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In the business of building green:

The value of low-energy residential buildings from customer and developer perspectives

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Abstract

An overarching aim of this research was to investigate the comprehensive value of green residential buildings as seen from two perspectives: that of the developer and that of the occupant (the customer). The dissertation consists of studies presented in seven papers. The studies conducted to investigate the developer's perspective focused on construction cost and potential profit (papers I and VII). The customer's perspective was examined with three approaches: the impact that energy and environment have on the decision to purchase (or rent) an apartment (paper V), willingness to pay for a green apartment (paper VI) and finally, the occupants' satisfaction with the dwelling and indoor environment (papers II, III and IV).

The first paper examines whether increased investment costs are profitable, taking into account the reduction in operating costs. The investment viability is approached by comparing investment in conventional and green residential building, particularly passive houses, using real construction and post-occupancy conditions. The increased investment costs in energy-efficient building were also the focus of paper VII. In this paper, the aim was to study how technologies used in energy-efficient residential building construction affect the available saleable floor area and how this impacts on the profitability of the investment. Potential losses and gains of saleable floor area in energy-efficient buildings were assessed using a modelled building and analysed with the help of the average construction cost.

Papers II and IV present results from a study of occupants' satisfaction and indoor environmental qualities. Both papers aim at comparing and analysing responses from occupants living in green and conventional buildings. Paper III focuses on a similar subject, but investigates occupants' satisfaction among all adults living in multi-family buildings in Sweden, providing a national context for the results presented in papers II and IV. The results indicate that occupants are generally satisfied with their dwellings, but indoor environment proved to have a statistically significant effect on overall satisfaction.

The results in paper V indicate that energy and environmental factors have a minor impact on customers' decision to purchase or rent an apartment. However, availability of information on building energy and environmental performance may have an effect on the likelihood of the buyers' being interested in environmental qualities and consequently an impact on their decision. The study presented in paper VI shows that customer interest in energy and environmental factors has a significant impact on stated willingness to pay for green dwellings. The paper discusses the stated willingness to pay for low-energy buildings and buildings with an environmental certificate and attempts to assess the rationale of the stated willingness to pay for low-energy dwellings given potential energy savings.

Keywords: sustainability, green buildings, residential buildings, low-energy, energy-efficiency, construction cost, profitability, occupant satisfaction, indoor environment quality (IEQ)

Abstrakt

Fokus i detta forskningsprojekt har legat på att undersöka värdet av gröna bostäder ur ett brett perspektiv, dvs både genom att studera byggherrens och de boendes (kundens) synpunkter. I avhandlingen ingår sju uppsatser. Undersökningen av byggherrens synpunkter fokuserades på kostnader och potentiella inkomster (uppsats I och VII). Kundernas åsikter undersöktes på tre olika sätt: vilken effekt energi och miljö faktorer hade på beslut att köpa eller hyra en lägenhet (uppsats V), betalningsvilja för gröna bostäder (uppsats VI) och slutligen de boendes trivsel samt nöjdhet med inomhusmiljön (uppsats II,III och IV).

Den första uppsatsen syftar till att undersöka om ökningen av investeringskostnader vid byggande av gröna byggnader kan täckas av framtida energibesparingar och minskning av driftkostnad. Investeringens lönsamhet undersöktes genom att jämföra skillnader i byggkostnader mellan konventionella och gröna bostäder med skillnader i driftskostnader givet olika antaganden om energipriser och räntekrav. Huvudfokus i uppsats VII var också byggkostnader, men denna gång undersöktes hur nya tekniska lösningar påverkar boarea och lönsamhet av energieffektiva bostäder. Genom att konstruera en modell av ett typhus analyserades potentiella ökningar i boarea med nya lösningar och hur detta påverkade lönsamheten i olika geografiska lägen (prisnivåer).

Uppsatserna II och IV presenterar resultat från boendeundersökningar. Båda uppsatserna syftar till att undersöka boendes trivsel och nöjdhet med inomhusmiljö samt att testa skillnaden i svar från boende i gröna och konventionella bostäder. Uppsats III fokuserar också på inomhusmiljön, men analysen gjordes på svaren som samlades in under *Boverkets projekt BETSI* och resultaten är därmed representativa för alla vuxna som bor i flerfamiljshus i Sverige. Uppsats III ger därmed en national kontext för uppsatserna II och IV. Resultaten visar att boende trivs i sina bostäder, men inomhusmiljön har en statistiks signifikanta effekt på allmän nöjdhet faktor..

Resultaten i uppsats V tyder på att energi- och miljöaspekter spelar mindre roll i beslutet att köpa eller hyra en lägenhet. Den synliga informationens tillgänglighet angående byggnadens energi- och miljöprestanda, påverkar kundens intresse för dessa faktorer och därmed indirekt hushållets beslut. Resultaten i uppsats VI pekar på att kunderna, som är intresserade av byggnaders energi och miljö prestanda, är villiga att betala mer för gröna bostäder. I uppsats 6 diskuteras betalningsvilja för låg-energi byggnader och för byggnader med miljöcertifikat samt utvärderas om den angivna betalningsviljan är rationell beslut när man tar hänsyn till nuvärdet av framtida energibesparingar.

Nyckelord: hållbarhet, gröna byggnader, bostäder, låg-energi, energieffektivitet, byggkostnad, lönsamhet, boende nöjdhet, inomhusmiljö

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Zalejska-Jonsson A., Lind H. and Hintze S., (2012) "Low-energy versus conventional residential buildings: cost and profit." *Journal of European Real Estate Research,* vol. 5 issue 3, pp: 211-228

Paper II

Zalejska-Jonsson A. (2012), "Evaluation of low-energy and conventional residential buildings from occupants' perspective." *Building and Environment* Vol. 58, pp: 135-144

Paper III

Zalejska-Jonsson A. and Wilhelmsson M. (2013) "Impact of perceived indoor environment quality on overall satisfaction in Swedish dwellings." *Building and Environment* Vol. 63, pp: 134-144

Paper IV

Zalejska-Jonsson A. "Parameters contributing to occupants' satisfaction: Occupants' insights into green and conventional residential buildings"; *Facilities* (forthcoming)

Paper V

Zalejska-Jonsson A. (2013) "Impact of energy and environmental factors in the decision to purchase or rent an apartment: The case of Sweden." *Journal of Sustainable Real Estate* vol. 5 (forthcoming)

Paper VI

Zalejska-Jonsson A. (2013) "Stated WTP and rational WTP: willingness to pay for green apartments in Sweden" Submitted to *Sustainable Cities and Society*

Paper VII

Zalejska-Jonsson A.; Lind H. and Hintze S. (2013). "Energy-Efficient Technologies and the Building's Saleable Floor Area: Bust or Boost for Highly-Efficient Green Construction?" Buildings 3, no. 3, pp: 570-587.

1. Introduction

The existing policies and regulations are directing companies towards adopting a more environmentally conscious path for business operation. One example is the European Directive for Building Performance from 2002 (directive 2002/91/EC) and later re-cast in 2010 (directive 2010/31/EU), which has sculptured the future of the building industry for many Europeans countries. From a developer perspective, it might be wise to add a “green element" to the company strategy, as it might be a way to adapt to the future market conditions.

However, the fact that regulations propel applications of energy-efficient solutions in building construction does not demonstrate the investment feasibility of green buildings. Would developers lose or benefit by building green? Do customers care? Do customers value the environmental elements while purchasing an apartment? This thesis attempts to answer these questions and assess a comprehensive value for green buildings.

1.1. Aim and research questions

Considering climate change policies, high emission (Co2) levels, energy prices and financial market crises, the pressure on the construction industry has never been greater. However, as part of adjusting to change, a company must keep stakeholders satisfied and make a satisfactory profit.

The profit, however, should not be considered as an ultimate goal; it is rather a consequence of delivering a value to customers and therefore defined as the difference between a price that customers are willing to pay and the cost of performing activities involved in creating the product (Porter, 2008). From the long term perspective, high profit is achieved if the value delivered to the customer is the same as the value perceived by the customer (Aaker, 2001; Porter, 2008).

The intention of this thesis was to investigate comprehensive value of “green” residential buildings as seen from two perspectives: that of the developer (the company) and of the occupant (the customer). I believe that the focus in any business should be on the customer. It is the customer who allows the company to generate the income. It is the customer who is willing to purchase a dwelling for the price that allows the company to make a profit. It is the customer who makes the final judgement of whether the goods have attained the level of satisfaction. In the case of apartment purchase, satisfaction may be impacted by various factors, for example the perceived quality of the apartment (building), satisfaction with indoor and outdoor environment (even neighbourhood) or a profit made at the point of sale of the apartment.

If we simplify, the developer’s profit depends on the income and the construction costs. The company may decide to differentiate from its competitors, for example, by building green instead of conventional building, if this strategy contributes to higher value. There are reasons to believe that green building has the potential to present better living quality for occupants in the form of better indoor environment, reduced requirement for energy and low environmental impact. The choice of building green may be profitable if the above-mentioned qualities are perceived as important by the customers, and if they are willing to pay more for green dwellings.

Following this reasoning, the objectives and research questions in this thesis were to:

- Discuss potential barriers to and opportunities for high-performance green building development
- Explore the cost difference between construction of conventional and low-energy green building
- Investigate investment potential and factors contributing to the profitability of green residential buildings
- Investigate the importance of environmental factors in customers' decision to purchase or rent an apartment
- Study occupants' willingness to pay for green buildings
- Explore customers' perceived product value by investigating occupants' overall satisfaction
- Study the delivered value of products as perceived by customers by investigating occupants' perceived satisfaction with indoor environment quality

In the further part of this chapter, I discuss different terms describing buildings designed and constructed with environmental goals, notions that often appear in the literature and practice (section 2). In this section, I attempt to array concepts and lay out the relationship between them. I also specify the practical definition of "green" buildings used in this research. The third section I devote to the general research method applied in this thesis and discuss some limitations and potential bias. In the fourth section, I briefly summarize the papers included in this thesis and the chapter ends with overarching conclusions and suggestions for further research (section 5 and 6 respectively).

2. Definitions

Buildings that are designed and constructed to minimize environmental impact are often referred to as "sustainable buildings", "green buildings", "low-energy", "energy-efficient" or "high-performance", "passive house " and "(nearly) zero energy buildings". Sometimes it is safe to use them as synonyms, but sometimes similarities are vague. This section aims to review definitions proposed in the literature and attempts to capture differences and similarities between the above-mentioned notions.

2.1. Sustainable building

Sustainable development (sustainability) in its core focuses on the importance of responsibility for present actions and for future generations (WCED, 1987). The goal is to combine best practice from economic, social and environmental aspects. The strategies for defining and achieving sustainability goals may vary depending on people's beliefs and expectations, political aspirations and even economic status. Consequently, contextualizing sustainability in buildings has proved to be challenging.

The sustainability goals may be defined at a specific point in time, hence making the aims reachable, but in the long term perspective sustainability changes, evolves, is adapted to the new status and therefore achieving sustainability goals should be seen as a continuous process of transformation (Bagheri and Hjorth, 2007; Berardi, 2013). This "metamorphosis" and the three-dimensional (economic, social and environmental) nature of sustainability (Kohler, 1999) are fundamental for sustainable development, and separation of these domains can lead to mistaken conclusions. Kohler (1999) explains that sustainability, if applied in the built environment, must still be described in three unbreakable frameworks, where ecological sustainability aims to protect resources and ecosystems, economic sustainability is divided into investment and running costs, and social and cultural aspects refer to comfort, wellbeing and the protection of human health.

The multi-dimensionality of sustainability, the variation in goals depending on time, location, circumstances and actors involved contributed to the many ways in which the concept of sustainability could be defined. Berardi (2013) recaptured discussions on sustainability and used CIB's ten redefined principles for sustainable building and principles reported in the Sustainable by Design Declaration of the International Union of Architects to define sustainable building as:

> *"A healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity, and life-cycle quality value, and which promotes a sense of sustainable community. (..) a sustainable building should increase:*
>
> - *demand for safe building, flexibility, market and economic value;*
> - *neutralization of environmental impacts by including its context and its regeneration;*
> - *human wellbeing, occupants' satisfaction and stakeholders' rights;*
> - *social equity, aesthetics improvements, and preservation of cultural values"*
>
> (Berardi, 2013)

However, the multi-dimensionality of sustainability and the complexity of building systems created a trap which many sustainability assessment systems have fallen into (see for example Reed et al., 2009; DeLisle et al., 2013). Capturing all the aspects of sustainability and setting measurable goals might be impossible to achieve or could result in an assessment tool that was far too complex to use. This may explain why assessment systems focused on environmental aspects evaluated during the time-limited designing and construction phase, and rarely considered the whole life-cycle stretching to operation and in-use assessment. There have also been voices that questioned the possibility of fulfilling all sustainability aspects (Goodland and Daly, 1996; Williams and Millington, 2004; Cooper, 1999; Pearce, 2006).

2.2. Green Building

A Google search for "green building" gives over 1,740,000,000 hits and "green building definition" appears on 65,800,000 sites. Generally, the term is often used in relation to buildings constructed with more ambitious environmental goals than in conventional buildings.

Kibert (2008) defines a "green building" as: *"a healthy facility that is designed, built, operated and disposed of in a resource-efficient manner using an ecologically sound approach*". The term "green building" gained its popularity mostly due to the efforts of various agencies, organizations and councils that are successfully promoting this concept. The U.S. Environmental Protection Agency (www.epa.gov) states that “green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment”. This is achieved by efficient use of resources, occupant health protection and reduction of waste and pollution. Nowadays, there are many organizations and programmes which aim to promote ”green” or “sustainable” building concepts, e.g., the World Green Building Council (www.worldgbc.org), the U.S. Green Building Council (www.usgbc.org), the Swedish Green Building Council (www.sgbc.se) and the GreenBuilding Programme (GBP) initiated by the European Commission (www.eu-greenbuilding.org).

A “green” building may have different levels of “environmental involvement” or “shades of green” from so-called “light green” to “deep green” (Cole, 1999). The “light” level includes highly efficient choices like energy-efficient lighting, whereas “deep green” refers to more demanding commitments (e.g. regarding design or financial inputs) such as choice of environmentally accepted materials or implementation of solar energy collectors.

The fundamental objective of a “green” environmental assessment method is to promote designing, constructing and owning buildings with improved environmental performance (Cole, 1999). There are differences between the “green” assessment method, which is based on relating the building to a “typical” practice without defining an ultimate goal, and the “sustainable” method, which should assess the building against declared (locally and globally) sustainable conditions (Cole, 1999). The difference between concepts of green and sustainable building was discussed by Berardi (2013).

In practice, the general rule is that in order to be labelled a “green” or “sustainable” building, it must comply with specific standards and their environmental impact must be assessed. Numerous assessment methods have been developed all over the world. The most known and commonly used are: LEED (origin US), BREEAM (origin UK), Green Star (origin Australia), and CASABEE (Japan). To-date, almost every country has introduced an environmental assessment method, either newly created methods, or modified or adjusted versions of earlier established systems (e.g. LEED India). Building assessment and certification is a process. Assessment is carried out against specified criteria and points are awarded for complying with specified standards. Finally, the total number of points indicates the level of building performance.

Environmental assessments promote environmental awareness, but also provide a framework for the work of professionals and opportunities for certification and labelling of buildings even in in compliance with governmental policies (Reed et al., 2009). Each rating system has certain advantages but also some shortfalls. The greatest problems are lack of transparency and the difficulty in rating comparisons (Reed et al., 2009). The reasons for this are that each assessment method is more or less tailored to the country of origin with reference to general rules, construction standards or climate conditions. Moreover, various assessment methods address different criteria or assign to them different weight.

Some building environmental assessment methods try to capture the complexity of a building and therefore tools include rather a long list of criteria, making the assessment quite complex. This complexity is another criticism against rating tools. Since there are quite a number of factors where building may score points, some of the areas (sometimes important ones like energy or material) may be left aside, but the final score may still be high.

2.3. Energy-efficient building

Building life cycle is counted as 50-100 years and during this time the total energy associated with a building may be divided into energy that is directly connected with the building itself-- energy needed for the building's construction, operation, rehabilitation and demolition, and embodied energy, which is the sum of all energy needed to manufacture and transport goods (all material and technical installations) (Sartori and Hestnes, 2007). The question of how embodied energy and operating energy influence the total energy used in a building's life cycle is the subject of discussion in the literature. Results differ depending on building type, production year, climate zone and finally energy measures used to analyse a building's performance. Energy used in buildings can be expressed in end-user energy or primary energy. The primary energy measures energy at the natural source level, and indicates energy needed to obtain the end-use energy, including extraction, transformation and distribution losses (Sartori and Hestnes, 2007) focusing on energy resources and the process in the supplying system. Hence, two different buildings may indicate the same end-energy performance but differ significantly in performance measured in primary energy, due to different energy sources (Gustavsson and Joelsson, 2010).

2.4. Low-energy building and the passive house concept

Low energy and the passive house concept essentially build on the same idea, that the heating energy in the building can be minimized through an airtight and well insulated building shell. However, whereas the former is rather a guideline and rarely specified in practical values (e.g. heat load or space heating minimum), passive house is a standard and gives specific recommendations with regard to the achievement of heating energy savings.

2.4.1. Low-energy building

It is generally understood that a low-energy building should achieve better or significantly better performance values than those specified in the Building Regulations. The supply of energy needed for heating/ cooling can be decreased only if the energy losses can be minimized. The energy leakage can be reduced by minimizing thermal bridges, including very good thermal insulation for the whole building envelope (very low heat transfer coefficient values for walls, foundations and roof), and energy efficient windows. In order to achieve good indoor comfort, an appropriate ventilation system should be installed (Krope and Goricanec, 2009).

There are some definitions of low energy buildings. In Switzerland, for example, low energy buildings are promoted by the non-profit organization MINERGI®. MINERGI® is registered as a "quality label for new and refurbished buildings"." MINERGI-Standard" requires that buildings "do not exceed more than 75% of the average building energy consumption and that fossil fuel consumption must not be higher than 50% of the consumption of such a buildings" (www.minergie.ch).

The Forum for Energy-efficient Buildings (*Forum för energieffektiva byggnader* - FEBY), the organization that promotes building and renovation to energy-efficient standards in Sweden (www.energieffektivabyggnader.se), was the first in Sweden to officially recognize two types of low-energy houses: passive house and mini-energy house (Forum för energieffektiva byggnader, 2009a, Forum för energieffektiva byggnader, 2009b). A passive house was recognised as a low-energy house, which aims at "*significantly better* performance than required by Swedish Building Regulations BBR

16 (BFS 2008:20)" (Forum för energieffektiva byggnader, 2009a). A mini-energy house, like the low-energy house, was expected to have "*better* building performance than defined in Swedish Building regulations BBR 16 (BFS 2008:20)" (Forum för energieffektiva byggnader, 2009b).

The latest changes in Swedish Building Regulations (BBR2012) introduced a definition of low-energy and very low-energy buildings. Definitions included in BBR2012 describe low-energy buildings as buildings in which the space heating energy requirement[1] is lower than 75% of the requirements specified by current Building Regulations (9:8); space heating for very low-energy building should not exceed 50% of this requirement.

2.4.2. The passive house concept

The passive house concept as known today is the result of experience from many years of low-energy house construction. Among the many who have contributed to expanding knowledge and development of the passive house concept are: Professor Bo Adamson, architect Hans Eek, Robert Borsch Laaks, and Wolfgang Feist (Passive House Institute, Darmstadt, Germany; www.passive.de).

There are two definitions of "passive house" in Sweden: one international definition, promoted by the Passive House Institute in Darmstadt, Germany and a second, which has been formulated by the Forum for Energy-efficient Buildings (FEBY)(PHPP, 2007). The latter description of "passive house" is based on the same concept; however, adjustments to generally used standards in Sweden may slightly influence energy calculation results.

The Passive House Institute (PHI) defines a passive house as: *"a building for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air."* (Passive House Institute, Darmstadt, Germany, www.passiv.de)

Wolfgang Feist, the founder of PHI, explains that fundamental to the passive house concept is thermal comfort, which is achieved by very good insulation of the airtight building envelope and by minimization of thermal bridges; hence overall heat losses are very small. Airtight building construction and good thermal insulation allow the building to retain warm air better during the winter season and leakage of cold outdoor air is minimized. Due to those attributes, the requirement for heating is significantly reduced and therefore the heating system may be simplified to complementary heating (e.g. heating with fresh air via an adequate ventilation system) or even be unnecessary. Even though the specific space heating (15 kWh/m^2) and/or heat load (10W/m^2) values for passive house must not be exceeded (Feist, et al., 2005), Feist explains that these measures are a consequence of concepts and energy-efficient design and not an aim in itself and that the difference in climate conditions calls for specific system solutions with regard to design, construction, ventilation and heating/cooling installation systems (Feist, First Step; What can be a Passive House in your region with your climate?, Passive House Institute, Darmstadt, Germany). Criteria for passive houses are briefly described in table 1.

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[1] Space heating is understood as the sum of the energy distributed to the building and required for its general operation, heating, cooling and warm water.

Table 1. Passive house criteria PHI (Passive House Institute, PHPP 2007)

Space heating demand*	≤15kWh/m^2 (reference area) annually
Heat load*	≤10 W/ m^2 (reference area)
Primary energy (including domestic electricity, heating/cooling, building operation electricity)	≤120 kWh/ m^2 (reference area)annually
n_{50}-leakage rate (Pa50)	≤0,6 h^{-1}
Ventilation, with heat recovery efficiency	≥75%
*PHI certification requires that specific space heating or heating load values must be fulfilled	

In order to minimize heat and electricity demand, the Passive House standard requires that the annual demand of primary energy (sum of heating, hot water, auxiliary and household electricity) must not exceed 120 kWh/m^{2}a (per net floor area within the thermal envelope). By referring to primary energy, Passive House standard marks the importance of the energy source.

The airtight house requires a ventilation system which can also be used for heating. The supplied air is fresh and unpolluted; however, in order to achieve a very low heating energy demand, heat recovery from exhaust air must be utilized (Waltjen, et al., 2009). PHI recommends that ventilation aggregate units should have a minimum of 75% heat recovery efficiency. It is absolutely fundamental that a hygienic requirement (minimum fresh air volume of 30 m3/h per person) is fulfilled.

2.4.3. Swedish passive house standard

Even though development of the industrial construction of passive houses in Sweden is relatively slow, the first passive house that fulfils PHI standards was built as early as 2001. Designed by Hans Eek, 20 terrace houses in Göteborg (Lindås) became a milestone in low- energy building construction and showed that the Passive House concept can be successfully realised in the Scandinavian climate.

In 2007, *the Forum for energy efficient buildings (FEBY)* published the first Swedish passive house standard, which was replaced by new version in 2009, and later updated in 2012. According to a market report (Forum för energieffektiva byggnader, 2009c), 400 dwellings had been built to Swedish passive house standard in Sweden by March 2009, and it was calculated that in 2011 the Swedish passive house market would reach 3000 dwellings (Passivhuscentrum, http//www.passivehuscentrum.se).

It is specified that passive houses should achieve thermal comfort with minimum heating energy and maintain it by rational heat distribution of a hygienic air flow (Forum för Energieffektiva Byggnader, 2009a). Air heating is possible but not necessary as it is possible that heating can be delivered via a conventional heating system.

2.5. Zero-energy building

In the recast of the European Council Directive regarding Building Performance (2010/31/EU), yet another description of energy-efficient and environmentally conscious building was introduced:

(nearly) Zero Energy Buildings. A zero energy building might be generally described as a building that should be able to achieve a neutral life cycle, securing its low energy requirements from renewable energy sources. The literature shows that there are many different ways to specifically define what constitutes zero energy building (Hernandez and Kenny, 2010; Lund et al., 2011; Marszal and Heiselberg, 2011; Marszal et al., 2011; Sartori et al., 2012).

2.6. Conventional building (benchmark)

In order to be able to assess building performance, it is necessary to determine the benchmark, in other words, the standard that allows evaluation and objective interpretation of results. In the building industry, the construction standards can be used for benchmarking; hence, buildings which fulfil valid Swedish Building Regulations are considered here as the benchmark for new building construction and referred to as conventional buildings.

2.7. Overview of definitions

The aim of this chapter is to present different concepts related to environmental qualities of buildings and discuss the intentions behind those descriptions. Sustainable, green and energy-efficient buildings aim at adopting resource-efficient solutions, although these terms cannot always be safely used as synonyms. The sensible question is then how those different terms relate to each other.

Can energy-efficient building be “green”? Energy performance is only one of many assessment fields in environmental assessment methods (BREEAM, LEED or Green Star) and therefore if building environmental performance can be demonstrated in other assessment areas (e.g. material, water, waste) then the energy-efficient building can be named “green”. On the other hand, it is possible to reverse the question: is green building energy-efficient? A report prepared by the National Building Institute for the U.S. Green Building Council (Turner and Frankel, 2008) indicates that, on average, the energy performance of LEED buildings is better than the national average; however, in some cases, the predicted performance of the LEED buildings and the measured values differ significantly. Moreover, studies by Newsham et al. (2009) showed that there is “no statistically significant relationship between LEED certification level and energy use intensity”. Additionally, the report from BREEAM Consultation (2010) suggested shortcomings in energy efficiency assessment, indicating that BREEAM credits for energy efficiency in buildings should be strengthened and BREEAM certificated buildings performance monitored. A pitfall of building assessment tools might be the complexity of evaluation and the fact that the weight of individual parameters may only to some extent affect the final result. On the other hand, assessment methods allow the comprehensive environmental value of buildings to be highlighted.

It is possible to approach building evaluation using a three-dimensional framework: environmental, social and economic. Schnieders and Hermelink (2006) argued for sustainable value for passive houses, contending that “user-oriented design” and a focus on high quality in indoor environment contribute to the social component and that very low energy demand helps on the road to fulfilling environmental end economic conditions. Considering that the success of zero-energy building depends on successfully foreseeing future (energy) needs and securing them with renewable energy sources, this means that success in zero-energy building could fit into the definition of sustainable buildings. Figure 1 illustrates the relationship between different concepts related to environmental qualities of buildings.

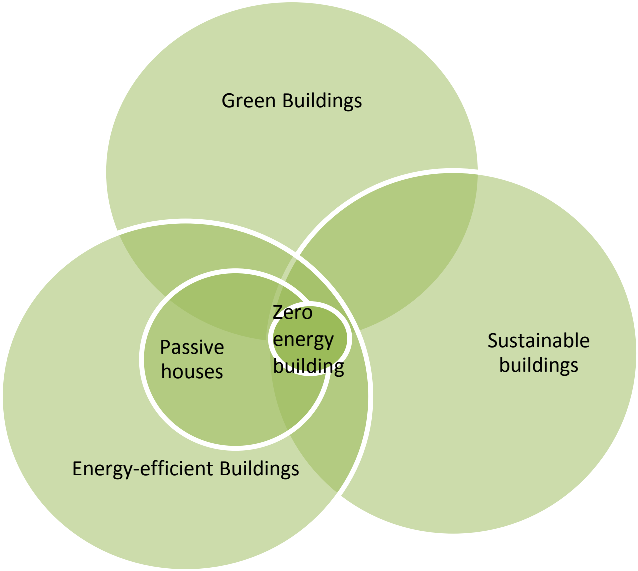

Figure 1. Overview of relationship between different concepts related to environmental qualities of buildings

Sustainable, green or energy-efficient buildings define concepts that ultimately aim at promoting better construction and responsible use of resources. However, it is the choices made in the course of design, production, management, operation and demolition which ultimatelly determine the resource-efficiency and total environmental impact of the building.

2.8. Practical definition used this thesis

Buildings designed and constructed with the goal of minimizing impact on the environment are expected to perform better than conventional buildings. In this study, buildings that fulfilled or nearly fulfilled passive house standard or/and buildings which were certified according to one of the environmental schemes for buildings were considered as buildings that have the potential to achieve sustainability goals. In this thesis, I refer to these buildings as *green*, *energy-efficient and low-energy* buildings. These terms are often used as synonyms, though I am aware of limitations within each term.

