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Evaluation of low-energy and conventional residential buildings from occupants' perspective

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ABSTRACT

The aim of this paper is to investigate building performance from the occupants' perspective and to compare how the residents in low-energy multi-family buildings and conventional buildings, respectively, perceive the comfort of, and satisfaction with, indoor elements. Additionally, the study explores differences in living-in, operation and management in low-energy and conventional residential buildings. The key data was obtained by surveys sent to occupants of carefully selected comparable buildings: three low-energy and three conventional residential buildings. Responses were compared and statistical difference was tested by the Mann–Whitney test and the Kruskal–Wallis test. Findings indicate that both low-energy and conventional residential buildings have satisfied and less satisfied tenants. The occupants' satisfaction might decrease if thermal discomfort leads them to use supplementary heating; however, use of supplementary cooling does not have the same significance. Problems and concerns regarding ventilation and heating appeared in both types of buildings. Results suggest that, compared with conventional buildings, low-energy residential buildings required the same or less system adjustment, which suggests that, from a lifecycle perspective, the low-energy buildings are the better investment. Occupants' responses suggest that the "green" profile of the building has a positive impact on their environmental awareness and behaviour. This paper shows that occupants' feedback is an important part of comprehensive building performance assessment, indicating areas for improvement relevant for developers and housing managers. The presented results show that problems often identified as specific to low-energy buildings also appear in conventional buildings.

1. Introduction

With its latest directive on the energy performance of buildings [1], The European Council established new goals for members of the European Union. Article 9a Directive 2010/31/EU clearly states that "Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings". The fundamental concept of "nearly zero-energy building" combines two ideas: firstly, that the amount of energy which must be supplied to the building is very small and secondly that the energy should come from renewable sources. Technically, these goals can be reached by using passive house technologies: i.e. by building air-tight buildings and using very well insulated and highly energy-efficient materials and products, space heating requirements can be significantly reduced [2,3].However, regardless of the energy requirement, a building must deliver indoor comfort to the users and occupants.

The comfort delivered with a building is often individually customised to the occupants' preferences and liking, as occupants who find themselves in what is generally understood as thermal discomfort would seek ways to restore their comfort [4–6]. Strategies commonly used include actions such as opening windows, changing clothing (see the extensive literature on thermal comfort adaptive strategies, for example [3,6–8]), and in more extreme cases purchasing and using additional heating or cooling equipment such as electric radiators or cooling fans. Whereas the former actions are generally considered to be common adaptive behaviour, the latter can be regarded as rather "radical".

It is relevant to consider the consequences of these "extreme" actions in the context of building performance. Firstly, they suggest problems with building performance, which can be related to a number of different elements such as design, construction or the need for adjustment or fine-tuning of installed heating or cooling systems. Secondly, use of "plugged-in" heating or cooling equipment is not reflected in measured building performance records, because occupants are responsible for their own electricity usage. Thirdly, electric heating radiators may affect the quality of the

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indoor climate, contributing to dry air. Finally, since these residents need to take more 'radical' action, this may influence their perceived environmental control and hence their satisfaction [9]. In the case of low-energy buildings, these 'radical adaptive strategies' would not only suggest problems with indoor comfort, but also question the possibility of achieving the energy-efficiency goals.

One way to learn about building performance is via post-occupancy building evaluation (PROBE series see for example [29,30–32]). Post-occupancy building performance investigation in low-energy residential buildings has mainly focused on examining differences between measured and expected values of energy and water consumption [10–14]. Yet, including occupant feedback in post-occupancy building performance evaluation is very important since it is the occupant's behaviour that influences the building performance. This was showed in many studies, for example by Gill et al. [15], who correlated measured data in low-energy dwellings in the UK with occupant survey responses and concluded that tenants' behaviour is a significant factor in the deviation between calculated and observed energy consumption.

Moreover, information received form occupants allows for better understanding of measured data and capturing potential problems in building performance [16,17]. For example in a case study in Sweden [18,19], the performance of 20 terraced houses build according to passive house standards was investigated. Interviews conducted with tenants revealed that there were a few problems with the heating system, and the temperature between the different floors and between the gable and the middle dwellings differed significantly. This was later confirmed by detailed measurements.

Another measurement of building performance is occupants' satisfaction level [15,33,34]. Overall occupant feedback on low-energy buildings indicates high tenant satisfaction, although a few problems with thermal comfort and ventilation have also been reported. Occupant feedback received from users of 12 advanced solar low-energy houses [20] was generally positive; however, some tenants mentioned overheating problems while others were disturbed by noise caused by the heat pump and ventilation system. Results from occupant satisfaction in two surveys conducted in CEPHEUS projects in Germany [3] show that occupants were generally very satisfied, yet indicated some concerns about ventilation efficiency particularly with regard to "removing of odours". In Vienna, interviews conducted with tenants during studies of low-energy and passive residential blocks showed occupant satisfaction to be relatively high, yet tenants indicated concerns with humidity values in winter [21].

Till now, the studies have indicated some potential problems in low-energy building performance, although the question whether the problems are specific to this type of building or are common in residential buildings is still unanswered. The studies were based mainly on monitored data during post-occupancy evaluation, sometimes compared to expected values or building standards, but very seldom benchmarked against other building performance, particularly not against conventional building performance [12–15,20,36–39]. In particular, very little is known about occupants' satisfaction and their perception of building performance. Most comparative studies conducted in this area focused on commercial rather than on residential buildings [31,33,35,40,41].

The aim of this paper is to assess building performance from the occupants' perspective and evaluate how residents in low-energy multi-family buildings perceive the comfort of, and satisfaction with, indoor parameters compared with the perception of residents in conventional buildings. The additional aim of this study is to explore differences between living-in, operation and management of low-energy and conventional residential buildings, respectively.

In order to investigate these issues, six case studies, on three low-energy residential buildings and three conventional buildings, were carefully selected. Information about the buildings and dwellings was obtained mainly by an occupant survey and interviews with occupants and housing management companies.

2. Method and data collection

2.1. General research design

The objective of this multi-case study was to investigate occupants' satisfaction with indoor climate in low-energy and conventional residential building and to capture any differences between living-in, operation and management of low-energy and conventional residential buildings, respectively.

