgren, 1998; Plehn et al., 2000; Seifert, 2000). In some cases, the whole building process has been reorganized in order to reach good IAQ in schools, offices and/or dwellings in Sweden (Samuelsson, 2000), Norway (Johnsen, 1997 and Flatheim, 2000), Canada (Canadian Standards Association, 1994), and in Minnesota in USA (Carmody et al., 2000). In addition, some buildings have been constructed, e.g. for allergic people in Sweden (Björck, 2000; Blomsterberg and Carlsson, 1997).

This paper describes the follow-up investigation of the case building (the seven-storied apartment house) that was constructed according to the Finnish Classification (Tuomainen et al., 1997). In our previous paper (Tuomainen et al., 2001), we described, how the 7-day ventilation period just before the occupants moved in affected the levels of indoor air chemical pollutants, what kind of IAQ was finally achieved in the building, and how the 5-month occupancy influenced certain indoor air parameters [temperature, relative humidity (RH), CO, CO₂, total volatile organic compounds (TVOC), formaldehyde, acetaldehyde, ammonia, total suspended particles (TSP), and odour intensity]. In the present study, the same indoor air parameters added with data on the size distribution of particle counts and the concentrations of biological agents (fungi, bacteria, and indoor allergens) have been measured and evaluated again after 1, 2, and 3 years of occupancy.

The perceived IAQ and prevalence of symptoms among the occupants are also discussed. Furthermore, the additional costs due to the high-quality construction work are estimated.

Materials and methods

Study buildings

Two blocks of flats located next to each other in a suburban area were investigated: the case building was built by following the instructions of the Finnish Classification whereas the control building was constructed in the conventional way. More detailed information on the construction practices of the case building was presented in an earlier paper (Tuomainen et al., 1997). As the main differences between the case and control buildings, the mechanical supply and exhaust ventilation with a design ventilation rate of 1.7 l/h was installed in the case building, while the control building was equipped with the mechanical ventilation with a design ventilation rate of 0.8 l/h. In addition, keeping of any furred pets or smoking indoors were forbidden in the case building. The other differences in the design of the buildings are described by Tuomainen et al. (2001). All 27 apartments in both the buildings were rented out, those in the case building to people with respiratory diseases and their families.

IAQ measurements

The IAQ measurements in the buildings were conducted after 1, 2, and 3 years of occupancy. Because the case building was completed about 18 months later than the control building, the IAQ measurements were carried out in the buildings at different times of the year: in the case building in May and in the control building in November. The measured indoor air parameters as well as used methods and equipment are described in Table 1. The IAQ measurements were conducted every occasion in the same six apartments (one per each floor) of both the buildings. The corresponding apartments in the case and control building were of the same size, located equally in the buildings, and were selected before the occupants moved into the buildings. In each apartment, the measurements were performed in the living-room and bedroom at a height of 1.5 m. The doors between the rooms were closed for at least 1 h before the measurements and the doors to the corridors were closed all the time.

Questionnaire study

The questionnaire used was modified from the MM40 (Andersson et al., 1993) and the Tuohilampi

Table 1 Summary of the methods and equipment in the IAQ measurements

Parameter	Method/equipment	Sampling time
Temperature	TSI Q-trak 8551 (TSI Incorporated, Shoreview, MN, USA)	1 h
Relative humidity (RH)		
Carbon dioxide (CO ₂)		
Carbon monoxide (CO)		
Ammonia (NH ₃)	Collected in diluted sulphuric acid and analyzed with an ion-specific electrode (The Ministry of Social Affairs and Health, 1997; Arbetarskyddsstyrelsen, 1997)	3–4 h
Aldehydes (H _x CO)	Collected in dinitrophenylhydrazine cartridges and analyzed by a high-pressure liquid chromatography equipped with a diode array detector (Waters Sep-Pak® DNPH-Silica Cartridge, 1992)	2–4 h
Total volatile organic compounds (TVOC)	Collected into Tenax TA and analyzed with thermal desorption, gas chromatography with a mass selective detector [European Collaborative Action (ECA), 1997; Wolkoff, 1995]	1.5 h
Total suspended particles (TSP)	Sampled onto cellulose acetate membrane filters and determined by a gravimetric method (SFS 3860, 1988)	4–6 h
Size range of particles	Optical particles counter HIAC/Royco, model 5000 (Pacific Scientific Instruments, Grants Pass, OR, USA)	1.5–5 h
Cat (Fel d 1), dog (Can f 1) and house dust mite (Der p 1) allergen levels in settled dust	Vacuumed into cellulose acetate/cellulose nitrate filters and analyzed with the immunochemical enzyme-linked immunosorbent assay method (Raunio et al., 1998)	2 min/m ² from living room carpets
Fungal spores	Collected on 2% malt extract agar (MEA) and dichloran glycerol agar (DG18) with a six-stage impactor (Andersen 10–800), incubated for 7 days at 20–25°C (Andersen, 1958)	15 min
Bacteria	Collected on tryptone glucose yeast agar with a six-stage impactor (Andersen 10–800), incubated for 7–14 days at 20–25°C (Andersen, 1958)	15 min
Odour	Trained panel of seven to 10 members (Bluyssen et al., 1989; Fanger, 1988)	–