The benchmark, to which we can relate construction costs, building performance, perceived satisfaction and indoor quality, is a conventional building, designed and constructed according to current Swedish Building Regulations (BBR).

3. Method

3.1. The quasi-experimental approach

In this thesis, the assessment of energy-efficient green buildings has been generally made by comparison to conventional buildings, based on the premise that evaluation can only be achieved by referring to an acceptable base line, providing a benchmark for performance. One of the methods that builds on the concept of comparing similar groups is the quasi-experimental study. 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 studies from medical experiments and psychology to analysis of policies, industries and services (Bussing, 1999; Fagan and Iglesias, 1999; Reed and Rogers, 2003; Eliopoulos et al., 2004; Atterhög 2005).

The advantage of the quasi-experimental method is the possibility of controlling variables that may have a potential impact on measured variables. The buildings selected in this research were paired as closely as was possible, considering the location of buildings, their size, production year and potential customer segment. Firstly, I have searched for multi-family buildings that fulfill the research definition of green building. After selecting the green buildings, I have looked for controlled objects, conventional buildings that fulfill in the best manner the above-mentioned objectives. During the course of this research, a total of ten energy-efficient green and ten conventional multi-family buildings have been carefully selected.

The quasi-experimental approach was used to investigate whether there is a difference between the opinions of occupants living in green and conventional building occupants focusing on investigating occupants' overall satisfaction, perceived quality of indoor environment and potential problems appearing in the building. The results were described in papers II and IV. In papers V and VI, the same method was applied; however, the focal points were the importance of environmental factors from a customer perspective and occupants' willingness to pay for green buildings, respectively.

The papers are included in the thesis chronologically, i.e. according to the time when the papers were written, rather that ordered according to method used or (developer or customer) perspective investigated. Figure 2 presents design and methods applied in the thesis.

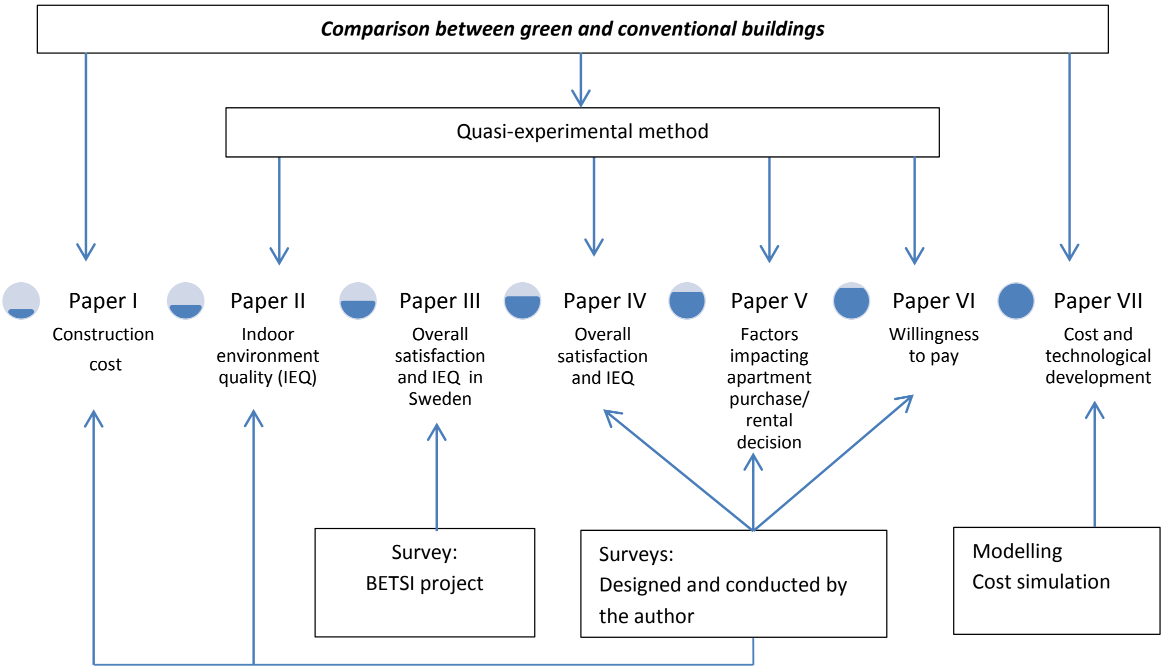

Figure 2. Design and methods applied in the thesis.

3.2. Limitations

Unfortunately, in reality we are unable to control all the factors and we must accept nearly-perfect solutions. Each property is unique in form, design and exposure to local climate conditions. These elements may have an effect on building performance, but also on occupants' opinion. Secondly, certain limitations come from the approach itself. The buildings were specifically chosen due to their characteristics and not randomly selected. Even though the buildings described in this thesis represent the majority of multi-family energy-efficient buildings constructed in Sweden, they may not be representative of the total population.

In this thesis, both a quantitative and a qualitative approach were applied. The number of observations (papers II,III,IV, V and VI) allows for a quantitative approach in data analysis; on the other hand, the approach employed in data collection (quasi-experimental study, survey questionnaire, interviews) is often used in qualitative research and therefore subject to criticism for being subjective, difficult to replicate and posing problems of generalization (Bryman, 2012).

Since I was unable to triangulate data collected via the survey with real construction costs (paper I) or prices (paper VI) or in-use measurements such as energy consumption (papers II,III and IV), the present study is largely based on experience and the personal opinion of respondents. Consequently, the analysis may include errors related to the formulation of the questions, respondents' subjective opinion and their selective memory (Schwarz and Oyserman, 2001).

Finally, challenges may emerge while constructing, estimating and interpreting regression models when the data set has a paired structure, as in the case of data based on observation of twins. Carlin et al. (2005) suggested that the pairing characteristics of data should be taken into consideration when fitting it to a regression model. The authors indicated that the assumption of a difference between outcome values for a given difference between covariate values being equal when comparing two unrelated individuals and two twins may be untrue. After discussion, the authors suggest that more adequate results are computed if the general model includes a coefficient for pair effect.

Since certain characteristics of green building are not as directly explanatory of conventional building characteristics as is the case in twin studies, it is possible that concerns regarding statistical models indicated in Carlin et al. (2005) may not apply in our case. However, considering limitations of research design, data collection and analysis, the results should be interpreted with caution.

3.3. Theory and tested hypothesis

It is my conscious choice not to include a theory chapter in this part of the thesis. The reason is that the scientific theories which underpin this research are eclectic: selected and used as was considered most relevant in regard to the objective and framework of the particular study. Consequently, the theoretical background and the literature review are presented in the respective papers included in the thesis.

The reader might also be surprised by how rarely I have used the word "hypothesis" in the thesis. This, however, does not mean that no hypotheses are put forward or tested. The propositions are indeed stated silently and the results of various statistical tests aim to help find the answer to and explain the studied phenomena as indicated in the objectives.

4. Summary of the papers

The results of this research are presented in seven papers (the structure is presented in figure 3). *Paper I* focused on the developers' perspective and investigated the cost and investment viability of green and conventional buildings. *Papers II-VI* focused on the occupants' perspective, investigating how the perceived indoor environment affects occupants' satisfaction. *Papers II and IV* aimed at comparing responses from occupants living in green and conventional residential buildings and focused on differences in occupants' satisfaction, operation and management between those two types of buildings. *Paper III* presents a more general picture of residential buildings in Sweden by analysing overall satisfaction and the perceived indoor environment quality on a national level. *Paper III* uses data from a survey commissioned by the Swedish National Board of Housing, Building and Planning (*Boverket*), with results being representative of all adults living in multi-family apartments in Sweden. *Papers V* and *VI* aimed at investigating the importance of environmental factors in customers' purchasing decisions and analysing stated willingness to pay for green buildings, respectively. Results presented in the latter paper are also interesting from a developers' perspective, as willingness to pay represents potential income for the developer. Finally, *paper VII* looked at profit and construction costs of energy-efficient buildings considering gains and losses of saleable floor area. This paper explored the effect that new energy-efficient products may have on the profitability of energy-efficient building construction.

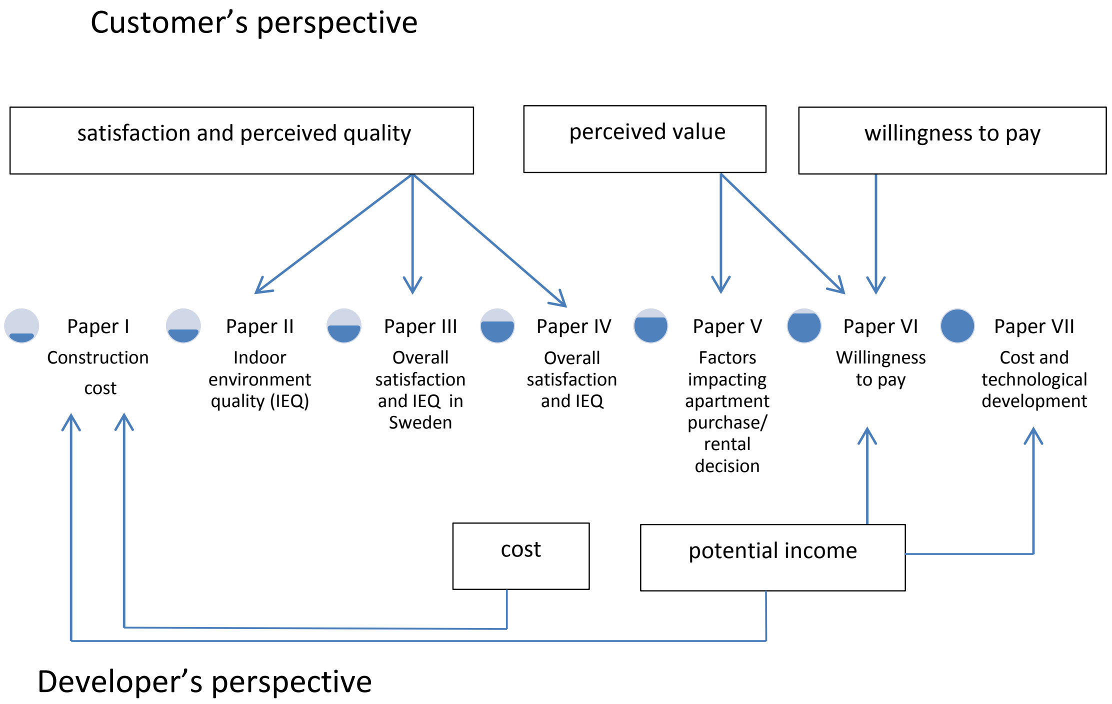

Figure 3. Structure of the thesis.

Paper I

Zalejska-Jonsson A., Lind H. and Hintze S., (2012) "Low-energy versus conventional residential buildings: cost and profit." ***Journal of European Real Estate Research,*** **vol. 5 issue 3, pp: 211-228**

The aim of this paper was to investigate the cost and investment potential of low-energy and conventional residential buildings, considering reduction in operating cost. The profitability of investment in "green" and conventional residential building was evaluated using an equity investment model: net present value. The assessment of the difference in construction cost was based on responses received from a survey addressed to chief executives and project managers of construction companies that had experience of construction of low-energy multi-family buildings in Sweden. The estimate for operating cost was based on the difference in energy requirement between low-energy and conventional buildings and on responses received from a survey and interviews conducted with housing managers.

The responses received from private and public construction companies implied that labour and material cost varied most between "green" and conventional construction. Interestingly, respondents stated that the labour cost decreased with increasing experience of low-energy construction and the development of construction technologies may constitute the greatest contribution to the development of low-energy building construction.

The results indicate that at 5 per cent higher construction costs for low-energy buildings and at the assumed energy prices, considering a holding period of 20 years, the energy savings are sufficient to defray the extra investment cost.

Paper II

Zalejska-Jonsson A. (2012), "Evaluation of low-energy and conventional residential buildings from occupants' perspective." ***Building and Environment*** **Vol. 58, pp: 135-144**

The paper aimed at assessing building performance through investigating occupants' satisfaction with indoor environment in residential buildings. The paper focused on differences that may occur between operation, management and satisfaction of tenants living in low-energy and conventional buildings. The study was limited to multi-family buildings with rental apartments. Survey responses received from 256 tenants living in low-energy and conventional multi-family buildings were used to create a data set.

The results indicated that satisfied and dissatisfied tenants live in both low-energy and conventional buildings. Tenants living in low-energy buildings showed high satisfaction with air quality and sound insulation in their dwellings, but were more prone to experience colder temperatures and chose to use supplementary heating. However, concerns about heating and ventilation were reported in both types of buildings.

Interestingly, occupants living in green buildings indicated that they were proud to live in an environmentally conscious building. Occupants indicated that their environmental awareness increased and affected their behaviour.

Feedback received from housing managers indicated that there is relatively little difference in operating low-energy and conventional buildings; however, adjustment of HVCA insulation and heating could be challenging. It seemed that housing managers and occupants experienced problems particularly with the efficiency and effective operation of the HVAC system.

Paper III

Zalejska-Jonsson A. and Wilhelmsson M. (2013) "Impact of perceived indoor environment quality on overall satisfaction in Swedish dwellings." *Building and Environment* Vol. 63, pp. 134-144

The ambition of this paper was to investigate the impact that aspects of indoor environment quality may have on occupants' satisfaction. The analysis is based on survey responses collected during the project *BETSI* commissioned by *Boverket* (The Swedish National Board of Housing, Building and Planning). The results are representative for all adults living in multi-family apartments in Sweden.

The results indicate that perception of indoor air quality has the greatest effect on occupants' overall satisfaction. It was found that experiencing problems with draught, dust and too low temperature negatively affects overall satisfaction.

Occupants' satisfaction may also be affected by both building and individual characteristics. It was found that the relative importance of factors impacting overall satisfaction may differ depending on location, building construction year, occupant gender and lifestyle.

Paper IV

Zalejska-Jonsson A. "Parameters contributing to occupants' satisfaction: Occupants' insights into green and conventional residential buildings"; paper accepted for publication in *Facilities*

The goal of this paper was to study the impact of perceived indoor environment quality on occupants' satisfaction, and by investigating buildings with both rental and owned apartments, we aimed to explore whether apartment tenure may have an effect on the difference between green and conventional buildings.

The findings showed that occupants are very satisfied with their apartments. The analysis indicated no statistically significant difference in the opinion of occupants living in green and conventional buildings; however, a statistically significant difference was found between occupants living in rental and owned apartments.

The lowest satisfaction scores were given to thermal comfort. Findings imply that satisfaction with thermal comfort varies between occupants depending on the time of year. Generally, occupants in green buildings found indoor temperature too low in the winter, but more satisfactory in the summer than those living in conventional buildings. The opinion of owners of green and conventional dwellings differed at a statistical level. Occupants living in green apartments indicated they were more pleased with sound quality than those living in conventional dwellings. With regard to acceptance of air and light quality, the difference in occupants' opinion was significant depending on apartment tenure, but not on the environmental profile of the buildings. It was found that perception of thermal quality and of air quality have a significant effect on occupants' overall satisfaction.

The findings also indicated that building performance and occupants' satisfaction can be affected by the owner's ability to ensure that the HVAC system works effectively. The findings indicate that buildings with owned apartments are more vulnerable to this kind of problem, often because of the owner's limited technical competence, failure or lack of communication with installation or construction companies. In the case of buildings with rental apartments, the responsibility of housing managers is to secure effective system operation.

Paper V

Zalejska-Jonsson A. (2013) "Impact of energy and environmental factors in the decision to purchase or rent an apartment: The case of Sweden" Paper accepted for publication in *Journal of Sustainable Real Estate* vol. 5

The focus of this paper is on examining how the impact of energy and environmental building features are being factored into decisions to rent or buy apartments. The paper demonstrates that energy and environmental building performance environmental factors have rather a minor impact on the purchasing or renting decision. Our findings indicate that when discussing the impact of energy and environmental factors on a customer purchase decision, information availability should be considered. Moreover, the results suggest that availability of information on building environmental features increases the likelihood of the buyers' interest in this information.

Paper VI

Zalejska-Jonsson A. (2013) " Stated WTP and rational WTP: willingness to pay for green apartments in Sweden" Submitted to *Sustainable Cities and Society*

Considering that green buildings are expected to require lower operating costs, provide better indoor environment and have a lower impact on the environment than conventional buildings, it is rational to believe that a customer is willing to pay extra if perceived benefits from renting or buying green property are more beneficial than those from conventional buildings.

The aim of this paper was to study stated and rational willingness to pay for green apartments in Sweden. A database of responses from occupants living in green and conventional multi-family buildings was used to investigate the existence of WTP and to test differences in opinion between respondents living in green or conventional buildings and condominiums or rental apartments.

The responses indicate that people are prepared to pay more for very low-energy buildings but not as willing to pay for a building with an environmental certificate. It was found that interest in and the perceived importance of energy and environmental factors affect the stated WTP. The results indicate that a stated willingness to pay for low-energy buildings of 5% can be considered a rational investment decision.

Paper VII

Zalejska-Jonsson, Agnieszka; Lind, Hans; Hintze, Staffan. 2013. "Energy-Efficient Technologies and the Building's Saleable Floor Area: Bust or Boost for Highly-Efficient Green Construction?" Buildings 3, no. 3: 570-587.

The paper explored floor area losses that developers encounter when constructing energy-efficient buildings and investigated the possible effect of new technologies on construction cost and floor area balance.

The results show that the profitability of constructing energy-efficient buildings can be significantly reduced due to floor area losses. The paper shows that construction of energy-efficient buildings and introducing very energy-efficient technologies may be energy- and cost-effective even when compared with conventional buildings. This result indicates that policies aiming at high energy-efficient construction should actively promote and support the implementation of the newest technologies.

5. Results and contribution

The ambition of this thesis was to investigate the comprehensive value and assess the investment potential of green residential buildings. The research showed that building highly energy-efficient green buildings can be an attractive investment from both the developer and the customer perspective. New technologies and experience can contribute significantly to decreasing construction costs and consequently improve profitability. Moreover, the improved transparency and comparability of information may influence customers' interest in energy and environmental factors. Environmental education is also a significant factor, particularly in assessing the price that the customer is willing to pay.

The research results imply that constructing green residential buildings is a rational strategy for a developer. However, there is a probable risk that a company may see the potential in green strategy, but yet not be willing to deliver the product. Kirchhoff showed (2000) that the strategy of overcompensating is rational if there is a very low risk of a company being exposed if it fails to apply to the green standards. Unfortunately, this issue may apply to the building industry. Building regulations really require developers to present evidence of complying with the building standards, and research has shown (e.g. Bordass et al., 2001; Leaman and Bordass, 2001) that the gap between designed and constructed buildings is significant.

In the case of building construction in Sweden, the latest Swedish Building Regulations (BBR2012) indicate that developers should verify through calculation and measurement those buildings whose energy requirements are fulfilled (9:2). It is suggested that the validation of energy requirements should be carried out over a 12-month period and results should be disclosed two years after occupancy of the building. Disclosure of energy consumption values, which may be adjusted by taking into account outdoor temperature and users' behaviour, may not be sufficient to secure good quality low-energy building construction. The message of this thesis is that building energy consumption values may not tell the whole story. Developer responsibility needs to extend to the post-occupation phase. It is imperative that developers not only design, build and sell highly energy-efficient green buildings, but also ensure that the building is energy-efficient during the operation phase. This thesis shows that post-occupancy assessment, feedback from occupants and improved commissioning strategies are the methods that developers should consider. Failing to validate energy-efficiency and quality of indoor environment calls into question the value of the product delivered to the customer.

Finally, the results presented in the thesis indicate the customers' high level of overall satisfaction with purchased or rental apartments. On the other hand, the delivered quality indicated by level of acceptance of indoor environment was satisfactory, but showed a potential for improvement. Particularly, greater value can be delivered in the case of perceived thermal quality. Considering that perceived quality of indoor environment has an effect on occupants' satisfaction and that occupants' behaviour may have an effect on building performance, it is very important to further examine and attend to these issues.

This thesis makes a humble contribution to better understanding occupants' needs and expectations; it contributes to knowledge of low-energy residential buildings and takes a small step towards understanding factors that affect green building development.

6. Future studies

The results presented in this thesis indicated a few issues that need further attention and investigation. First, future study should focus on how responsibility for securing efficient building operation can be applied in a business model. The gap between building construction and operation has been discussed for many years now; however, the need to find the most appropriate solution has never been more urgent.

Secondly, global warming requires change that is the responsibility of all of us, as a group and as individuals. Future research could explore further how communication can improve environmental awareness, education and affect customers' behaviour and the decision-making process.

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Paper I

Low-energy versus conventional residential buildings: cost and profit

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Abstract

Purpose – The purpose of this paper is to investigate the commercial aspect of "green" building construction and whether increased investment costs are profitable taking the reduction in operating costs into account. The investment viability is approached by comparing investment in conventional and "green" residential building, particularly passive houses, using real construction and post-occupancy conditions.

Design/methodology/approach – The key data were obtained by surveys and personal interviews. The first survey was directed to the companies which had experience of building low-energy housing and the second survey to housing companies that actively manage operation of low-energy houses.

Findings – Findings indicate that low-energy buildings are considered an interesting and sound business opportunity, and investment analysis indicates that low-energy houses (particularly passive houses) can be more attractive investments than conventional residential buildings. The long-term strategy of building low-energy buildings can give competitive advantages. The government initiative and the construction regulations are found to be necessary in eliminating the initial barrier to energy-efficient projects and achieving long-term environmental goals.

Originality/value – This paper provides insights into the investment decisions and contributes to the understanding of the construction, operation and profitability of energy-efficient residential buildings.

Keywords Low-energy buildings, Residential buildings, Cost, Profit, Sweden, Construction industry, Energy

Paper type Research paper

1. Introduction

1.1 Background

Accurately evaluating property is challenging, and seems even more so when sustainability values are involved. Sustainability features are expected to contribute to the property value (Meins *et al.*, 2010), so the sustainable attributes of a building should be included in property valuation models (Lorenz *et al.*, 2007; Lorenz and Lutzkendorf, 2008). On the other hand, uncertainties concerning the financial and environmental potential of "green" buildings contribute to doubt on the part of participants and property investors. Financial and insurance institutions seek strong evidence of profitability in green projects (Nelson *et al.*, 2010) before they are willing to support them. Investors and developers defend this reluctance by expressing concerns about the extra cost of "green" buildings and the highly speculative return on investment and payback period (Issa *et al.*, 2010).

The authors would like to thank reviewers and the Editor for their constructive comments and suggestions. The presented study is part of a research project which is funded by SBUF, The Development Fund of the Swedish Construction Industry.

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In seeking empirical evidence, a few research studies have focused on the linkage between cost and income premium in energy-efficient and sustainable properties. Matthiessen and Morris (2004) compared the LEED[1] and non-LEED certified projects and concluded that, though costs vary between building projects, there is no significant statistical difference between LEED and non-LEED certificated buildings; both categories include low- and high-cost buildings. They have also pointed out that a number of factors can influence the economic results, so comparison with an average construction budget yields little information. Schnieders and Hermelink (2006) examined residential energy-efficient buildings in Europe and concluded that constructing a passive house costs 0-17 per cent more than constructing a conventional house; on average, the specific extra investment was found to be 8 per cent of the total building cost. Other research (Miller *et al.*, 2009) has demonstrated that the more environmentally friendly a building is and therefore the higher the LEED certified level, the higher the extra cost of building green. On the other hand, emerging results indicate that green labelled commercial buildings can generate higher rental income (Eichholtz *et al.*, 2009) and that the relationship between green rating level (i.e. LEED) and effective rental premium is significant (Eichholtz *et al.*, 2010).

Exploring the correlation between price premium and "green building" certification appears to be relatively more common in the commercial than the residential market, which might be related to accessibility of data. A few studies have been done in Switzerland where Banfi *et al.* (2008) analysed willingness to pay for energy saving measures in Switzerland's residential buildings, concluding that willingness to pay for energy-efficiency attributes is similar to the cost of implementing those attributes. Values for willingness to pay estimated by the authors are comparable to results received by Ott *et al.* (2006), where they were able to capture the effect of Minergie standards[2] using the hedonic pricing model and conclude that price for Minergie single-family homes in Zurich was 9 per cent (±5 per cent) higher than that of comparable properties. Analysis of the rental market in Switzerland indicates that Minergie tenants are willing to pay a 4.9 per cent increase in gross rent (Salvi *et al.*, 2010).

In Sweden, low-energy houses have been examined in several studies, focusing mainly on life cycle energy assessment (Gustavsson and Joelsson, 2010) and simulation as well as measured values (Karlsson and Moshfegh, 2006; Wall, 2006). Although the general economic assessment of low-energy houses has been approached (Karlsson and Moshfegh, 2006, 2007), the investment viability and life cycle costing analysis of low-energy buildings has yet to be assessed.

1.2 Purpose and significance of the study

The financial rationale of "green" buildings is often questioned by practitioners, who point to the importance of risk, construction complexity, and other real-life conditions that often have considerable effects on investment feasibility. This paper, therefore, compares investments in conventional and "green" residential property (particularly low-energy housing – LEH) using real construction and post-occupancy conditions. The key information was obtained from private and public housing companies in Sweden involved in constructing both types of housing. Furthermore, we also discuss challenges related to constructing energy-efficient housing and incentives that might be needed to accelerate development of the LEH market in Scandinavia.

Accordingly, this paper aims to:

1. Investigate the difference in investment cost between low-energy and conventional housing (CH).
2. Evaluate the profitability of low-energy houses accounting for energy savings.
3. Investigate housing development companies' incentives to construct energy-efficient housing.
4. Explore whether further incentives are needed to accelerate low-energy residential development.

The study is part of a research project investigating the comprehensive value of LEH and its investment potential. The findings should further the development of the low-energy building market and improve present understanding of the construction and operation of energy-efficient residential buildings.

1.3 Scope and limitations

The environmental impact of a building depends on many factors, including energy (e.g. embodied energy, energy used during the building operation, and energy used during construction), materials, use of water and other resources. This research focuses on "green" residential buildings, where special attention is paid to building energy performance; in other words, the investigation focuses on low-energy residential buildings, and particularly in the passive house standard.

We particularly address the cost side of investment and explore whether increased investment costs are profitable, taking the reduction in operating cost into account. The investment costs one defined here as total production cost.

Low-energy buildings require a better insulated envelope, which may increase the thickness of walls, and a reduced ratio between living space and total built area, which in turn influences the number of square meters available for sale, and affects investment viability. This construction aspect of low-energy buildings is not discussed in this paper, but will be explored in further studies.

In this paper, we use term investor to refer to municipal (public) companies that build residential buildings with apartments for rent. The private developer, who builds residential properties with the intention of keeping and managing them as rental property, is also regarded by the authors as an investor. The role of banks and financial companies is not discussed in depth, though the issue and implications of bank strategies towards low-energy construction are significant and worthy of further studies.

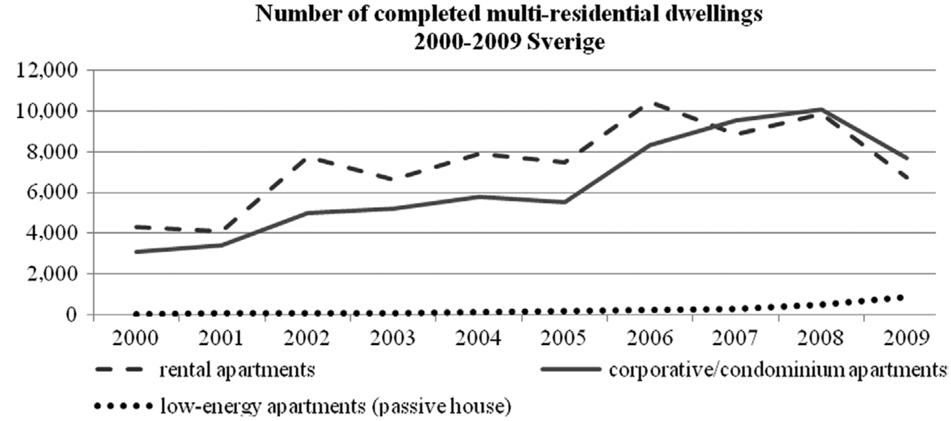
The study is limited by data availability and the number of observations, as relatively few low-energy multi-family residential buildings have been built to date in Sweden (Figure 1).

