Parameters contributing to occupants' satisfaction: Occupants' insights into green and conventional residential buildings

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Purpose

The aim of this paper is to investigate the overall satisfaction of occupants of green and conventional residential buildings and their perception of indoor environment quality (IEQ) and to study factors that may cause occupants' dissatisfaction.

Method

Data was collected through a survey sent to occupants of comparable green and conventional multi-family buildings. The difference in responses between occupants of green and conventional buildings was analysed using a Mann-Whitney (rank sum) test. The ordered logistic models were applied to the data to test whether the overall satisfaction changes depending on the level of acceptance of indoor environment quality and whether the building environmental profile and the apartment tenure affect occupant satisfaction.

Findings

The results show that both categories of occupants are very satisfied with their apartments and that there is no statistically significant difference between the stated overall satisfaction of occupants living in green and conventional buildings, although a difference was found in acceptance level for thermal and sound quality. The research highlights the importance of occupant feedback, user-friendly technical installations and the ability to control indoor environment. This knowledge is important for designers, engineers and developers alike in enabling them to improve dwelling quality and minimize post-occupancy problems.

Research limitations

It was not possible to include physical measurements of IEQ parameters; the analysis is based only on occupants' responses, which may carry a certain subjectivity.

Originality

The paper contributes to the understanding of IEQ from occupant perspective and to knowledge on green building performance.

Keywords: occupants' satisfaction, green buildings, indoor environment quality (IEQ), overall satisfaction, sustainability

Paper type: research paper

1. Introduction

The built environment has been identified as one of the greatest contributors to global energy use and greenhouse gas emissions, but also as the industry that holds the greatest potential for improvement. The response of the construction industry was a "green wave" (Kibert, 2008), lifting environmental awareness and engagement to the strategic level. The environmental commitment has been applied in practice, and buildings constructed with the goals of minimizing environmental impact and maximizing efficient use of resources are often referred to nowadays as green or sustainable buildings. However, combining best practice for economic, social and environmental aspects in the built environment required rather a high level of commitment and confidence, and green construction struggled to find its momentum. The reluctance towards building "green" was associated with a degree of uncertainty regarding return on investment, satisfaction with indoor environment and total environmental impact (Winther and Hestnes, 1999; Leaman and Bordass, 2007; Karlsson and Moshfegh, 2007, Mahdavi and Doppelbauer, 2010; Issa et al. 2010). This called in question the three fundamental aspects of sustainability: economic, environmental and social.

During the last decade, many research projects have investigated whether the above-mentioned concerns were justified. The findings indicate that construction cost for what are generally considered green buildings was higher than for conventional buildings (Mathiessen and Morris, 2004; Schnieders and Hermelink, 2006; Zalejska-Jonsson et al, 2012), but the environmentally profiled buildings transact a sale premium on the commercial (Dermisi 2009; Miller et al., 2009, Eichholtz et al, 2010, Fuerst and McAllister, 2011;) and residential market (Banfi, Farsi et al. 2008; Bloom et al., 2011; Brounen and Kok, 2011).

Schnieders and Hermelink (2006) argued that buildings constructed according to the passive house concept fulfil three-dimensional sustainability goals. The authors concluded that, by achieving very low energy demand, "user-oriented design" and high indoor quality, passive house buildings meet social, economic and environmental expectations. Comparison between low-energy and passive house building indicated that the considerable difference in space heating demand and somewhat better indoor conditions offered by passive house building offset the higher embodied energy and initial construction cost (Mahdavi and Doppelbauer 2010). On the other hand, D.S. Parker's (2009) study indicates that while constructing environmentally profiled buildings like passive and zero energy buildings, efficiency may be over-emphasized, which may result in failing to achieve an economic advantage.

However, some research showed that green building performance does not always reflect expectations (Abbaszadeh et al 2006; Leaman and Bordass 2007; Paul and Taylor 2008, Monfared and Sharples, 2011; Deuble and de Dear, 2012; Gou Z., et al. 2012). Investigation of residential dwellings in Sweden indicated problems with heating system efficiency and temperature variation (Isaksson and Karlsson 2006; Karlsson and Moshfegh 2007; Zalejska-Jonsson, 2012) and reported problems with overheating and dissatisfaction with the efficiency of the cooling system (Leaman et al., 2007; Armitage et al., 2011). Some problems with the efficiency of the ventilation system were also reported (Schnieders and Hermelink, 2006; Monfared and Sharples, 2011).

A study on low-energy and conventional rental residential buildings in Sweden (Zalejska-Jonsson, 2012) showed that HVAC systems can be challenging to commission, and adjusting the system to occupants' needs requires attention and knowledge from housing managers. The literature has also indicated a gap between occupants' behaviour and their expectations of system efficiency and functionality (Brown and Cole, 2009; Gupta and Chandiwala ,2010; Stevenson and Leaman, 2010; Gram-Hanssen 2010). Thus, a general misunderstanding of how the HVAC system works or an incomplete commissioning of the system may be comprehended by occupants as due to ineffective operation, which would negatively impact their satisfaction. Consequently, we may hypothesize that building performance and occupants' satisfaction can be affected by the owner's ability to ensure effective operation.

This paper contributes to the discussion on green building value by investigating the impact of perceived indoor environment quality on occupants' satisfaction. Contrary to earlier research that studied occupants' satisfaction in green and conventional residential buildings, which was based on single or pair case studies (ex. Isaksson and Karlsson, 2006; Sawyer et al, 2008;), this paper presents results from quasi-experimental research where seven green and seven conventional buildings were selected as study objects. Considering that occupants have a distinctive knowledge of building performance, knowledge that was acclaimed through interaction between occupants and the building (Nicol and Roaf, 2005), the paper uses survey responses received from occupants to examine the effect that the "green" factor may have on their satisfaction. The analysis is based on 477 survey responses, which allows us to apply quantitative analysis and therefore to test the statistical significance of the effect of green building on occupants' satisfaction and acceptance of indoor quality. Additionally, by investigating buildings with both rental and owned apartments, we were able to study whether apartment tenure may have an effect on the difference between green and conventional buildings.

The paper takes part in the discussion on factors impacting occupants' perceived indoor environment quality and overall satisfaction (Humphreys, 2005; Lai and Yik, 2009; Frontczak et al. 2012a)and contributes to the broad literature on post-occupancy and occupant behaviour.. It relates to the debate and theories on preferences and practices of indoor environment comfort (Brager and de Dear 1998; Chappells and Shove 2005; de Dear 2011).

2. Method

2.1. Study design

We have applied a quasi-experimental methodology (Bohm and Lind, 1993) to capture differences between occupants' overall satisfaction and perception of indoor environment depending on building environmental profile. In this approach, objects are selected and grouped in such a way that all the relevant independent variables match except for the variable whose effect the researcher attempts to study (Nyström 2008). A quasi-experimental method has been applied in various scientific studies from psychology to analysis of policies, industries and services (Bussing 1999; Reed and Rogers 2003; Eliopoulos, Harris et al. 2004; Atterhög 2005).