In order to secure sufficient data and cover the variation in number of observations, three pairs of case studies were selected. Each group included one low-energy and one conventional housing complex. Low-energy residential buildings are defined here as buildings that fulfil or almost fulfil Swedish passive house standards [22], and as conventional buildings (CH) we understand buildings that have been built according to valid building regulations and standards, which in Sweden generally refers to the Planning and Building Act (PBL) and Building Regulations (BBR).

The studied low-energy residential buildings were selected according to the following criteria:

- Multi-family residential buildings meeting or almost meeting Swedish passive house standards
- Occupants should have moved in no later than the end of 2009, allowing them to experience winter and summer in their new apartments
- Multi-family residential buildings with a relatively high number of apartments (i.e. at least 20 apartments)
- The buildings should not target one specific tenant segment (i.e. housing for the elderly and students was not considered)
- Publicly or privately owned rental apartment buildings

Some limitations arise in the approach of comparing two buildings. Even in the case of the same design, construction method and production year, every property is unique due to its location. The location of a building influences not only the attractiveness of the property, but also building performance by the difference in exposure to sun and climate conditions (such as the wind). Therefore, it was very important that conventional housing was not selected at random but carefully chosen, to allow optimal comparison with the low-energy building. It was crucial that the control buildings were located in the same region and neighbourhood, had a similar number of apartments, were of similar production year, and preferably owned and managed by the same housing companies. Finally, it was essential that buildings in the control group did not aim to excel in energy efficiency, but the goal was to fulfil general requirements of building standards and regulations in Sweden.

2.2. Description of studied buildings

The buildings are divided into three groups (pairs) according to their locations. All low-energy (LEH) and conventional (CH) housing apartments are located on the West Coast of Sweden. The size of buildings and number of apartments in the complex vary although they are comparable in pairs. For example, in location A, the low-energy building (LEH A) includes 115 apartments and the conventional building has 85 apartments (CH A), whereas in location B, the low-energy and conventional buildings comprise 32 and

38 apartments respectively. Detailed description of all six cases is presented in Table 1.

All buildings have a concrete frame construction and are equipped with a mechanical ventilation system. The LEH buildings were constructed using passive house technologies, i.e. the buildings are very well insulated and highly energy-efficient windows are installed. All low-energy buildings are equipped with a central mechanical heat-exchange ventilation system, and heated by warm supply air using the ventilation system. If the temperature of the supply air is too low, the systems use auxiliary heating supported by electricity or district heating to distribute warm air of the set temperature to each dwelling. The temperature and air flow can be centrally adjusted by the housing manager; to some extent, residents can also regulate the temperature in their apartments. Only LEH C is equipped with additional comfort floor heating in the hall and bathroom; this heating was installed to avoid a “cold floor experience”. In all conventional buildings, there is a central heating system with radiators installed in each apartment. Temperature can be individually adjusted by thermostats and centrally by the housing manager. In all buildings, water is heated by district heating, although in LEH A and LEH C approximately 30% of the total hot water heating demand comes from renewable energy generated from solar panels.

Individual metering systems for domestic electricity and water usage are installed in all LEH dwellings. Residents of LEH buildings pay a basic rent to the owner (a municipal company) and pay additional fees for individual consumption of domestic electricity, hot and cold water, and supplementary heating. In the conventional apartments, domestic electricity is individually metered, but water and heating are included in the rent and calculated according to generally used templates and factors.

2.3. Data collection

Information about the perceived satisfaction and indoor comfort was obtained by an occupant survey. The survey was addressed to all registered residents over 21 years old and sent by ordinary mail in September–October 2010. Respondents could complete the questionnaire on paper using the enclosed return envelope or on-line using an Internet link indicated in the cover letter.

The questionnaire was divided into four parts, where part 1 contained questions about the reasons the occupants had for choosing this particular building; part 2 covered their general perception of indoor climate, including thermal comfort during the summer and winter periods, and the quality of sound insulation and air. The third part included questions about residents’ behaviour and in the last part of the questionnaire a few background questions were asked. The survey took approximately 10–15 min to complete.

Each question was built as single- or multiple-choice in a structured format but also included a comment box, allowing respondents to add some information or elaborate their answer. By allowing space and encouraging personal opinions, we have been able to gather “inside” information about the quality of the building and “in-use characteristics” of the apartment [17,23]. Those voluntary answers helped to capture some of the key problems and main reasons for occupants’ satisfaction and dissatisfaction.

Information obtained about self-reported behaviour is bound to include some errors related to the questionnaire itself, such as the formulation of the question, the given choice of answers and the respondents’ memory of the perceived behaviour [24]. Respondents’ selective memory may have an impact on the results presented here; however, the aim of this study is to capture whether the phenomenon exists, and thus the very detailed information is not required.

The statistical difference in responses from different respondents groups, particularly between LEH and CH occupants, was tested by the Mann–Whitney test (the rank sum Wilcoxon test) and the Kruskal–Wallis test. Additionally, non-parametric Spearman rank correlation was conducted to test correlation between perceived general satisfaction and building quality, and perceived quality of indoor environment — air, acoustic, light and thermal, — where the thermal parameter was expressed by use of supplementary heating and cooling. An ordinary logistic regression model was fitted to responses assessing the relation between perceived general building quality and perceived quality of indoor environment elements.

Additional data about general low-energy residential building performance and about challenges in operation and maintenance was obtained by semi-structured interviews with property managers.

3. Results and discussion

3.1. Response rate

The residents of the selected buildings varied widely, from single people, families with young children, families with teenage children, to middle-aged people (usually retired). Most respondents lived in two- to four-room apartments with a kitchen. The demographic structure of the LEH and CH occupants was very similar.

The response rate was in total 50% and 42% for low-energy buildings (LEH) and conventional buildings (CH), respectively (Table 2). There is no general indication that respondents were more motivated to express their particular dissatisfaction or satisfaction with their apartment. The demographic characteristics of respondents in the study do not suggest disproportion in collected responses.

In order for the responses to be comparable, the first part of the survey contains questions regarding priorities when choosing the apartment. The main reasons for seeking a new apartment were usually private and related to new lifestyle or family issues, for example, a new baby, divorce, or changes in health or financial circumstances. The most decisive factors were acentral location, good surroundings, neighbourhood safety, ample apartment size, and good apartment design.