This paper is organized as follows: the theoretical background and local context are reviewed in Section 2, the methodology and data collection are described in Section 3, the results are included in Section 4, investment analysis inputs and results in Sections 5 and 6, respectively, finally, the conclusions are presented in Section 7.

2. Theoretical overview

2.1 The Swedish context: construction standard

The Swedish Building Regulations (BBR) had long emphasized building safety, comfort, and indoor environmental quality, although after the energy crisis of the 1970s the issue of energy used in buildings became a greater priority (Boverket, 2002).



Source: SCB, Statistics Sweden – www.scb.se; Passivhuscentrum – www.passivhuscentrum.se

Figure 1.
Housing construction in Sweden (2001-2009)

The National Board of Housing, Building and Planning in Sweden gradually incorporated energy requirements into its building code. The changes in the Building Regulations not only limited energy consumption in newly built buildings, but also included standards for the average *U*-value of the building envelope and further considered the energy source issue, by tightening rules for buildings using electric heating systems (Elmroth, 2009). Stricter energy requirements and discouraging the installation of electric heating are part of the government's environmental strategy.

These regulations, however, will change again, since EU Directive 2010/31/EU specifies that by end of December 2020 all new buildings should meet the standards for nearly zero-energy buildings. Assuming that construction takes two-three years on average and that post-building assessments need an additional two to three years, meeting the 2020 building standards will require considerable expertise and experience in building energy-efficient buildings. It is crucial to collect information about these experiences now to draw conclusions and learn lessons.

2.2 Low-energy buildings

A strict definition of what constitutes a "low-energy" house or residential building is difficult to find. It is generally assumed that low-energy buildings should consume significantly less energy than the levels specified in the Building Regulations. The key objective of such a building is energy-efficient design that allows the minimization of energy consumption throughout its life cycle (Summerfield *et al.*, 2009). Specifications that facilitate energy-efficiency gains include compact construction, minimum thermal bridge value, an air-tight building envelope, a thermally insulated building and energy-efficient windows, and finally appropriate choice of heating and ventilation systems (Krope and Goricanec, 2009).

Forum för Energieffektiva Byggnader (FEBY – the Forum for Energy-Efficient Buildings), the organization that promotes building and renovation to energy-efficient standards in Sweden, recognizes two types of low-energy houses: passive houses and mini-energy houses, stating that low-energy houses should aim to achieve better (FEBY, 2009b) or significantly better performance (FEBY, 2009a) than stated in the Swedish Building Regulations. A brief comparison of passive house standards according to FEBY (2009a) and the Swedish Building Regulations BBR 16 (Boverket, 2009) is presented in Table I.

2.3 Profitability and investment viability

a. Profit. The objective and the result for most companies is profit (p), which can be presented as difference between (discounted) income (i) and cost (c), $p = i - c, p \rightarrow \max$.

In Sweden, we can distinguish two housing markets: the owned and the rental markets, where municipal (or private) companies own the property and rent out dwellings. In most cases, the separate organization within the company is responsible for maintenance and operation of the building. In this paper, we refer to this organization as the housing management company. In the case of housing owned by municipal or

Standard for various climate zones in Sweden	FEBY Passive house standard, 2009	Swedish Building Regulation BBR16
Specific energy demand[c] requirement for zone (I) north	$\leq 58\,\mathrm{kWh/(m^2 A^{f}_{temp+garage})}^{a}$ $\leq 34\,\mathrm{kWh/(m^2 A_{temp+garage})}^{b}$	$\leq 150\,\mathrm{kWh/(m^2 A^{e}_{temp})}^{a}$ $\leq 95\,\mathrm{kWh/(m^2 A_{temp})}^{b}$
Specific energy demand requirement for zone (II) central	$\leq 54\,\mathrm{kWh/(m^2 A_{temp+garage})}^{a}$ $\leq 32\,\mathrm{kWh/(m^2 A_{temp+garage})}^{b}$	$\leq 130\,\mathrm{kWh/(m^2 A_{temp})}^{a}$ $\leq 75\,\mathrm{kWh/(m^2 A_{temp})}^{b}$
Specific energy demand requirement for zone (III) south	$\leq 50\,\mathrm{kWh/(m^2 A_{temp+garage})}^{a}$ $\leq 30\,\mathrm{kWh/(m^2 A_{temp+garage})}^{b}$	$\leq 110\,\mathrm{kWh/(m^2 A_{temp})}^{a}$ $\leq 55\,\mathrm{kWh/(m^2 A_{temp})}^{b}$
Heat loss	$\leq 0.30\,\mathrm{l/s\,m^2} \pm 50\,\mathrm{Pa}$, according to SS-EN 13829 standard	Quantitative values not specified
U-value ($\mathrm{W/m^2\,K}$)	U (for windows) $\leq 0.90 - 0.80\,\mathrm{W/m^2K}$ according to standards SS-EN 12567-1	U (average for building envelope) $\leq 0.50\,\mathrm{W/m^2K}^{a}$
	U (for building envelope elements) $\leq 0.15\,\mathrm{W/m^2K}$	U (average for building envelope) $\leq 0.40\,\mathrm{W/m^2K}^{b}$ U value for windows is not specified
Annual heating load[d] for climate zone (I) north	$\leq 12\,\mathrm{W/(m^2 A_{temp+garage})}$ $\leq 14\,\mathrm{W/(m^2 A_{temp+garage})}$	Installed electrical power for heating of dwellings with electric heating, $\leq 5.5\,\mathrm{kW}$
Annual heating load for climate zone (II) central	$\leq 11\,\mathrm{W/(m^2 A_{temp+garage})}$ $\leq 13\,\mathrm{W/(m^2 A_{temp+garage})}$	Installed electrical power for heating of dwellings with electric heating, $\leq 5.0\,\mathrm{kW}$
Annual heating load for climate zone (III) south	$\leq 10\,\mathrm{W/(m^2 A_{temp+garage})}$ $\leq 12\,\mathrm{W/(m^2 A_{temp+garage})}$	Installed electrical power for heating of dwellings with electric heating, $\leq 4.5\,\mathrm{kW}$

Notes: [a]For dwellings without electric heating systems; [b]for dwellings with electric heating systems; [c]specific energy demand: refers to the amount of energy that must be delivered to the building over a certain period of time (i.e. annually) to achieve good indoor climate and building operation; value includes heating, hot water, and energy used for general building operation; domestic electricity is not included; expressed in $\mathrm{kWh/m^2}$; expressed in purchased energy, i.e. end-use energy, measured at final level, purchased from distributor; [d]annual heating load: describes the maximum amount of energy that must be delivered to the building at a particular time (usually the coldest day) to achieve good indoor climate; expressed in $\mathrm{W/m^2}$; [e]Atemp: refers to the area within the thermal envelope where the temperature should be kept over 10°C (www.boverket.se/Kontakta-oss/Fragor-och-svar/Bygg-och-konstruktionsregler/Om-avsnitt-9-i-BBR/Atemp); [f]Atemp + garage refers to the Atemp area and garage area included within the thermal envelope (FEBY, 2009a)

Table I. Brief comparison of passive house standards according to FEBY (2009a) and the Swedish Building Regulations BBR 16 (Boverket, 2009) private companies, *i* equals rental, *c* includes initial cost of building design and construction as well as operation and maintenance costs.

In the first case, where buildings are built for sale, i.e. a private person is the owner and the occupant, consequently the interpretation of the profit equation changes and *i* becomes the selling price of the property. Since the selling price is strongly related to market conditions and the data for market value of LEH is very limited, in this study the focus is on rental housing. The issues related to economic viability of LEH investment on tenant-owned market will be addressed in our further research.

Rents for residential apartments in Sweden are the result of collective bargaining between municipal housing companies and private property owners on one side and the local tenants' union on the other. The rent level is not really dependent on the apartment's quality factors like indoor comfort, but rather related to location, buildings production year or size (Lind, 2011).

Since the rent is not decided by the market, one cannot really observe rent changes caused by market preferences related to property quality or indoor comfort, therefore we can assume that rent $= i$ is constant and equal in conventional and LEH. In such cases, the investor's only strategy for obtaining positive profit is to focus on cost.

b. Investment assessment. An attractive investment is one that offers the investor a satisfactory return on equity (Jaffe and Sirmans, 2001). Whether or not return on invested capital is deemed satisfactory depends on the investor's objectives, but a potentially good investment can be identified using equity investment models, net present value (NPV), internal rate of return (IRR), and payback period (Jaffe and Sirmans, 2001). Generally, the outcome of an investment evaluation of a real estate development project is determined by the total investment cost, net operating income generated on real estate, and the required rate of the return over the expected holding period (Hoesli and MacGregor, 2000; Geltner *et al.*, 2007). NPV can be described by the following function:

$$NPV = \sum_{n=1,i=n}^{n} \frac{NOI_i}{(1+R)^n} + \frac{RV_n}{(1+R)^n} - TIC, \quad RV_n = \frac{NOI_i}{rRV} \tag{1}$$

NPV	net present value of equity.
NOI_i	net operating income through *i* periods.
n	expected holding period.
RV_n	residual value in the nth period.
rRV	expected yield from property.
TIC	total investment cost.

Consequently, IRR can be described as:

$$0 = \sum_{n=1,i=n}^{n} \frac{NOI_i}{(1+IRR)^n} + \frac{RV_n}{(1+IRR)^n} - TIC \tag{2}$$

IRR	internal rate of return on equity.

Input data used in investment models are based on estimates; the more accurate the cost and income valuations, the greater the likelihood an attractive investment can be identified (Hoesli and MacGregor, 2000).

3. Method and data collection

3.1 Investors

Information about low-energy buildings in Sweden was collected through survey and personal interviews.

The survey questionnaire was sent to municipal housing companies that build rental housing and to private construction companies that build housing for sale or rent. The survey was addressed to the companies that took part in the construction of low-energy multi-family buildings over the last decade. It was estimated that approx. 1,000 energy-efficient dwellings had been build in that time (i.e. till 2010). It is appraised that the companies who responded to our survey have been involved in 85-90 per cent of these projects. All respondents were asked to answer questions from the position of an investor (i.e. client) and not that of contractor (some companies might have participated in construction projects as contractor, investor, or both). The number of survey recipients per company varied depending on company size and the number of low-energy projects carried out. The survey was addressed to chief executives (i.e. those responsible for new projects and housing development) and project managers. The notification of survey questionnaires were sent to 34 companies (93 people) that had participated in at least one LEH project in Sweden. Answers were collected using an on-line questionnaire from February to March 2010; 34 completed questionnaires were collected for a response rate of 37 per cent. We have received answers from 24 different companies (i.e. 71 per cent of the contacted companies), 16 respondents represented public and 18 private companies. Some of the biggest construction companies in Sweden took part in the survey, including listed companies (e.g. Skanska, NCC, and PEAB) and large municipal housing companies, such as Svenska Bostäder, whose 2009 turnover was approximately EUR 300 million (http://svenskabostader.se). 12 face-to-face, open-ended interviews were conducted between September 2009 and September 2010 to acquire a better understanding of the technical and economic challenges of building LEH in Sweden. The interviewees represented nine companies, five private (seven interviewees) and four public companies (five interviewees).

3.2 Operation and management companies

Data on the operation and management of low-energy dwellings was obtained by survey and personal interviews. Survey questionnaires were sent to housing companies identified by market research as actively managing low-energy buildings. Only multi-family residential buildings with rental apartments were the subjects of study.

Low-energy buildings were identified in the building stock of 18 public housing companies. The notification of survey questionnaires was sent to the person or people responsible for managing and operating identified low-energy residential buildings (30 recipients) in the 18 companies. The number of survey recipients per company varied depending on the size of the housing company and the number of low-energy buildings in the building stock. Answers to an on-line questionnaire were collected from November to December 2010. Nine people, each representing a different housing company, completed the survey.

Additionally eight interviews were conducted with representatives of housing management companies over a period of approximately one year, i.e. December 2009-February 2010. Four interviews were face-to-face, open-ended interviews and four were scheduled telephone interviews. The interviewees represented two private and four public companies. The goal of the interviews was to acquire a deeper understanding of the different challenges of operating and managing low-energy versus CH.

4. Results and analysis

4.1 Investment cost

Most respondents stated that the total investment cost of LEH was less than 10 per cent greater than that of traditional buildings. Just over half of the public companies estimated that the extra total investment cost was in the 5-10 per cent range, while only one quarter of the private companies gave this answer. Most of the private companies, i.e. approximately 60 per cent, estimated that the extra investment cost of LEH was 5 per cent or lower (Figure 2).

Public and private companies' opinions differ to some extent concerning the cost estimates. This difference may be because private companies tended to have more accurate information about individual cost components (e.g. operation, materials, and design). In addition, private companies may have procurement advantages, and their workers can find savings on site during construction by discovering innovative and practical solutions.

Administration and design. Administration costs in LEH are no higher than in CH, except in the case of "demonstration projects", where the increased costs often relate to organizing lectures and on-site visits. Nearly two-thirds of the respondents said that LEH construction material was more expensive than CH material, which may relate to the higher unit prices of more energy-efficient material (e.g. insulation and windows). Labour and design costs are also higher on LEH budgets. The architect team, installation designer team (e.g. for HVAC), and energy coordinators must work together to deliver a low-energy building design. Collaboration and active engagement throughout the design and construction processes as well as work precision may translate into more hours of work for both the design and building teams.

Private companies (60 per cent) estimate that the design cost tends to be higher by approximately 10 per cent in LEH projects; 40 per cent of public companies agree with this estimate, though 50 per cent of public companies consider the design cost to be about the same as in CH projects.

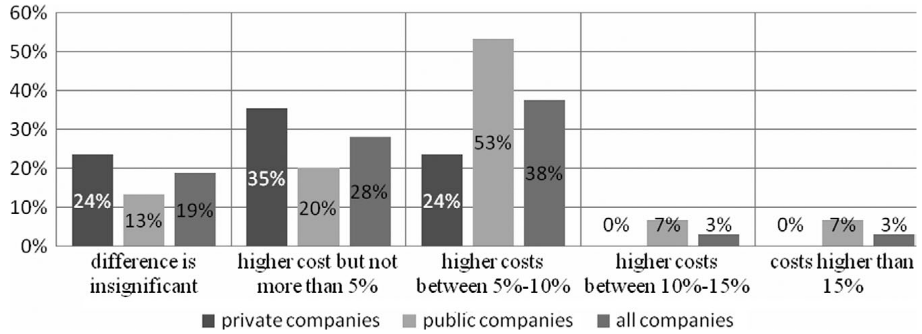


Figure 2.
Total investment cost of green buildings compared with that of traditional residential buildings

Material. Materials are estimated to cost approximately 10 per cent more for LEH construction and installation approximately 5 per cent more. Investors stated that, even though some installation costs (e.g. of a more advanced ventilation system) may be more expensive, savings from not installing a heating system balanced the total installation cost. Other significant material cost components are windows and insulation, which are estimated to cost approximately 10 per cent more in LEH projects. One-third of public companies estimated the insulation cost to be up to 20 per cent more expensive. This cost estimate was not supported by any of the private companies. Moreover, one fourth of private companies disagreed with the window cost estimate, and believed this cost was no higher than in CH buildings.

Labour. According to most respondents, labour costs are approximately 10 per cent higher in LEH than CH projects. Respondents agreed that LEH construction requires more knowledge on the part of the builder, though they did not agree (65 per cent) that there was a greater risk of mistakes in the LEH construction process.

4.2 Operation and maintenance costs

Operation. Regarding the estimated operating cost, most public and private companies expected significant savings in operating low-energy buildings. This belief seems to be confirmed by housing management companies, which also cited cost reductions of at least 20-40 per cent for LEH operation. The reduction in operating cost is based mainly on reduced energy requirements. Investors anticipate that achieving the estimated energy efficiency may require more system adjustments than usual. In practice, the technical installations are not considered to be a particular problem. Housing managers believe that LEH installations require just as much adjustment as do CH installations, though the need for adjustment comes earlier in LEH than in conventional dwellings. Housing managers admit that balancing LEH systems can be challenging, and that the biggest problems are insufficient auxiliary heating efficiency in cases in which air heating systems were installed and adjusting the air flow and temperature in those systems.

Maintenance. One-third of public companies believed that low-energy buildings would require less maintenance in the future, whereas only one fifth of private companies thought the same. This difference in opinion may depend on differences in experience, since municipal companies own, manage, and are in charge of operating and maintaining their building stock, whereas private companies less often assume that responsibility.

Energy consumption. Metering energy consumption in buildings poses some challenges. Individual metering systems for domestic electricity are common in Sweden, though metering heating and hot water, especially when systems are connected to district heating, presents some problems. The difficulty comes partly from the significant cost of installing the most appropriate individual metering system for data collection. According to housing managers, the estimated energy consumption reflects the actually metered energy consumption fairly well. Nonetheless, most newly built LEH are equipped with individual metering systems, so the resident's individual consumption cost is irrelevant to the general investor. Tenants of LEH pay basic rent to the building owner and additional charges for the individual consumption of cold and hot water and domestic electricity. The situation is slightly different in conventional buildings, where rent usually includes hot water and heating (calculated and charged according to commonly used templates) and only domestic electricity is charged according to the individual tenant's consumption.

4.3 Experience and expertise

Survey results suggest that more private (60 per cent) than public (30 per cent) companies noted that prior experience of LEH projects significantly increased efficiency and profitability in ensuing LEH projects. This difference of opinion may be based on the extent of prior construction experience. However, by managing and operating low-energy buildings, municipal companies may gain knowledge and experience that allows them to reduce operation and maintenance costs in LEH and increase efficiency in existing housing stock. Housing managers seem to confirm this hypothesis, since a majority fully or partly agree that experience from earlier LEH projects allows for an increase in efficiency and decrease in operation and maintenance cost in both new built LEH and existing stock (conventional buildings).

The results from our survey suggest that construction companies are in the learning process and are yet to find the optimal solution for benefiting from scale economics, i.e. industrialization and standardization (Figure 3).

4.4 Barriers and incentives

Most investors recognized the business value of low-energy buildings and expressed willingness and readiness to invest in low-energy projects (90 per cent), though many respondents pointed out that the marginal cost of saving 1 kWh of energy is very high if the building space heating should be lower than 50 kWh/m^2.

The survey results indicate that government needs to play a more active role in encouraging low-energy construction. Public companies particularly stress the need for financial stimulants (e.g. tax reductions or subsidiaries) whereas private companies indicate that buildings regulations and standards are not stimulating enough for low-energy buildings development (Figure 4). The last finding is very interesting as it may suggest that building companies underperform due to less demanding standards.

Building low-energy houses is important if one is to be competitive on the market. This is clear for respondents of our survey (particularly private firms) according to whom constructing LEH is good business and, by doing so, the company will strengthen their market position (Figure 5).

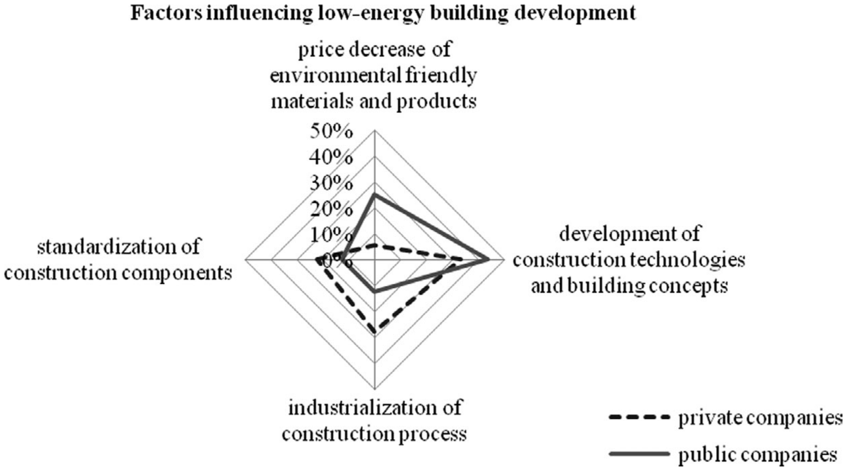


Figure 3.
Factors that have greatest impact on development and growth of low-energy building construction

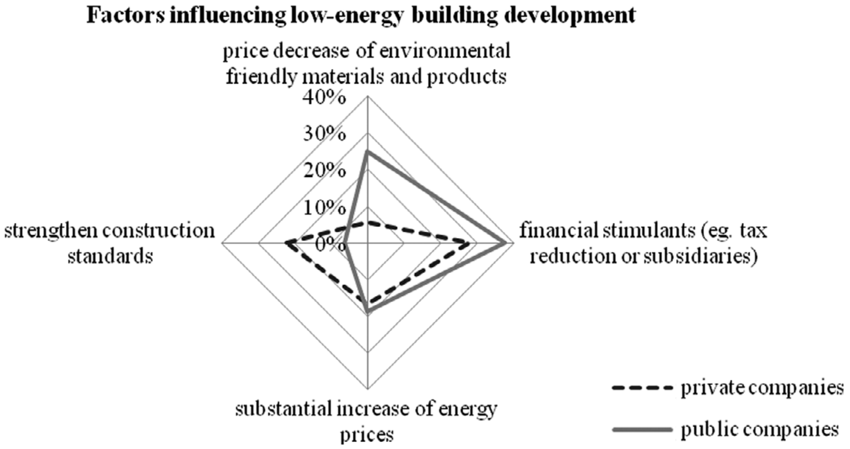


Figure 4.
Decisive factors influencing low-energy building development

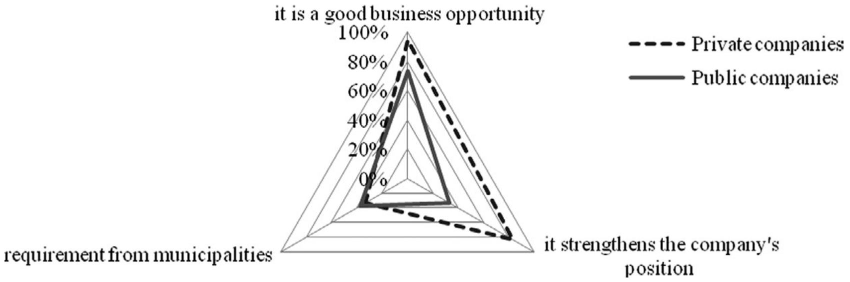


Figure 5.
Rationale for building low-energy buildings

5. Investment assessment: assumptions

5.1 Input data

We attempt to answer the profitability question by evaluating investment in multi-family low-energy building (passive house standard) and the benefits from energy savings. The general assumptions are presented in Table II and the motives behind them are presented below. A sensitivity analysis is carried out to observe changes in results if assumptions are changed. In the economic assessment, the NPV model is used (equation (1)).

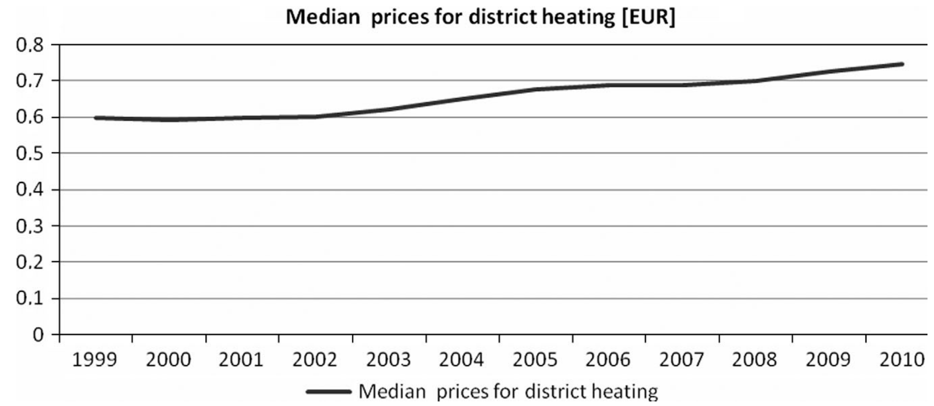
Construction cost (average) in multi-family buildings in Sweden in 2009 (EUR/m^2 living area)	3,000
LEH construction cost difference	5%
Real interest rate	3%
Domestic heating (used for hot water and heating) (EUR/kWh)	0.075
Annual energy price increase	2.5%
Energy savings (kWh/m^2), a	60
Holding period	20 years
Exit yield	5%
Additional m^2 value at the end of holding period (EUR/m^2)	143.8
NPV (20 years) (EUR/m^2)	13.1

Table II.
Base case assumptions for live cycle costing analysis

Energy savings. The difference between LEH and CH investments can be expressed by extra investment cost and consequently energy savings. The energy savings are calculated based on the difference between energy requirements for building operation (inclusive space heating) according to Swedish Building Regulations (Boverket, 2009) for conventional houses (CH) and the passive house standard (FEBY, 2009a) for low-energy houses (LEH). The specific energy demand in Sweden varies depending on climate zone and, in southern Sweden for newly built buildings, it should not exceed 110 kWh/m^2 (leavings space) for conventional buildings and 50 kWh/m^2 for passive houses (Table I).

Energy prices. The central question is what energy price is rational to assume? In the last decade, energy prices in Sweden increased by over 325 per cent and within one year the price can increase by 10 per cent (SCB Statistics Sweden – www.scb.se). Since low-energy building owners benefit most from savings resulting from minimum requirement for space heating and since the most common source for heating in multi-family houses in Sweden is district heating (75 per cent, SCB Statistics Sweden – www.scb.se), we use the mean district heating price. Analysis is done with real prices; however, we assume that the energy price trend is going to hold and therefore we include an annual energy price increase of 2.5 per cent in real terms. The assumed base energy price is EUR 0.075 per kWh. The average price growth in the last five years is shown in Figure 6.

Rate of return. The mean for the Swedish ten-year nominal government bond rate in 2010 (1 January 2010-1 January 2011) was approx. 2.9 per cent (Sveriges Riksbank, Central Bank in Sweden – http://riksbank.com) whereas reported inflation for 2010 was 2.1 per cent (HICP[3]), indicating that the real rate was approx. 0.8 per cent. In the calculations below, a real rate of 3 per cent is used. This is higher than the current real government bond rate, which is motivated with addition for risk. The assumption of 2 per cent risk is in line with the generally used risk level for market risk (Adair and Hutchison, 2005; Hutchison *et al.*, 2005; Hordijk and Van de Ridder, 2005; Lorenz *et al.*, 2006). Since the discount rate is based on the risk-free rate and risk premium, it may reflect the risk-reduction potential of sustainable buildings (Lorenz *et al.*, 2006;



Source: Based on data from Svensk Fjärrvärme – www. svenskfjarrvarme.se/Statistik –Pris/Fjarrvarmepriser

Figure 6.
Annual price change for district heating in dwellings (EUR/kWh), 2000-2010

Lorenz and Lutzkendorf, 2008), which relates to the fact that "green" buildings are less sensitive to changes in energy prices, are characterized by reduced impact on the environment and require lower maintenance cost. On the other hand, there might be uncertainties related to construction technologies, inappropriate solutions and production quality. Those issues should be addressed when assessing specific property projects; however, the calculations presented in this paper are done on the market level and therefore a more general risk value is used, which in order to avoid too optimistic assumptions is set equal for both LEH and CH projects.

Construction cost. The construction cost of conventional buildings is based on the average building total production cost of new-multifamily buildings in Sweden in 2009, which was approx. 3,000 EUR/m^2 living area (SCB, 2010). This cost includes land price, fees for connection of utilities, ground and site works on construction plot and works related to construction of the building. The construction cost of passive houses is estimated based on results from our survey and considered to be 5 per cent higher than the construction cost of CH.

Building residual value. Exit yield is assumed to be 5 per cent; the higher value for exit yield than that for rate of return is motivated by the higher uncertainty when the period is further into the future. The analysis is carried out for holding periods of 20 years.