The green and conventional residential buildings were carefully selected and paired in such a way that building characteristics were comparable and only differed in energy and environmental performance. While selecting and matching buildings, two principal rules were established. Firstly, a “green” building was defined as a building designed and constructed with high energy-efficiency or environmental goals. Only buildings with very low energy requirement (close to passive house standard) and buildings registered or certified according to a building environmental scheme were considered as “green”. It was imperative that the control building, i.e. the conventional building, was constructed according to current Swedish Building Regulations, but did not aim at better environmental or energy performance. Since the study focused on newly constructed residential buildings, fine-tuning and some operational adjustments were expected to be necessary and therefore our second rule was that each building under study had to have been in operation for at least one year. This requirement ensured that most of the occupants were able to experience each season at least once.

2.2. Data collection

Data collection in 2012 took place in two periods: May - June and September - October. The survey was sent by regular mail to all occupants of the selected buildings, who at the time of the survey were at least 21 years old. The envelope was addressed to individuals and included a cover letter, survey questionnaire and return envelope. The particulars (name and address) were obtained from a publicly accessed online database. Persons invited to participate in the survey could submit their answers in paper form using the return envelope or answer online using the link indicated in the cover letter. All participants were offered a gratuity in the form of a scratchcard costing approx. 0.3 euro. Only respondents who submitted their contact details received a letter of appreciation and a gratuity. All participants were ensured that responses would be treated as anonymous. In order to fulfil this promise, the names and other details were kept confidential and filed separately.

The participants were asked to answer the survey within 10 days. A reminder was sent to non-respondents two weeks after the first invitation letter. Answers received in paper form were manually added to the database. The survey conducted in 2012 was addressed to 1200 persons and 477 responses were received, which resulted in 40% of the total response rate. Detailed information about the response rate for each building is presented in table 1.

Table 1. Response rate

green/ conventional	ownership/ rental	questionnaire sent	response	response rate	pair number	Survey date
Green	Ownership	35	18	51%	1	2012 spring
Green	Ownership	21	14	67%	2	2012 spring
Green	Ownership	55	24	44%	3	2012 spring
Green	Ownership	58	31	53%	4	2012 autumn
Green	Ownership	63	35	56%	5	2012 autumn
Green	Rental	175	63	36%	6	2012 autumn
Green	Rental	53	14	26%	7	2012 autumn
Conventional	Ownership	91	38	42%	1	2012 spring
Conventional	Ownership	47	28	60%	2	2012 spring
Conventional	Ownership	63	38	60%	3	2012 spring
Conventional	Ownership	85	33	39%	4	2012 autumn
Conventional	Ownership	85	30	35%	5	2012 autumn
Conventional	Rental	196	56	29%	6	2012 autumn
Conventional	Rental	173	55	32%	7	2012 autumn
Conventional	Rental	369	111	30%		
Green	Rental	228	77	34%		
Total	**Rental**	**597**	**188**	**31%**		
Conventional	Ownership	371	167	45%		
Green	Ownership	232	122	53%		
Total	**Ownership**	**603**	**289**	**48%**		
Total	**Conventional**	**740**	**278**	**38%**		
Total	**Green**	**460**	**199**	**43%**		
Total		**1200**	**477**	**40%**		

2.3. Survey design and questionnaire

The questionnaire was developed by the authors and based on a questionnaire used in a previous study (Zalejska-Jonsson, 2012). The survey questionnaire is divided into four sections and consists of in total 33 questions. The first part investigated which factors impacted customer purchasing decisions (3 questions) and the second part focused on occupants' overall satisfaction with their apartment and perception of indoor environment quality (17 questions). The third part aimed at obtaining information about respondents' perception of building environmental certification and willingness to pay for buildings with an environmental profile (6 questions). The final section asked a few background questions (7 questions). The questionnaire included structured, closed questions, single- or multiple choices. Respondents were offered the possibility of placing their comments in the spaces assigned in each question. This paper focuses mainly on responses regarding overall satisfaction and perceived indoor quality and background questions. Table 2 presents examples of questions investigating perceived overall satisfaction and perceived indoor environment quality.

Table 2. Examples of survey questions

	Question	possible answers
Overall satisfaction	What is your general opinion about your apartment?	very satisfied (5)* satisfied (4) acceptable (3) dissatisfied (2) very dissatisfied (1)
Indoor environment quality	How would you describe Thermal Quality /Air Quality / Sound Quality/ Day Light Quality in your apartment?	very good (5) good (4) acceptable (3) bad (2) very bad (1)
Problems	Did you find it necessary to use supplementary heating [equipment] in order to achieve good indoor comfort during winter?	yes, almost every day (4)** yes, sometimes (3) yes, only once or twice (2) no, never (1)
	Did you find it necessary to use supplementary cooling [equipment] in order to achieve good indoor comfort during summer?	yes, almost every day (4)** yes, sometimes (3) yes, only once or twice (2) no, never (1)
	Did you experienced problems with following: • dry air • fumes from cooking own food • fumes from neighbours' cooking • noise from ventilation or fans • outdoor noise • indoor noise e.g. neighbours' TV • difficulty in controlling indoor temperature	yes, very often (3)*** yes, sporadically/sometimes (2) no, never (1)

*Questions regarding perceived satisfaction offered answers on a five-step scale from very good to very bad, numbers in brackets indicate values assigned in the analysis.

**Questions regarding use of supplementary heating/cooling offered alternatives on a four-step (frequency) scale

*** Questions regarding potential problems experienced by occupants offered alternatives on a three-step scale.

2.4. Limitations

The method adopted in this study is subject to some limitations and potential errors related to the questionnaire itself. As in our earlier study (Zalejska-Jonsson, 2012), we have attempted to pair buildings as closely as possible, with regard to building location, size, production year and potential customer segment. However, each property is unique in form, design and exposure to local climate conditions. These elements may have an effect not only on building performance, but also on occupants' opinions.

Secondly, buildings described in this paper were specifically chosen due to their characteristics and not randomly selected. This addresses issues with comparability, but results should be interpreted with caution.

Finally, we were not able to collect in-use data (such as energy consumption) and cross-reference with survey responses. Consequently, our analysis is solely based on occupants' responses, which may include errors related to the formulation of the questions, respondents' subjective opinion and their selective memory (Schwarz and Oyserman 2001).

2.5. Brief description of buildings

The buildings were selected and paired in such a way that building characteristics were comparable and only differed in energy and environmental performance. The studied cases included multi-family buildings with rental apartments (owned by municipal companies) and condominiums, with apartments owned by tenants.

All the selected green apartments are very-low-energy buildings. The green buildings were constructed in line with the passive house concept and the majority of the green buildings fulfilled or almost fulfilled Swedish passive house standard. The green buildings used higher thermal insulation, higher energy-efficient windows (at least 0.9 W/m2K) and achieved higher air-tightness of the building envelope ($n<0.6h^{-1}$ at ±50Pa). The majority employ air heating and are equipped with efficient waste heat recovery systems. However, each building is characterized by a specifically designed heating and cooling system (HVAC). The HVAC system differs in design, placement of supply-air devices, location of temperature sensors, installed aggregate, and steering and control system.

In general, the conventional buildings were connected to a district heating network and equipped with a standard heating system with thermostat-controlled radiators. Forced ventilation was installed in kitchens and bathrooms. It was understood that conventional buildings were built according to applicable Swedish Building Regulations.