Occupants who chose to live in LEH indicated calculated energy requirement and environmental factors as important aspects in their decision to rent the apartment, while CH occupants indicated that those factors were somewhat less important. This difference in responses was found to be statistically significant at $p < 0.01$ level. The difference in opinions may be related to the fact that housing advertisements for LEH buildings tend to highlight environmental benefits and low energy consumption, whereas information brochures for conventional buildings do not include this kind of information. Thus, simple lack of information might be the reason for energy and environmental playing a secondary role in choosing the apartment. Interestingly, the vast majority of LEH respondents (75%) answered that the fact that their buildings were constructed as low energy buildings had no impact on the decision to rent the apartment.

We can, therefore, conclude that the same main factors influenced the decision-making for residents of both low-energy (LEH) and conventional houses (CH), suggesting that low-energy buildings had not been chosen by only “environmentally focused” tenants (Fig. 1). This observation allows for a more unbiased comparison of responses between tenants of LEH and CH.

Table 1
Detailed information about the studied buildings.

Location	Location A		Location B		Location C	
	West coast of Sweden; N 57° 42′; E 11° 58′		West coast of Sweden; N 57° 55′; E 12° 31′		West coast of Sweden, N 56° 54′; E 12° 29′	
	LEH A	CH A	LEH B	CH B	LEH C	CH C
Local	Approx. 5 km from Central Station Facing bay and inner courtyard	Approx 5 km from Central Station Facing bay and inner courtyard	Approx 2.5–3 km from Central Station, sea view, park nearby	Approx 0.5 km, central location	Approx 2 km from Central Station, close to park and	Approx 0.5 km, Central Station
Distance between LEH and CH	A few metres, neighbouring condominium		Ca 2.5 km		Ca 2 km	
Orientation	Front facade: south-east, south-west	Front facade: west, north	Front facade: north	Front facade: south-west	Front facade South-west	Front facade south west
Production year	2008	2009	2008/2009	2007/2008	2009	2004/2005
Total area	14 875 gross space	13 235 gross area	3 554 m^2 gross area	1 255 m^2 gross area	4 785 m^2 gross area[a]	–
Number of buildings	2	3	3	2	2	1
Number of stories/levels	5	4 and 5	4	3	8	3
Number of dwellings	115	85	32	38	54	42
Size of dwellings	From 1.5 room to four rooms and kitchen, from 50 m^2 to 108 m^2	From 2 to 4 rooms and kitchen From 53 m^2 to 128 m^2	From 1 to 4 rooms and kitchen From 40 m^2 to 131 m^2	From 1 to 4 rooms and kitchen From 33 m^2 to 88 m^2	From 2 to 4brooms with kitchen, from 57 m^2 to 78 m^2	From 1 to 3 rooms and kitchen, from 41 m^2 to 67 m^2
Construction elements	Pile foundations, concrete and steel framing, Walls U-factor 0.14 W/m^2K; windows triple glazing $U = 1.1$ W/m^2K Plastered façade	Pile foundations, Concrete framing and prefabricated elements Plastered façade	Concrete framing, Walls U-factor 0.16 W/m^2K; windows triple glazing $U = 1.0–0.7$ W/m^2K Plastered façade elements	Concrete framing, Bick and Plastered façade	Concrete framing Walls U-factor 0.10 W/m^2K; windows triple glazing $U = 0.9$ W/m^2K Plastered façade elements	Concrete framing, façade plastering and wood elements
Heating	Air-heating, district heating, additional electricity supported auxiliary heating in dwellings (limited usage), additional sun-panels for water heating	District heating, radiators in rooms	Air-heating, district heating	District heating, radiators in rooms	Air-heating, district heating, floor heating in bathroom and hall, additional sun-air-panels for water heating	District heating, radiators in rooms
Ventilation	Connected to air-heating system, central mechanical heat-exchange ventilation system (MVHA)	Mechanical ventilation system	Connected to air-heating system, central mechanical heat-exchange ventilation system, (MVHA)	Mix mode ventilation system	Connected to air-heating system, central mechanical heat-exchange ventilation system, (MVHA)	Mechanical ventilation system
Calculated annual energy requirement for heating	12 kWh/m^2 (heating) 13 kWh/m^2 (hot water)	Not disclosed	13 kWh/m^2 (heating)	Not disclosed	25 kWh/m^2	Not disclosed

[a] This project includes four identical multi-family buildings, in total 108 apartments. Production was divided into two stages, two buildings in each, 54 apartments. In this study, the focus is only on the first stage. Total gross area for four buildings: 9570 m^2.

Table 2
Number of questionnaires and response rate.

	LEH A	CH A	LEH B	CH B	LEH C	CH C	LEH total	CH total
Number of dwellings	115	95	32	31	54	33	201	159
Questionnaires sent	180	149	44	46	91	43	315	238
Received	94	56	19	23	42	22	156	100
Response rate	52%	38%	43%	50%	46%	51%	50%	42%

LEH – Low-energy multi-family building (housing); CH – conventional building.

3.2. Experienced temperature

On average, more LEH residents than CH residents found the indoor temperature too cold in winter; consequently, more LEH residents find it necessary to use supplementary electric heating (Fig. 2), which is significant at $p < 0.01$ level.

Satisfaction with indoor temperature during summer is nearly the same in both types of building, but CH tenants seem to use supplementary cooling somewhat more often (Fig. 3), though statistical difference in responses was found not to be significant. Interestingly, it was found that occupants under 50 years old were more likely to use supplementary cooling than those of 60 years and older ($p < 0.05$).

Overall, tenants adapted to the cooler indoor temperatures by putting on additional sweaters or socks, or sitting under a blanket. During summer, the most frequently mentioned adaptation strategies were using window shading and creating cross-ventilation by opening windows and doors. Similar findings regarding adaptive strategies of low-energy building occupants were found by Isaksson and Karlsson [18].

Detailed analysis revealed that residents of LEH B experienced the most problems with thermal comfort (See Figs. 4 and 5). As can be seen in Figs. 2–4, the statistical results might sometimes be misleading and the context of each case might have an impact on the general results. These findings are in line with conclusions presented by Leaman and Bordass [25].

3.2.1. Location A

3.2.1.1. LEH A. Residents of LEH A were generally pleased with the indoor temperature all year round (50%); however, both tenants and housing managers reported that the central ventilation and air supply system was difficult to adjust. The most exposed dwellings i.e. corner apartments of the building required higher-temperature supplied air, whereas residents of apartments located on the middle floors of the building found the temperature too high. Unfortunately, the installed system did not allow a wide enough range of adjustments for each dwelling.