6. Results from investment analysis

6.1 Base case scenario

In the base case scenario, we assumed the base energy price (EUR 0.075 per kWh) and the extra investment cost 5 per cent (more investment cost than in the conventional residential building). With those assumptions (see Table II for details), in holding periods of 20 years, computed NPV was positive and equal to 13.1 EUR/m^2, indicating that potential energy savings are sufficient to defray the extra investment cost required in LEH and consequently that construction of LEH is an attractive investment alternative. If the owner decides to sell the property after 20 years for a price equal to the estimated residual value (end of holding/calculation period), it is expected that the potential energy savings will generate additional value of 144 EUR/m^2 of LEH building.

6.2 Sensitivity analysis

There are, of course, uncertainties in the assumed values; therefore we have performed a sensitivity analysis (Table III) where one variable is subject to change, keeping other variables constant.

The results of our survey indicate that efficiency increases with experience in LEH construction, which suggests that the extra investment cost will decrease in the future. Sensitivity analysis shows that one point change in extra investment cost has significant impact on computed NPV (Table III). This variable can be controlled by the company to the highest degree.

The investment analysis is very sensitive to assumed base energy price and energy price fluctuation. Even in Sweden, energy price for district heating can vary significantly depending on distributor and region. Investing in low-energy building (passive house standard) in the regions where energy prices are higher is particularly attractive.

Table III.
Sensitivity analysis, NPV computed at 20 year holding period, one variable was subject to changes, the other as in the base case scenario (Table II)

	NPV, 20 years (EUR/m^2)
Base energy price (EUR/kWh)	
0.06	− 19.50
0.07	2.25
0.08	24.0
0.09	45.8
0.1	67.5
Annual energy price increase (%)	
1.5	− 7.6
2.0	2.4
2.5 (base case scenario)	13.1
3.0	24.8
3.5	37.3
Rate of return (%)	
3.5	1.7
3.58 (IRR)	0
4	− 8.7
Extra investment cost (%)	
6	− 16.9
5 (base case scenario)	13.1
4	43.3
3	73.3
2	103.3

Investment analysis indicates that if extra investment cost is 6 per cent or higher, or base energy price is 0.6 EUR or less, the potential energy savings are insufficient to cover extra initial investment. This would also be the case if the real energy price increase is lower than 1.5 per cent or if the real interest rate is set to 3.8 per cent or higher.

7. Conclusions

In this paper, we have attempted to investigate investment viability in LEH in Sweden. We have analysed investments in conventional and low-energy residential property using real construction costs and post-occupancy conditions, with consideration to energy savings potential. Key data was obtained by surveys addressed to private and public housing companies, involved in constructing both types of housing, and to housing management companies responsible for maintenance and operation of conventional and low-energy residential buildings.

Quantitatively, the costs of labour (e.g. training, hours worked, and required work accuracy) and of high energy-efficient materials, such as insulation, windows, and more advanced mechanical ventilation systems with heat recovery, add up to a higher investment cost for low energy buildings. At the same time, high accuracy of construction work and energy efficiency material are absolutely necessary for constructing air-tight, well-insulated, and energy-efficient buildings. Achieving qualitative objectives and future energy savings requires the transforming of conventional building processes, changes in work sequencing, the active involvement of all project participants in the building process (e.g. architect, installation team, construction workers, and investor/owner), and understanding of qualitative and quantitative objectives on the part of all project participants.

Despite regarding low-energy residential buildings as more expensive, public and private companies consider this to be a good investment opportunity. This opinion is supported by our investment analysis, which suggests that the present value of potential energy savings is higher than the extra investment cost required in LEH.

Can we expect a reduction of cost in LEH construction? The construction industry particularly benefits by "learning-by-doing": practical experience and spread of knowledge between workers is central for efficient management of construction projects (Styhre, 2009). The survey respondents agreed that experience gained during prior LEH projects improves the efficiency and profitability of ensuing projects. Improvements in construction processes due to experience and learning (Turner, 2010), competence, ongoing monitoring (Turner, 1999) as well as reduction in cost, for example, due to better procurement, technical development, strategic partnerships, and cost driver control (Porter, 1985), allow the investor and developer to control investment costs and improve their market position. Consequently, investment cost for low-energy buildings is expected to decrease, which as the sensitivity analysis shows, significantly improves profitability.

Foreseeable changes in the political and legal environment might be an important argument for LEH construction. The European Council with its latest directive regarding energy performance of buildings (European Parliament and Council, 2010) established new goals for European Union Members. 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 "nearly zero-energy building" combines two ideas: first that the amount of energy which must be supplied to the building is very small and second that the source of this energy should come from renewable sources. This means that experience and expertise in building energy-efficient buildings are fundamental and the organizations that choose to be ahead and are quick learners may have an opportunity to benefit from knowledge and cost control in low-energy construction.

What form of action can stimulate acceleration of LEH construction? Experience in low-energy building construction is fundamental for achieving national and European Union environmental goals; promoting and actively supporting building low-energy buildings should be one of the government's priorities. This suggests that construction regulations and financial incentives, such as tax reductions or subsidies, may act primarily as "catalysts" covering, to a certain extent, the extra cost of low-energy construction and eliminating the initial barrier to energy-efficient projects.

Notes

1. LEED is a voluntary certification system which provides third party verification that a building or community was designed and built with the aim to reduce environmental impact; building performance is assessed in five key areas (sustainable site development, water and energy efficiency, material selection and indoor environmental quality) and rated on a point scale whose total determines certification level (www.usgbc.org).
2. Minergie is a label, supported by the Swiss Confederation, Swiss cantons and industry, particularly focusing on building low and very low energy consumption and promoting highly energy-efficient choice of material (www.minergie.ch).
3. HICP – Harmonised Index of Consumer Prices; CPI index which has been calculated using a common methodology across EU countries.

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Paper II

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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

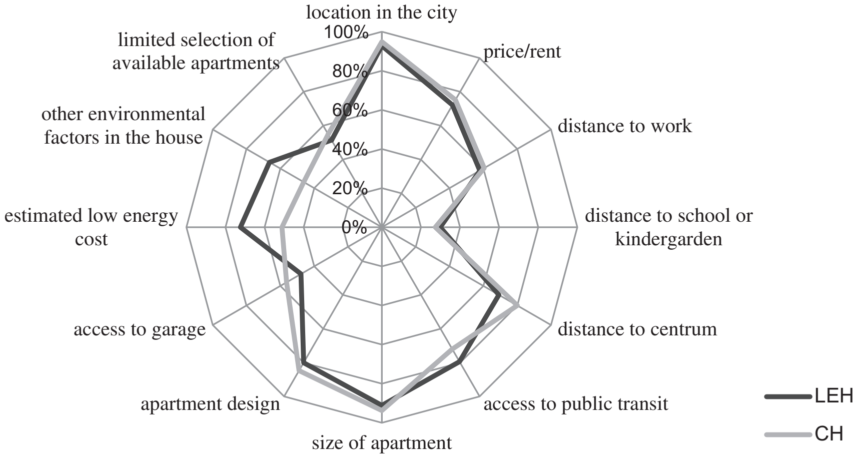

Fig. 1. Decisive and important factors influencing apartment rental decisions.

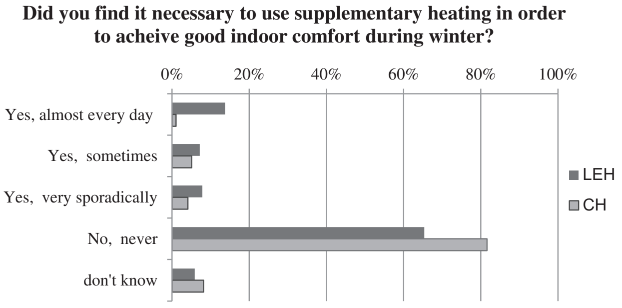

Fig. 2. Use of supplementary heating in winter.

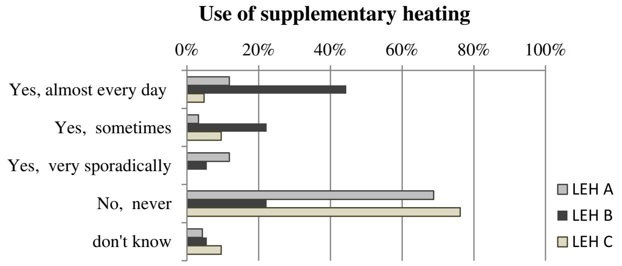

Fig. 4. Use of supplementary heating in order to achieve good indoor comfort during winter in low-energy buildings.

"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

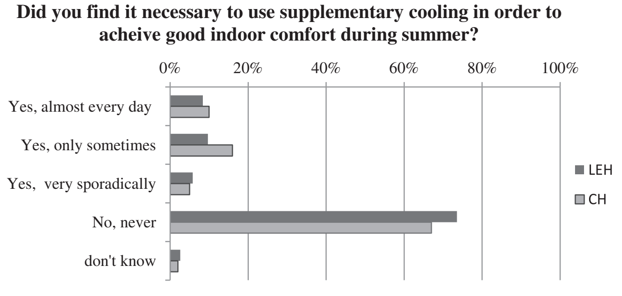

Fig. 3. Use of supplementary cooling in summer.

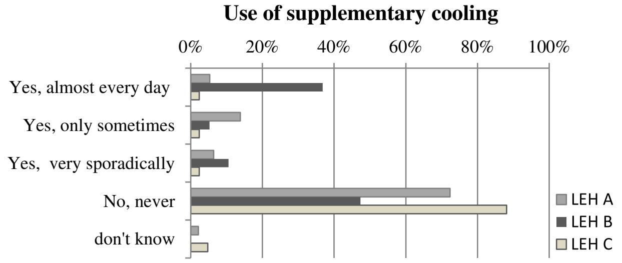

Fig. 5. Use of supplementary cooling in order to achieve good indoor comfort during summer in low-energy buildings.

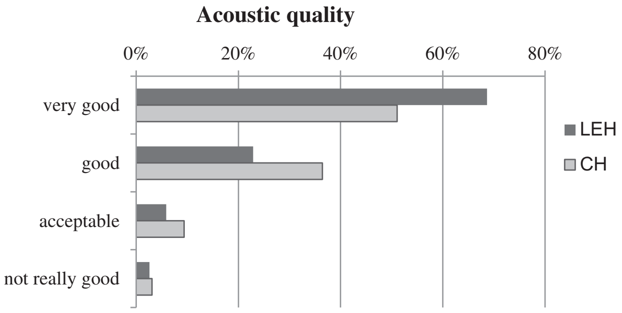

Fig. 6. Satisfaction with indoor climate, quality of sound insulation.

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 $p < 0.05$.

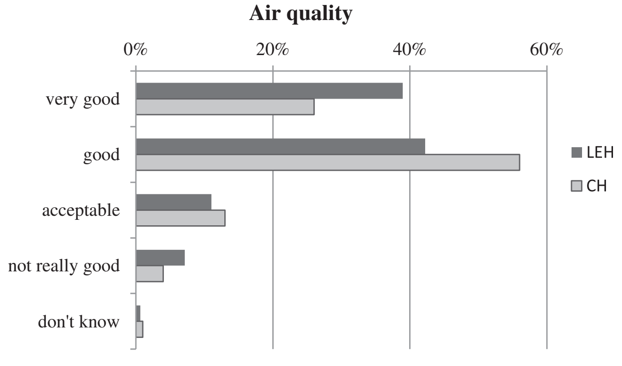

Fig. 7. Satisfaction with indoor climate, air quality assessment.

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)

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 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

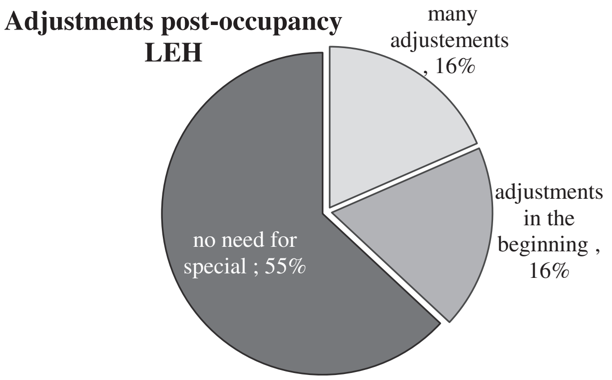

Fig. 8. Required system adjustments low-energy buildings (LEH).

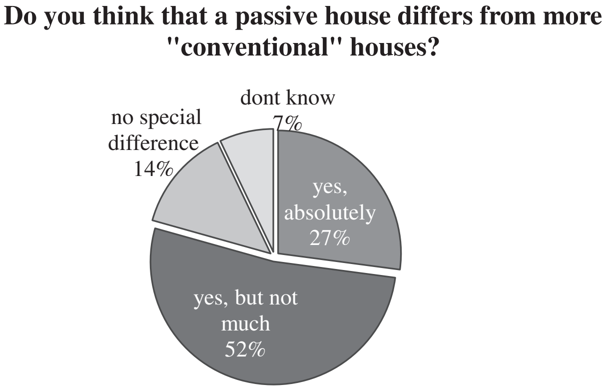

Fig. 10. General difference between LEH and CH.

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

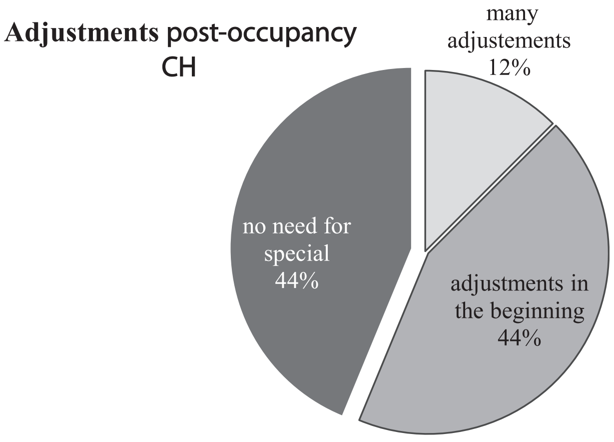

Fig. 9. Required system adjustments conventional buildings (CH).

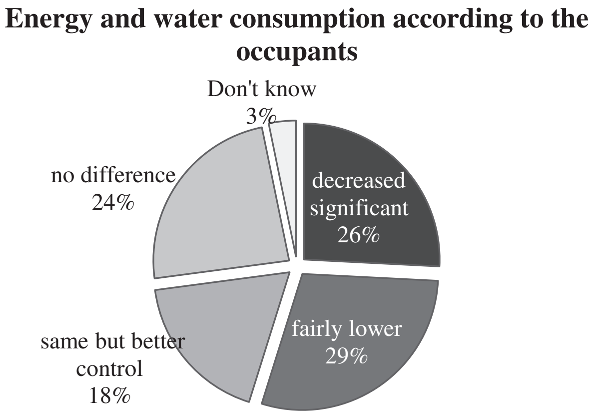

Fig. 11. Effect of individual metering on energy and water consumption in LEH.

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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Paper III

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Impact of perceived indoor environment quality on overall satisfaction in Swedish dwellings

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ABSTRACT

The aim of this paper is to contribute to the discussion on how satisfaction with different aspects of indoor environment contributes to occupants' overall satisfaction. The analysis is based on survey responses collected during a unique project commissioned by The Swedish National Board of Housing, Building and Planning. The results are representative of adults living in multi-family buildings in Sweden. The analysis shows that generally satisfaction with air quality has the highest impact on occupants' overall satisfaction. The occurrence of problems with indoor environment quality, particularly draught, dust and too low indoor temperature may affect occupants' overall satisfaction. However, it is demonstrated that the importance impact of perceived indoor environment quality on overall satisfaction is affected by individual and building characteristics.

1. Introduction

Building occupants are recognised more than ever as consumers, where building performance, comfort and usability are among the factors affecting customer satisfaction. Learning about and understanding occupants' needs is important for all actors involved in the building and operation process – from designers, engineers, and developers to facility managers. Their business goal is, after all, to provide customers extra value, which turns into profit. Hence, understanding what is included in occupants' satisfaction is an important issue.

Research has demonstrated that the quality of the indoor environment has considerable impact on human health, stress, productivity and wellbeing. Therefore, it is rational to conclude that the way in which occupants perceive indoor environment will impact their overall satisfaction. A large body of literature has shown that this hypothesis is correct, but it has proved to be a complex and difficult task to determine how important the measured aspects of indoor environment are to the occupants and how these aspects can be combined to produce overall satisfaction [22].

A few studies have approached the challenge and investigated the extend to which acceptance of indoor environment factors impact on occupants' overall satisfaction. Frontczak et al. [19] used panel data collected by the Center for Built Environment (CBE) through post-occupancy surveys sent to office buildings to investigate which indoor environment quality (IEQ) parameters affect occupants' satisfaction most. The results suggest that the three most important parameters for occupant satisfaction were space available for individual work, noise level and visual privacy. The impact of the main indoor environment parameters, i.e. thermal, visual, acoustic and air quality,[1] on office occupants' satisfaction was as follows: noise level, sound privacy, temperature, amount of light and air quality.

Kim and de Dear [27] distinguished between factors that have a linear and a non-linear relationship with overall satisfaction. Similarly to the Frontczak et al. [18] study, noise satisfaction was found to have the highest impact of the IEQ parameters on occupants' satisfaction. Temperature, followed by air and light quality was found to have negative impact on occupants' satisfaction. Kim and de Dear [27] used the Kano Model to differentiate between IEQ factors that impact overall satisfaction in negative, positive or in both directions. They concluded that 'temperature' and 'noise' had predominantly negative impact on occupants' overall satisfaction when expectations were not met; however, if the building

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[1] Literature survey conducted by Frontczak and Wargocki [20] shows that thermal, visual, acoustic and air quality are the main indoor environment parameters contributing to satisfactory indoor environment.

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performed well, overall satisfaction was not impacted. On the other hand, ‘air quality’ and ‘amount of light’ were qualified as proportional factors and influenced overall satisfaction in both directions. It was found that occupant ratings were high when the building performed well and poor when it underperformed.

On the other hand, a study conducted on commercial spaces in Hong Kong [29,30] showed fairly different results, indicating that thermal comfort had the highest impact on overall IEQ acceptance, followed by air, noise and visual quality. An investigation conducted in China also suggests that thermal comfort has the highest impact on overall satisfaction [12].

The importance ranking of perception of IEQ may differ in residential buildings. An occupant survey conducted in Danish homes [19] showed that thermal, acoustic, air and visual quality are positively correlated with overall satisfaction with indoor environment, indicating that by a marginal difference, the relation between overall acceptability and air quality was the highest, followed by visual, acoustic and thermal quality.

However, studies based on indoor environment evaluation of occupants living in Hong Kong apartments indicate that thermal comfort has the highest importance impact on overall IEQ [28,30]. This was followed by noise and air quality.

Humphreys [22] deliberated whether overall satisfaction can be described by stable relative weights of different aspects of indoor environment and concluded that generally level of thermal and air quality is more important that lighting and humidity; however, relative weights can differ between occupants, depending on their requirements. The literature review showed that occupants ranked importance of satisfaction with IEQ was inconsistent.

It would be reasonable to state that if occupants experience problems with IEQ, the satisfaction decreases. Even though problems with IEQ have been discussed earlier in the literature [1,5,10,21,28,30,39], as far as the authors are aware, the impact of IEQ problems on occupants' overall satisfaction has not been explored by a quantitative model approach. Applying a quantitative model allows us to measure the extent to which the appearance of a particular IEQ problem affects overall satisfaction.

The aim of this study was to contribute to the discussion of the impact of satisfaction from aspects of indoor environment on overall satisfaction and investigate how the occurrence of different problems with IEQ affects occupants' overall satisfaction. This paper investigates the effect that perception of indoor environment quality has on overall satisfaction of occupants in residential buildings in Sweden. The analysis is based on survey responses collected during a unique project commissioned by The Swedish National Board of Housing, Building and Planning (*Boverket*). The results provide insights into how occupants perceive indoor environment and into the set of problems appearing in dwellings in Sweden. The results are representative of adults living in multifamily buildings in Sweden and contribute to the existing knowledge about perceived comfort and occupants' satisfaction.

2. Literature review

Overall satisfaction and perception of indoor environment, being a subjective evaluation, can be impacted by various contextual factors. The literature provided evidence that individuals' characteristics and building characteristics contribute significantly to how occupants perceive their comfort.

2.1. Building characteristics

2.1.1. Location and climate differences

Outside conditions may have an impact on occupant perception of indoor environment and become a contributing factor to defining what constitute satisfactory indoor conditions. For example, cold climatic conditions may be an important factor in occupants' preference for higher indoor temperature [40]. Becker and Paciuk [3] also showed that thermal adaptation and perception of comfort may be impacted by contextual variables, such as local climate. Humphreys' [22] analysis of over 4600 responses from office occupants in five different countries showed that ranked importance of satisfaction factors for overall comfort varies between countries.

2.1.2. Building design and construction

Zhang and Altan [40] investigated the difference in perceived IEQ and occupants' overall satisfaction in conventional and environmentally concerned building and reported that occupants presented different satisfaction levels for their thermal and visual environment. A study of educational and office buildings in the UK and in India [37] showed that occupants' overall satisfaction varies depending on the ventilation mode applied in the buildings. Moreover, dwelling quality, size and design were also demonstrated to have significant impact on residents' satisfaction. [16,31,33].

2.2. Individuals' characteristics

2.2.1. Gender

Lai and Yik [29] investigated how perception and importance ranking of indoor environment differs depending on time spent in the building and depending on gender. It was concluded that both factors may have an impact on how occupants rate the importance of indoor environment aspects. It was found that female workers were slightly more sensitive to air quality than men, ranking odour and air cleanness before noise. Odour was also the most important factor for male workers; however, air cleanness was ranked as the third attribute after noise. Thermal comfort was ranked as least important by both groups.

Women were found to be relatively more sensitive to thermal sensation [4,15]; however, men were found to have a lower level of thermal acceptability than women [25]. It was suggested that the difference in tolerance for the thermal environment between men and women might be related to physiological characteristics but also to life style differences [25]. On the other hand, research conducted in 20 office buildings in the US showed that the mean level for thermal satisfaction was 30% lower for female than male occupants, indicating that women are less satisfied with thermal quality than men [14]. Other studies showed limited or no difference between women and men in relation to indoor environment perception [18] or sensitivity to sound level [21].

2.2.2. Age

Older respondents were found to be more satisfied with dwellings than younger ones [15,16,26], and age was found to have negative impact on overall satisfaction [33,38]. Research indicates that there is a difference in thermal sensation and thermal acceptance between age groups [14,25]. Age was also found to be significant and one of the more powerful predictors in investigations of the relationship between traffic noise exposure and self-reported health status [9]. Clearly, a fit between dwelling design and occupants expectations and requirements may affect how occupants perceive their housing. The elderly may require dwellings to be fitted with features that enable easier access (e.g. lifts) or that are easy to control but less technically advanced. Finally, occupant perception may vary depending on their housing career [32] and previous residence experience [33].

2.2.3. Lifestyle and health

The latest literature survey exploring the effects of IEQ on occupants shows that there is rather limited literature exploring how life style and health may impact occupant satisfaction with indoor environment

[20]. Life style and health were found to have no influence on satisfaction with IEQ. However, a more recent study conducted on public low-cost housing in Malaysia [33] showed negative correlation between residential satisfaction and family size and whether the wife stayed at home or was working, which would indicate that occupants' satisfaction may be impacted by life style. Lai and Yik [29] demonstrated that the importance of IEQ attributes differs depending on length and frequency of occupants' stay in the building.

The literature review indicates that occupants' satisfaction depends on satisfaction with indoor environment parameters but the perception can vary depending on individual and building characteristics. Therefore, in this paper we tested for the impact that individual and building characteristics have on occupants' overall satisfaction. The tested characteristics were based on a literature review but also depended on availability of data.

3. Data

A database was created using data collected during a unique project commissioned by the Swedish National Board of Housing, Building and Planning – *Boverket*. The particular focus of this project has been data collection on health, indoor environmental quality, energy performance, and the technical and maintenance status of Swedish building stock. The data was obtained by: inspections and measurements of buildings, and surveys addressed to residents of single houses and apartment buildings [8].

Defining the nationally representative sample required multi-stage sampling, clustering and stratification. The first three stages in the sample selection process were coordinated and the same was done for the whole project. In the first step, a sample of municipalities was selected, in the next stage, a sample of valuation units was made and in the third step, a building was selected. The fourth step of sampling was designed only for the particular leg of the project, i.e. for the indoor environment quality and health surveys or inspections and measurements. The fourth stage aimed at sampling households and individuals. Detailed information about the survey population design can be found in [8].

Everyone who lived in Sweden and was over one year of age was included in the definition of target population. The population was divided in three groups: young children (1–12 years old), teenagers (13–17 years old) and adults (18 years old and older). For each group, a separate questionnaire was distributed. This paper focuses only on adult occupants of multi-family apartment buildings.

In order to conduct the analysis and present results which are representative for the whole country, analytical weights were used. The data set and final analysis weights were received from the data producer (*Boverket*, Swedish National Board of Housing, Building and Planning). The analysis weights are the final value which was estimated by including a sample selection and non-response adjustment factor and post-stratification factor [23]

3.1. Questionnaire design

The questionnaire was addressed to all selected residents in May–June 2008 and posted by ordinary mail. The inhabitants were asked to fill in a survey questionnaire that included 35 questions divided into six parts.

Questions in the first part asked respondents for their general opinion about the indoor environment and if certain problems appeared in their apartment. The following three parts asked more detailed questions about the thermal comfort, air quality and sound quality, particularly about experience of different problems with indoor environment quality. The fifth part included questions about the respondent's health and the last part gathered background data about the respondents. The questions about general satisfaction rated the respondent's perception on a five-point ordinal scale from "very satisfied" (1) to "very dissatisfied" (5). Questions which asked the respondent to evaluate the indoor environment parameter (thermal comfort, air and sound quality) gave the respondent a choice from a five-point ordinal scale from "very good (1)" to "very bad (5)". In the case of questions referring to potential problems, a respondent could choose one of three answers: "yes, the problem occurs often (approximately once a week), "yes, the problem occurs sometimes" or "no, never happens". With reference to sound quality, additional frequency questions were included, but responses to those are not analysed here.

3.2. The data used and its limitations

The paper presents results based on total responses ($N = 5756$) from questions regarding overall satisfaction, general satisfaction with air quality and general satisfaction with sound quality, and experience of indoor environment quality problems as well as the background questions. The analysis of responses regarding more detailed problems with thermal comfort, air quality and sound quality is not presented in this paper.

Including physical measurements in the statistical analysis would allow the subjective responses to be related to objective measurements; however, even though data from measurements and on-site investigations was available, it was a conscious decision not to include those indicators in the model. When the objective indicators were introduced, the responses from the survey had to be matched with measurements and many observations had to be excluded. Introduction of physical values also required adjustment and substantial increase of weights needed for data analysis. This added complexity to the analysis and difficulty in interpreting the results.

4. Statistics analysis

Ordinal logistic regression was chosen due to the nature of the data; that is, variables are in ordered categories, measuring opinion and frequency using a rated scale so that responses are ordered [6]. Results are reported in the form of odds ratios and interpreted in this paper as likelihood of decreasing overall satisfaction if the predictor variable is increased by one unit while other variables are kept constant [18]. Odds ratios were used to rank the impact of variables on overall [19].

$$\text{Overall satisfaction} = ß_1\text{TC} + ß_2\text{Air}Q + ß_3\text{Sound}Q \quad \text{model 1}$$

β – odds ratios are interpreted as the likelihood of decreasing overall satisfaction if satisfaction with thermal or air or sound quality decreases by one unit while other variables are kept constant.

Likewise, overall satisfaction may be impacted by the appearance of problems with IEQ.

$$\begin{aligned}\text{Overall satisfaction} = {} & \alpha_1(\text{too high temperature}) \\ & + \alpha_2(\text{too low temperature}) \\ & + \alpha_3(\text{unstable temperature}) + \alpha_4(\text{draft}) \\ & + \alpha_5(\text{stuffy air}) + \alpha_6(\text{dry air}) \\ & + \alpha_7(\text{unpleasant smell}) + \alpha_8(\text{dust}) \\ & + \alpha_9(\text{static electricity}) \\ & + \alpha_{10}(\text{cigarette smell}) \\ & + \alpha_{11}(\text{noise}) \quad \text{model 2}\end{aligned}$$

α – odds ratios interpreted as likelihood of decreasing overall satisfaction if a particular problem with IEQ appears.