questionnaire series especially designed to characterize respiratory symptoms and diseases (Susitaival and Husman, 1996). The questionnaire study was conducted five times: before the occupants moved in to the case building, after 5 months, and after 1, 2, and 3 years of occupancy in both the buildings. The questionnaire inquired about the situation during the past 3 months. The questionnaires were always sent by mail before the IAQ measurements to the occupants of the building under study. In the control building, each family was asked to fill in one questionnaire and the response rate varied from 63 to 89% during the follow-up. In the case building, all the family members were requested to fill in the questionnaire, but in practice mainly the occupants with respiratory diseases answered the questionnaire and the response rate was 89–100%.

The questionnaire included the following questions:

- Personal and living environmental characteristics (six questions)
- Living habits, e.g. smoking and pets (four questions)
- The presence of disturbing factors in the home environment such as high temperature, odour, noise (13 questions)
- Grade for IAQ (scales 4–10), advantages and defects of the apartment and living environment (three questions).

- The occurrence of different symptoms, e.g. headache, irritation (nasal, cough, and skin) (23 questions)
- Allergic symptoms (four questions)
- Common opinion of the health state and general satisfaction to the life (eight questions).

Data handling and statistical analyses

Descriptive statistics (mean, s.d., median, and range) were used to characterize the data of the IAQ measurements. The questionnaire data were analyzed with the statistical package SPSS/PC⁺ (SPSS, Inc., Chicago, IL, USA). The prevalence of the most disturbing factors in the indoor environment and perceived symptoms reported by the occupants were calculated. When the prevalence exceeded 30%, the finding was interpreted as significant (Andersson, 1998).

The area-specific emission rates (SER_a, µg/m²h) of TVOC, formaldehyde, acetaldehyde, and ammonia were calculated in order to determine the effect of low-emitting building materials in the case building when the influence of different ventilation systems and air change rates in the buildings was eliminated (Tuomainen et al., 2001). The differences in SER_a between the case and the control building were tested with the Mann–Whitney *U*-test. Otherwise, the levels of indoor air parameters measured at different times in the

buildings were not examined statistically, because there are many confounding variables within and between the buildings, and the results for the apartments and rooms are dependent on each other and on different occasions.

Results

IAQ in the buildings

During the follow-up period, the temperature varied from 22 to 26°C in the case building and from 19 to 23°C in the control building. The range for RH was 22–40% in the case building and 20–35% in the control building. The S1 target levels (22–25°C and RH 30–60%) set for the case building were not quite reached. The CO concentrations were at the S1 level (<2 part per million [p.p.m.]) in both the buildings. The CO₂ concentrations were clearly lower in the case building (range: 334–726 p.p.m.) than in the control building (range: 410–1430 p.p.m.): the mean CO₂ concentrations of 12 measurements (in six apartments) after 1, 2, and 3 years of occupancy were 407, 508 and 490 p.p.m. in the case building, and 871, 736 and 673 p.p.m. in the control building, respectively. In both the buildings, however, the CO₂ concentrations were below the S1 level (<1000 p.p.m.).

The concentrations of chemical pollutants, their area-specific emission rates and the target levels for the case building are presented in Table 2. In general, the levels of chemical pollutants were lower in the case building than in the control building. The TVOC levels had a decreasing tendency over the follow-up period, while

the aldehyde levels remained low all the time. The concentrations of TVOC and formaldehyde in the case building were below the class S1 limit. The most common VOC in the buildings are listed in Table 3. The most frequent VOCs in both buildings included terpenes (limonene, α -pinene, 3-carene), 2-ethyl-1-hexanol, toluene, and nonanal. In addition, decamethylcyclopentasiloxane was commonly found in the case building. The ammonia concentrations in the case building were at the S1 level after the 1-year occupancy but surprisingly exceeded the S1 limit in the second year and achieved the S1 level again in the third year. The values of SER_a for TVOC during the whole follow-up period, and SER_a for ammonia after the 1-year occupancy were significantly lower in the case building compared with the values in the control building. On the other hand, the SER_a values for aldehydes were higher in the case building than in the control building.

The odour intensity ranged from 1.1 to 5.7 decipol in the case building and from 1.8 to 6.7 decipol in the control building, being somewhat higher in the control building than in the case building after 2 and 3 years of occupancy. No temporal variation in the values was detected in the case building and the odour intensity did not reach the S1 level (<2 decipol) during the follow-up period.