Comments submitted by occupants suggest that while some residents have “no problem at all” with indoor temperature, some experienced that it was “warm all year round”, and some, on the other hand, felt a “cold floor”, “somewhat cold during winter” and “chilly sometimes”. The self-reported temperature (by tenants) during summer varied between 20 and 26 °C, and in winter between 16 and 23 °C.

During winter time, some residents found it “necessary” to use supplementary heating (11% quite often and 11% seldom or very seldom). However, a few mentioned that “it would be useful, but expensive”, so they chose not to use it. A number of tenants said that an “additional sweater” and “warm slippers” help a lot. Another adaptive strategy used by tenants was “to light more candles”.

The most troubling factor during the summer period seems to be “too high temperature in bedroom”, which made some residents use cooling fans, particularly during night time. A number of tenants liked or felt it was “absolutely necessary” to open windows. Apart from this, tenants said they wore light clothing and used window shading.

3.2.1.2. CH A. The majority of respondents in CH A (60%) were pleased with the temperature all year round; 30% indicated it was too warm in summer and 11% felt too cold in winter. The heating system in CH A was fine-tuned relatively late in the season, and tenants sometimes found the indoor temperature too high in the first winter. This was reflected in tenants’ comments stating it was

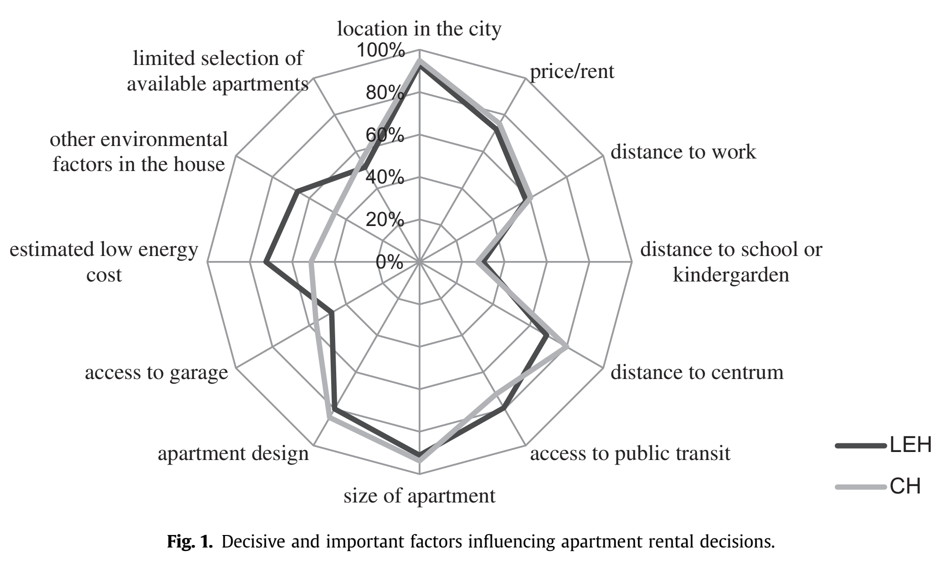

Fig. 1. Decisive and important factors influencing apartment rental decisions.

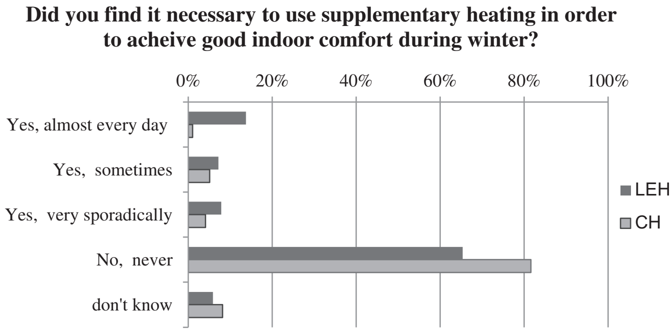

Fig. 2. Use of supplementary heating in winter.

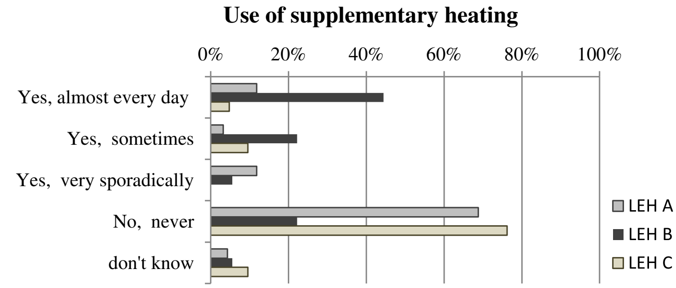

Fig. 4. Use of supplementary heating in order to achieve good indoor comfort during winter in low-energy buildings.

"too warm even in winter", "warm in winter even with opened windows". However, sporadically, occupants experienced too cold temperatures as well. The tenants' self-reported temperature in summer generally varied from 18 to 28 °C, and during winter from 18 to 27 °C.

Since effective adjustment of the heating system was made only late in the spring, most of the occupants did not feel the need to use supplementary heating (80%), although a few people (four respondents) declared having used it sometimes. On the other hand, nearly 50% of respondents stated they had (to some extent) used supplementary cooling, such as fans.

3.2.2. Location B

3.2.2.1. LEH B. Very low indoor temperatures experienced during winter were a great concern for many respondents. Tenants' self-reported temperature in winter was as low as 14–15 °C and not higher than 22 °C. These extreme conditions forced many residents (70% respondents) to use supplementary electric heating. Respondents noticed that the indoor temperature was somewhat "better" during the second winter, but still "too low". Occupants were also dissatisfied with the fact that they "needed to supplement heating and pay for it". At the time of conducting this study, the housing company was investigating the situation and assessing various solutions to this problem. Further detailed research is needed to determine at what design or building stage this problem could have been prevented. A thorough investigation is crucial; however, discussion of the probable causes of this situation and actions which can be taken to improve it is outside the scope of this paper.

During summer, 50% of respondents experienced too warm temperatures indoors and were more likely to use a supplementary cooling device (Fig. 5).