Table 1
Building characteristics.

Location	Binary variables	Per cent in sample
	North	11%
	Central	58%
	South	31%
Construction year		
	<1960	46%
	1961–1975	32%
	1976–1985	7%
	1986–1995	10%
	1995–2005	5%

The statistics analysis was conducted in four stages:

In the first stage, the main models (model 1 and model 2) were applied to the data. Model 1 aimed to test whether occupants' satisfaction with thermal comfort, air and sound has a significant impact on overall satisfaction. The second model aimed to estimate the impact which potential problems with IEQ may have on occupants' overall satisfaction. Odds ratios were used to rank the impact of predictor variables on the response variable. The second stage of the analysis tested whether individual and building characteristics have significant impact on perception of indoor air quality and overall satisfaction. This was achieved by including controlling binary variables in both models (model 1a and model 2a).
In the third stage, main regression modes were applied (model 1b and model 2b) to separate sub-groups in order to estimate what impact individual and building characteristic have on overall satisfaction. Odds ratios were used to rank the impact of predictor variables on the response variable. The order was compared with results from the main model.
Finally, to test if and which variables have a significant effect on a particular sub-group, interactive variables were included in the main models (model 1c and model 2c). Interactive variables measured the effect which the predictor variable may have on a particular sub-group. The interaction effect between variables is interpreted in multiplicative terms [11].

As discussed before, overall satisfaction may be impacted by different factors and therefore control variables and sub-groups were created according to the following characteristics.

4.1. Building characteristics

- Location

Sweden's geographical location, extending from latitudes 55° to 70°N, contributes to the fact that local climate in Sweden may differ significantly. This variation is recognised in Swedish Building Regulations, in which building requirements are adjusted depending on climate zone. Swedish Building Regulations specify three climate zones: north, central and south. Taking this and previous research into consideration, the database was divided into three sub-groups, depending on building location and control variables for north, central or south location; these sub-groups were included in the models.

- Building construction year

The literature research indicates that building characteristics such as design, building heating or ventilation system may impact on occupants' satisfaction. Taking into account all of this information was not feasible; however, by including a variable describing building construction year, we were able to group buildings that present similar technical standards.

Table 2
Residents' characteristics.

Individuals characteristics	Binary variables	Per cent in sample
Gender	Male	47%
	Female	53%
Life style[a]	Away 0–4 h	32%
	Away 5–9 h	45%
	Away >10 h	23%
Health[b]	Smoker	14%
	Non-smoker	86%
Age	≤35 years	34%
	36–50 years	22%
	51–65 years	22%
	≥66 years	23%

[a] Represented by time spent away from the apartment on weekdays.
[b] Represented by the fact that the occupant was or was not a smoker.

4.2. Individuals' characteristics

- Gender

The literature review indicates that previous studies fail to give consistent results regarding the impact of gender on perception of IEQ and overall satisfaction. The aim of this paper is to contribute to this discussion by including gender as a control variable and by testing whether IEQ weighting into overall satisfaction differs between female and male occupants in dwellings in Sweden.

- Age

It is expected that occupants overall satisfaction and IEQ perception differs depending on for example housing career, previous housing experience, expectations and requirements. Therefore, we expect that age, being the best available proxy for the above mentioned factors, has a significant impact on occupant satisfaction.

- Life style and health

There is a fairly limited amount of research into how life style and health choices impact occupants' overall satisfaction. The goal is to add to existing knowledge, and therefore the following control variables were included in the analysis: a smoking habit and the time the occupant spends away from the apartment on weekdays. It is expected that a smoking habit can affect people's perception of indoor environment and therefore impact overall satisfaction. It is also expected that an occupant's absence from a dwelling impacts the interaction between occupant and dwelling. On the other hand, longer presence in the apartment may relate to exposing occupant to potential problems for a longer time, and consequently making the occupant more sensitive to specific problems, for example, unstable temperature or noise.

A Brant test for parallel regression assumption was conducted for each regression. The proportional odds assumption was satisfied in both models and the use of ordinal logistic models was justified. The results are reported with Confidence Intervals that present reliability of estimates at 95%. Generally, the results were considered statistically significant when $p < 0.05$.

5. Sample characteristics

A summary of individual and building characteristics is presented in Tables 2 and 3 respectively. The responses received from

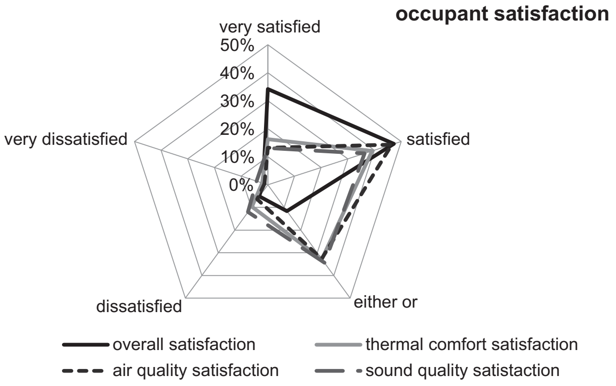

Fig. 1. Overall satisfaction and satisfaction with thermal comfort, air and sound quality in residential apartments in Sweden.

the north part of the country represent 11% of all responses, the central 57% and south 32%, which reflects population distribution in Sweden (Table 1). An almost equal quantity of responses was received from male and female occupants (Table 2).

6. Results

6.1. Overall satisfaction and satisfaction with thermal, air and sound quality

Generally, occupants are very satisfied with their apartments (mean 1.93, where 1 = very satisfied and 5 = very dissatisfied; see Table 4), though satisfaction with IEQ is relatively lower. Fig. 1 visualises the level of satisfaction with IEQ and compared to overall satisfaction. This difference might indicate that even though satisfaction with indoor environment parameters has an impact on overall satisfaction, there are other factors affecting occupants' general satisfaction.

Sound quality is the parameter that occupants are least satisfied with (Table 3), however, it is the air quality that has the highest impact on overall satisfaction (Table 4). The results indicate that if the occupant is dissatisfied with air quality, there is a 2.65 times likelihood that the overall satisfaction decreases (Table 4).

6.2. Overall satisfaction and problems with IEQ

The problem experienced most often by the occupants is related to dust and outside noise. The mean for variables has been ordered from the largest to the smallest, showing problems which are observed most frequently in Swedish apartments (Table 5). The hypothesis is that overall satisfaction will decrease if a specific indoor environmental quality (IEQ) problem appears. The proportional ordinal logistic model describes the relationship between overall satisfaction and problems that an occupant may experience in the building. The impact of the following IEQ problems was investigated: too high temperature, too low temperature, unstable temperature, draught, stuffy air, dry air, unpleasant smell, dust, static electricity, cigarette smell and noise (model 2). Odds ratios were used to rank the IEQ problems regarding their importance for overall satisfaction (Table 6).

Table 3
Overall satisfaction mean values.

	Mean	Standard error	Confidence intervals (95%)	*N*
General satisfaction	1.93	0.12	1.90–1.95	5570
Air quality satisfaction	2.35	0.11	2.33–2.38	5660
Thermal comfort satisfaction	2.42	0.12	2.39–2.44	5585
Sound quality satisfaction	2.58	0.13	2.55–2.60	5623

1, Very satisfied; 2, satisfied; 3, either or; 4, dissatisfied; 5, very dissatisfied.

Table 4
Satisfaction thermal comfort, air and sound quality impact on overall satisfaction, $p < 0.001$; (model 1).

	Odds ratios	Confidence intervals (95%)	
Air quality satisfaction	2.651	2.436	2.885
Thermal comfort satisfaction	1.814	1.691	1.946
Sound quality satisfaction	1.560	1.463	1.663

N, 5339; pseudo-R2, 0.179.

As shown in Table 6, the problem with draught in the apartment is the most important factor that can influence general satisfaction and should that problem appear, there is a 1.60 times likelihood that the overall satisfaction decreases. Interestingly, draught is not the issue that occurs most often in the apartments in Sweden. The problems of dust and too low temperature seem to occur in apartments most frequently and the analysis indicates that if this happens, the general satisfaction decreases (odds ratio 1.56 and 1.49).

On the other hand, the problems related to too high temperature, unstable temperature in the apartment, sensing cigarette smell and experiencing static electricity were found to be not statistically significant.

6.3. Overall satisfaction and building characteristics

6.3.1. Location

6.3.1.1. Satisfaction with IEQ. The analysis indicates that there is a significant difference in overall satisfaction depending on location. The results (model 1a) suggest that adults who live in apartments in the north and central part of Sweden are less likely to be dissatisfied than those living in the south of Sweden (Table 7).

In order to test the effect of particular variables, the model with interactive variables (model 1c) was applied to the data. The results suggest that dissatisfaction might be related to the thermal comfort; the effect of *thermal comfort* for adults who live in apartment blocks in southern parts is 1.44 (CI(95%) 1.24–1.67) times the effect of *thermal comfort* for those who live in the rest of the country. Occupants living in the central part of Sweden seem to be more sensitive to sound quality, as the effect of sound quality on residents in central Sweden was found to be 1.31 (CI(95%) 1.16–1.49) times the effect for those who live in the rest of Sweden. This has

Table 5
Problems experienced in residential apartments in Sweden, depending on location ("problem does not occur" = 0, "problem occurs sometimes" = 1, "problem occurs often" = 2).

Experienced problem	Mean	Standard error	Confidence intervals (95%)	*N*
Dust	0.657	0.009	0.63–0.67	5547
Outdoor noise	0.649	0.009	0.63–0.66	5530
Too low temperature	0.549	0.008	0.53–0.56	5564
Unstable temperature	0.527	0.008	0.51–0.54	5479
Stuffy air	0.471	0.008	0.45–0.48	5542
Too high temperature	0.430	0.008	0.41–0.44	5543
Cigarette smell	0.409	0.008	0.39–0.42	5559
Dry air	0.399	0.008	0.38–0.41	5534
Draught	0.391	0.008	0.37–0.40	5561
Unpleasant smell	0.362	0.008	0.34–0.37	5560
Electric stat	0.148	0.005	0.13–0.15	5531

Table 6
Impact on overall satisfaction ranked according to odds ratios, $^{*}p < 0.001$; (n) not significant, (model 2).

Experienced problem	Odds ratio	CI (95%)	
Draught	1.602*	1.442	1.780
Dust	1.560*	1.426	1.707
Too low temperature	1.490*	1.338	1.661
Unpleasant smell	1.486*	1.331	1.659
Dry air	1.433*	1.290	1.592
Stuffy air	1.389*	1.245	1.551
Outdoor noise	1.171*	1.074	1.277
Cigarette smell	0.952(n)	869	1.043
Electric stat	0.940(n)	0.814	1.085
Too high temperature	1.035(n)	0.937	1.144
Unstable temperature	1.070(n)	0.961	1.206

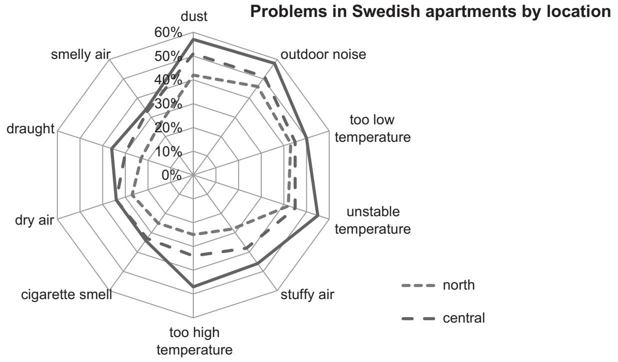

Fig. 2. Problems experienced in apartments in Sweden, presented by location.

been confirmed in the third step of analysis, when main model 1 was applied only to sub-groups created according to location of the building (model 1b). A certain alteration in ranking order was found for buildings located in the central and north parts of Sweden (Table 10). The results suggest that satisfaction with sound quality has higher importance impact for occupants in central and north than it has for those who live in the south part of Sweden.

Problems with IEQ. Interestingly, occupants living in the south of Sweden most frequently experience problems with IEQ, particularly problems related to thermal comfort (Fig. 2).

The analysis indicates that there is a significant difference in how the occurrence of a particular problem influences general satisfaction depending on location in Sweden.

The effect of a specific IEQ problem for different zones has been tested (model 2c) and the results demonstrate that inhabitants who live in apartments in southern Sweden are more sensitive to thermal comfort problems related to unstable and too low temperature, as the effect of *unstable temperature* for the south was 1.62 (CI(95%) 1.26–2.08) times that for the rest of the country and the effect of *too low temperature* for the south was 1.52 (CI(95%)1.20–1.92) times that for the rest of the country.

The results also show that importance ranking of IEQ problems for overall satisfaction was altered when model 2b showed that *problems with too low temperature* (odds ratio 2.01) and *unstable temperature* (odds ratio 1.51) had the highest importance for overall satisfaction for occupants living in southern Sweden (Table 12). This means that, should the occupant encounter problems with too low temperature indoors, the likelihood of overall satisfaction decreasing would be 2.01. For buildings located in the north of Sweden, problems with air quality may have the highest impact on overall satisfaction, i.e. *dust* and *unpleasant smell*. Problems with *outdoor noise* have a higher importance ranking for occupants living in the north of Sweden.

Table 7
Relationship between overall satisfaction and satisfaction with IEQ, model 1 and model 1a (including control variables).

	Main model 1	Model 1a and dummy variables
Satisfaction with air quality	2.651* [2.43–2.88]	2.742* [2.51–2.99]
Satisfaction with thermal comfort	1.814* [1.69–1.94]	1.746* [1.62–1.87]
Satisfaction with sound quality	1.560* [1.46–1.66]	1.515* [1.41–1.62]
Zone north		0.702* [0.57–0.86]
Zone central		0.736* [0.65–0.83]
Woman		0.918(n) [0.82–1.02]
Smoker		1.011(n) [0.86–1.18]
<1960		1.396*** [1.06–1.82]
1960–1975		1.149(n) [0.87–1.51]
1976–1985		1.318(n) [0.94–1.83]
1986–1995		1.096(n) [0.80–1.49]
Away 5–9 h		0.823*** [0.70–0.96]
Away >10 h		0.837*** [0.70–1.00]
≤35 years		2.109* [1.74–2.55]
36–50 Years		1.970* [1.60–2.41]
51–65 Years		1.700* [1.40–2.06]
R2	0.184	0.189
N	5175	5175

$^{*}p \leq 0.001$; $^{**}p \leq 0.01$; $^{***}p \leq 0.05$; $(n)\ p > 0.05$.

6.3.2. Construction year

6.3.2.1. Satisfaction with IEQ. A significant difference in general satisfaction was found depending on building construction year. Results (model 1a) indicate that occupants in buildings constructed before 1960 are more likely to be less satisfied than occupants living in recently constructed dwellings (Table 7). The results show (model 1b) that satisfaction with air quality has the highest ranking importance for overall satisfaction regardless of building construction year, yet satisfaction with sound quality has increased its impact in ranking for buildings constructed between 1976 and 1985 and 1986 and 1995 (Table 10). For buildings constructed between 1961 and 1975, odds ratio for thermal comfort increased to 2.06 compared with the main model. This could mean that should occupants be less satisfied with thermal quality, there is a 2.06 times likelihood that the overall satisfaction decreases. Even though this increase did not have an impact on ranking, it is interesting when comparing it with further results.

Analysis with interactive variables (model 1c) indicates that occupants in buildings constructed between 1976 and 1985 (odds

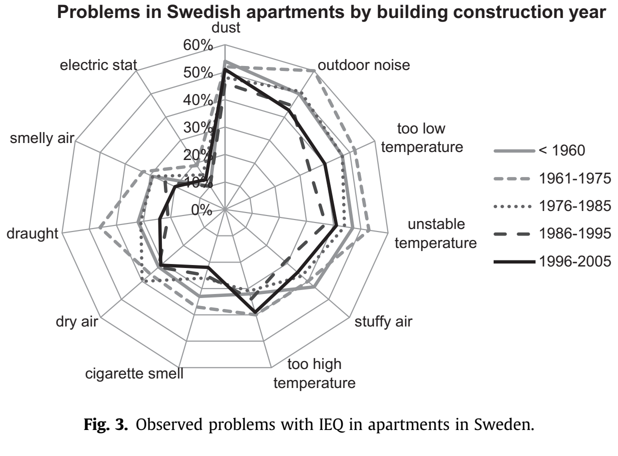

Fig. 3. Observed problems with IEQ in apartments in Sweden.

Table 8
Relationship between overall satisfaction and problems with IEQ, model 2 and model 2a (including control variables).

Variables	Main model 2	Model 2a (with dummy variables)
Draught	1.602* [1.44–1.78]	1.624* [1.45–1.81]
Dust	1.560* [1.42–1.70]	1.543* [1.40–1.69]
Too low temperature	1.490* [1.33–1.66]	1.382* [1.23–1.54]
Unpleasant smell	1.486* [1.33–1.65]	1.536* [1.37–1.71]
Dry air	1.433* [1.29–1.59]	1.591* [1.42–1.77]
Stuffy air	1.389* [1.24–1.55]	1.261* [1.12–1.41]
Outdoor noise	1.171* [1.07–1.27]	1.126** [1.02–1.23]
Unstable temperature	1.076(n) [0.96–1.20]	1.048(n) [0.932–1.17]
Too high temperature	1.035(n) [0.93–1.14]	0.915(n) [0.82–1.01]
Electric stat	0.940(n) [0.81–1.08]	0.945(n) [0.81–1.09]
Cigarette smell	0.952(n) [0.86–1.04]	0.918(n) [0.83–1.01]
Zone north		0.939(n) [0.76–1.15]
Zone central		0.812* [0.71–0.92]
Woman		0.849** [0.75–0.95]
Smoker		1.036(n) [0.88–1.21]
$<$1960		1.597* [1.23–2.07]
1960–1975		1.850* [1.41–2.41]
1976–1985		1.825* [1.31–2.53]
1986–1995		1.175(n) [0.86–1.59]
Away 5–9 h		1.032(n) [0.87–1.21]
Away $>$10 h		1.071(n) [0.89–1.28]
$\leq$35 Years		2.027* [1.65–2.48]
36–50 Years		2.178* [1.76–2.68]
51–65 Years		1.322** [1.08–1.61]
R2	0.110	0.12
N	5054	5023

*$p \leq 0.001$; **$p \leq 0.01$; ***$p \leq 0.05$; (n) $p > 0.05$.

ratio 1.48, CI (95%) 1.17–1.88) and 1986 and 1995 (odds ratio 1.24, CI (95%) 1.01–1.54) are more sensitive to *sound quality* than occupants of other buildings. The effect on *satisfaction with thermal comfort* for buildings constructed between 1961 and 1975 was 1.18 times the *satisfaction with thermal comfort* for other buildings, meaning that occupants living in apartment buildings constructed between 1961 and 1975 are marginally more sensitive to thermal comfort.

6.3.2.2. Problems with IEQ. The figure shows most problems with IEQ were observed in buildings built in Sweden in the mid-sixties to mid-seventies (Fig. 3).

The influence of building construction year on overall satisfaction was tested (model 2b). The results showed that the importance impact of IEQ problems varied depending on building construction year (Table 12). Model 2c, with interactive variables was applied to data to test which problem affects a particular sub-group.

6.3.2.3. Buildings constructed before 1960. For building constructed before 1960, *problems with draught* (odds ratio 1.76) *and problems with dust* (odds ratio 1.60) were found to have the highest impact on overall satisfaction, which was in line with the main model (Table 12). Analysis with interactive variables indicates that the effect of *problems with unstable temperature* was 1.37 times that for other buildings (CI (95%) 1.07–1.73).

6.3.2.4. Buildings constructed between 1961 and 1975. For buildings constructed between 1961 and 1975, rating importance has changed if compared to the main model; the highest impact on occupants' overall satisfaction seems to be from problems related to thermal comfort (*problems with too low temperature* – odds ratio 2.11 and *problems with draught* – odds ratio 1.75). Analysis with interactive variables confirms that the effect of *problems with too low temperature* for buildings constructed between 1961 and 1975 was 1.64 (CI(95%) 1.26–2.00) times that of *too low temperature* for other buildings. Interestingly, the effect of *problems with outdoor noise* was found to be statistically significant and was 1.26 times

Table 9
Relationship between overall satisfaction and satisfaction with IEQ applied to sub-groups, model 1b (individuals characteristics).

Variables	Main	Age				Life style			Gender		Health	
sub-groups	model 1	Under 35 years	36–50 Years	51–65 Years	More than 66 years	Away for less than 4 h on weekday	Away for 5–9 h on weekday	Away for more than 10 h on weekday	Woman	Man	Smoker	Non-smoker
Satisfaction with air quality	2.651* [2.43–2.88]	2.425* [2.02–2.88]	2.789* [2.36–3.34]	2.886* [2.39–3.47]	2.839* [2.30–3.37]	2.322* [2.053–2.65]	2.548* [2.21–2.92]	3.151* [2.65–3.74]	2.780* [2.47–3.11]	2.588* [2.27–2.94]	4.786* [3.61–6.33]	2.438* [2.22–2.66]
Satisfaction with thermal comfort	1.814* [1.69–1.94]	1.779* [1.51–2.08]	1.738* 1.50–2.01]	1.810* [1.54–2.11]	1.537* [1.33–1.76]	1.94* [1.74–2.16]	1.930* [1.71–2.16]	1.434* [1.23–1.66]	1.989* [1.81–2.18]	1.626* [1.45–1.81]	1.544* [1.26–1.88]	1.881* [1.74–2.03]
Satisfaction with sound quality	1.560* [1.46–1.66]	1.317* [1.14–1.51]	1.729* [1.49–1.99]	1.912* [1.66–2.19]	1.483* [1.32–1.66]	1.732* [1.56–1.92]	1.507* [1.36–1.66]	1.546* [1.34–1.77]	1.551* [1.42–1.69]	1.549* [1.402–1.71]	1.684* [1.42–1.99]	1.522* [1.41–1.63]
R2	0.179	0.114	0.213	0.235	0.160	0.201	0.164	0.179	0.194	0.162	0.255	0.166
N	5339	1015	1034	1429	1861	2145	2169	1195	2952	2338	628	4639

*$p \leq 0.001$; **$p \leq 0.01$; ***$p \leq 0.05$; (n) $p > 0.05$.

Table 10
Relationship between overall satisfaction and satisfaction with IEQ applied to sub-groups, model 1b.

Variables sub-groups	Main model 1	Location			Construction year				
		North	Central	South	<1960	1961–1975	1976–1985	1986–1995	1996–2005
Satisfaction with air quality	2.651* [2.43–2.88]	1.442* [1.15–1.80]	2.755* [2.44–3.10]	3.026* [2.61–3.49]	2.755* [2.17–3.48]	2.471* [2.12–2.86]	2.435* [199–2.97]	3.207* [2.48–4.14]	2.454* [2.04–2.94]
Satisfaction with thermal comfort	1.814* [1.69–1.94]	1.486** [1.22–1–81]	1.565* [1.422–1.72]	2.369* [2.08–2.68]	1.840* [1.50–2.24]	2.067* [1.81–2.35]	1.376* [1.16–1.61]	1.436* [1.20–1.71]	2.151* [1.84–2.50]
Satisfaction with sound quality	1.560* [1.46–1.66]	1.529* [1.29–1.86]	1.719* [1.56–1.88]	1.346* [1.20–1.50]	1.504* [1.25–1.80]	1.401* [1.24–1.57]	2.376* [2.03–2.78]	1.956* [1.65–2.31]	1.698* [1.49–1.91]
R2	0.179	0.084	0.180	0.208	0.163	0.178	0.210	0.214	0.210
N	5339	714	2786	1839	664	1754	940	851	2145

$^{*}p \leq 0.001$; $^{**}p \leq 0.01$; $^{***}p \leq 0.05$; (n) $p > 0.05$.

that of *problems with outdoor noise* for other buildings (CI (95%) 1.04–1.52).

6.3.2.5. Buildings constructed between 1976 and 1985. For buildings constructed between 1976 and 1985, the importance ranking has also changed and variables with the highest importance are problems related to air quality (*problems with unpleasant smell* (odds ratio 2.74), *stuffy air* (odds ratio 1.70)). Interactive variables confirm that occupants living in buildings constructed between 1976 and 1985 are more sensitive to problems with air quality. The effect of *unpleasant smell* for this building group was 1.82 (CI (95%) 1.18–2.79) times the effect of *unpleasant smell* for other buildings.

6.3.2.6. Buildings constructed between 1986 and 1995. Results show that for buildings constructed between 1986 and 1995, the variables describing problems with air quality were placed first in the importance ranking. They also showed that *problems with stuffy air* (odds ratio 1.82) and *problems with unpleasant smell* (odds ratio 1.82) and *problems with dust* (odds ratio 1.58) had the highest impact on overall satisfaction for these buildings. Sensitivity to air quality problems was indicated by the analysis with interactive variables, where *problems with cigarette smell* were found to have a statistically significant effect for buildings constructed between 1986 and 1995 (odds ratio 1.55, CI (95%) 1.11–2.18).

6.3.2.7. Buildings constructed between 1996 and 2005. Interestingly, the highest impact on overall satisfaction for occupants living in the most recently constructed buildings (1996–2005) came from *problems with too low temperature* (odds ratio 2.11). This was followed by issues related to air quality: *problems with unpleasant smell* and *problems with stuffy air.* Interactive variables were found to be statistically not significant.

6.4. Overall satisfaction and individuals' characteristics

6.4.1. Gender

6.4.1.1. Satisfaction with IEQ. The analysis indicates that gender does not have a statistically significant impact on how occupants perceive overall satisfaction. The effect of satisfaction with thermal comfort, air and sound quality was tested (model 1c) and results show that the effect of thermal comfort is statistically significant, being 1.24 times the effect for women than the effect of *thermal comfort* on men, indicating that women are more sensitive to thermal discomfort.

6.4.1.2. Problems with IEQ. Results generated from the second model (model 2c) show that problems with *stuffy air* (odds ratio 1.49(CI(95%) 1.19–1.85)), *draught* (odds ratio 1.25(CI(95%) 1.01–1.55)), and *dust* (odds ratio 1.25(CI(95%) 1.04–1.50)) have a greater effect on women than on men. This was confirmed in the importance ranking in the female sub-group (Table 9). The results show that *problems with draught* (odds ratio 1.73), *problems with dust* (odds ratio 1.72) and *problems with stuffy air* (odds ratio 1.66) have the highest impact on women's overall satisfaction. This implies that if the problem with draught appears, there is a 1.73 times likelihood that women's overall satisfaction would decrease, if other variables were kept unchanged.

6.4.2. Age

6.4.2.1. Satisfaction with IEQ. Results from model 1a show (Table 7) that occupants' age has significant impact on overall satisfaction and that younger occupants are more likely to be dissatisfied (odds ratio 2.10) Interestingly, the importance of satisfaction with noise increased for occupants between 36 and 65 years; for group 51–65 this IEQ aspect was ranked higher than thermal comfort (Table 9), which is different if compared to results from the main model and to results from the model 1 if applied to other age sub-groups (model 1b).

6.4.2.2. Problems with IEQ. Should the problems with IEQ appear, it is most likely that younger occupants will be dissatisfied (Table 8). It can be noticed that the impact of IEQ problems on overall satisfaction varies depending on age group.

Analysis with interactive variables (model 2c) suggests that the youngest group, occupants of 35 years and below, are affected by *problems with unpleasant smell* (odds ratio 1.44, CI (95%) 1.15–1.81) and *problems with high temperature* (odds ratio 1.29, CI (95%)1.04–1.59). The age group between 51 and 65 was found to be affected most by *problems with unstable temperature* (odds ratio 2.17, CI (95%) 1.59–2.95), whereas the effect of *problems with noise* is statistically significant and has 1.38 (CI (95%) 1.09–1.74) times the effect on the oldest group (over 66 years).