In the case building, the TSP levels (range: 1–49 $\mu\text{g}/\text{m}^3$) were clearly at the S1 level (<60 $\mu\text{g}/\text{m}^3$) during the follow-up period, while the levels (range: 4–216 $\mu\text{g}/\text{m}^3$) were higher in the control building. In the control building, the TSP levels increased with the occupancy time (the mean TSP levels of six samples after 1, 2, and 3 years of occupancy were 8, 37, and 78 $\mu\text{g}/\text{m}^3$). The

Table 2 The concentrations and mean area-specific emission rates (SER_a) of TVOC, ammonia, formaldehyde and acetaldehyde in the case and control buildings. Also target levels for indoor climate (S1) in the case building were given (Seppänen et al., 1995)

Parameters	Case building			Control building			Target level for indoor climate (S1) in the case building	P-value to SER _a
	1 year	2 years	3 years	1 year	2 years	3 years		
TVOC ($\mu\text{g}/\text{m}^3$)							<200	After 1 year: 0.014** After 2 years: 0.006** After 3 years: <0.0009**
Mean $\pm$ s.d.	70 $\pm$ 28	45 $\pm$ 27	28 $\pm$ 9	931 $\pm$ 1068	330 $\pm$ 234	265 $\pm$ 340		
Range	32–115	12–101	17–54	40–2800	72–890	72–1293		
SER _a $\pm$ s.d.	89 $\pm$ 12	56 $\pm$ 10	34 $\pm$ 4	542 $\pm$ 234	189 $\pm$ 43	147 $\pm$ 52		
Ammonia ($\mu\text{g}/\text{m}^3$)							<20	After 1 year: <0.0009** After 2 years: 0.326 After 3 years: 0.954
Mean $\pm$ s.d.	4 $\pm$ 3	27 $\pm$ 11	15 $\pm$ 6	61 $\pm$ 19	44 $\pm$ 13	33 $\pm$ 10		
Range	1–9	10–47	8–26	27–84	21–70	19–46		
SER _a $\pm$ s.d.	5 $\pm$ 1	32 $\pm$ 4	20 $\pm$ 2	33 $\pm$ 5	25 $\pm$ 3	18 $\pm$ 2		
Formaldehyde ($\mu\text{g}/\text{m}^3$)							<30	After 1 year: 0.310 After 2 years: 0.024** After 3 years: 0.023**
Mean $\pm$ s.d.	13 $\pm$ 4	16 $\pm$ 7	12 $\pm$ 6	23 $\pm$ 5	23 $\pm$ 9	17 $\pm$ 5		
Range	3–18	8–38	7–28	16–29	10–43	10–28		
SER _a $\pm$ s.d.	16 $\pm$ 2	20 $\pm$ 3	15 $\pm$ 2	14 $\pm$ 2	13 $\pm$ 1	10 $\pm$ 1		
Acetaldehyde ($\mu\text{g}/\text{m}^3$)							*	After 1 year: 0.108 After 2 years: <0.0009** After 3 years: –
Mean $\pm$ s.d.	9 $\pm$ 5	24 $\pm$ 8	9 $\pm$ 2	29 $\pm$ 69	27 $\pm$ 9	–		
Range	1–20	9–37	5–13	2–186	12–38	–		
SER _a $\pm$ s.d.	12 $\pm$ 2	30 $\pm$ 3	11 $\pm$ 1	23 $\pm$ 21	15 $\pm$ 2	–		

s.d., standard deviation; ‘–’, not measured; * No target level; ** $P < 0.05$, a statistically significant difference between the case and control building.

Table 3 The most frequent VOC-compounds in the buildings during the 3-year occupancy

Time of the sampling	Case building compound	Range of conc. $\mu\text{g}/\text{m}^3$	Control building compound	Range of conc. $\mu\text{g}/\text{m}^3$
After 1 year	Limonene	<1*–37	Hexanal	<1–120
	3-Carene	<1–16	Limonene	<1–210
	α -Pinene	4–11	Nonanal	<1–56
	Toluene	<1–13	α -Pinene	<1–90
	Nonanal	2–8	3-Carene	<1–56
	Xylene	<1–4	2-Ethyl-1-hexanol	<1–30
After 2 years	Decamethylcyclopentasiloxane	<1–21	2-Ethyl-1-hexanol	<1–74
	2-Ethyl-1-hexanol	2–26	2-Methoxyethoxyethanol	<1–93
	α -Pinene	<1–13	Limonene	<1–85
	Menthol	<1–6	3-Carene	<1–85
	Nonanal	3–7	α -Pinene	6–52
	Toluene	<1–9	Toluene	3–46
After 3 years	Decamethylcyclopentasiloxane	<1–10	2-Butoxyethoxyethanol, acetate	<1–141
	3-Carene	<1–12	Cyclohexanone	<1–35
	2-Ethyl-1-hexanol	1–10	2-Ethyl-1-hexanol	<1–59
	1-Butanol	<1–6	Limonene	<1–45
	Nonanal	3–5	2-Butoxyethoxyethanol	<1–23
	α -Pinene	<1–12	α -Pinene	<1–25

*Limit of detection, <1 $\mu\text{g}/\text{m}^3$

same trend was not seen in the case building (the mean TSP levels were 2, 29, and 9 $\mu\text{g}/\text{m}^3$, respectively).