3.2.2.2. CH B. Generally, tenants who responded to our survey were pleased with the indoor temperature, although a few persons mentioned that it could become cold sometimes. Likewise in the summer period, where the majority (60%) answered that the temperature was good, a few persons indicated that it could become fairly warm. Due to higher temperatures in the summer, some people decided to use fans or an AC aggregate. The issue mentioned by tenants was the possibility to better regulate temperature particularly in the bedroom. Tenants' self-reported temperature in summer generally varied from 19 to 25 °C, and during winter between 18 and 21 °C.

3.2.3. Location C

3.2.3.1. LEH C. The majority (51%) of LEH C tenants were pleased with the indoor temperature during winter. A few, however, experienced a "cold floor" and "chilling when sitting still for longer time", but most occupants of LEH C were pleased with the thermal comfort of their apartments. Responses from LEH C described the indoor temperature in winter as evenly distributed at approximately 20–21 °C, regardless of the location of the dwelling in the building.

3.2.3.2. CH C. Opinions on indoor temperature during winter months were divided equally in CH C between those who were satisfied and those who thought it was sometimes too cold. Indoor summer temperatures were somewhat less comfortable as nearly 60% indicated that it could sometimes be too hot, leading to 30% of the respondents using cooling equipment such as a fan or AC. The self-reported indoor temperature in summer was on average 24–25 °C and in winter 20–22 °C.

3.3. Perceived quality of air, acoustic and light

LEH residents assigned relatively higher assessment scores, hence expressed higher satisfaction, with sound insulation: 69% of LEH residents described sound insulation as "very good" in comparison to 51% in CH (Fig. 6). This difference in responses was

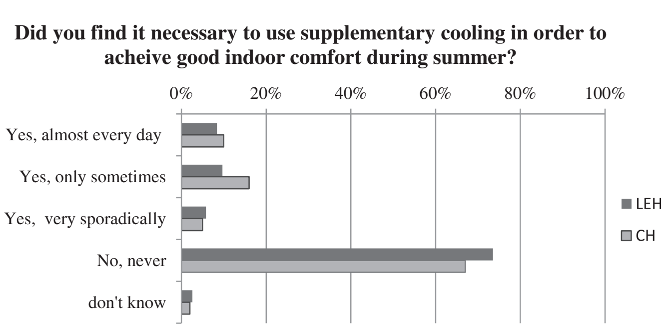

Fig. 3. Use of supplementary cooling in summer.

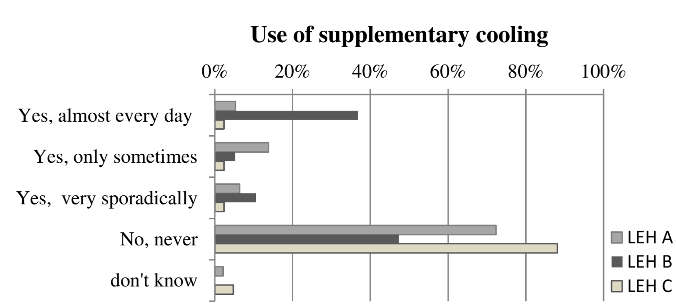

Fig. 5. Use of supplementary cooling in order to achieve good indoor comfort during summer in low-energy buildings.

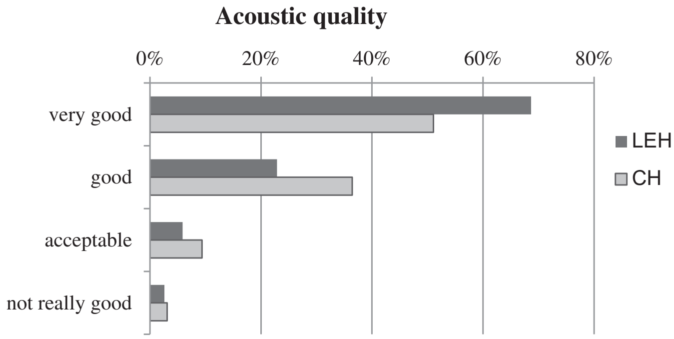

Fig. 6. Satisfaction with indoor climate, quality of sound insulation.

statistically significant at $p < 0.01$. LEH tenants appreciated the sound insulation from neighbours and outside noise, which may be largely related to the thick, well-insulated walls and high-quality windows used in LEH construction.

Air quality was marginally better scored by LEH residents, where 39% assessed air quality as “very good” compared to 26% by CH residents, although LEH negative responses were also relatively higher than those in CH (Fig. 7). Still, the difference between LEH and CH responses was found not to be statistically significant. There was, however, a statistically significant difference in responses depending on location, where occupants in location B indicated to be less satisfied with air quality than those in other locations. Satisfaction with daylight was high: approximately 90% and similar in both building types.

3.4. General satisfaction

Generally, residents are very pleased with their apartments. All buildings, except CH C, whose production year was 2004, are considered to be new production: they were constructed in 2008–2009 and the occupants in general described them as “fresh, modern and light”. Over ninety percent of the residents in locations A and C declared that they “like” or “like very much” their apartment; satisfaction with LEH apartments was marginally higher than that in CH, but not statistically significant. However, the general satisfaction with the estate in location B is much lower than in other locations (74% in LEH B and 82% in CH B), yet the Kruskal–Wallis rank test indicates the difference in responses in three locations are not significant at $p = 0.1$ level (χ^2 with tiles $p = 0.11$).

There is no significant difference in the assessment by LEH and CH respondents’ of general building quality. The vast majority of respondents described it as “good” or “very good”. The perceived quality of the buildings differed, however, depending on location, where tenants in location B indicated less satisfaction at a significance level of $p < 0.05$.

In general, the results indicate that male respondents are less satisfied with building quality than female respondents, the difference being significant at $p < 0.01$ level. There is also a significant difference in perception of general building quality depending on age, where younger respondents, below 40 years old, were more satisfied with building quality than those of 60 years old and more ($p < 0.01$).

A Spearman correlation was performed to test whether the fact that occupants used supplementary heating or cooling had an impact on the general satisfaction and perceived building quality. These perceptions were correlated with five parameters: two variables related to thermal comfort (supplementary heating and cooling), and perceived quality of air, acoustic and light. The correlation between the factors was rather weak but significant, except for the correlation between supplementary cooling and general satisfaction and perceived building quality, respectively. These correlations were found to be not significant, indicating that general occupants’ satisfaction will not decrease should they need to use, for example, a fan or AC during summer (See Table 3). However, occupant satisfaction may decrease if the occupant needs to use additional heating during winter.