This was reflected in this sub-group's importance ranking, where *problems with unpleasant smell* were found to have the highest impact on overall satisfaction for the youngest respondents' group and *problems with unstable temperature* for age group 50–65 (Table 11).

6.4.3. Life style

6.4.3.1. Satisfaction with IEQ. The analysis indicates that life style has a statistically significant impact on occupants' overall satisfaction (Table 7). It was found that occupants who are absent from the apartment for more than 4 h on weekdays are less likely to be dissatisfied than those who were absent for less than 4 h. The effect of *satisfaction with sound quality* is 1.24 (CI(95%) 1.04–1.38) time on occupants leaving the apartment for less than 4 h than the effect on other occupants (model 1c).

6.4.3.2. Problems with IEQ. Occupants' perception of IEQ problems seems to be impacted by the number of hours that they spend in the apartment on weekdays (Table 12). For occupants who leave the apartment for less than 4 h, the problems that have the highest

Table 11
Relationship between overall satisfaction and problem with IEQ applied to sub-groups, model 2b.

Model 2 applied to separate	General model 2	Gender		Age				Health		Life style		
Sub-groups	Reference values	Woman	Man	Under 35 years	36–50 Years	51–65 Years	More than 66 years	Smoker	Non-smoker	Away 0–4 h	Away 5–9 h	Away >10 h
Draught	1.602*	1.733*	1.412*	1.823*	1.587*	1.566*	1.322**	1.900*	1.471*	1.123(n)	1.834*	1.823*
	[1.44–1.78]	[1.50–1.99]	[1.19–1.67]	[1.44–2.29]	[1.27–1.98]	[1.20–2.04]	[1.09–1.60]	[1.44–2.49]	[1.30–1.65]	[.95–1.32]	[1.55–2.16]	[1.43–2.32]
Dust	1.560*	1.725*	1.391*	1.528*	1.499*	1.342**	1.424*	1.404***	1.591*	1.509*	1.673*	1.319**
	[1.42–1.70]	[1.53–1.94]	[1.20–1.60]	[1.23–1.88]	[1.23–1.82]	[1.10–1.63]	[1.21–1.66]	[1.07–1.83]	[1.44–1.75]	[1.30–1.74]	[1.44–1.93]	[1.08–1.60]
Too low temperature	1.490*	1.557*	1.502*	1.511*	1.399**	1.017(n)	1.532*	1.521***	1.501*	1.402*	1.483*	1.480*
	[1.33–1.66]	[1.34–1.80]	[1.26–1.77]	[1.18–1.93]	[1.11–1.76]	[0.80–1.28]	[1.24–1.88]	[1.06–2.18]	[1.33–1.68]	[1.8–1.66]	[1.24–1.76]	[1.16–1.87]
Unpleasant smell	1.486*	1.532*	1.487*	1.864*	1.259(n)	1.460**	1.207(n)	3.370***	1.329*	1.706*	1.580*	1.297***
	[1.33–1.65]	[1.32–1.77]	[1.24–1.77]	[1.47–2.35]	[.98- 1.60]	[1.12–1.90]	[.96–1.50]	[2.28–4.97]	[1.18–1.49]	[1.41–2.05]	[1.32–1.88]	[1.02–1.63]
Dry air	1.433*	1.397*	1.559*	1.756*	1.043(n)	1.865*	1.679*	1.145(n)	1.518*	1.428*	1.606*	1.286***
	[1.29–1.59]	[1.21–1.61]	[1.32–1.83]	[1.36–2.25]	[0.82–1.32]	[1.47–2.36]	[1.39–2.02]	[0.83–1.56]	[1.35–1.70]	[1.21–1.67]	[1.34–1.91]	[1.01–1.63]
Stuffy air	1.389*	1.666*	1.134(n)	1.083(n)	1.988*	1.489*	0.945(n)	1.240(n)	1.447*	0.939(n)	1.439*	1.723*
	[1.24–1.55]	[1.43–1.93]	[0.96–1.33]	[0.86–1.35]	[1.51–2.60]	[1.18–1.87]	[0.72–1.23]	[0.89–1.71]	[1.28–1.63]	[0.77–1.13]	[1.21–1.70]	[1.35–2.18]
Outdoor noise	1.171*	0.944(n)	1.409*	1.162(n)	1.191(n)	0.976(n)	1.556*	858(n)	1.250*	1.481*	1.088(n)	1.208(n)
	[1.07–1.27]	[0.83–1.06]	[1.23 –1.60]	[0.96–1.39]	[0.97–1.45]	[0.81–1.17]	[1.31–1.83]	[0.67–1.09]	[1.13–1.37]	[1.28–1.71]	[0.94–1.24]	[0.00–1.45]
Unstable temperature	1.076(n)	1.003(n)	1.069(n)	0.935(n)	1.197(n)	2.079*	0.774***	1.932*	0.917(n)	1.176(n)	1.292**	0.833(n)
	[0.96–1.20]	[0.85–1.17]	[0.90–1.27]	[0.72–1.20]	[0.93–1.52]	[1.61–2.67]	[0.61–0.97]	[1.35–2.74]	[0.80–1.03]	[0.97–1.42]	[1.07–1.55]	[0.65–1.05]
Too high temperature	1.035(n)	1.004(n)	1.049(n)	1.171(n)	0.869(n)	0.571*	1.053(n)	0.801(n)	1.149***	1.084(n)	1.047(n)	0.808(n)
	[0.93–1.14]	[0.87–1.15]	[0.90–1.21]	[0.93–1.47]	[0.71–1.06]	[0.45–0.71]	[0.84–1.31]	[0.58–1.08]	[1.03–1.28]	[0.92–1.27]	[0.89–1.22]	[0.65–1.00]
Electric stat	0.940(n)	0.854(n)	1.102(n)	0.879(n)	0.950(n)	1.399***	0.901(n)	0.630(n)	1.047(n)	0.874(n)	1.021(n)	0.882(n)
	[0.81–1.08]	[0.71–1.02]	[0.86–1.40]	[0.61–1.26]	[0.69–1.29]	[1.03–1.88]	[0.70–1.16]	[0.38–1.02]	[0.89–1.22]	[0.70–1.09]	[0.80–1.29]	[0.64–1.20]
Cigarette smell	0.952(n)	1.001(n)	0.934(n)	0.779***	0.862(n)	1.10(n)	1.225***	0.972(n)	0.970(n)	0.986(n)	0.777*	1.246***
	[0.86–1.04]	[0.88–1.13]	[0.81–1.07]	[0.64–0.94]	[0.70–1.05]	[0.89–1.35]	[1.00–1.49]	[0.54–1.74]	[0.88–1.06]	[0.84–1.15]	[0.66–0.90]	[1.02–1.51]
R2	0.110	0.135	0.08	0.122	0.104	0.124	0.075	0.173	0.107	0.086	0.145	0.109
N	5054	2763	2247	987	986	1360	1721	602	4387	1988	2056	1142

$^{*}p \leq 0.001$; $^{**}p \leq 0.01$; ***p ≤ 0.05; (n) $p > 0.05$.

Table 12
Relationship between overall satisfaction and problem with IEQ applied to sub-groups, model 2b.

Model 2 applied to separate	General model 2	Location			Construction year				
Sub-groups	Reference values	North	Central	South	<1960	1961–1975	1976–1985	1986–1995	1996–2005
Draught	1.602*	1.706**	1.607*	1.386*	1.766*	1.758*	1.060(n)	0.980(n)	0.621**
	[1.44–1.78]	[1.20–2.40]	[1.38–1.85]	[1.16–1.65]	[1.30–2.38]	[1.46–2.11]	[0.82–1.35]	[0.70–1.35]	[0.471–0.81]
Dust	1.560*	2.245*	1.630*	1.391*	1.602*	1.587*	0.894(n)	1.589*	1.692*
	[1.42–1.70]	[1.63–3.08]	[1.44–1.83]	[1.17–1.65]	[1.24–2.06]	[1.34–1.87]	[0.71–1.11]	[1.26–1.99]	[1.38–2.06]
Too low	1.490*	0.431*	1.497*	2.011*	1.049(n)	2.111*	1.489**	1.174(n)	2.115*
temperature	[1.33–1.66]	[0.30–0.61]	[1.28–1.73]	[1.66–2.43]	[0.76–1.44]	[1.73–2.56]	[1.17–1.89]	[0.86–1.56]	[1.69–2.63]
Unpleasant	1.486*	1.796**	1.370*	1.578*	1.393***	1.415**	2.740*	1.826**	2.035*
smell	[1.33–1.65]	[1.18–2.73]	[1.18–1.58]	[1.30–1.91]	[1.03–1.87]	[1.14–1.74]	[2.09–3.58]	[1.29–2.57]	[1.56–2.64]
Dry air	1.433*	1.612**	1.500*	1.363*	1.464***	1.712*	1.117(n)	1.258(n)	1.109(n)
	[1.29–1.59]	[1.13–2.28]	[1.29–1.74]	[1.14–1.61]	[1.08–1.97]	[1.39–2.09]	[0.88–1.41]	[0.92–1.70]	[0.90–1.36]
Stuffy air	1.389*	1.214(n)	1.441*	1.316**	1.177(n)	1.578*	1.706*	1.828*	1.914*
	[1.24–1.55]	[0.82–1.77]	[1.23–1.68]	[1.09–1.57]	[0.86–1.59]	[1.28–1.94]	[1.30–2.22]	[1.31–2.54]	[1.54–2.37]
Outdoor	1.171*	1.699*	1.171***	1.084(n)	0.975(n)	1.415*	1.263***	1.245(n)	1.426*
noise	[1.07–1.27]	[1.26–2.28]	[1.03–1.32]	[0.93–1.26]	[0.76–1.24]	[1.20–1.66]	[1.01–1.56]	[0.99–1.56]	[1.18–1.71]
Unstable	1.076(n)	1.119(n)	0.952(n)	1.512*	1.308(n)	0.931(n)	0.901(n)	1.28(n)	1.487**
temperature	[0.96–1.20]	[0.74–1.68]	[0.81–1.11]	[1.23–1.84]	[0.93–1.82]	[0.76–1.14]	[0.68–1.18]	[0.92–1.77]	[1.15–1.91]
Too high	1.035(n)	1.014(n)	1.085(n)	0.829***	0.975(n)	1.093(n)	0.956(n)	1.353***	1.089(n)
temperature	[0.93–1.14]	[0.70–1.45]	[0.94–1.24]	[0.69–0.99]	[0.72–1.30]	[0.912–1.31]	[0.74–1.22]	[1.05–1.74]	[0.87–1.34]
Electric stat	0.940(n)	1.005(n)	0.998(n)	0.915(n)	1.16(n)	0.683***	0.712***	0.984(n)	0.822(n)
	[0.81–1.08]	[0.67–1.49]	[0.80–1.22]	[0.70–1.18]	[0.76–1.77]	[0.52–0.88]	[0.51–0.99]	[0.67–1.42]	[0.55–1.22]
Cigarette	0.952(n)	0.602**	1.199**	0.768**	0.883(n)	0.981(n)	0.958(n)	1.383***	0.827(n)
smell	[0.86–1.04]	[0.44–0.82]	[1.05–1.83]	[0.65–0.90]	[0.68–1.14]	[0.83–1.15]	[0.77–1.18]	[1.05–1.81]	[0.65–1.05]
R2	0.110	0.113	0.118	0.123	0.083	0.169	0.114	0.140	0.139
N	5054	678	2655	1721	637	1636	876	809	1096

$^{*}p \le 0.001$; $^{**}p \le 0.01$; $^{***}p \le 0.05$; (n) $p > 0.05$.

impact on overall satisfaction are problems with *unpleasant smell* (odds ratio 1.70), *dust* (odds ratio 1.50) and *outdoor noise* (odds ratio 1.48). Analysis with interactive variables (model 2c) indicates that the effect of *problems with outdoor noise* on occupants who leave the apartment for less than 4 h is 1.44 (CI(95%) 1.18–1.75) times the effect of *outdoor noise* on other occupants. Occupants who leave the apartment for 5–9 h on weekdays were found to be more sensitive to *draught* (odds ratio 1.31, CI (95%) 1.06–1.62) and *unstable temperature* (odds ratio 1.27, CI(95%) 1.06–1.60).

6.4.4. Heath

6.4.4.1. Satisfaction with IEQ. A smoking habit was found to be not statistically significant (model 1a, Table 7). However, analysis with model 1b indicates that people who smoke are more sensitive to the effect of *satisfaction from air quality*, which is 1.82 (CI(95%) 1.43–2.31) times the effect of *air quality* for non-smokers.

6.4.4.2. Problems with IEQ. The results (model 2c) show that the effect of *problems with unstable temperature* for smokers is 2.02 (CI(95%) 1.45–2.81) and *unpleasant smell* 2.15 (CI(95%) 1.52–3.03) times the effect those variables have on non-smokers. This is reflected in the importance ranking of IEQ problems in the group of smokers. The results showed that for occupants who smoke, *problems with unpleasant smell* (odds ratio 3.37) had the highest impact on overall satisfaction, followed by *problems with unstable temperature* (odds ratio 1.93) (Table 11).

7. Conclusions

This paper examined the effect that perception of indoor environment quality has on overall satisfaction and what influence the characteristics of individuals and building may have on overall satisfaction. The database used to investigate the issue was created from a fraction of data collected during a unique project commissioned by the Swedish National Board of Housing, Building and Planning. The nationally representative sample allows general conclusions to be drawn on how residents living in apartments in Sweden perceive indoor environment quality and how it influences their overall satisfaction. Even though the data used is based on information received from residents and therefore may present some level of subjectivity [2], it is the interaction between occupant and the building [34] that gives residents the very distinctive knowledge about building performance.

Although the data used carries a certain subjectivity, the subjective ratings proved to predict overall comfort better than objective indicators [17]. The pseudo-R2 for tested models was under 25%, suggesting that occupant satisfaction can only partly be explained by satisfaction with indoor air quality. However, even with those limitations, the presented analysis contributes to understanding the interaction between overall satisfaction and perception of IEQ.

Occupants living in apartment buildings in Sweden are in general very satisfied. Satisfaction with thermal comfort, sound and air quality was shown to have an impact on overall satisfaction, and satisfaction with indoor air was found to have the highest impact. These findings support results from earlier studies where satisfaction with air quality had the highest correlation with the acceptability of the overall environment [13,18] and impact on subjective well-being [35].

The most often observed problem with IEQ in Swedish apartments was dust, outdoor noise and problems with too low indoor temperature. Even though the problem of noise was the second most observed problem, the analysis indicated that outdoor noise did not have a high impact on overall satisfaction. The factors having the highest importance impact on overall satisfaction were draught, dust and too low temperature. However, the relative importance of problems with IEQ influencing overall satisfaction may differ depending on location, building construction year, occupant gender and life style.

Occupants in the southern part of Sweden showed higher sensitivity to issues related to thermal comfort, particularly problems related to indoor temperature. Interestingly, occupants living in the north part of Sweden, where local climate is considered to be more severe, reported that problems with indoor temperature may appear but are much less persistent than in southern Sweden. This may indicate a difference in building construction in Sweden. It is possible that buildings in the south are miscalculated with regard to indoor performance or that assumptions used in indoor comfort simulations are underestimated.

Different indoor environment problems seem to have an effect on occupants' overall satisfaction depending on building construction year. Generally, buildings constructed before 1975 indicated sensitivity to thermal comfort problems. This might be related to the fact that those buildings were built with insufficient insulation and the energy efficiency of windows is not as high as in the newest construction. Additionally, a considerable number of dwellings constructed between 1961 and 1975 belong to "The million home building scheme"[2] and many of them require substantial renovations [24]. Problems related to air quality were found to have the highest impact on overall satisfaction of occupants who live in buildings constructed between the mid-seventies to mid-nineties, which may also be explained by the building techniques and technology used. After the energy crisis in the seventies, issues regarding energy consumption and energy efficiency in buildings became more important, reflected in improvements in the airtightness of buildings. However, as buildings became more airtight, solutions regarding ventilation systems also emerged as a compelling issue.

The paper has shown that weighting aspects of indoor environment is not stable and differs depending on the characteristics of buildings and individuals. The occurrence of IEQ problems influences overall satisfaction, but how occupants perceive the importance of problems with the indoor environment varies between different populations.

Further studies should focus on understanding relationships between factors impacting occupants' satisfaction and explore the structure created by causal effects between the related variables. An interesting approach for analysis could be factor analysis and structural modelling. Exploring whether a variable is causally linked to one particular variable or to a group of variables could give better understanding of the relationship between indoor environment, behaviour and occupant satisfaction. This knowledge could lead to further improvements in indoor climate simulation programmes and building construction.

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[2] Housing scheme introduced in Sweden in 1964 and aiming at construction one million dwellings within ten years period (1965–1974) [7,36].

Paper IV

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.

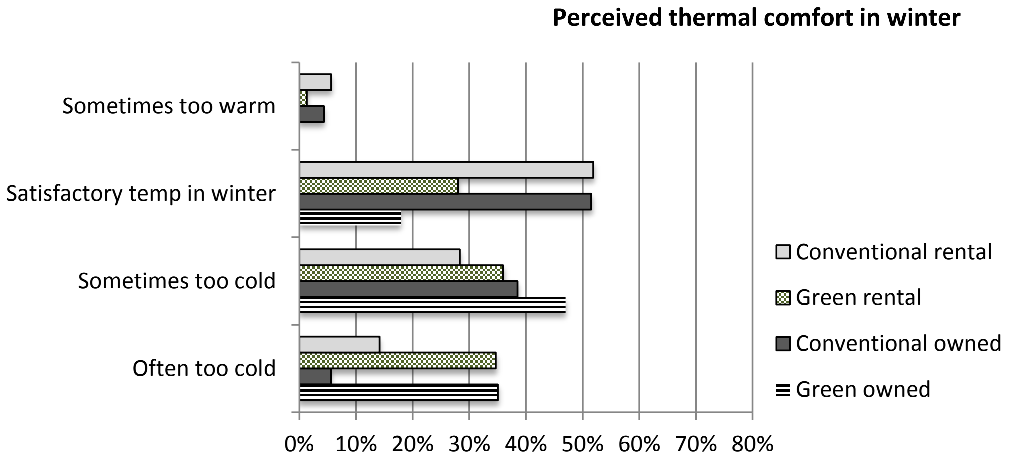

Figure 1. Perceived thermal quality in winter season

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.

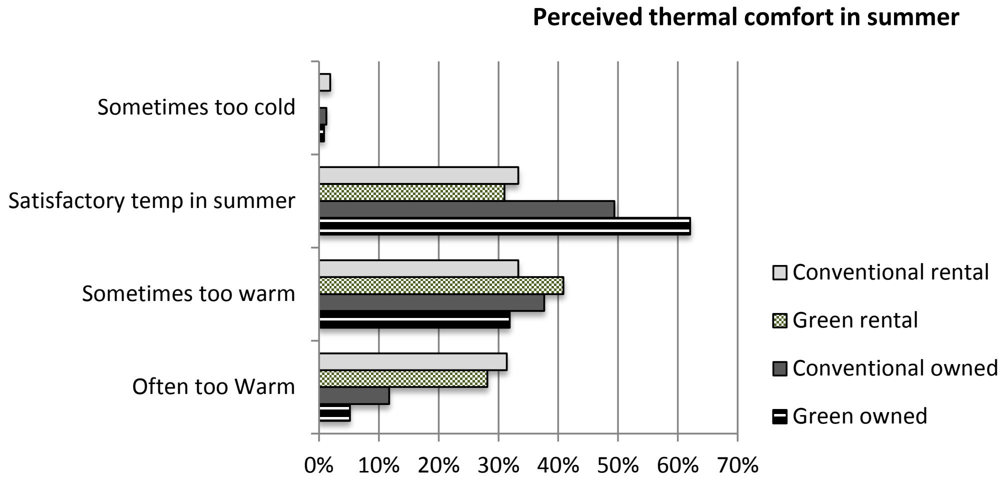

Figure 2. Perceived thermal quality in summer season

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.

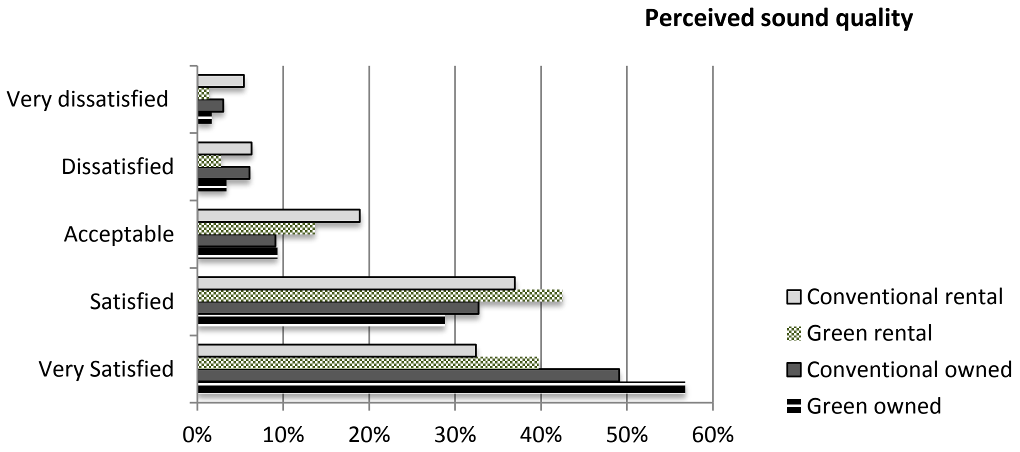

Figure 3. Perceived sound quality

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.

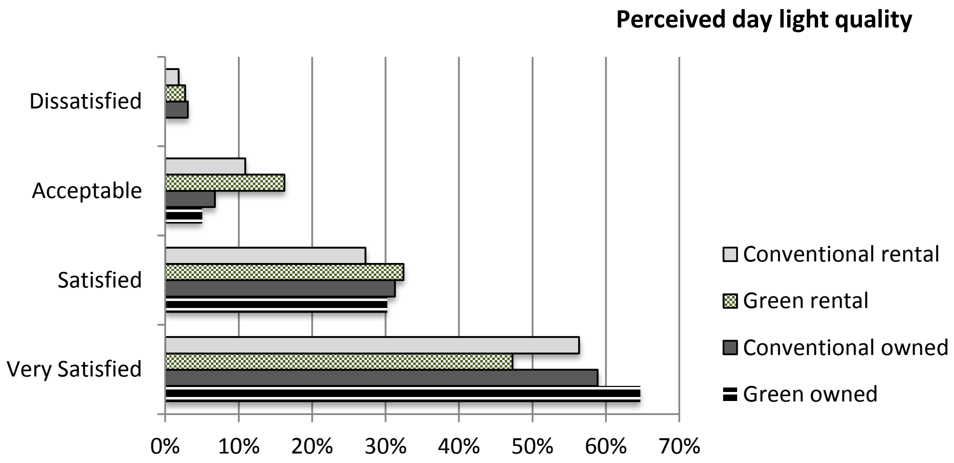

Figure 4. Perceived quality of daylight.

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.

Acknowledgement

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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 quality	4.41	4.50	4.27	4.43	4.39	4.56	4.46	4.21	4.30
	(.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 quality[1]	3.58	3.59	3.56	3.25	3.81	3.12	3.92	3.45	3.64
	(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	1.41	1.52	1.24	1.65	1.25	1.89	1.26	1.27	1.22
heating/cooling	(.69)	(.76)	(.52)	(.80)	(.55)	(.83)	(.58)	(.55)	(.50)
system [1]	463	280	183	190	273	116	164	74	109
Required	1.72	1.89	1.45	1.92	1.58	2.30	1.61	1.34	1.53
adjustments to the	(.74)	(.75)	(.62)	(.79)	(.66)	(.70)	(.66)	(.53)	(.67)
system [2]	454	274	180	186	268	113	161	73	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

* $p \leq 0.01$; **$p \leq 0.05$; *** $p \leq 0.1$

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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Paper V

Impact of energy and environmental factors in the decision to purchase or rent an apartment: The case of Sweden

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Abstract

This paper examines the importance of environmental factors in the residential property market. The paper presents results from a quasi-experimental study and survey responses from 733 occupants of green and conventional buildings. The study demonstrates that energy and environmental building performance factors have rather a minor impact on the purchasing or renting decision. Our findings indicate that when discussing the impact of energy and environmental factors on a customer purchase decision, the availability of information should be considered.

Keywords: residential buildings; green buildings; environment, energy, sustainability; purchasing decision

Introduction

The greening of the built environment is a long process. The barriers decelerating green building development were often related to uncertainty and doubts about the financial feasibility and profitability of building green (Issa et al., 2009). Recent literature provides evidence against this skepticism, indicating that green labeled buildings transact higher prices on the commercial (Dermisi 2009; Miller et al., 2009, Eichholtz et al., 2010a, Eichholtz et al., 2010b, Fuerst and McAllister, 2011a; Fuerst and McAllister, 2011b, Kok and Jennen, 2012) and the residential market (Ott et al., 2006; Mandel and Wilhelmsson, 2011; Brounen and Kok, 2011; Addae-Dapaah and Su Jen Chieh, 2011).

However, there is some difficulty in separating “the green variable” from the other factors, such as building design, and consequently abstracting the impact that variables have on transaction prices. Moreover, it is also unclear whether the choice to purchase or rent a green building is the customer’s conscious choice related to a building’s green features. It is uncertain whether a potential buyer or tenant is being informed about green aspects of building and whether information about energy and building environmental performance is important to the customer.

Brounen and Kok (2011) concluded that customers take into account information extracted from the building energy certificate; however, a study conducted in New Zealand (Eves and Kippes, 2010) indicated that the public is generally aware of energy and environmental issues but these factors play a minor part in the final house purchase decision. Correspondingly, findings from studies in Germany, Singapore and Australia indicate that house buyers seldom consider information about building energy and environmental performance to be an important factor in their decision-making process (Addae-Dapaah and Su Jen Chieh, 2011; Amecke, 2012; Bryant and Eves, 2012). The research also shows that a potential apartment buyer (Addae-Dapaah and Su Jen Chieh, 2011) may be unaware of green building labeling or confused about the difference between label ratings.

The literature also indicates that environmental awareness may not be a sufficient argument to motivate making more environmentally friendly decisions (Raisbeck and Wardlaw, 2009). The research suggested that neither arguments about more individual aspects like “improved liveability”, “cost savings” or “other people opinion”, nor arguments of greater scale, such as “concern for future generations” can be considered significant enough to motivate investing in the construction of sustainable houses.

The focus of this paper is on examining how the impact of energy and environmental building features are being factored into decisions to rent or buy apartments. The analysis is based on over 730 survey responses collected during a quasi-experimental study among occupants of conventional and green multi-family buildings in Sweden. The paper presents results from a study conducted on the Swedish residential market and contributes to the international literature on customer attitudes towards building sustainability features. The results contribute to the discussion on factors that may affect a prospective owner or tenant while they are searching for an apartment (Collen and Hoekstra 2001; Earnhart 2002; Jim C.Y. and Chen, 2007; Reed and Mills, 2007; Chau et al., 2010; Goodwin, 2011).

1. Background

1.1. Brief characteristics of housing market in Sweden

The Swedish housing sector consists of about 4.5 million dwellings, approximately 55% of which are multi-family dwellings and 45% single-family dwellings. Most of the multi-family dwelling stock is made up of rental apartments (nearly 70%) owned by private and municipal organizations, while one third consists of owned dwellings, a Swedish form of condominium.

The rent system in Sweden is controlled and the annual charges in rents are the result of negotiations between the municipal housing companies and the Swedish Tenants' Union. The rent levels in the private sector are set comparably to those in the municipal sector (Svensson, 1998; Lind, 2003; Atterhög and Lind, 2004; Wilhelmsson et al., 2011). The utility fees are usually included in the rent (except for household electricity consumption). The fees for heating and water consumption tend to be calculated based on generally accepted norms, rather than related to actual consumption. By contrast, utility fees in condominiums are generally related to the household's real consumption.