The number distributions of the airborne particles in both the buildings during the 3-year occupancy are illustrated in Figure 1. In both the buildings, the highest particle counts were measured in the size fractions of <1 μm , while the proportion of large particles (>5 μm) was low. In general, the particle counts in every size fraction were lower in the case building than in the control building over the whole follow-up period. In both the buildings, the particle counts in all the size fractions after the 1-year occupancy were surprisingly low that hampers the estimation of particle accumulation in the apartments. When the results of the third year are compared with the results obtained at the time when the occupants moved in and after the 5-month occupancy, the particle counts in all the size fractions had increased with the time of occupancy in the case building. The similar trend was not seen in the control building, where the variation in the counts was large.

During the 3-year follow-up period, airborne microbial levels remained low in the case building. The fungal concentrations were below 80 cfu/ m^3 , and no accumulation of fungal spores in the apartments was observed over time. The bacterial concentrations ranged from 10 to 570 cfu/ m^3 and the levels increased slightly with the occupancy time: the mean counts of six samples after 1, 2, and 3 years of occupancy were 80, 130 and 200 cfu/ m^3 , respectively. In the control building, the microbial concentrations varied from 2 to 1000 cfu/ m^3 for fungi and from 60 to 3900 cfu/ m^3 for bacteria. No temporal tendency, however, was detected in those counts.

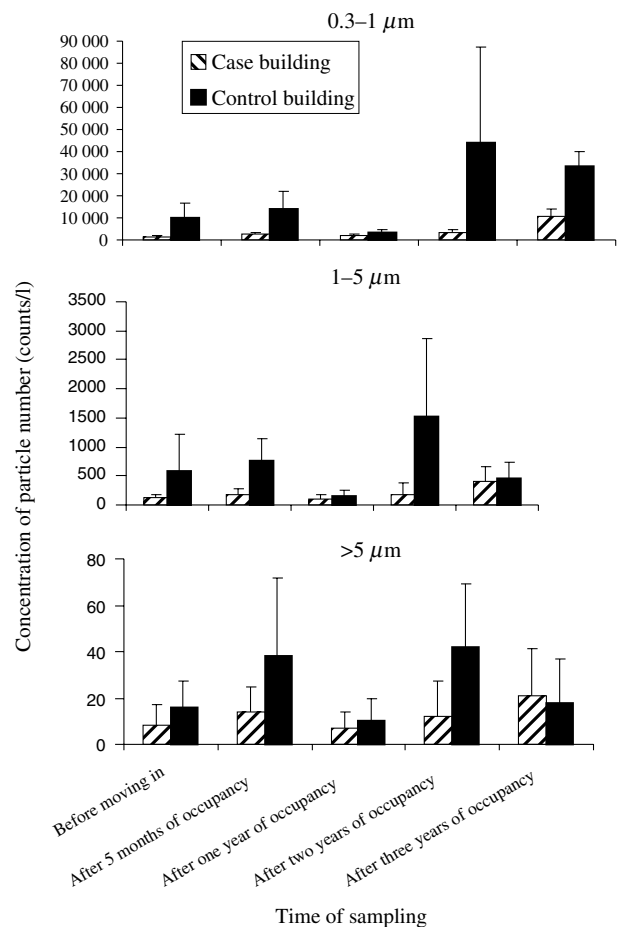


Fig. 1 The particle number distributions during the follow-up period in the case and control building. The bars describe the mean values of three apartments

House dust mite allergen (Der p 1), a cat (Fel d 1), and a dog allergen (Can f 1) were determined in the settled dust in the case building only after the 5-month and 1-year occupancy and in the control building after 1, 2, and 3 years of occupancy. In both the buildings, the content of Der p 1 in the settled dust was very low ($<0.02 \mu\text{g/g}$) being below the detection limit ($0.009 \mu\text{g/g}$) in 82% of all the dust samples. In the case building, where pets are not allowed to keep, the levels of Fel d 1 and Can f 1 also remained low during the first year of occupancy; the range for Fel d 1 was $0.04\text{--}0.6 \mu\text{g/g}$ and for Can f 1 $0.1\text{--}6.5 \mu\text{g/g}$. In the control building, the Fel d 1 levels varied from 0.09 to $90 \mu\text{g/g}$ and the Can f 1 levels from 0.03 to $3111 \mu\text{g/g}$ during the follow-up period. There were signs of Fel d 1 accumulation in the control building; the mean Fel d 1 content of four samples was $0.7 \mu\text{g/g}$ after 1 year, $17 \mu\text{g/g}$ after 2 years, and $24 \mu\text{g/g}$ after 3 years of occupancy. For Can f 1, the trend was opposite; the mean Can f 1 content was 691, 619, and $10 \mu\text{g/g}$, respectively.