The results presented are in line with other studies. Frontczak et al. [26] has also found positive correlation between indoor environment parameters and acceptability of overall indoor environment. The reported correlation between factors was stronger, though similar to that in the present study, which indicates that air, sound, light and thermal comfort have an impact on occupants’ general satisfaction.

Ordinary logistic model regression was fitted to the results to test the relation between indoor environment elements and perceived general satisfaction. The results (Table 4) indicate that sound quality and use of supplementary cooling have no statistical significance on general satisfaction. However, should the occupant use supplementary heating, it is more likely that his or her general satisfaction decreases. Results also suggest that an occupant that is

Table 3
Spearman correlation coefficients (*should occupant use supplementary heating, the satisfaction deceases).

Parameter	Occupants general satisfaction Coefficients (p)	Perceived building quality Coefficients (p)
Use of supplementary cooling	−0.1069 (0.1199)	−0.0408 (0.5522)
Use of supplementary heating	−0.1736 *(0.0112)	−0.1799 (0.0082)
Perceived sound insulation quality	0.2845 (0.0000)	0.2157 (0.0015)
Perceived light quality	0.2659 (0.0001)	0.2081 (0.0022)
Perceived air quality	0.3820 (0.0000)	0.2730 (0.0000)

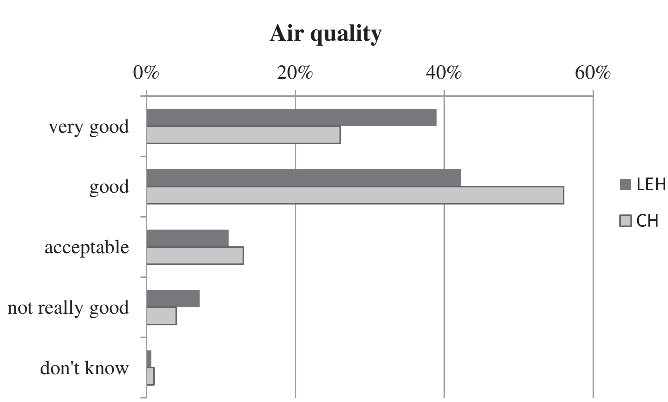

Fig. 7. Satisfaction with indoor climate, air quality assessment.

Table 4
Ordinary logistic regression model between general satisfaction and light, air, sound insulation quality as well as usage of supplementary heating and cooling, $N = 215$; $\chi^2 = 40.78$.

	Coefficient	Standard deviation	Z	p
Light quality	0.4161	0.2086	1.99	0.046
Air quality	0.7149	0.1932	3.70	0.000
Acoustic quality	0.2712	0.2046	1.33	0.185
Supplementary heating	−0.5049	0.1493	−3.38	0.001
Supplementary cooling	0.0665	0.1562	0.43	0.670

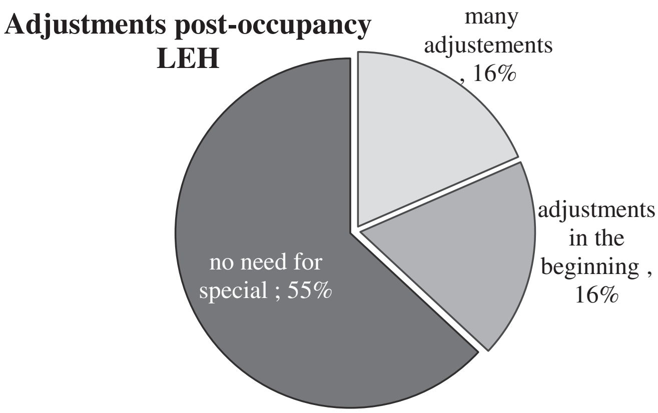

Fig. 8. Required system adjustments low-energy buildings (LEH).

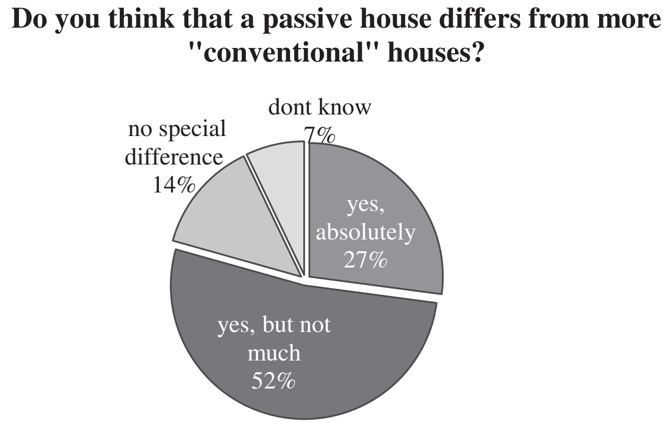

Fig. 10. General difference between LEH and CH.

satisfied with air quality is more likely to experience higher general satisfaction. Results confirm the relation between general satisfaction and perceived quality of indoor comfort, although findings should be interpreted with caution, particularly due to the sample size.

3.5. Technical issues

Installing the most accurate heating system in low-energy buildings is crucial, both to provide residents with good thermal comfort and from a financial perspective. A system that needs constant adjustment and operator attention affects management and operation costs. The studied housing management companies stated that LEH buildings did not generally require more system adjustments than did conventional buildings. They pointed out that auxiliary heating inefficiency and challenges in adjusting the air flow in forced-air heating systems were among the most important problems encountered in LEH management and operation. Additionally, actual costs were observed to be in line with estimates, and were at least 40% lower than those in conventional houses.

On the whole, LEH tenants described positively the minimal system adjustments that were necessary; rather, it was in the CH buildings that more intrusive adjustments were needed (Figs. 8 and 9), this difference in responses being significant at $p < 0.1$ level. No statistically significant difference was found between the opinions of LEH and CH occupants regarding difficulty of technical equipment. The older people (age 60 and more) were more likely to find equipment complicated to use ($p < 0.05$).