The difference in housing tenure relates not only to size of financial investment, risk and profit or loss possibilities on the housing market, but also responsibility for and commitment to building operation and maintenance. In the case of condominium apartments in Sweden, the owners form an association, which is responsible for decisions regarding building services, maintenance and renovation. The tenant is relieved of these obligations, as maintenance and renovation services are included in the tenant contract and are the responsibility of the house owning company (Lind and Lindström, 2011).

Considering that the Swedish housing market is characterized by a strong rent regulation system (Lind, 2003) and an accompanying queuing system, the decline in newly constructed rental dwellings (figure 1) may affect the importance of factors impacting the decision to rent an apartment. It is possible that, in the case of low vacancy in housing stock and the limited availability of new dwellings, a potential tenant chooses an apartment because it is obtainable rather than because it satisfies needs and requirements. However, since the vacancy levels differ across Sweden (Klingborg, 2000; Wilhelmsson et al., 2003) the above scenario may apply only in some municipalities. Even though the local market analysis is outside the scope of this paper, we expect that the low availability of newly constructed dwellings may have an impact on customer decisions to rent.

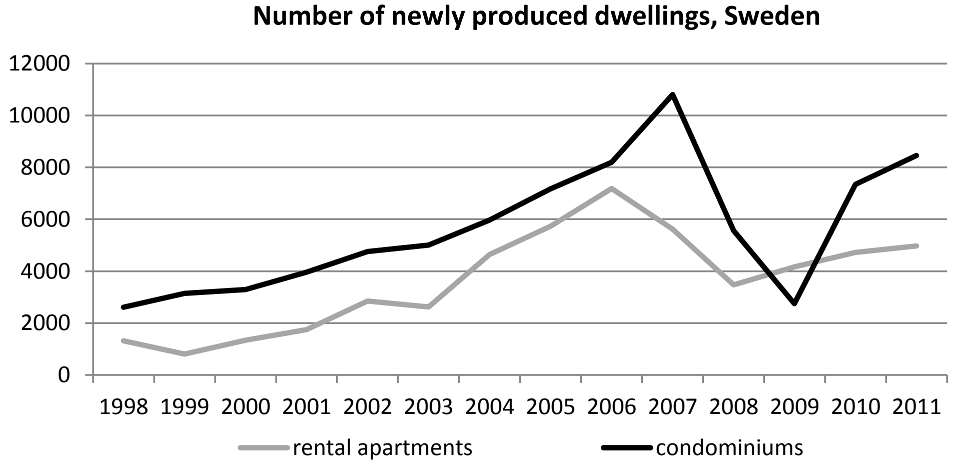

Figure 1. Newly produced dwellings between 1998 - 2011, source SCB (http://www.scb.se)

1.2. The green residential market in Sweden

The increasing awareness of and focus on energy and environmental issues on the residential market is best demonstrated by the construction of very low-energy housing. Currently, the Swedish Building Regulations expect that space heating in a residential building constructed in southern Sweden (e.g. Stockholm) should not exceed 90 kWh/m2 annually (Boverket, 2011). Very low-energy buildings are often constructed to passive house standard (the Swedish standard was introduced by *The Forum for Energy-Efficient Buildings, Swedish:Forum för energieffektiva byggnader - FEBY*) and are expected to have significantly lower energy demand for space heating, even down to 50% of the requirements stipulated by the Swedish Building Regulations. The Swedish Center for Zero Energy Buildings (Swedish: Sverige Centrum för Nollenergihus; http://www.nollhus.se) estimated that by the end of 2012, approximately 2000 highly energy-efficient residential buildings would be built and an additional 1320 buildings would be under construction. These figures, however, represent only a small percentage of total residential building production.

At present, no residential buildings in Sweden are certified according to internationally recognized environmental building schemes such as BREEAM; however, the Swedish scheme *Environmental building* (Swedish: Miljöbyggnad, http://www.sgbc.se/certifieringssystem/miljoebyggnad) has attracted a few developers and residential owners. The *Environmental building* (Miljöbyggnad) is a voluntary certification process. The building environmental evaluation focuses on three areas: energy, indoor environment and material (Malmqvist et al., 2011). The assessment process has adopted a rating system where different credits are assigned depending on which performance targets the building has achieved. Finally, the credits gained during the assessment are added together and determine the *Environmental building* (*(*Miljöbyggnad) certification level. Depending on the energy and environmental goals achieved, the building can be granted brown, silver or gold certification. The *Environmental building* (Miljöbyggnad) has been developed and adjusted to Swedish norms and standards, enabling the relatively easy applicability of the *Environmental building* (Miljöbyggnad) requirements in a building construction process.

Another environmental building scheme emerging on the residential market is Nordic Ecolabel *Svanen* (http://www.svanen.se/en/). The eco-labeling is determined through environmental analysis from a lifecycle perspective. The label is already known for eco-certifying various group products from appliances, through furniture to building material. The label recently introduced environmental certification for building and the scheme slowly gaining popularity among housing developers in Sweden.

2. Method and data collection

2.1. Study design

The data presented in this article are part of a four-year study aiming at capturing differences in the apartment purchasing and rental decision, overall satisfaction and perception of indoor environment among occupants living in green and conventional buildings. This paper focuses only on factors contributing to the purchasing and rental decision and the analysis; results regarding the remaining data are presented in other articles (Zalejska-Jonsson, 2012; Zalejska-Jonsson; 2013).

The research was designed as a quasi-experimental study (Bohm and Lind, 1993; Nyström 2008) in which green and conventional residential buildings were selected and paired in such a way that building characteristics were comparable and only differed in their energy and environmental performance. Care was taken to select cases that match as closely as possible in regard to building production year, building location, size and potential customer segment.

Firstly, we have chosen the green building objects. *Green building* was defined as a building designed and constructed with high energy efficiency or environmental goals. Only buildings with a very low energy requirement (calculated space heating lower than 60kWh/m2 annually), and buildings registered or certified according to a building environmental scheme were considered. Secondly, we have selected conventional buildings i.e. the control buildings. It was imperative that the *control building* was constructed according to current Swedish Building Regulations, but did not aim at better environmental or energy performance. The study focused only on newly constructed multi-family buildings.

2.2. Data Collection

Data collection was conducted in three rounds. The first data collection took place in 2010 and included three pairs of multi-family buildings. The data collection in 2012 was divided into collection periods: late spring (three pairs) and early autumn 2012 (four pairs). The studied cases included multi-family buildings with rental apartments (owned by municipal companies) and condominiums, with apartments owned by tenants.

2.3. Survey Design and Questionnaire

The survey questionnaire was divided into four sections and consisted in total of 33 questions investigating factors affecting the decision to purchase or rent an apartment, respondents stated willingness to pay for green buildings, and occupants' satisfaction. In this section, we describe only the questions that are relevant to the article.

The first section examined the importance of different factors that could have an impact on occupants' decision to purchase or to rent the apartment. The factors were selected based on the extensive literature describing preferences in choice of residence. Respondents were asked to indicate how the following factors contributed to their apartment purchase or rental decision: location, price, apartment size, apartment design, calculated low energy consumption, environmental factors (other than energy), accessibility to public transport and limited choice of available apartments. Respondents could choose one of the following answers: decisive, important but not decisive, less important and unimportant.

In the second section, respondents were ask to indicate what information regarding building energy and environment performance they had received before purchasing or renting the apartment. Respondents were given a list that included items such as expected annual energy consumption, and environmental or climate certification. Respondents could also indicate other information in the comment box. Additionally, in the later part of the questionnaire, respondents were asked to indicate what they perceived as the meaning and value of building environmental certification. The final section of the questionnaire included demographic questions that are used to analyze the data.

A survey was addressed only to all adult occupants, i.e. occupants who at the time of the data collection were at least 21 years old. This constraint was imposed to ensure that the responses represent the choice of the individual rather than that of the parents or the guardian.

The survey was sent by regular mail. The envelope was addressed to individuals and included cover letter, survey questionnaire and return envelope. The particulars (name and address) were obtained from a publicly accessed online database. People 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. EUR 0.3. 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 fulfill 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. The survey was addressed to 1753 persons and 733 responses were received, which resulted in a 42% response rate. Detailed information about the response rate for each building and tenure is presented in table 1.

Table 1. Response rate for the survey

pair number	green/ conventional	ownership/ rental	questionnaire sent	response	response rate	Survey date
1	Green	Condominium	35	18	51%	2012 spring
2	Green	Condominium	21	14	67%	2012 spring
3	Green	Condominium	55	24	44%	2012 spring
4	Green	Condominium	58	31	53%	2012 fall
5	Green	Condominium	63	35	56%	2012 fall
6	Green	Rental	175	63	36%	2012 fall
7	Green	Rental	53	14	26%	2012 fall
8	Green	Rental	180	94	52%	2010 fall
9	Green	Rental	44	19	43%	2010 fall
10	Green	Rental	91	42	46%	2010 fall
1	Conventional	Condominium	91	38	42%	2012 spring
2	Conventional	Condominium	47	28	60%	2012 spring
3	Conventional	Condominium	63	38	60%	2012 spring
4	Conventional	Condominium	85	33	39%	2012 fall
5	Conventional	Condominium	85	30	35%	2012 fall
6	Conventional	Rental	196	56	29%	2012 fall
7	Conventional	Rental	173	55	32%	2012 fall
8	Conventional	Rental	149	56	38%	2010 fall
9	Conventional	Rental	46	23	50%	2010 fall
10	Conventional	Rental	43	22	51%	2010 fall
	Conventional	Rental	607	212	35%	
	Green	Rental	543	232	43%	
	Conventional	Ownership	371	167	45%	
	Green	Ownership	232	122	53%	
	Total		1753	733	42%	

2.4. Statistical Analysis

In the first stage of the analysis, descriptive statistics were used. In the second step, the statistical difference in responses from occupants of green and conventional buildings was tested by the Mann-Whitney (rank sum) test. Thirdly, statistical models were applied. The literature shows that the demographic factors may impact environmental behavior and perception of energy efficient measures (Barr et al., 2005; Nair et al., 2010). The statistical models applied to the data are described as a function of the following variables: age (age), gender (if women =1), whether the household was a family with children (family=1), number of occupants per dwelling (occupants), dwelling size described as number of rooms (room), apartment tenure (if condominium=1) and environmental profile (if green=1). The independent variables are importance of ENERGY factor for apartment choice (model 1) and importance of ENVIRONMENTAL factors for apartment choice (model 2).

The impact of individuals' characteristics on the importance of energy and environmental factors for the decision to purchase or rent an apartment was tested with logistic models. The 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 , 2001). A Brant Test for a parallel regression assumption was conducted for each regression. The proportional odds assumption was satisfied in both models and the use of ordinal logistic models was justified.

The results are reported in the form of odds ratios and are interpreted in this paper as the likelihood of energy or environmental factors being important in the decision to purchase or rent an apartment if the predictor variable is increased by one unit while other variables are kept constant.

The statistical analysis was performed in STATA. In order to test the internal consistency of the data, a Cronbach alpha test was conducted and the computed coefficient of 0.67 was considered satisfactory.

2.5. Limitations

There are certain limitations in the presented study. The analysis is largely based on the stated personal opinion of respondents and consequently, the results may include errors related to the formulation of the questions, respondents' subjective opinion and their selective memory (Schwarz and Oyserman, 2001). Moreover, occupants responses might be affected by post-purchase rationalization, and therefore responses may inaccurately describe the impact of certain factors on the decision to purchase (or rent) an apartment.

Secondly, the quasi-experimental approach was introduced to ascertain the comparability between paired buildings; however, each property is unique, f in design or location, for example. Consequently, the uniqueness of each property imposed a certain limitation on the degree to which paired buildings could have been matched. In the result, the buildings are paired best to the abilities, because certain compromises had to be made (for example in geographical location, size of the estate or number of dwellings).

Finally, the information regarding participants' income was not collected during the survey. Consequently, the financial status of the families was not included in the analysis, which may particularly affect the results computed from statistical models (omitted variables bias).

3. Results

3.1. Description of respondents

Gender distribution is very similar in the sub-groups green and conventional owned dwellings and green and conventional rental apartments: approx. 55% respondents were females. There are certain differences in age distribution among respondents between the sub-groups (figure 2 and 3). The largest group of respondents in green owned apartments were between 31 and 40 years old (37%), whereas in conventional buildings, this group of occupants accounted for only 18%. There was a higher percentage of older respondents (over 60 years old) living in owned than rental apartments. The Mann-Whitney (rank sum) test indicated that there is a statistically significant difference in respondents' age between condominiums and rental apartment, but no statistically significant difference was found between green and conventional buildings. The difference between building tenure groups may be related to various factors such as occupants' financial status and financial security, family situation, or health.

Approximately 35% of the respondents living in rental apartments, both green and conventional, are families with children. The proportion of families with children in green owned apartments was found to be much higher (43%) than in conventional buildings (25%).

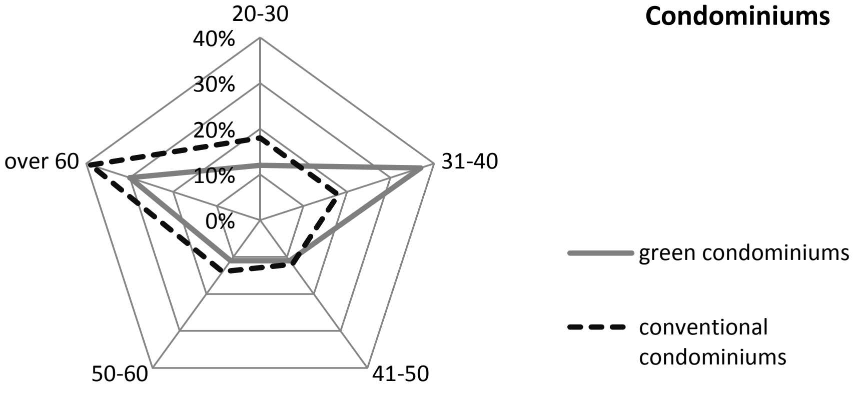

Figure 2. Respondents' age distribution, occupants living in condominiums

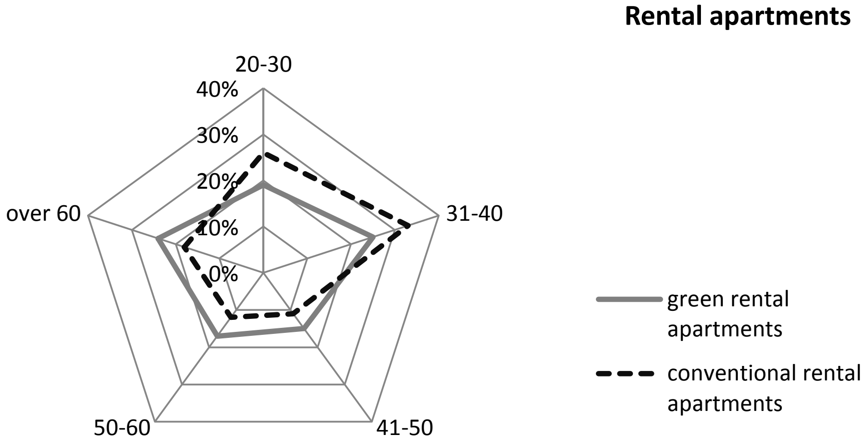

Figure 3. Respondents' age distribution, occupants living in rental apartments

3.2. Factors impacting on the apartment purchasing or renting decision

The analysis reveals that the most important factors considered in the respondents' decision to purchase and rent were apartment size and location (table 2). Considering that the search for a new apartment is often prompted by lifestyle changes such as starting a family, going through a divorce or changes in health, it is understandable that apartment size would have the highest importance and it had the highest mean value among all responses (3.34), with 3.37 for owned apartments and 3.33 for rental apartments. Table 2 shows determinants for apartment purchase or rental, expressed as mean values and ranked from the most to least important.

The second most important factor was building location; however, the mean values for location and apartment size differ only marginally. The location of the buildings relates not only to geographical position but also to the sense of familiarity and social life. Many respondents indicated in their comments that their choice of apartment search area was strongly related to the fact that they wanted to stay close to family and friends.

The importance of factors which customers consider in the decision to buy (or rent) an apartment might be affected by the characteristics of the local market. Table 6 (appendix) presents mean values for factors as indicated by respondents living in the paired buildings. The results show that even though importance ranking of factors may vary, the top four factors affecting purchase/rental decision are the same i.e. dwelling size, design, location and accessibility. The energy and environmental factors still had a minor impact, ranked not higher than fifth place.

Table 2. Mean values for factors impacting purchase and rental decision

factors	mean value for all buildings [mean; (std.dev); no observation]	mean value for condominium	mean value for rental apartments
apartment size	3.34	3.37	3.33
	(.63)	(.62)	(.64)
	704	281	423
location	3.28	3.34	3.24
	(.60)	(.56)	(.63)
	711	282	429
apartment design	3.08	3.21	3.00
	(.71)	(.65)	(.744)
	692	276	416
access to public transport	3.11	3.26	3.01
	(.77)	(.69)	(.80)
	695	276	419
price / rent	3.00	3.27	2.81
	(.69)	(.58)	(.69)
	700	281	419
estimated energy consumption	2.61	2.76	2.52
	(.86)	(.82)	(88)
	687	275	412
distance to work	2.58	2.46	2.66
	(.94)	(.99)	(.90)
	659	261	398
environmental factors (other than energy)	2.51	2.54	2.50
	(.85)	(.82)	(.874)
	680	270	410
limited choice of available apartments	2.43	2.223	2.562
	(1.03)	(.97)	(1.04)
	657	257	400
distance to school	1.96	1.97	1.96
	(1.08)	(1.10)	(1.07)
	636	251	385

For purpose of analysis factors are ranked from highest to lowest impact; 4= decisive, 3= important but not decisive, 2= not very important, 1= unimportant

The Mann-Whitney test was conducted to examine the difference in responses received from occupants living in condominiums and rental apartments. The results indicate that responses between occupants differ significantly in many respects (table 3). Not surprisingly, the price had a more decisive impact on the decision when purchasing compared to renting an apartment: 35% of apartment owners indicated that price played a decisive part in their apartment choice; only 11% of tenants indicated the same. Energy consumption was found on a statistically significant level to be more important for owners than for tenants. Again, this is not surprising, considering that energy consumption relates to space heating, which is often included in the rental fee in Sweden. Interestingly, environmental factors have an equal and relatively low impact on the decision to buy or to rent an apartment.

The apartment design value seems to be more important when purchasing than when renting an apartment, the difference being statistically significant at $p \leq 0.01$ (table 3). One third (33%) of apartment owners indicated apartment design as having a crucial impact on their decision to buy an apartment, compared with 24% responses among tenants.

As expected, the analysis indicated a statistically significant difference in opinion regarding the importance of availability of dwellings (table). The rental control, shortage of newly constructed apartments and queuing system may explain the difference in responses.

Table 3. Differences in responses between occupants living in owned and rented apartments

	Mann-Whitney test for difference between condominium and rental apartments [p, probability]
FACTORS	
building location	0.0454**
apartment price	0.0001*
apartment size	0.479
apartment design	0.0003*
estimated energy consumption / cost	0.0004*
environmental factors	0.455
access to public transport	0.0001*
distance to work	0.026**
distance to school	0.938
limited choice of available apartments	0.0001*
CERTIFICATION	
importance of environmental certification for buildings	0.314

Results marked in the tables as *indicate statistically significant at $p \leq 0.01$ and with ** statistically significant at $p \leq 0.05$

The local context may also provide a better explanation for statistically significant differences between responses of occupants living in condominiums and rental apartments (table) and between occupants of green and conventional buildings (table). The results of the Mann-Whitney test conducted on responses of occupants living in the paired buildings are presented in table 7 (appendix). The results confirm that the purchase of an apartment is a very careful decision that depends on customers' specific needs and requirements. The results indicate a difference in opinion regarding energy and environmental factors.

One of the limitations of the study is the difference in geographical location of paired buildings, as the green and the conventional building are not always situated in close proximity to each other. This is a case in pairs 3, 5 and 10, which may explain the statistical difference in opinion regarding the importance of distance to school. In the mentioned cases, green buildings were located in newly developed areas of the city.

3.2.1. Difference between green and conventional buildings

We tested separately the difference between green and conventional building occupants' responses within a particular tenure group i.e. among occupants living in condominiums and rental apartments. According to the Mann-Whitney test, only energy, environmental factors ($p \leq 0.01$), and distance to school ($p \leq 0.05$) are statistically different between the two sub-groups, green and conventional condominium (table 4). For rental apartment buildings, a statistically significant difference was found only for energy and environmental factors.

Table 4. Mann-Whitney test for sub-groups owned and rental apartments

Variable	Mann-Whitney test for difference between green and conventional buildings , condominiums [p, probability]	Mann-Whitney test for difference between green and conventional buildings, rental apartments [p, probability]
FACTORS		
building location	0.636	0.175
apartment price	0.485	0.267
apartment size	0.461	0.281
apartment design	0.525	0.693
estimated energy consumption / cost	0.0001*	0.0003*
environmental factors	0.0001*	0.0001*
access to public transport	0.643	0.561
distance to work	0.444	0.522
distance to school	0.026**	0.699
limited choice of available apartments	0.859	0.132
CERTIFICATION		
importance of environmental certification for buildings	0.0006*	0.880

Results marked in the tables as *indicate statistically significant at $p \leq 0.01$ and with ** statistically significant at $p \leq 0.05$

The aspects related to building energy and environmental performance had greater importance for people living in green buildings. This may be related to the fact that people who choose to live in a green residence are more environmentally conscious and indicate more interest in those factors. Indeed, when respondents were asked to indicate their opinion on the importance of environmental certification for buildings, more than half of the respondents in green owned apartments (56%) responded that environmental certification is important and that it may have a positive impact on building value (figure 4). This opinion was shared by approximately one third of the respondents living in conventional buildings (36%). A statistically significant difference in opinions was confirmed by the Mann-Whitney test ($p<0.001$). On the other hand, there is no significant difference in responses received from occupants in rental apartments. Just over 40% of respondents living in green and conventional rental apartments believe that environmental certification for buildings is important and has an impact on building attractiveness (figure 4) .

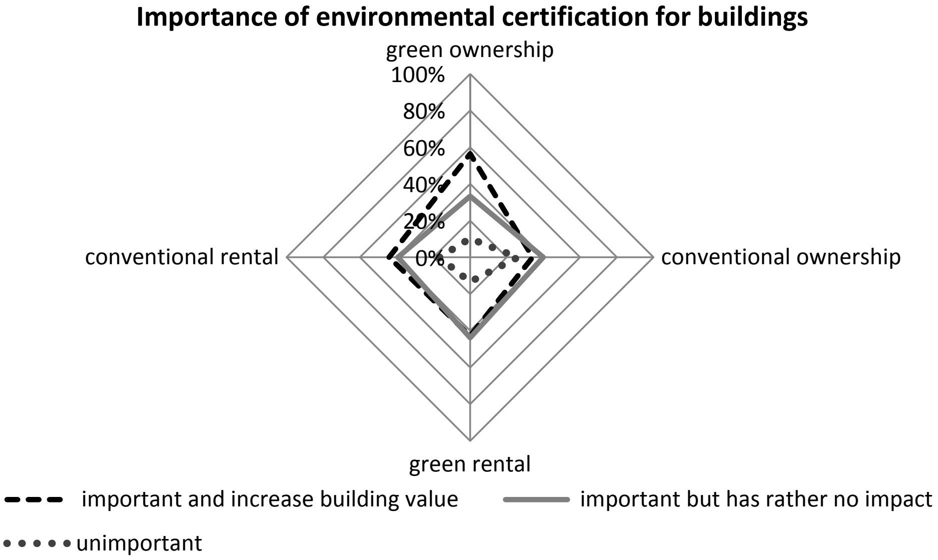

Figure 4. Importance of environment certification for buildings

However, it is important to distinguish between environmental literacy or environmental education (Stables and Bishop, 2001) and asymmetry of market information. The first concepts relate to ecological awareness (David, 1974), understanding of, and taking action on, environmental issues. The latter refers to a situation where people's access to information is "uneven". It was clear from the study that information about building performance and environmental impact was generously presented to the prospective buyers of green buildings. On the other hand, the same information was less likely to be given to buyer and tenants of conventional buildings, unless explicitly demanded. Approximately two thirds of the respondents who owned apartments in conventional condominiums indicate that they “do not know”, “do not remember” or “did not receive” any information about building energy or environmental performance. However, about 90% of the respondents living in green buildings remember being given information about expected energy consumption or building environmental impact. Approximately 60% of occupants living in rental green apartments remember receiving information about building energy or environmental performance, whereas 85% respondents living in conventional rental apartments “do not remember” or “did not received” such information.

This results are in line with findings from a study by Bryant and Eves (2012) suggesting that availability of information on building environmental features and the sellers’ attitude increases the likelihood of the buyers’ interest in this information.

3.2.2. Effect of individuals’ characteristics on importance of energy and environmental factors

The ordered logistic models were fit to the data to test the impact that individuals’ characteristics may have on the importance of environmental and energy factors in apartment purchase and rental decisions.

The results reveal a 2.40 odds probability that energy is a more important factor for occupants of green buildings than conventional buildings (table 5), suggesting that if people perceive energy as an important factor, they are more likely to purchase or rent a green dwelling (odds ratio the for environment is 2.42). The results indicate that energy factors are more important for those who live in condominiums than those who rent (1.85 odds probability). The results are not surprising considering that owners have full responsibility for energy consumption bills. On the other hand, in the case of tenants, the space heating costs may be included in the rental fee and are often calculated as a fixed fee rather than related to actual consumption.

The analysis reveals that individual characteristics may have an impact on the importance of energy and environmental factors in the decision to purchase or rent an apartment. The analysis shows that the energy and environmental factors are more important for female than male respondents (odds ratio 1.36).The results reveal that the importance of energy and environmental factors increases for the older groups of respondents. The group of oldest respondents (50-60 and over 60 years old) are most likely to consider energy and environmental factors to be important in their decision to rent or purchase an apartment. The findings are in line with results of the study conducted in New Zealand, which revealed that older housing buyers were most aware of the importance of energy and environmental aspects in the house purchasing decision (Eves and Kippes, 2010).

Table 5. Ordinal logistic regressions: importance of energy and environment factors

	importance of ENERGY factor, model 1			importance of ENVIRONMENTAL factors , model 2		
	odds ratio	p, probability	conf. interval (CI 95%)	odds ratio	p, probability	conf. interval (CI 95%)
number of rooms	1.11	.335	.89-1.39	.88	.300	.71-1.11
occupants	.97	.839	.76-1.24	1.11	.382	.87-1.41
older: 31-40	1.17	.490	.74-1.84	1.36	.163	.86-2.16
older: 41-50	1.65	.077***	9.94-2.89	2.60	.001*	1.46-4.62
older: 51-60	5.60	.000*	3.14-9.98	4.11	.000*	2.35-7.17
older: over 60	4.87	.000*	2.90-8.17	4.01	.000*	2.41-6.65
woman	1.36	.047**	1.01-1.85	1.81	.000*	1.33-2.46
family	.88	.631	.52-1.47	1.13	.630	.68-1.85
condominium	1.85	.000*	1.34-2.55	1.15	.362	.84-1.58
green building	2.40	.000*	1.75-3.29	2.42	.000*	1.77-3.30
No of observations	616			609		
Pseudo R2	.094			.065		

Results marked in the tables as *indicate statistically significant at p≤0.01, with ** statistically significant at p≤0.05 and with *** statistically significant at p≤0.1

4. Summary and conclusions

A quasi-experimental approach and results from a survey among occupants of green and conventional buildings were used to study the impact of energy and environmental factors on customer decisions to purchase and to rent an apartment.

It was demonstrated that apartment size and location have the greatest effect on the decision to purchase or rent an apartment. The analysis indicates that perception of the importance of energy and environmental factors differs depending on apartment tenure and whether the respondent was living in a green or a conventional building.