Perceived IAQ and symptoms of the occupants

The perceived IAQ reported by the occupants in both the buildings is presented in Figure 2. Before the occupants moved into the case building, they experienced stuffy air (nearly 80% of occupants), unpleasant odour (about 60%), dust and dirt (about 60%), noise (about 35%), and varying temperature (about 35%) in their former dwellings. There were no significant differences in the results between the occupants with asthma and the other members of the families. After the 5-month occupancy, the indoor climate was regarded as good in both the buildings; only draught (42%) and low temperature (39%) in the case building and noise (45%) in the control building were reported. The frequency of complaints was slightly higher among the asthmatic occupants than among the other family members in the case building. During the first 2 years of occupancy, no significant disturbing IAQ factors were detected in the case building, whereas about 30–40% of the occupants in the control building complained of dry air, draught, passive smoking, and stuffy air. In the third year, the asthmatic occupants perceived dry air and draught (35 and 30%) in the case building. In the control building, the most disturbing factors were draught ($>60\%$), low temperature, passive smoking, and dry air.

The prevalence of different self-reported symptoms among the occupants in the buildings is illustrated in Figure 3. In the former dwellings, the occupants with asthma had a large variety of respiratory, skin and general symptoms. Over 60% of them reported nasal symptoms, hoarseness, and dryness of throat and fatigue. The other family members had a hoarse, dry throat, and suffered from fatigue. During the first year

in the case building, the prevalence of symptoms decreased distinctly among the asthmatic occupants; only fatigue and nasal symptoms were reported, while the other family members had only fatigue. However, the symptoms of the asthmatic occupants increased in the second and third years: 33–56% of them had nasal symptoms, cough, fatigue, skin, and eye symptoms. This kind of trend was not observed among the other family members. During the follow-up period, 22–42% of the occupants in the control building reported fatigue, skin and nasal symptoms. There were no significant differences in the prevalence of any symptoms between different periods of the questionnaire study.

Design and construction costs

The design and construction costs of the case building were compared with those of the control building. As a whole, the costs of the case building were 10% (about 96 EUR/m^2) higher than those of the control building. The distribution of the additional costs comprised the following items:

- An effective ventilation system (equipment, design, and installation work): 52%
- Drying of concrete structures from RH 90 to 85% before installation of finishing materials: 18%
- Special windows for saving heating energy and control of radiation temperature (k -value 1.1): 12%
- The use of the Finnish Classification during the construction, e.g. extra cleaning, special arrangements (separate central vacuum cleaner): 9%
- Central cleaning system: 9%.

Over 50% of the extra costs were composed of the delivery price, design and installation of the more versatile ventilation system. On the other hand, the use of classified, low-emitting building materials did not raise the costs. There were no clear differences in the operation costs between the building over the follow-up period.

Discussion

As we presented in our earlier paper (Tuomainen et al., 2001), after the completion of the buildings and after the 5-month occupancy, the levels of indoor air pollutants were throughout lower in the case building than in the control building. The largest differences between the buildings were observed in the TVOC and ammonia levels. In the case building the target S1 levels were reached by all other parameters except by the odour intensity within 5 months. We concluded that careful construction works (e.g. moisture control before installation of finishing materials and clean work in the construction site), the effective ventilation