The main problematic issue that was highlighted in all buildings was the ventilation system. The most troublesome was the spread of cooking fumes through the ventilation system into other apartments. LEH occupants, in general, were happier with the ventilation system than were CH occupants. Some tenants in low-energy and conventional buildings described the air as dry, but this characterisation was more often used in LEH. A few LEH residents complained about problems with kitchen exhaust fans, the low suction of which could be related to very air-tight building construction, creating under-pressure in parts of the dwellings.

3.6. Behaviour

Interestingly, even though the low-energy profile of a building had a limited influence on the decision to rent the apartment, LEH residents were generally proud to live in environmentally friendly buildings. Moreover, they also suggested that living in the energy-efficient buildings increased their environmental awareness (self-reported), making their behaviour more environmentally friendly.

In general, most LEH residents stated that there is some difference between low energy buildings and conventional buildings (Fig. 10). Approximately one third of LEH residents said that the difference between low-energy and conventional houses with regard to occupant behaviour is rather small. Two main differences

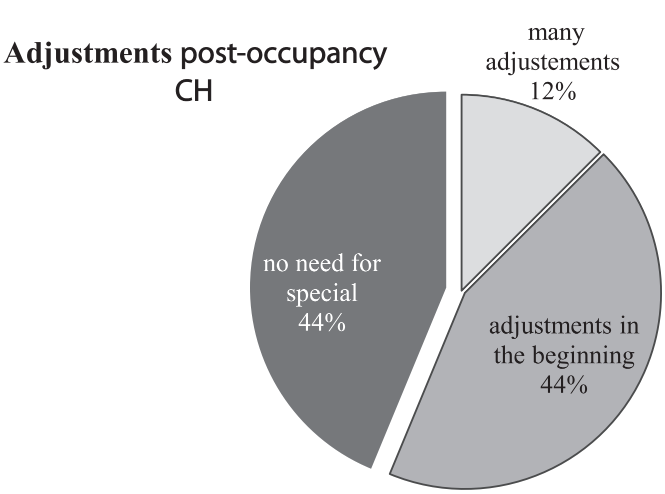

Fig. 9. Required system adjustments conventional buildings (CH).

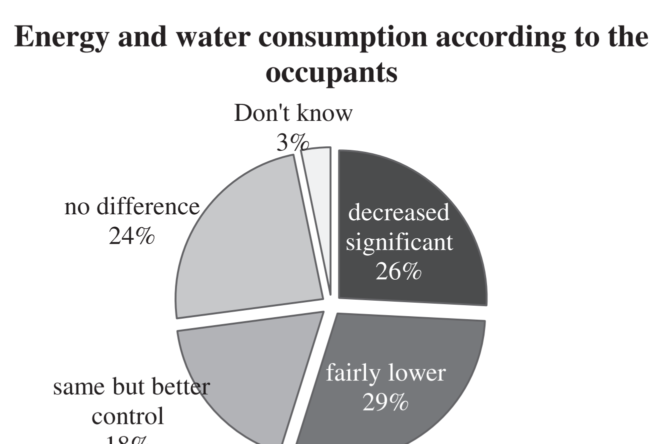

Fig. 11. Effect of individual metering on energy and water consumption in LEH.

have been mentioned: clothing habits and awareness of energy and water consumption. LEH residents often wore sweaters and slippers, and used blankets, especially when sitting still for longer periods of time. For most respondents, this behavioural change was not expressed as a problem, but simply a general observation.

On the other hand, greater control and awareness of energy and water consumption was clearly a positive attribute. This was mainly due to the individual metering systems installed in LEH buildings, but some tenants said they paid more attention to their consumption due to the environmental profile of the building. Overall, fifty percent of the LEH residents believed they generally spent less on energy and water consumption than they would otherwise (Fig. 11).

4. Conclusions

Conventional and low-energy residential buildings in Sweden were compared based on occupant survey results and housing management company feedback. Evidence reviewed here indicates that occupants can provide important feedback on building performance and call attention to good and bad solutions. Even though survey data could not been triangulated with in-use measures and results may carry a certain weight of subjectivity, the results of this study are interesting and worth discussing as they demonstrate occupant opinion and indicate some potential challenges regarding the performance of residential buildings in general.

The findings indicate that satisfied and less satisfied tenants live in both types of buildings, low-energy and conventional. Statistical analysis indicates that the occupants' satisfaction may decrease if thermal discomfort leads tenants to use supplementary heating, but use of supplementary cooling does not have the same significance. The occupants in low-energy buildings ranked air quality and sound insulation higher than that in conventional building. The indoor comfort was generally considered good or very good, even though some problems regarding ventilation systems and space heating were reported. However, those concerns were expressed in both types of building.

The results of the study provide further support for adaptive model theory, as occupants sought adaptive opportunities and applied behaviour adaptation strategies, such as changing clothes, using window blinds, or opening windows. However, in the cases when indoor temperature did not fulfil expectations and comfort could not be gained by common adaptive strategies, occupants considered or even used supplemental heating/cooling equipment to achieve thermal comfort. Those actions occurred in low-energy buildings but also in conventional buildings.

The study provides valuable information for prospective investors and owners regarding the financial implications of building operation costs (e.g. energy cost) in low-energy buildings. Since the actual costs were observed to be in line with estimates, and were at least 40% lower than in conventional houses [27] and low-energy residential buildings required system adjustment that was the same as, or less than, that in conventional buildings, this suggests that, from a lifecycle perspective, the low-energy buildings are a better investment. On the other hand, reported problems with ventilation and space heating suggest that comprehensive post-occupancy evaluation is essential for improving the quality of developments and correcting errors which occur repeatedly in housing projects.

It is worth mentioning that the latest changes in Building Regulations in Sweden instruct housing developers to follow energy consumption during the first two years after occupancy [28]. However, it is expected that this assessment will be mainly based on metering the total energy consumption required for the building operation (electricity, hot water and heating, excluding household electricity consumption) rather than comprehensive post-occupancy assessment. It could, however, be argued that conducting a comprehensive assessment which includes occupant feedback can be more informative and relevant to the developer than only analysis of relative measures.

Finally, recognizing the importance of national environmental goals and in view of European building performance policy [1], the present results are valuable to policy makers. The results indicate that environmental issues are not really the primary concern when people choose to rent an apartment. However, the fact that low-energy buildings are more environmentally friendly gives residents greater post-occupancy satisfaction and fosters greater environmental awareness.