There was also a noticeable difference in design and installed system between owned and rental buildings. The system installed in the buildings with rental apartments were mainly centrally operated and managed by the housing managing organization appointed by the building owner. The heating and cooling systems installed in buildings with owned apartments were semi-central or individually controlled (see table 3).

The differences between design, construction and applied HVAC system may be expected to have an impact on occupants' perception of indoor environment quality. Based on earlier studies (ex. Engvall et al., 2004), we anticipate that occupants' responses may indicate potential problems in building performance; however, the study did not focus on investigating the difference in indoor environment in relation to the technical solutions employed and did not aim at conducting building performance evaluation. Therefore, the paper is limited to general discussion only and does not provide a detailed evaluation of the technical solutions used in the buildings.

Table 3. Brief description of buildings

pair number	green/ conventional	ownership/ rental	location	number of dwellings	production year	heating system
1	Green	Ownership	East Coast	20	2010 autumn	individual, air heating
2	Green	Ownership	West Coast	25	2010 summer	individual, air heating
3	Green	Ownership	West Coast	28	2010 autumn	semi-central , air heating
4	Green	Ownership	East Coast	37	2011 autumn	individual, air heating
5	Green	Ownership	East Coast	36	2011 autumn	semi-central, radiators
6	Green	Rental	East Coast	97	2010 autumn	central, air heating
7	Green	Rental	East Coast	32	2011 winter	central, air heating
1	Conventional	Ownership	East Coast	57	2010 autumn	semi-central, radiators
2	Conventional	Ownership	West Coast	57	2008 autumn	semi-central, radiators
3	Conventional	Ownership	West Coast	40	2011 winter	semi-central, radiators
4	Conventional	Ownership	East Coast	60	2011 autumn	semi-central, radiators
5	Conventional	Ownership	East Coast	53	2011 summer	semi-central, radiators
6	Conventional	Rental	East Coast	100	2011 summer	central, radiators
7	Conventional	Rental	East Coast	95	2011 winter	central, radiators

2.6. The data analysis

2.6.1. Difference in responses between occupants of green and conventional buildings

The analysis of the data was conducted in five steps. In the first step, descriptive statistics were used. Secondly, the statistical difference in responses from occupants of green and conventional buildings was tested by the Mann-Whitney (rank sum) test. The data has been divided into two groups: owned and rental apartments, and consequently, the difference in responses between green and conventional buildings was tested within those groups as well.

2.6.2. Occupants' satisfaction and acceptance of indoor environment

In the third step, a statistical model was fitted to the data to examine the contribution of perceived indoor quality to occupants' overall satisfaction. An ordered logistic regression was chosen due to the nature of the data, which has ordered categories measuring opinion and frequency using a rated scale so that responses are ordered (Borooah V.K., 2001).

Overall Satisfaction = ƒ (perceived satisfaction with thermal quality, air quality, sound quality, day light quality) equation 1

A Brant Test for the parallel regression assumption was conducted (Brant R. 1990). The proportional odds assumption was violated for responses ordered on a five-step scale (very dissatisfied=1, dissatisfied=2, acceptable=3, satisfied=4 and very satisfied=5) Therefore, the responses of an ordered five-step scale of dependent and independent variables were converted to a three-step scale, where the occupants' satisfaction and acceptance of indoor environment could be described as unsatisfactory=1, acceptable=2 or satisfactory=3. After the conversion, a Brant Test was conducted showing that the proportional odds assumption was satisfied and the application of an ordinal logistic model (equation 1) was justified. By applying data to the sub-groups, it was possible to demonstrate whether overall satisfaction changes depending on the level of acceptance of indoor environment quality and whether the building environmental profile and the apartment tenure affect occupant satisfaction.

Results are presented in the form of an odds ratio and interpreted as the probability that overall satisfaction increases if the satisfaction with indoor environment parameter increases, keeping other variables constant. The odds ratio allows us to rank the effect that acceptance of indoor environment has on overall satisfaction (Frontczak et al, 2012b).

2.6.3. Occupants' dissatisfaction and problem with indoor environment quality

In the fourth stage, the analysis aimed to investigate the impact that problems with indoor environment quality may have on occupants' satisfaction. To facilitate investigation of the results, the responses were assigned decreasing values, such that occupant dissatisfaction could be described as dissatisfied=3, acceptable= 2 and satisfied=1. A Brant Test was conducted and results indicated that the proportional odds assumption was satisfied and the application of ordinal logistic models (equations 2-5) was justified.

Dissatisfaction with thermal quality =ƒ (Experienced problems with thermal comfort)
equation 2

Dissatisfaction with air quality =ƒ (Experienced problems with air quality)
equation 3

Dissatisfaction with sound quality =ƒ (Experienced problems sound quality)
equation 4

Overall Dissatisfaction = ƒ (Experienced problems with Indoor Environment Quality)
equation 5

Results are presented in the form of an odds ratio and interpreted as the probability that overall dissatisfaction increases if the problem with indoor environment appears, keeping other variables constant.

2.6.4. Occupants' response to discomfort

The variable that describes occupants' usage of supplementary heating or cooling might be a proxy for the problem with thermal comfort that impacts occupants' perceived satisfaction, but it may also capture the reverse effect, in other words, the occupants' reaction to dissatisfaction with thermal quality. Therefore, we applied model 6 to the data and tested whether there is a relationship between use of supplementary heating/cooling and dissatisfaction with thermal quality.

Behaviour (Use of supplementary heating/cooling) =ƒ (dissatisfaction thermal quality)
equation 6

A Brant Test for the parallel regression assumption was conducted. The proportional odds assumption was fulfilled for use of supplementary heating but violated for use of supplementary cooling; therefore only results from model 6 and the dependent variable described as usage of supplementary heating are reported and discussed.

2.6.5. Impact of individual and building characteristics

Since the previous studies showed that aspects of individuals' (ex. Mohit, Ibrahim et al. 2010; Choi et al. 2012) and building characteristics (James, R., 2007; Steemers and Manchanda 2010; Dekker et al. 2011; Zalejska-Jonsson and Wilhelmsson, 2013) may have a significant impact on the overall satisfaction and the perceived indoor environment quality, the following control variables were included in the models (1-6): age, gender, building with environmental profile (green building), apartment tenure (owned dwellings) and proxy for apartment size (number of rooms).

In order to test the internal consistency of the data, the Cronbach alpha test was conducted. The test was performed in STATA and computed a coefficient of 0.76, which was considered satisfactory.

3. Results

3.1. Description of respondents

The gender distribution is very similar in the owned and rental apartments and in the sub-groups green and conventional buildings: the majority of the respondents were women. Approximately 60% of all respondents lived in owned apartments. Nearly one third of all respondents constituted occupants in the age range between 31 and 40 years old. There was a difference in age distribution depending on apartment tenure. A higher percentage of younger respondents, below 30 years old, lived in rental apartments, whereas a higher percentage of older respondents (over 60 years old) were occupants of owned apartments.

The majority of occupants living in green apartments (37%) were between 31-40 years of age. In conventional owned apartments, the majority group (approx. 40%) consists of people of 61 years old and older, whereas in conventional rental apartments younger occupants dominated (table 4).

The relative majority of all respondents (40%) live in three-room apartments. On average, two adults per dwelling and approx. 23% respondents indicated that a child or a teenager lives in their apartment.