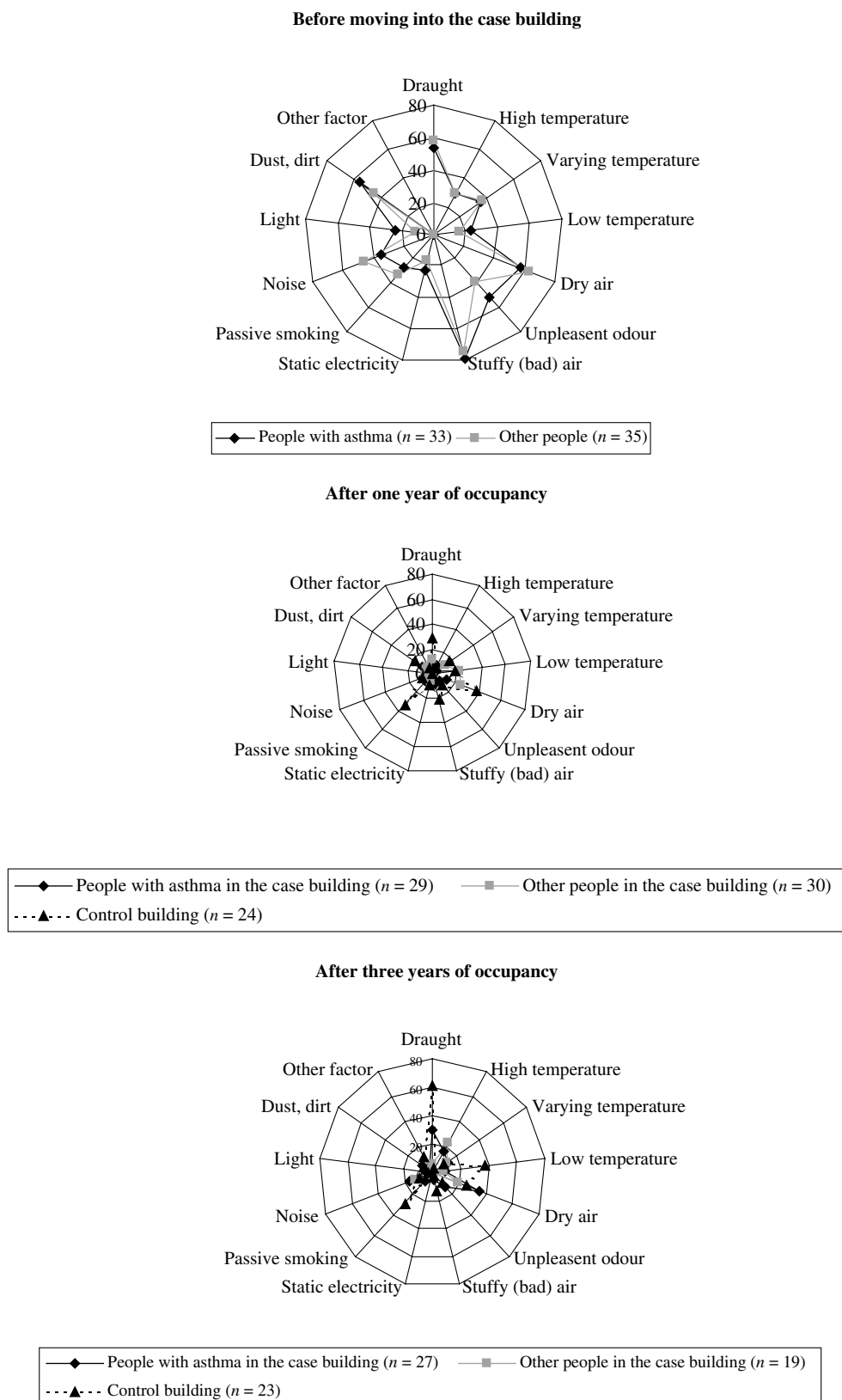


Fig. 2 The most disturbing factors in the indoor environment reported by the occupants in the case and control building before moving into (case building) and after one and three years of occupancy