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References

[1] European Parliament and Council. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Off J Eur Union 2010;L153/13.
[2] Feist W, Schnieders J, Dorer V, Haas A. Re-inventing air heating: convenient and comfortable within the frame of passive house concept. Energ Build 2005; 37:1186–203.
[3] Schnieders J, Hermelink A. CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. Energy Policy 2006;34:151–71.
[4] Nicol F, Roaf S. Post-occupancy evaluation and field studies of thermal comfort. Build Res Inform 2005;33(4):338–46.
[5] Shove E, Chappells H, Lutzenhiser L, Hackett B. Comfort in a lower carbon society. Build Res Inform 2008;36(4):307–11.
[6] de Dear R. Revisiting an old hypothesis of human thermal perception: alliesthesia. Build Res Inform 2011;39(2):108–17.
[7] de Dear R, Brager G. Developing and adaptive model of thermal comfort and preference. ASHRAE Trans 1998;104(1):145–67.
[8] Gossauer E, Wagner A. Post-occupancy evaluation and thermal comfort: state of the art and new approaches. Adv in Build Energ Res 2007;1:151–75.
[9] Leaman A, Bordass B. Productivity in buildings: the 'killer' variables. Build Res Inform 1999;27(1):4–19.
[10] Wall M. Energy-efficient terrace houses in Sweden: simulations and measurements. Energ Build 2006;38(6):627–34.
[11] Wojdyga K. An investigation into the heat consumption in a low-energy building. Renewable Energy 2009;34:2935–9.
[12] Kalz D, Herkel S, Wagner A. The impact of auxiliary energy on the efficiency of the heating and cooling system: monitoring of low-energy buildings. Energ Build 2009;41:1019–30.
[13] Molin A, Rohdin P, Moshfegh B. Investigation of energy performance of newly built low-energy buildings in Sweden. Energ Build 2011;43:2822–31.
[14] Dall' OG, Sarto L, Galante A, Pasetti G. Comparison between predicted and actual energy performance for winter heating in high-performance residential buildings in the Lombardy region (Italy). Energ Build 2012;47:247–53.
[15] Gill Z, Tierney M, Pegg I, Allan N. Low-energy dwellings: the contribution of behaviours to actual performance. Build Res Inform 2010;38(5):491–508.
[16] Leaman A, Stevenson F, Bordass B. Building evaluation: practice and principles. Build Res Inform 2010;38(5):564–77.
[17] Gupta R, Chandiwala S. Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. Build Res Inform 2010; 38(5):530–48.
[18] Isaksson C, Karlsson F. Indoor climate in low-energy houses—an interdisciplinary investigation. Build Environ 2006;41:1678–90.
[19] Karlsson J, Moshfegh B. A comprehensive investigation of a low-energy building in Sweden. Renewable Energy 2007;32:1830–41.
[20] Thomsen K, Schultz J, Poel B. Measured performance of 12 demonstration projects—IEA Task 13 "advanced solar low energy buildings". Energ Build 2005;37:111–9.
[21] Mahdavi A, Doppelbauer E-M. A performance comparison of passive and low-energy buildings. Energ Build 2010;42:1314–9.
[22] Forum for Energieffektiva Byggnader, FEBY. FEBY Kravspecification för passivhus. City, Sweden: FEBY; 2009.
[23] Fink A. How to conduct surveys, a step-by-step guide. 4th ed. USA: SAGE Publications Inc.; 2009.
[24] Schwarz N, Oyserman D. Asking questions about behavior: cognition, communication, and questionnaire construction. Am J Evaluation 2001;22(2):121–60.
[25] Leaman A, Bordass B. Are users more tolerant of 'green' buildings? Build Res Inform 2007;35(6):662–73.
[26] Frontczak M, Andersen R, Wargocki P. Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing. Build Environ 2012;50:56–64.

[27] Zalejska-Jonsson A, Lind H, Hintze S. Low-energy versus conventional residential buildings: cost and profit. J Eur Real Estate Res 2012;5(3).
[28] Boverket. Regelsamling för byggande, BBR. Supplement fabruari 2009. 9 Energihushållning. Karlskrona, Sweden: Boverket; 2009.
[29] Bordass B, Cohen R, Standeven M, Leaman A. Assessing building performance in use 2: technical performance of the probe buildings. Build Res Inform 2001; 29(2):103–13.
[30] Leaman A, Bordass B. Assessing building performance in use 4: the probe occupant surveys and their implications. Build Res Inform 2001;29(2):129–43.
[31] Gou ZH, Lau S, Chen F. Subjective and objective evaluation of the thermal environment in a three-star green office building in China. Indoor Built Environ 2012;21(3):412–22.
[32] Stevenson F, Rijal HB. Developing occupancy feedback from a prototype to improve housing production. Build Res Inform 2010;38(5):549–63.
[33] Lee YS, Kim SK. Indoor Environmental quality in LEED-certificated buildings in the U.S. J Asian Architect Build Eng 2008;7(2):293–300.
[34] Abbaszadeh S, Zagreus L, Lehrer D, Huizenga C. Occupant satisfaction with indoor environmental quality in green buildings. In: Proceedings of healthy buildings; 2006. Lisbon, p. 365–70.
[35] Kalz DE, Pfafferott J, Herkel S, Wagner A. Building signatures correlating thermal comfort and low-energy cooling: in-use performance. Build Res Inform 2009;37(4):413–32.
[36] Gill Z, Tiernet M, Pegg I, Allan N. Measured energy and water performance of an aspiring low-energy/carbon affordable housing site in the UK. Energ Build 2011;43:117–25.
[37] Filippin C, Beascochea A. Performance assessment of low-energy buildings in central Argentina. Energ Build 2007;39(5):546–57.
[38] Karlsson J, Moshfegh B. Energy demand and indoor climate in a low energy building-changed control strategies and boundary conditions. Energ Build 2006;38(4):315–26.
[39] Rosa DA, Christensen JE. Low-energy district heating in energy-efficient building areas. Energy 2011;36(12):6890–9.
[40] Paul WL, Taylor PA. A comparison of occupant comfort and satisfaction between a green building and a conventional building. Build Environ 2008; 43(11):1858–70.
[41] Zhang YF, Altan H. A comparison of the occupant comfort in a conventional high-rise office block and a contemporary environmentally-concerned building. Build Environ 2011;46(2):535–45.