Table 4. Respondent distribution depending on gender, age and apartment size

	general	Green owned	Conventional owned	Green rental	Conventional rental
Gender					
woman	56%	53%	57%	58%	57%
man	44%	47%	43%	42%	43%
Age					
21-30 years	19%	12%	18%	17%	32%
31-41 years	31%	37%	18%	37%	42%
41-50 years	13%	11%	12%	20%	11%
51-60 years	13%	11%	14%	17%	9%
61 years and more	24%	30%	39%	9%	6%
Apartment size					
1 room	1%	1%	0%	0%	3%
2 rooms	24%	15%	38%	17%	17%
3 rooms	40%	34%	36%	41%	51%
4 rooms	28%	35%	25%	27%	25%
5 rooms	7%	14%	2%	15%	3%
6 rooms	0%	0%	0%	0%	1%

3.2. Overall satisfaction

Occupants were found to be very pleased with their dwellings and over 90% of occupants stated they were satisfied or very satisfied with their apartment. The analysis indicates that occupants in owned apartments are marginally more satisfied than those living in rental apartments, the mean value being 4.52 for occupants of owned apartments and 4.37 for tenants in rental apartments (table 5). The difference was found to be statistically significant by the Mann-Whitney rank sum test with probability 0.03 (table 6). No statistically significant difference was found in overall satisfaction between occupants of green and conventional buildings. The mean for overall satisfaction in green buildings was 4.44 (for owned apartments 4.44 and for rental apartments 4.43) and in conventional buildings 4.48 (for owned apartments 4.58 and for rental apartments 4.33).

Generally, occupants indicated that they were satisfied or very satisfied with building quality (4.25 mean value), and no statistically significant difference was found in opinions between different groups.

3.3. Thermal quality

3.3.1. Perceived thermal comfort

Responses indicate that occupants are generally satisfied with indoor environment (table 5), though satisfaction with thermal comfort was rather low. The results indicate that there is no statistically significant difference in the perception of the thermal quality by occupants of owned and rental buildings. On the other hand, the responses show that the difference in acceptance of thermal quality is statistically significant between green and conventional buildings (table 6). The occupants of green apartments indicate less satisfaction with thermal quality (mean value 3.25) than those in conventional buildings (mean value 3.71). Only 8% of occupants living in green apartments indicated that they were very satisfied with thermal quality and nearly one fourth (23%) stated they were dissatisfied or very dissatisfied. In comparison, nearly 25% of occupants in conventional buildings claimed to be very satisfied with thermal quality and only 9% indicated that they were dissatisfied or very dissatisfied. The owners of green dwellings indicated the lowest acceptance level for thermal quality compared to other occupants (mean value 3.12, table 5).

The responses revealed that satisfaction with indoor temperature differs depending on the time of year. The majority of occupants in green buildings, approximately 80% occupants in green owned and 70% in rental apartments, stated “it is too cold in the apartment during winter” (figure 1). The same opinion was shared by 50% of occupants in conventional owned and 28% in conventional rental dwellings. On average, the occupants of conventional dwellings stated that the perceived temperature during the winter season was between 19 and 21 degrees Celsius. Occupants of green apartments experienced the temperature in their apartments as much lower, varying between 16 and 20 degrees Celsius.

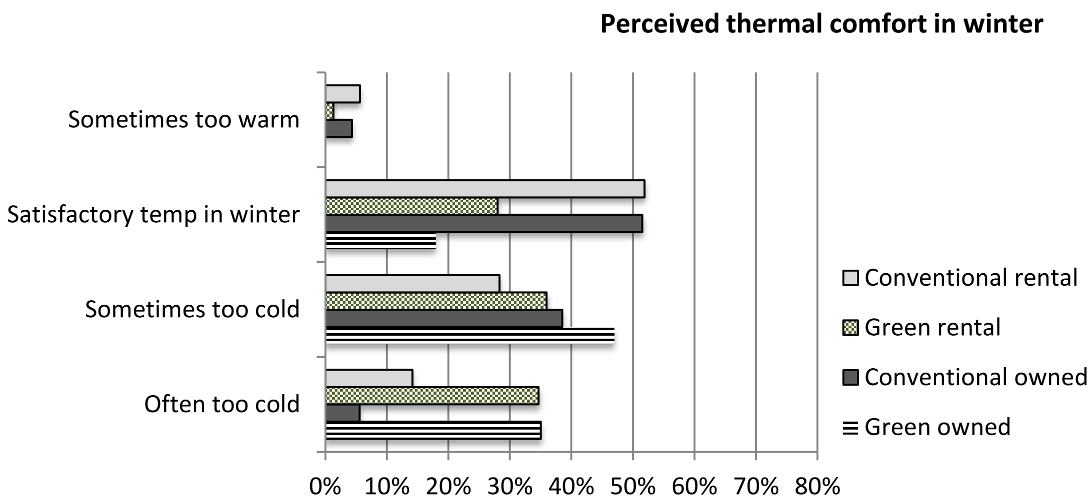

Figure 1. Perceived thermal quality in winter season

Interestingly, occupants in green owned apartments were more pleased with indoor comfort in summer than other respondents (figure 2). The perceived temperature in green dwellings was given as on average 21-22 degrees, whereas conventional buildings were perceived to have a higher indoor temperature during summer, on average 23-24 degrees with a risk of overheating (temperature higher than 26 degrees) stated by 15% of respondents. In comparison, approximately 5% of the respondents in green buildings indicated the same.

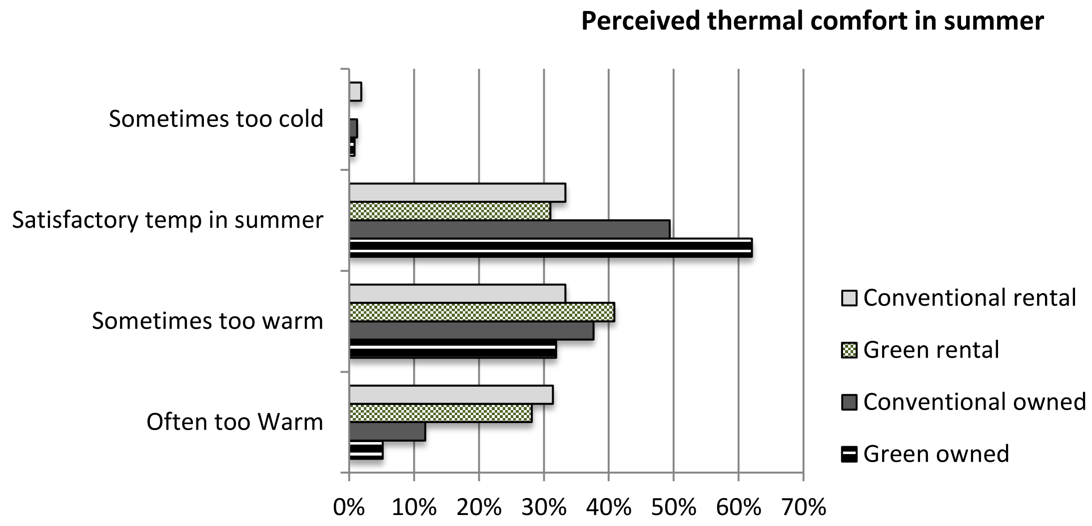

Figure 2. Perceived thermal quality in summer season

3.3.2. Occupant strategies to deal with thermal discomfort

When experiencing thermal discomfort, people attempt to restore their comfort by applying different strategies, such as adjusting clothing or changing thermostat settings (see the extensive literature on adaptive comfort strategies, for example, Brager, de Dear 1998, de Dear 2011). According to our survey results, occupants were fairly dissatisfied with thermal quality. A few comments from occupants of green buildings indicated that the main source of discomfort was “a very cold floor” and “wrong ”, “insufficient” or “not calibrated heating system”. On the other hand, many occupants in conventional buildings stated problems with “draught” and “cold air stream from ventilation ducts”. Respondents mentioned that they tended to handle the problem by “setting radiator thermostats to a much higher temperature”.