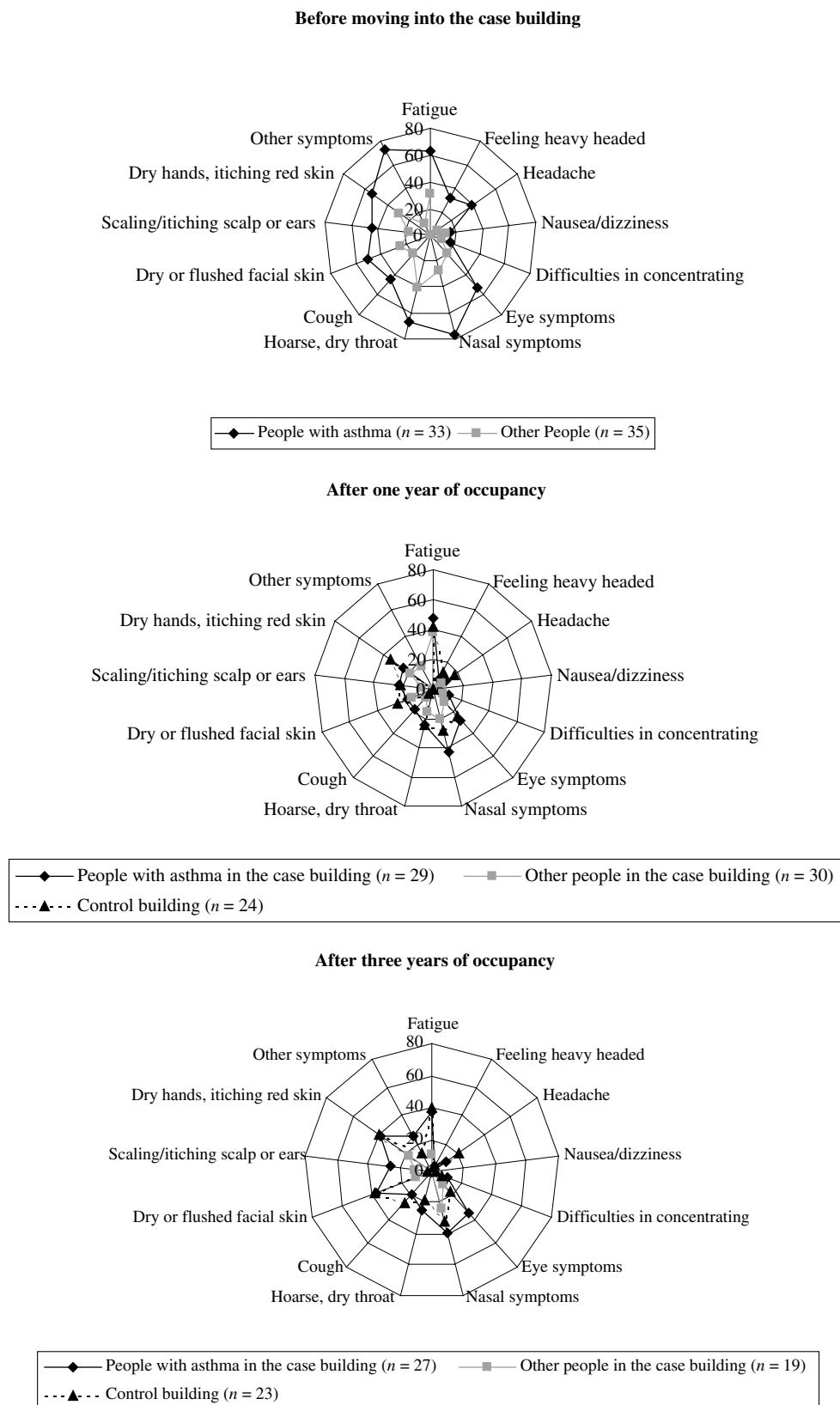


Fig. 3 The perceived symptoms reported by the occupants in the case and control building during the follow-up

system, use of low-emitting building materials, and a 1-week ventilation period before the occupants moved in resulted in the good IAQ in the case building.

(Tuomainen et al., 2001). The similar trend in the difference in IAQ between the study buildings was continued during this follow-up period up to 3 years.

We stated previously that the extra drying of concrete constructions before the installation of finishing materials mainly explained the lower ammonia levels in the case building compared with those in the control building after the completion of the buildings (Tuomainen et al., 2001). The follow-up results showed that the ammonia concentrations in the control building remained at a high level for 2 years, until a slight decrease in the concentrations was observed in the third year. In the case building, the ammonia concentrations increased temporarily above the S1 level in the second year. A detailed examination revealed that this was due to problems with the functioning of the sewer system of the building that occurred just before the IAQ measurements. Intensive cleaning during the case building construction work (e.g. the use of a separate central vacuum cleaner) and at the time of completion could also result in the lower particle counts compared with those in the control building at the beginning of the follow-up period.

Advantages of the effective ventilation system regarding IAQ in the case building are incontestable, although a lack of refrigeration and humidification in the system makes it difficult to maintain the indoor air temperature and RH at the S1 level under all sub-arctic climate conditions, e.g. in hot or cold weather, as shown by IAQ monitoring during the follow-up. Up to one order of magnitude lower levels of CO₂, airborne bacteria, fungi, and particles as well as TVOC in the case building compared with the control building during occupancy were mainly or partly influenced by a twofold higher ventilation rate (according to design values) and the controlled supply air system with efficient filtration in the case building. A decreasing effect of ventilation on levels of microorganisms, VOC, CO₂, and particles have also been reported previously (Hodgson et al., 2000; Liddament, 2000; Reponen et al., 1989, 1992; Salthammer, 1999; Seppänen et al., 1999). In this study, the filtration of supply air with an EU7 type filter obviously resulted in the lower particle counts, particularly in the size fraction of 1–5 µm and >5 µm and the lower concentrations of fungi in the case building. The similar findings were previously reported by Reponen et al. (1989, 1992), Jamriska et al. (2000), and Liddament (2000). In the control building, the mechanical uncontrollable exhaust ventilation could be a reason for a large variation in the particle counts and bacterial levels. However, the differences in air pollutant levels between the buildings cannot be explained completely by the different ventilation systems, because other factors, such as the season and occupancy, also affected the results (Luoma and Batterman, 2001; Van Winkle and Scheff, 2001). For example, the IAQ measurements in the case building in May 2000 occurred at the peak of the birch pollen season (Yli-Panula and Rantio-Lehtimäki, 1995) that

might have had an effect on the increased particle counts in the two largest size fraction. On the other hand, the higher fungal concentrations in the control building were probably due to the fact that the sampling was performed in the autumn when fungal levels are high outdoors (Reponen et al., 1992). No exceptional indoor fungal sources, e.g. water damages were found in the building.