Difficulty in influencing room temperature was found to be the most frequently experienced problem with the indoor environment (table 7). Nearly 80% of green building occupants said they had experienced problems with temperature control; by comparison, only 55% of the occupants in conventional buildings had the same opinion. The survey respondents described a few ways in which they tackled the problem of poor control over room temperature. In the winter, some occupants used “millions of candles” and “wore thicker sweaters, socks and slippers”. In the summer time, many occupants found opening windows and cross-ventilation a satisfactory strategy.

However, if occupants experience uncomfortable temperatures as problematic, they may make a decision to purchase supplementary heating or cooling equipment in order to ensure a satisfactory thermal environment. This may be considered an extreme strategy; however, the survey results indicate that it is not an unlikely situation. Generally, one fourth of all respondents used supplementary heating. It seems that occupants living in green rental apartments use supplementary heating more often than those living in green owned apartments (mean value 2.25 and 1.66 respectively, where 1=No, I have never used supplementary heating/cooling, 2=Yes, I have used supplementary heating/cooling from sometimes, 3= Yes, I have used supplementary heating/cooling often). The Mann-Whitney rank sum test indicates a statistically significant difference between responses on usage of supplementary heating by occupants of green and conventional rental apartments (table 8). Interestingly, occupants living in rental apartments seem to use cooling more frequently than those in owned apartments (mean value 1.86 and 1.35, respectively).

The findings are very interesting for many reasons. Firstly, supplementary heating and cooling is achieved by plug-in equipment, which means that use is not recorded on building performance but as household electricity use. Consequently, the total energy consumption increases and so does the environmental impact. Secondly, the relatively high dissatisfaction with indoor thermal comfort indicates a more serious problem with building performance. It is extremely difficult to identify the source of this problem without detailed investigation of design, building fabric and installation system.

3.3.3. Controlling and understanding technical systems

In the buildings studied, the system installed in the buildings with rental apartments is mainly centrally operated and managed by the housing managing organization appointed by the building owner. The centralized system shifts most of the responsibility for tuning and operation onto the housing manager and leaves less control to the occupant. On the other hand, occupants in owned apartments have often taken on more technical responsibility, particularly in green buildings where in most cases a decentralized heating and ventilation system was installed. The survey responses indicate that the operating and fine-tuning of an HAVC system might be very challenging (table 9). Occupants in green owned apartments experienced certain problems with “system inefficiency”, “difficulty of fine-tuning” and even “user-unfriendly manual descriptions” (mean value for required adjustment 2.30). Technical solutions in apartments are considered to be “complicated and difficult to use”, by over 15% of apartment owners and 20% of green building occupants, whereas only 5% of the occupants in rental apartments and 5% in conventional dwellings agree with this statement. The difference is statistically significant (table 10).

3.4. Perceived air quality

The majority of occupants were satisfied or very satisfied with indoor air quality (mean value 4.14), yet occupants in rental apartments rated air quality somewhat lower (mean value 3.95) than those in owned apartments (mean value 4.20). Indeed, 44% of the respondents living in owned dwellings claimed to be very satisfied with air quality, while approximately 30% of those in rental apartments stated the same. Satisfaction with air quality in the rental green dwellings was found to be somewhat higher (mean value 4.05) that that in the conventional buildings (mean value 3.88). Perceived air quality was found to differ at a statistically significant level between rental and owned dwellings (table 6).

The respondents indicated that they experienced problems with cooking smells spreading in the apartment. Responses indicate that approx. 65% of the occupants in green rental and 57% in green owned apartments experienced problems with food fumes from their own cooking compared with approximately 50% in conventional buildings. Smelling neighbours’ cooking fumes in the apartment is not as frequent, but approx. 42% of occupants living in green rental and 28% in green owned apartments reported experiencing the problem. These results are comparable to approx. 20% of the responses in conventional rental apartments, and 10% of those in conventional owned apartments.

Earlier research has reported the problem of cooking fumes not being efficiently extracted by kitchen ventilation in low-energy buildings (ex. Schnieders and Hermelink, 2006; Zalejska-Jonsson, 2012). The inefficiency of forced ventilation in kitchens is often related to building airtightness ($n<0.6h^{-1}$ at ±50Pa) as incoming air-flow in highly air-tight buildings is not sufficient to compensate for exhausted air. The advice often given to the occupants in this case is to open windows or doors while cooking. This is a solution to the problem, but understandably has its setbacks in winter.

3.5. Perceived sound quality

A statistically significant difference in opinions regarding sound acceptance was found between rental and owned apartments (table 6). Satisfaction with sound quality was found to be higher in owned (mean value 4.25) than rented apartments (mean value 3.97). Occupants in green buildings ranked sound quality higher than those in conventional buildings, where 57% of the occupants in owned and 40% in rental green apartments stated they were very satisfied with sound quality (figure 3). This is comparable to 49% of the responses from occupants of conventional owned and 32% of rental conventional apartments. Interestingly, the analysis showed a statistically significant difference between responses from tenants in green and conventional rental dwellings. Occupants renting green apartments were found to be more satisfied with sound quality (mean value 4.16) than tenants living in conventional buildings (mean value 3.84).

Occupants in green dwellings seem to be disturbed by noise from ventilation systems and fans more often than those in conventional buildings (mean value for green buildings 1.72 and conventional 1.44, seen table). However, green building occupants generally reported experiencing fewer disturbances from outdoor noise. Approximately 15% of tenants living in conventional rental buildings indicated that they often experience problems with outdoor noise, compared with 5% in green rental apartments.

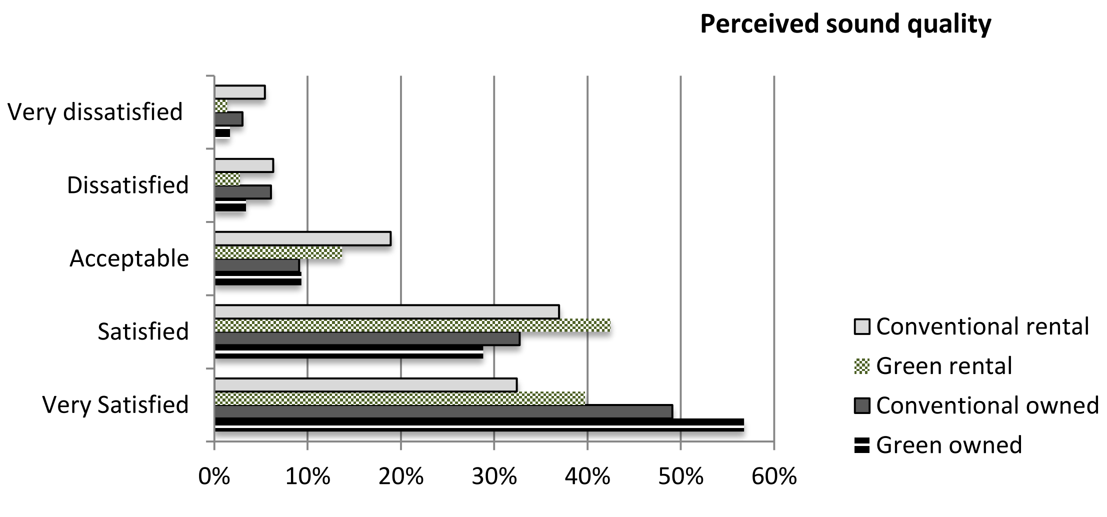

Figure 3. Perceived sound quality

3.6. Perceived daylight quality

Occupants living in owned and rental apartments were found to have significantly different opinions on perceived quality of daylight (table 6). The mean value for satisfaction with daylight in rental apartments was 4.27 and in owned apartments 4.51 (table 5). The majority of the occupants in green owned apartments (65%) stated they were very satisfied with daylight; however, tenants in green rental apartment seem to be less satisfied and nearly 20% of respondents in rental green buildings found daylight quality to be less than acceptable (figure 4). These are interesting findings, which could be investigated in further research.

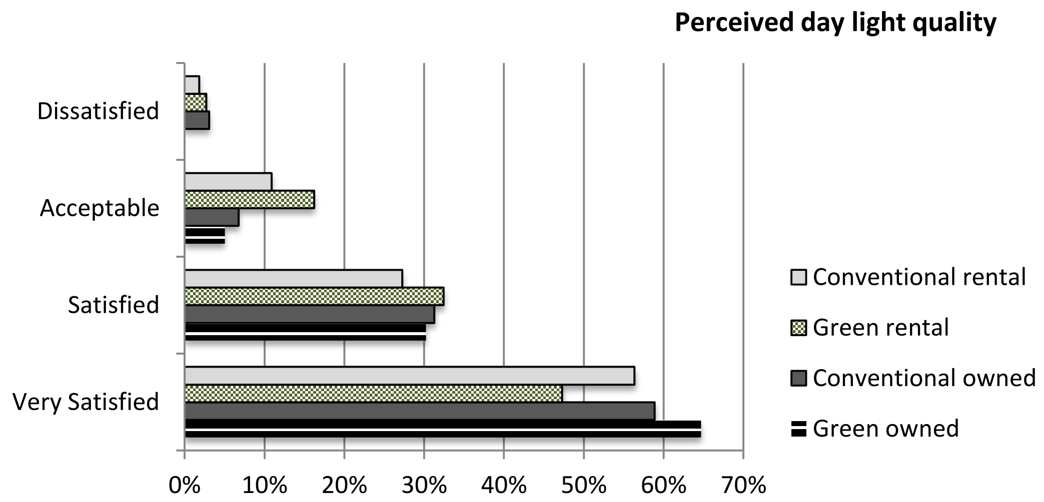

Figure 4. Perceived quality of daylight.

3.7. Factors influencing overall satisfaction

An ordered logistic model (equation 1) was applied to the data to test the effect that acceptance of indoor environment has on occupants' overall satisfaction. The results show that satisfaction with air quality has the greatest impact on their overall satisfaction. Should acceptance of air quality increase, there is a 3.26 odds probability that occupant satisfaction increases (table 11). This finding is in line with earlier studies (Zalejska-Jonsson and Willhelmsson, 2013), showing that air quality has the greatest impact on occupants' satisfaction in Swedish dwellings. The results also indicate that occupants who own apartments are more likely to be satisfied than tenants (odds ratio 3.42, table 11).

3.8. Factors affecting occupants' dissatisfaction

Results (eq. 2) show that if occupants have problems controlling indoor temperature, there is a 5.38 odds probability that their dissatisfaction with thermal quality increases. The inability to impact indoor temperature also has an impact on overall dissatisfaction. The results (table 12) indicate that there is a 2.92 odds probability (table 13) that, if the occupant experiences the problem, the overall dissatisfaction increases.

The use of supplementary heating was found to have a statistically significant effect on dissatisfaction with thermal quality (eq.2, table 11). However, the question is whether the dissatisfaction with thermal comfort increases because occupants use supplementary heating or occupants use supplementary heating in response to high dissatisfaction with thermal comfort. The causality is not obvious or exclusive. The results indicate that, if occupants' dissatisfaction with thermal comfort increases, there is a 1.87 odds probability (eq.6, table 14) that the occupant is likely to use supplementary heating. Moreover, there is a 4.40 odds probability that the occupant who uses supplementary heating is living in a green building, but less likely that the occupant is living in an owned dwelling. The results show a statistically significant relationship between behaviour and dissatisfaction in both models, but we are unfortunately unable to describe in more detail the effect of this phenomenon. This is a very interesting subject that could be further investigated in a more specifically designed experiment.

The greatest impact on occupants' dissatisfaction with air quality came from the problem of dry air (odds ratio 3.04, table 12) followed by the problem of smelling neighbours' food fumes (odds ratio 2.98). It is less likely that occupants living in green and owned dwellings are dissatisfied with air quality. The problem of smelling neighbours' food fumes was also found to have an impact on overall dissatisfaction (odds probability 3.45 odds probability for the model (eq.5), table 13).

The results suggest that occupants' dissatisfaction increases if they are disturbed by noise or voices heard through the walls (odds ratio 6.62, (eq. 4), table 12). However, it is the problem with outdoor noise that was found to have a statistically significant impact on overall dissatisfaction (2.52 odds probability (eq.4), table 13).

4. Concluding comments

The study aimed to investigate the overall satisfaction and the acceptance of the indoor environment and to test whether the building environmental profile affects occupant satisfaction. The analysis has been conducted based on survey responses collected from occupants living in comparable green and conventional buildings.

The results show that occupants are very satisfied with their apartments and that there is no statistically significant difference between the stated overall satisfaction of occupants living in green and conventional buildings. Occupants living in green apartments indicated higher satisfaction with the indoor environment than those in conventional buildings, except for thermal quality which received much lower satisfaction scores.

Apartment tenure seems to have significance in the perception of indoor environment quality, though closer analysis shows that occupants in rental green buildings rated sound and air quality higher than that in conventional rental apartments. It is possible that the statistically significant difference that was found between owned and rental apartments may be related to differences in monetary and psychological investment, socio-economic differences (Galster and Hesser 1981; Elsinga and Hoekstra, 2005; Diaz-Serrano, 2009; Bloze and Skak, 2012) or perception of housing management services (Paris and Kangari, 2005) rather than to the perceived quality of the buildings. On the other hand, there might be other factors contributing to the differences in occupant satisfaction between rental and owned apartments observable in this study. The dissimilarities could already have appeared in the design, construction or purchasing processes. Further studies should investigate whether and how building tenure affects design and construction of green buildings.