The effect of the use of low-emitting building and finishing materials on the TVOC levels was seen immediately after the completion of the buildings, although a 1-week ventilation period further decreased the concentrations in the case building (Tuomainen et al., 2001). The efficient ventilation in the case building caused a faster drop in the TVOC levels in the course of time compared with the situation in the control building. In addition, the significantly lower SER_a values of TVOC in the case building compared with that in the control building indicate a benefit of low-emitting materials. It should be noted that the SER_a values are only estimates for emissions rates of chemicals from interior surfaces, and it is not possible to consider trends for individual compounds or to ascertain the sources of the compounds. For example, the composition of the most common VOC identified showed that the occurrence of 2-ethyl-1-hexanol became more frequent in the course of time especially in the control building (Tuomainen et al., 2001). This compound was obviously derived from vinyl carpets, because it is a hydrolyzed product from phthalate esters that are typically used as plasticizer for PVC material (Lundgren et al., 1999; Yu and Crump, 1998). Colombo et al. (1993) showed that 2-ethyl-1-hexanol may adsorb on, for example, gypsum board from its primary sources. This observation or slight degradation of the phthalate esters from the carpet may explain the delayed appearance of the compound in the buildings. On the other hand, the higher SER_a values of formaldehyde and acetaldehyde may be misleading, because aldehydes have also other sources than building materials, e.g. textiles, house-hold products, upholstered furniture, and motor vehicle exhaust (Namiesnik et al., 1992; Viskari et al., 2000). As a whole, the levels of aldehydes were low in both the buildings, and formaldehyde concentrations remained at the S1 level.

The declining trend of the TVOC levels in the course of time in both the buildings indicates that occupancy and human activities had no permanent increasing effect on TVOC levels. Different cleaning habits between the occupants in both the buildings and the use of a central vacuum cleaner in the case building might also result in differences in the TSP levels and particle counts between the buildings. Overall, the occupancy and increase in the number of indoor sources caused a gradual increase in the particle counts and bacterial levels in the case building in the course of

time. The same conclusions were earlier made by Reponen et al. (1989). It has earlier been shown that levels of Fel d 1 and Can f 1 are significantly lower in dwellings where no pets are kept than in those with a cat or dog (Raunio et al., 1998). In addition, cat allergens tend to transfer with human's clothing from place to place and to accumulate in interior spaces in the course of time (Almqvist et al., 1999; Custovic et al., 1998; D'Amato et al., 1997; Patchett et al., 1997). The results of this study also support these findings. A prohibition against keeping furred pets retained the allergen levels low in the case building, while the presence of pets caused increased allergen levels with a high variation in the control building. Low Der p 1 levels in both the buildings were explained by a choice of sampling sites (carpets instead of mattresses), low RH levels and no signs of water damages. It is well-known that reservoirs of skin scales, e.g. mattresses and bedclothes and high moisture levels (absolute humidity < 7 g/kg and < 45% RH) in the ambient microenvironment favor the proliferation of house dust mites (Emenius et al., 2000; Luczynska et al., 1998).

According to the questionnaires, the occupants who moved into the case building experienced poor IAQ in their former dwellings, and they were satisfied with the IAQ of the case building during the whole follow-up period. In the control building, the occupants perceived worse IAQ than in the case building. The odour intensity results also supported this finding; the odour intensity was lower in the case building than in the control building after 2 and 3 years of occupancy. The S1 level was not, however, achieved in the case building despite low levels of chemical pollutants, which makes it doubtful if it is possible to reach such a low level in real life. On the other hand, this refers to the fact that human sensory evaluation offers different information on IAQ than chemical measurements.

Before moving into the case building, the asthmatic occupants suffered from various symptoms in their former dwellings, and the prevalence of symptoms decreased rapidly when they moved into the case building. However, some symptoms appeared again, although with a lower frequency, during the second and third year, and the asthmatic occupants reported

symptoms more often than the other family members of the occupants in the control building. This result is logical because asthmatic people have naturally more respiratory and general symptoms than healthy people, and they might have more expectancies regarding IAQ and home environment than other family members.

The results of this project contributed to the updating of the Finnish Indoor Classification (Seppänen and Säteri, 2001). The new version of the classification pays more attention to the whole building process. It emphasizes quality certification and moisture control during the construction, and offers more detailed instructions on how to achieve clean HVAC systems e.g. manufacture, storage, and installation processes. In addition, the target values were reconsidered, e.g. the S1 values for odour intensity and ammonia were raised and the value for CO₂ was decreased (the present S1 values are 3 decipol, 30 µg/m³, and 700 p.p.m., respectively), and some new parameters (e.g. smell of tobacco in some indoor occupancies) were presented.

Conclusion

This study showed that it is possible to reach high IAQ by careful design, proper materials and equipment and high-quality construction with reasonable additional costs that are marginal in the entire lifespan of the building. In addition, the study indicated that good IAQ can also be maintained during the occupancy, if sufficient information on factors affecting IAQ and guidance on the proper use and care of equipment are available for occupants.

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