Even though assessment of technological solutions introduced in the buildings was not the main focus of this study, we have anticipated that the systems employed may have an effect on occupants' perceptions. Indeed, the occupants in green buildings experienced more problems related to the insufficiency or inefficiency of the heating system than those in conventional buildings. Particularly occupants of green owned dwellings found the issue of fine-tuning challenging. Problems in understanding how the system works and with user-unfriendly solutions led to inefficient usage and difficulties in optimizing energy consumption. Consequently, occupants' satisfaction with thermal comfort in green buildings was lower than in conventional apartments. Our analysis demonstrates that occupants dissatisfied with thermal comfort are more likely to use supplementary heating.

Considering that understanding the heating and cooling system and being able to use it efficiently have an effect on total energy consumption (Gill, Tierney et al. 2010), the barrier to achieving energy goals and low environmental performance lies not only in building design but in the way in which buildings are operated. In order to address problems with uncertainty in building performance, a new operation and maintenance model might be considered; for example, the responsibility for fine-tuning and efficient use of the system could be shared with the installation contractor or producer. The requirement to assist with system commissioning during the first years of building operation could also be beneficial to the developer and installation producer, as knowledge gained during assistance provides important lessons and user experience affords an opportunity for product development.

The consequence of an uncompleted commissioning process is that the system is not able to deliver either the expected efficiency or the designed indoor quality. Moreover, since environmental and economic benefits of green buildings to a great extent depend on low-energy requirements and low-energy consumption, neglecting building operation prevents green buildings from achieving sustainability goals.

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Table 5. Mean values for occupants' overall satisfaction and perceived indoor environment acceptance (ranked in decreasing order)

	general	owned apartments	rental apartments	green apartments	conventional apartments	owned apartments		rental apartments	
						green	conventional	green	conventional
Overall satisfaction									
Mean	4.46	4.52	4.37	4.44	4.48	4.44	4.58	4.43	4.33
Std div	(.69)	(.64)	(.75)	(.73)	(.66)	(.74)	(.56)	(.71)	(.77)
Number obs	454	270	184	186	268	110	160	76	108
Perceived acceptance indoor environment									
Air quality	4.14	4.27	3.95	4.20	4.10	4.30	4.25	4.05	3.88
	(.86)	(.75)	(.97)	(.76)	(.92)	(.66)	(.81)	(.88)	(1.02)
	462	277	185	188	274	113	164	75	110
Natural light	4.41	4.50	4.27	4.43	4.39	4.56	4.46	4.21	4.30
quality	(.81)	(.69)	(.95)	(.75)	(.86)	(.60)	(.75)	(.91)	(.99)
	467	283	184	194	283	120	165	74	110
Sound quality	4.13	4.24	3.97	4.25	4.05	4.31	4.18	4.16	3.84
	(1.02)	(1.00)	(1.03)	(.92)	(1.07)	(.95)	(1.03)	(.86)	(1.11)
	469	285	184	193	276	120	165	73	111
Thermal	3.58	3.59	3.56	3.25	3.81	3.12	3.92	3.45	3.64
quality[1]	(1.02)	(1.03)	(1.01)	(1.05)	(.93)	(1.01)	(.90)	(1.08)	(.95)
	467	281	186	195	272	118	163	77	109

Very satisfied=5, Satisfied=4, Acceptable =3, Dissatisfied=2, Very dissatisfied= 1

Table 6. The Mann-Whitney rank sum test for differences in responses regarding overall satisfaction and perceived indoor quality between occupants living in owned and rental apartments and green and conventional apartments

Test M-W for difference in responses for overall satisfaction	owned / rental apartments	green/conventional building	green/ conventional for owned apartments	green/ conventional for rental apartments
Overall satisfaction	.03**	.63	.19	.41
Air quality	.00*	.54	.98	.36
Natural light quality	.02**	.95	.39	.26
Sound quality	.00*	.05**	.26	.07***
Thermal quality	.82	.00*	.00*	.24

* p≤0.01; ** p≤0.05; *** p≤0.1

Table 7. Mean values for perceived problems with indoor environment quality

Mean Std div Number obs	general	owned apartments	rental apartments	green apartments	conventional apartments	owned apartments		rental apartments	
						green	conventional	green	conventional
Problems with thermal quality									
Problems with control of indoor temperature[2]	1.86	1.87	1.83	2.06	1.70	2.15	1.65	1.90	1.79
	(.73)	(.72)	(.75)	(.71)	(.71)	(.71)	(.64)	(.68)	(.80)
	458	273	185	196	262	121	152	75	110
Use of supplementary heating [1]	1.34	1.27	1.44	1.55	1.19	1.66	1.30	2.25	1.30
	(.61)	(.53)	(1.10)	(1.13)	(.48)	(1.01)	(.74)	(1.22)	(.80)
	459	278	181	189	270	115	163	74	107
Use of supplementary cooling [1]	1.33	1.20	1.53	1.27	1.36	1.16	1.44	1.88	1.84
	(.99)	(.50)	(1.16)	(.91)	(.65)	(.56)	(.93)	(1.16)	(1.16)
	455	278	177	187	268	115	163	73	105
Problems with air quality									
Dry air[2]	1.33	1.27	1.42	1.32	1.34	1.26	1.28	1.42	1.43
	(.57)	(.51)	(.64)	(.57)	(.56)	(.49)	(.52)	(.68)	(.61)
	466	282	184	195	271	120	162	75	110
Food fumes/smell from own cooking[2]	1.70	1.73	1.66	1.70	1.71	1.65	1.79	1.78	1.59
	(.68)	(.70)	(.65)	(.67)	(.69)	(.69)	(.71)	(.64)	(.65)
	466	282	184	195	271	120	161	74	110
Food fumes/smell from neighbours[2]	1.23	1.17	1.33	1.34	1.16	1.25	1.11	1.47	1.24
	(.47)	(.41)	(.54)	(.53)	(.41)	(.47)	(.35)	(.59)	(.49)
	468	281	187	196	272	120	161	74	111
Problems with sound quality									
Indoor noise/ ventilation and fans[2]	1.53	1.61	1.41	1.58	1.49	1.70	1.53	1.39	1.43
	(.68)	(.72)	(.61)	(.69)	(.68)	(.72)	(.71)	(.59)	(.63)
	465	283	182	194	271	120	163	74	108
Outdoor noise[2]	1.54	1.46	1.65	1.34	1.68	1.25	1.62	1.46	1.77
	(.63)	(.60)	(.67)	(.56)	(.65)	(.51)	(.62)	(.62)	(.68)
	467	282	185	196	271	120	162	76	109
Indoor noise /voices[2]	1.47	1.32	1.71	1.42	1.52	1.30	1.34	1.61	1.78
	(.60)	(.51)	(.65)	(.57)	(.62)	(.52)	(.50)	(.59)	(.69)
	457	276	181	194	263	119	152	75	106

[1]No, I have never used supplementary heating/cooling=1; Yes, I have used supplementary heating/cooling sometimes=2, I have used supplementary heating/cooling often=3

[2] No, never happens=1, Yes=2, sometimes, Yes, often=3

Table 8. The Mann-Whitney rank sum test for differences in responses regarding problems with indoor environment between occupants living in owned and rental apartments and green and conventional apartments

Test M-W for difference in responses (probability)	owned / rental apartments	green/conventional apartments	green/conventional for owned apartments	green/ conventional for rental apartments
Problems with thermal quality				
Problems with control of indoor temperature	.54	.00*	.00*	.22
Use of supplementary heating	.02**	.00*	.00*	.00*
Use of supplementary cooling	.00*	.12	.01**	.80
Problems with air quality				
Dry air	.00*	.64	.87	.69
Food fumes/smell from own cooking	.39	.94	.09***	.03**
Food fumes/smell from neighbours	.00*	.00*	.00*	.00*
Problems with sound quality				
Indoor noise/ ventilation and fans	.00*	.12	.03**	.69
Outdoor noise	.01*	.09***	.02**	.74
Indoor noise /voices	.00*	.09***	.33	.11

* p≤0.01; **p≤0.05; *** p≤0.1

Table 9. Mean values for understanding and required adjustment of heating/cooling system

Mean Std div Number obs	general	owned apartments	rental apartments	green apartments	conventional apartments	owned apartments		rental apartments	
						green	conventional	green	conventional
Understanding of heating/cooling system [1]	1.41 (.69) 463	1.52 (.76) 280	1.24 (.52) 183	1.65 (.80) 190	1.25 (.55) 273	1.89 (.83) 116	1.26 (.58) 164	1.27 (.55) 74	1.22 (.50) 109
Required adjustments to the system [2]	1.72 (.74) 454	1.89 (.75) 274	1.45 (.62) 180	1.92 (.79) 186	1.58 (.66) 268	2.30 (.70) 113	1.61 (.66) 161	1.34 (.53) 73	1.53 (.67) 107

[1] no problem =1; difficult to understand only in the beginning=2; system is complicated and difficult to use

[2] no special adjustment required= 1; just a few adjustments needed= 2; many adjustments=3

Table 10. The Mann-Whitney rank sum test for differences in responses regarding understanding and required adjustment of heating/cooling system

Test M-W for difference in responses for building quality	owned / rental apartments	green/ conventional apartments	green/ conventional for owned apartments	green/ conventional for rental apartments
Understanding of technical system	.00*	.00*	.00*	.66
Required adjustments to the system	.00*	.00*	.00*	.07***

* p≤0.01; **p≤0.05; *** p≤0.1

Table 11. Ordered logistic model for occupant satisfaction (equation 1)

odds ratio probability confidence interval	overall satisfaction
air quality	3.26 (.00)* 1.64-6.50
thermal quality	2.11 (.02)** 1.10-4.03
sound quality	.93 (.85) .44-1.98
natural light quality	1.98 (.12) .82-4.77
green dwelling	1.19 (.76) .37-3.84
owned dwelling	3.42 (.03)** 1.10-10.62
Number rooms	1.24 (.54) .61-2.51
Number of occupants	1.48 (.16) .84-2.59
Age	1.08 (.71) .70-1.67
Gender	.43 (.12) .14-1.27
R2	.216
N observations	319

* p≤0.01; **p≤0.05; *** p≤0.1

Table 12. Ordered logistic model for occupant dissatisfaction with indoor environment (equation 2-4)

odds ratio probability confidence interval	Dissatisfaction with thermal quality (eq 2)	Dissatisfaction with air quality (eq 3)*	Dissatisfaction with sound quality (eq 4)
Use of supplementary heating [2]	2.07 (.00)* 1.35-3.18		
Use of supplementary cooling [2]	1.06 (.76) .70-1.59		
Problems with control of indoor temperature[2]	5.38 (.00)* 3.48-8.32		
Problems with dry air		3.04 (.00)* 2.14-5.40	
Problems with food fumes/smell from own cooking		1.50 (.07)*** .95-2.36	
Problems with food fumes/smell from neighbours		2.98 (.00)* 1.76-5.03	
Problems with indoor noise/ ventilation and fans			.93 (.77) .58-1.49
Problems with outdoor noise			1.73 (.04)** 1.02-2.93
Problems with indoor noise /voices			6.62 (.00)* 3.74-11.72
Green dwellings	1.01 (.96) .58-1.77	.43 (.01)** .22-.84	.96 (.90) .49-1.88
Owned dwellings	.91 (.74) .52-1.53	.54 (.06)*** .29-1.02	1.48 (.25) .74-2.94
Number of rooms	.91 (.62) .63-1.30	1.38 (.08)*** .995-1.99	1.30 (.24) .83-2.04
Number of occupants	1.09 (.54) .84-1.44	1.13 (.40) .84-1.53	.86 (.29) .63-1.13
Gender	.94 (.83) .56-1.57	.96 (.90) .84-1.53	.57 (.07)*** .30-1.06
Age	1.03 (.76) .83-1.27	#	.86 (.29) .65-1.13
R2	.205	.187	.186
No observations	314	399	331

* p≤0.01; **p≤0.05; *** p≤0.1

[1]No, I have never used supplementary heating/cooling=1; Yes, I have used supplementary heating/cooling sometimes=2, I have used supplementary heating/cooling often=3

[2] No, never happens=1, Yes=2, sometimes, Yes, often=3

parallel assumption not satisfied if control variable for age included

Table 13. Ordered logistic model for occupant dissatisfaction (eq. 5)

	Overall dissatisfaction
Use of supplementary heating [1]	1.49
	(.41)
	.57-3.91
Use of supplementary cooling [1]	.50
	(.16)
	.19-1.30
Problems with control of indoor temperature[2]	2.92
	(.04)**
	1.01-8.42
Problems with dry air	.54
	(.64)
	.17-2.99
Problems with food fumes/smell from own cooking	1.34
	(.54)
	.51-3.48
Problems with food fumes/smell from neighbours	3.45
	(.01)**
	1.28-9.34
Problems with indoor noise/ ventilation and fans	1.30
	(.56)
	.52-3.21
Problems with outdoor noise	2.52
	(.07)***
	.92-6.92
Problems with indoor noise /voices	.37
	(.05)***
	(.13-1.02
Green dwellings	.22
	(.07)***
	.04-1.15
Owned dwellings	0.06
	(.00)*
	.01-.35
Number of rooms	.86
	(.74)
	.39-2.02
Number of occupants	.81
	(.55)
	.41-1.60
Gender	3.11
	(.08)***
	.84-11.52
Age	.87
	(.67)
	.48-1.60
R2	.270
No observations	296

* p≤0.01; **p≤0.05; *** p≤0.1

[1]No, I have never used supplementary heating/cooling=1; Yes, I have used supplementary heating/cooling sometimes=2, I have used supplementary heating/cooling often=3

[2] No, never happens=1, Yes=2, sometimes, Yes, often=3

Table 14. Ordered logistic model for using supplementary heating (eq. 6)

	Use of supplementary heating
Dissatisfaction with thermal quality	1.87 (.00)* 1.23-2.84
Problems with control of indoor temperature[2]	1.49 (.09)*** .93-2.37
Green dwellings	4.40 (.00)* 2.40-8.05
Owned dwellings	.39 (.00)* .21-72
Number of rooms	.82 (.35) .55-1.23
Number of occupants	1.19 (.26) .92-1.55
Gender	.89 (.69) .55-1.42
Age	1.13 (.29) .93-1.38
R2	.159
No observations	322

* p≤0.01; **p≤0.05; *** p≤0.1

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