Generally, the energy and environmental factors were found to have rather a minor impact on the purchasing or renting decision. The findings are in line with results from studies conducted in Germany (Amecke, 2012) and New Zealand (Eves and Kippes, 2010). The analysis also indicates that individual characteristics may have an effect on the impact of energy and environmental factors on apartment purchasing or rental decisions.

Our findings indicate that when discussing the impact of energy and environmental factors on a customer's decision to purchase, information availability should be considered. Developers are more likely to inform prospective buyers about building environmental performance when the energy or environmental impact gives a positive signal and may increase selling value. The market information asymmetry has consequences. Firstly, potential buyers are informed of how exceptional green buildings are, yet they do not know what they can expect of conventional buildings. Secondly, the generously provided information creates specific expectations, which may have an impact on occupants' overall satisfaction. Finally, since the environmental benefits are not observable directly and even questioned by earlier research, the customer may have reservations about environmentally profiled buildings. Customer sceptism may be reflected in the perception of a higher investment risk and lower willingness to pay.

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Appendix

Table 6. Mean values for factors impacting purchase and rental decision, by paired buildings

factors (mean)	mean value for all buildings	pair 1	pair 2	pair 3	pair 4	pair 5	pair 6	pair 7	pair 8	pair 9	pair 10
size	3.34	3.52	3.32	3.37	3.40	3.21	3.41	3.27	3.29	3.35	3.30
location	3.26	3.36	3.75	3.32	3.16	3.29	3.02	3.19	3.42	3.22	3.23
accessibility	3.11	3.16	3.00	3.51	3.15	3.40	3.23	2.98	3.40	2.60	2.68
price	3.00	3.36	3.24	3.25	3.26	3.33	2.83	2.84	2.69	2.93	3.00
design	3.08	3.43	3.35	3.16	3.22	3.00	3.00	2.80	2.95	3.10	3.41
distance work	2.58	2.80	1.90	2.52	2.31	2.56	2.80	2.80	2.71	2.14	2.33
energy	2.61	2.79	3.02	2.88	2.93	2.32	2.37	2.25	2.54	2.81	2.89
distance school	1.96	2.25	1.79	1.98	1.96	185	2.28	2.13	1.75	1.61	1.75
environment	2.51	2.58	2.61	2.67	2.70	2.20	2.48	2.27	2.57	2.72	2.59
limited choice	2.43	2.05	2.54	2.35	2.37	2.00	2.61	2.67	2.50	2.54	2.45

Table 7. Differences in responses between occupants living in green and conventional building, by paired buildings

factors (Mann-Whitley test, p-probability)	difference between green and conventional	pair 1 condominium	pair 2 condominium	pair 3 condominium	pair 4 condominium	pair 5 condominium	pair 6 rental	pair 7 rental	pair 8 rental	pair 9 rental	pair 10 rental
size	0.73	0.20	0.71	0.00***	0.47	0.00***	0.02**	0.24	0.14	0.40	0.92
location	0.11	0.66	0.67	0.14	0.50	0.29	0.53	0.98	0.14	0.00***	0.04**
design	0.65	0.37	0.04**	0.01**	0.04**	0.71	0.77	0.22	0.33	0.93	0.83
accessibility	0.86	0.25	0.32	0.60	0.29	0.47	0.46	0.33	0.00***	0.39	0.54
price	0.02**	0.02**	0.58	0.07*	0.09*	0.55	0.74	0.78	0.22	0.00***	0.11
distance work	0.82	0.34	0.43	0.37	0.46	0.31	0.85	0.97	0.66	0.67	0.40
distance school	0.27	0.47	0.32	0.00**	0.55	0.01**	0.46	0.70	0.12	0.81	0.08*
energy	0.00***	0.00***	0.39	0.24	0.00***	0.00***	0.15	0.92	0.00***	0.46	0.21
environment	0.00***	0.05*	0.43	0.21	0.00***	0.01**	0.02**	0.97	0.00***	0.92	0.40
limited choice	0.30	0.75	0.98	0.25	0.45	0.06	0.42	0.15	0.75	0.03**	0.95

Results marked in the tables as *indicate statistically significant at *** p≤0.01 and with ** statistically significant at **p≤0.05; statistically significant at *p≤0.10

The results confirm that purchase of an apartment is a very careful decision that depends on customer specific needs and requirements. The geographical location of the building in reference to the city center and development of the neighborhood area could also have affected importance of factors.

Paper VI

Stated WTP and rational WTP: willingness to pay for green apartments in Sweden

Paper submitted to *Sustainable Cities and Society*

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Abstract

Green buildings are expected to require lower operating costs, provide better indoor environment and have a lower impact on the environment than conventional buildings. Consequently, if renting or buying green property is more beneficial, a customer may be willing to pay extra for green apartment. The aim of this paper is to study stated and rational willingness to pay for green apartments in Sweden. A database consisting of responses from 477 occupants living in green and conventional multi-family buildings was used to investigate the existence of WTP and to test the difference in opinion between respondents living in green or conventional buildings and condominiums or rental apartments.

The responses indicate that people are prepared to pay more for very low-energy buildings but not as willing to pay for a building with an environmental certificate. It was found that interest in and the perceived importance of energy and environmental factors affect the stated WTP. The results indicate that a stated willingness to pay for low-energy buildings of 5% can be considered a rational investment decision.

Keywords: residential buildings; green buildings; willingness to pay,

Introduction

The European Council decision on the energy performance of buildings (2010/31/EU, 2010) not only established new goals for European Union member states but also defined the future market for construction companies. For example, 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 “, which means that gaining competence in building energy-efficiently became an important issue for competitive companies. For the construction industry, the European Council decision was hardly revolutionary; rather, it was a confirmation that environmental issues are not just a trend but a strategic course, changing market conditions to which developers must be prepared to respond.

However, buildings constructed with environmental and energy goals require more knowledge, competence, and cooperation from design and construction teams, implying that the total construction cost for green buildings may be higher than for conventional ones (Zalejska-Jonsson et al., 2012). Traditionally, a profit-maximizing company facing increased cost seeks to increase its prices, which inevitably means that customers must be able and/or willing to pay for the extra cost. Green buildings are expected to require lower operating costs, provide better indoor environment and have a lower impact on the environment than conventional buildings. It is rational to believe that a customer is willing to pay extra if perceived benefits from renting or buying green property are more beneficial than those from conventional buildings.

The paper aims to examine stated willingness to pay (WTP) for low-energy and environmentally labeled buildings among owners and tenants living in green and conventional multi-family buildings in Sweden. We test how apartment tenure and the importance of energy and environmental factors during apartment purchase or rental impacts the stated WTP. Since, at the point of the study, the number of green apartments on the Swedish market was limited and the information regarding transactions was unavailable, the stated WTP could not be compared to the revealed WTP. Considering these data limitations, we attempted to evaluate the rationale of investment in green building from a private investor perspective (i.e. owner) considering their stated willingness to pay.

1. The literature review

1.1. WTP for green labeled buildings

Evidence of the willingness to pay for energy efficiency and environmental factors on the real estate market in the commercial property sector has demonstrated that green-labeled buildings can generate a price premium (Dermisi 2009; Miller et al., 2009, Eichholtz et al., 2010a, Eichholtz et al., 2010b, Fuerst and McAllister, 2011a; Fuerst and McAllister, 2011b, Kok and Jennen, 2012). Recent literature provides evidence that higher WTP for green-labeled buildings and energy-saving measures may also be detected on the residential market (table 1). Ott et al. (2006) demonstrated that prices for energy-efficient buildings, labeled with the energy and environmental label Minergie, were higher than for more conventional buildings. Results from a hedonic pricing model suggest that the price for Minergie single-family homes in Zurich was 9 percent (+/-5 percent) higher than that of comparable properties. A similar model was used in Colorado, USA, and results indicate a price premium for labeled houses, which demonstrated that Energy Star qualified buildings generated higher prices than those of comparable houses without an Energy Star label (Bloom et al., 2011). The adaptation of an energy label to the housing market in the Netherlands and the impact of such a label on the market was the focus of a study presented by Brounen and Kok (2011). The authors concluded that the price premium for energy-labeled property depends on the energy-label level and on the fact that consumers use the information disclosed by the energy label when purchasing housing property. The analysis indicates that green labels (high-energy labels “A”, “B” and “C”) generate a 3.7 percent premium. It was found that homes with the highest energy label, “A”, were sold at a 10 percent price premium compared with intermediate level “D”; however, homes at the lowest level “G” were transacted at a 5 percent discount.

A few studies have examined customers’ willingness to pay (WTP) for specified energy-saving measures rather than buildings with an energy or environmental label. In Switzerland, researchers used a choice experiment to evaluate the willingness of households to pay for energy-saving measures (Banfi, Farsi et al., 2008). A fixed logistic model was applied to data collected via telephone interviews in the summer of 2003, and results showed that both those living in rental apartments and those living in owned single-family houses are willing to pay more for ventilation systems, enhanced insulation of the façade, and energy-efficient windows. The WTP varies from 3%-13% depending on the energy-saving measure. A similar approach was chosen in a study of Korean households and their preferences for energy-saving measures (Kwak et al., 2010). Results indicate that households were prepared to pay more for more energy-efficient windows, thicker walls, and for installing a ventilation system. Mandel and Wilhelmsson (2011) showed that there was a positive WTP for environmental attributes among households that purchased single-family houses in the Stockholm area of Sweden in 2000. The analysis indicated that environmental awareness affects willingness to pay, and the calculated non-marginal WTP for environmentally aware households was about 2-4% higher for energy-efficient systems and 5-8% for water-reducing technologies.

Table 1. WTP for energy-saving measures and green residential buildings

Reference	Country	Research Method	Results
Ott et al., 2006	Switzerland	transaction prices	Price for Minergie single-family homes in Zurich was 9% (+/-5%) higher than that of comparable properties
Banfi et al., 2008	Switzerland	choice experiment	WTP measured as ratio between attribute coefficient and the rental price for apartments and the purchased price for single houses Façade: 3-6% (rental apartments) 3-7% (owned houses) Ventilation: 4 - 8% (rental apartments) 4-12% (owned houses) Windows: 10-13% (rental apartments) 8-13% (owned houses)
Kwak et al.. 2010	Korea	survey, choice experiment	MWTP for a) improved windows was $18.20; b) increased wall thickness 1mm was $1.20; c) installing ventilation system was $12.40
Mandel and Wilhelmsson, 2011	Sweden	transaction prices	Non-marginal WTP environmentally aware household was about 2-4% higher for energy-efficient systems and 5-8% higher for water-reducing technologies
Bloom et al., 2011	US, Colorado	transaction prices	Energy Star qualified homes generate higher prices than those of comparable properties
Brounen and Kok, 2011	Netherlander	transaction prices	Premium for energy-efficiency depends on label category; green labels (A,B,C) generate higher selling price (3.7%); A-label homes compared to D-label homes transact at 10.2% higher prices
Addae-Dapaah and Su Jen Chieh, 2011	Singapore	survey	Green-labeled buildings transacted at 5-12% price premium

1.2. Stated and revealed willingness to pay

There is an important distinction between stated and revealed willingness to pay. The revealed WTP is based on observed behavior and thus often uses transaction prices (e.g. Mandel and Wilhelmsson ,2011; Brounen and Kok ,2011). The stated WTP, on other hand, are based on intended choices and based on hypothetical responses collected through survey or interviews (e.g. Kwak et al. 2010).

In this article, the analysis and discussion is based on the stated WTP. There are different approaches to investigating stated preference, one of which is a contingent valuation survey and a choice experiment. In the contingent valuation method, respondents are asked to reveal their willingness to pay in a direct question (often a binary yes/no question), whereas in a choice experiment respondents are asked to select answers from multiple alternatives (Kling et al., 2012). Contingent valuation is frequently used for assessing monetary values on environmental amenities and services (Carson, 2000). The technique is often used to obtain information when goods and services are not available on the market and therefore there is seldom actual data regarding cost and sales. The respondents are asked to reveal their preferences, which are contingent upon the hypothetical market presented in the survey. Contingent valuation (CV) may be used for assessing willingness to pay for private and public goods and service, and produced estimates might be included in market analysis, cost-benefit analysis and even judicial processes (Portney, 1994; Kling et al., 2012).

The methodical approaches to the measurement of WTP have been the subject of a long and heated debate. The critics have been pointing out problems with the underlying assumptions for contingent valuation, survey bias and the reliability of produced estimates. Firstly, opponents argue that the results from CV indicate respondents' hypothetical opinion rather than a measure of preferences for the specific project or product, questioning respondents' familiarity and understanding of the studied subject (Diamond and Hausman, 1994; Hausman, 2012). Proponents agree that CV studies place respondents in a simulated market position, but contend that this method is no different than requesting customers to purchase "unfamiliar or infrequent commodities" (Hanemann, 1994).

Secondly, opponents have argued that the quality of CV is dependent on the survey design. The critics raise the issue of wording and phrasing, the order of questions and the problem of comparability of responses (Diamond and Hausman, 1994; Hausman, 2012. They have also pointed out the hypothetical response bias that leads to producing overstated values (Murphy and Stevens, 2004; Hausman, 2012). Hausman (2012) argues that the bias in answers is often related to the specific nature of contingent valuation surveys, as respondents are asked to indicate willingness to pay expressed in specific monetary value for a certain outcome, without the possibility of different alternatives or a discussion. Moreover, the respondents are often not informed about how their answers are going to be used and therefore might be more likely to choose the answer that pleases the interviewer. Additionally, the CV surveys often face what is known as the "embedding effect" or the "scope problem". The first to explore the problem were Kahneman and Knetsch (1992), who wrote that "the assessed value for public goods is demonstrably arbitrary, because willingness to pay for the same good can vary over a wide range depending on whether the good is assessed on its own or embedded as part of a more inclusive package". The issue is broadly discussed by Diamond and Hausman (1994) and Hausman (2012). Opponents of the CV method have also questioned the accuracy of responses indicating that respondents may not be answering the question that the interviewer had in mind (Diamond and Hausman, 1994; Hausman, 2012). Additionally, the CV may not be an accurate measurement because respondents may experience a "warm glow" and express support for the good cause rather than indicating their individual preference (Diamond and Hausman, 1994). The term "warm glow" describes the private value an individual may experience by contributing to a worthy cause (Kling et al., 2012).

Advocates of CV methodology argue that by implementing CV guidelines (Portney, 1994; Carson, 2000), conducting a reliable survey (Hanemann, 1994), and applying best practice protocols (Kling et al., 2012), the results obtained via CV can be reliable and any potential bias can be reduced. The survey bias and overestimation of stated WTP can be reduced: when the criterion of value are clearly stated, presenting respondents with information on how the results may influence policies or strategies (Kling et al. 2012), when participants are warned of a tendency to increase the values (Cumming and Taylor, 1999) and when certainty statements are included in the questionnaire (Blumenschein et al., 2008).

Finally, the critics consider the difference between stated willingness to pay and accepted willingness to pay to be the definitive and non-dismissible argument (Diamond and Hausman, 1994; Hausman, 2012). The proponents agree that a discrepancy exists between willingness to pay and to accept, but contrary to opponents, find results in line with neoclassical economic theory and behavioral economics, explaining that the predicted properties of welfare are often different (Carson, 2012).

Proponents of CV underline the fact that hedonic models and other tests based on market data are unable to provide complete information on measures of value, particularly if the value of the commodity is at least partly unrelated to consumption of complementary goods (Hanemann, 1994). Contingent valuation can capture this value, often referred to in the literature as “existence value”, “passive use value” or “non-use value” (Hanemann, 1994; Carson 2012).

1.3. The case of Sweden

Since the green residential market in Sweden is in an emerging phase, and consequently, empirical evidence for customer preference regarding green residential buildings is difficult to obtain, the data for this paper was collected through a survey. Most of the building apartments investigated in this study were sold between 2007 and 2010, when the economic crisis hit the real estate market quite hard and developers had to use different offers and discounts in order to make a sale. It is, therefore, difficult to compare sales prices, not knowing the price reduction and the contracted purchasing price.

In regard to rental apartments, the rental fees in Sweden are controlled and based on the agreement with the Tenant’s Union and often related to the building location, dwelling size and quality of the finish (for example, installed appliances) (Svensson, 1998; Atterhog and Lind, 2004; Lind, 2011). Consequently, the observed difference in rental fee between conventional and green apartments may not reflect the environmental value.

This paper does not aim to estimate the mean of willingness to pay as a reflection of an accurate monetary value that customers are ready to pay for green buildings, but rather to investigate the existence of WTP and to test the difference in opinion between respondents living in green or conventional buildings and condominiums or rental apartments. The interest of the paper is also whether the stated WTP is a rational decision in light of investment analysis theory.

2. Method and data collection

2.1. Study design

The study is based on a quasi-experimental method (Bohm and Lind, 1993), which was used to capture differences in purchasing and rental decision and overall apartment satisfaction among occupants living in green and conventional buildings. The research was designed as a multi-case study in which 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 cases, *a green building* was defined as a building designed and constructed with high energy efficiency or environmental goals. Only buildings with a very low energy requirement (close to passive house standard[i]) and buildings registered or certified according to a building environmental scheme were considered as green. It was imperative that *the conventional building* was constructed according to current Swedish Building Regulations but did not aim at better environmental or energy performance.

2.2. Data collection

The data was collected in 2012 in two collection periods: late spring and early autumn 2012. The studied cases included multi-family buildings with rental apartments (owned by municipal companies) and condominiums, with apartments owned by tenants. All selected green apartments are very low-energy buildings (with calculated annual space heating approx. 50 kWh/m2) and the majority have also been registered or certified by a building environmental scheme.

2.3. Survey design and questionnaire

The questionnaire

The survey questionnaire was divided into four sections and consisted of in total 33 questions. The first part investigated which factors impacted customer purchasing decisions and the second part focused on occupants' overall satisfaction with their apartment and perception of indoor environment quality. The third part aimed at obtaining information about respondents' perception of building environmental certification and willingness to pay for buildings with an environmental profile. The final section asked a few background questions. The questionnaire included structured closed questions, and single or multiple choices. Respondents were offered the possibility of placing their comments in the spaces assigned to each question.

The investigation of customer-stated WTP was not the sole aim of the survey; thus, the questionnaire is not a typical contingent valuation survey. The respondents were asked a direct question whether they were willing to pay a premium for dwelling in a low-energy building and an environmentally labeled building. The respondents had the possibility to indicate the size of the premium expressed as a percentage (5% or 10%) of the purchasing price (or rental fee) compared to a conventional building. The questionnaire also included questions asking for respondents' opinion on the implications of building environmental labeling.

The terminology and distinction between low-energy and labeled buildings was preliminarily imposed due to commonly used terms in public discussion regarding green residential properties in Sweden. We anticipated that respondents would be more familiar with those descriptions than with the term “green building”.

The survey collection

The survey was sent by regular mail to all occupants of the selected buildings, who at the time of the survey were 21 years of age. The envelope was addressed to individuals and included cover letter, survey questionnaire and return envelope. The particulars (name and address) were obtained from a publicly accessed online database. People 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. EUR 0.3. Only respondents who submitted their contact details received a letter of appreciation and a gratuity. All participants were ensured that responses would be treated anonymously. In order to fulfill this promise, all responses were coded.

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 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 case is presented in table 2.

Table 2. Response rates

building type	tenure	questionnaire sent	response	response rate	pair number
conventional	ownership	91	38	42%	1
conventional	ownership	47	28	60%	2
conventional	ownership	63	38	60%	3
conventional	ownership	85	33	39%	4
conventional	ownership	85	30	35%	5
conventional	rental	196	56	29%	6
conventional	rental	173	55	32%	7
total		**740**	**248**	**38%**	
green	ownership	35	18	51%	1
green	ownership	21	14	67%	2
green	ownership	55	24	44%	3
green	ownership	58	31	53%	4
green	ownership	63	35	56%	5
green	rental	175	63	36%	6
green	rental	53	14	26%	7
total		**460**	**199**	**43%**	
Total		**1200**	**477**	**40%**	

2.4. Statistical analysis

In the first stage of the analysis, descriptive statistics were used. In the second step, the statistical difference in responses from occupants of green and conventional buildings was tested by the Mann-Whitney (rank sum) test. Thirdly, statistical models were applied. Individuals' and building characteristics as well as the importance of energy and environmental factors for occupants' apartment purchase or rental decision are used as explanatory variables for stated WTP. The variables included in the statistical models 1 and 2 are presented in table 3.

LE(WTP)= ƒ(AGE, GENDER, FAMILY, OCCUPANTS, ROOMS, TENURE, PROFILE, ENERGY FACTOR)

(model 1)

ECB(WTP)= ƒ(AGE, GENDER, FAMILY, OCCUPANTS, ROOMS, TENURE, PROFILE, ENVIRONMENTAL FACTOR)

(model 2)

Table 3. Description of variables

	Description of variables
LE(WTP)	stated willingness to pay for low-energy building *(model 1)*
ECB(WTP)	stated willingness to pay for environmentally certified building *(model 2)*
AGE	respondent age
GENDER	variable describing respondent gender; if woman =1, if man=0
FAMILY	variable describing if occupants were a family with children
OCCUPANTS	variable describing number of occupants per dwelling
ROOMS	variable describing dwelling size measured in number of rooms
TENURE	variable if condominium =1, if rental=0
PROFILE	variable for building environmental profile, if green=1, if conventional =0
ENERGY FACTOR	variable describing importance that energy factor had while making decision to purchase or rent the apartment
ENVIRONMENTAL FACTOR	variable describing importance that environmental factors had while making decision to purchase or rent the apartment

Initially, the ordered logistic regression was chosen due to the nature of the data, which has ordered categories measuring opinion and frequency using a rated scale (Borooah, 2001); however, the Brant test indicated that the parallel regression assumption was violated. Therefore, responses of a three-stage ordered scale were converted to binary scale, where the dependent variable can be described either as a willing-to-pay premium or a not-willing-to-pay premium. After the conversion, a binary logistic model was applied to the data.

The results are reported in the form of odds ratios and interpreted in this paper as likelihood of willingness to pay if the predictor variable is increased by one unit while other variables are kept constant.

The results are considered to be statistically significant at $p \leq 0.05$, unless indicated otherwise. The internal consistency test (the Cronbach alpha test) was conducted and the computed coefficient of 0.63 was considered as satisfactory.

2.5. Limitations

The present study is largely based on the survey responses and, consequently, the analysis may include errors related to the formulation of the questions, insufficient communication, or misunderstanding of questions and respondents' subjective opinion (Diamond and Hausman, 1994, Schwarz and Oyserman 2001). Additionally, in line with the adopted quasi-experimental approach, the questionnaire was addressed to occupants living in the selected buildings. The condominiums and the rental apartments were specifically chosen due to building characteristics (location, production year, size, potential customer segment) and not randomly selected. Consequently, the presented results should be interpreted with caution.

The research study and consequently the survey questionnaire had multiple objectives; thus, the applied survey does not reflect the format of the contingent valuation survey. The presented results are, therefore, interpreted as an indication rather than an accurate and define measure of willingness to pay.

3. Results

3.1. Description of respondents

Gender distribution is very similar in the sub-groups green and conventional owned dwellings and green and conventional rental apartments: approx. 55% respondents were females. There are certain differences in age distribution among respondents between the sub-groups (figure 1). The majority of respondents in green condominiums represented two age groups: 31 and 40 (37%) and over 61 years old (30%). The largest group of respondents living in conventional condominiums were over 61 years old. On the other hand, the majority of respondents living in rental apartments, in both green and conventional, were 31-41 years old (see fig. 1). Generally, the difference in age distribution between rental and condominiums is, not surprisingly, that younger people entering their housing careers are living in rental apartments, whereas older people, being in the latter phase of their housing career, choose to live in owned apartments. The proportion of families with children in green condominiums was higher (43%) than in conventional buildings (25%).

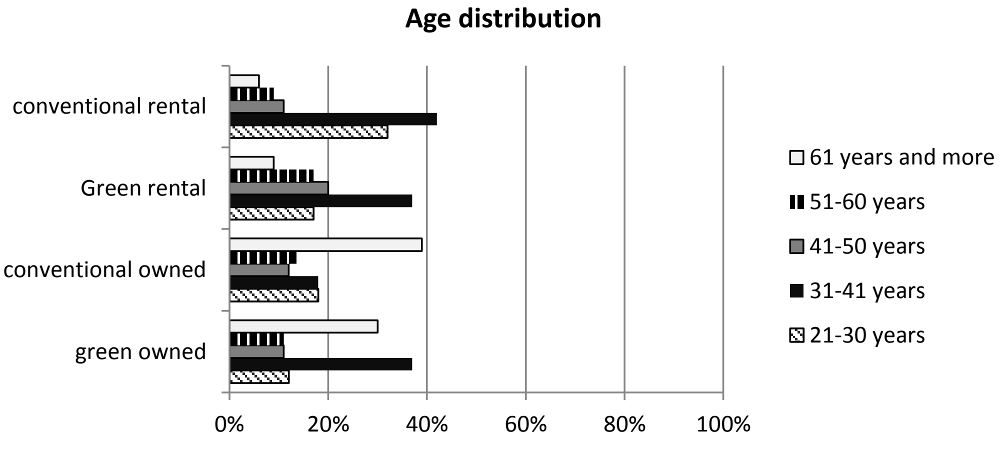

Figure 1. Respondents' age distribution

The largest group of respondents in green (40%) and in conventional (52%) rental apartments was living in 3-room dwellings (figure 2). On the other hand, the largest group of occupants of conventional condominiums declared to be living in 2-room (36%) and 3-room (38%) apartments. By comparison, the largest group of occupants in green condominiums was living in 3-room (35%) and 4-room (34%) apartments.

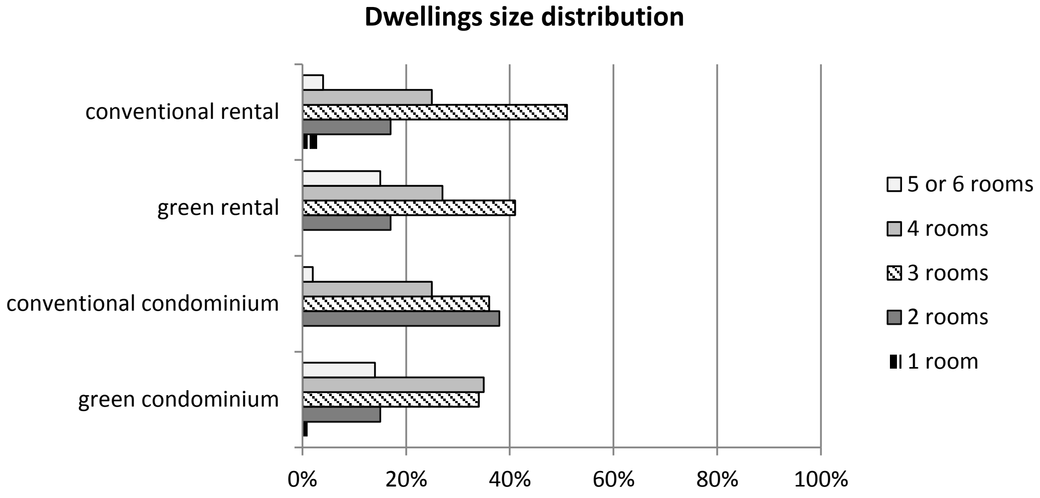

Figure 2. Dwelling size distribution

3.2. Willingness to pay premium purchasing price or extra rental fee for green buildings

The respondents are willing to include a premium in their purchasing price for low-energy buildings (1.84 mean) rather than for buildings with an environmental certificate (mean 1.49) (table 4).

Table 4. Mean values for stated willingness to pay

WTP (std) **no observ**	mean value for condominiums	mean value for rental apartments
WTP for low-energy building	1.841 (.62)	1.413 (.57)
	279	186
WTP for building with environment certificate	1.49 (.58)	1.289 (.52)
	279	183

response scale: 1= not willing to pay extra purchasing price / rental fee, 2= yes, 5% premium, 3= yes, 10% premium

3.2.1. Condominiums

The results indicate that the WTP for green condominiums is higher than among in conventional apartments. One fifth of green building occupants stated that they are willing to pay as much as 10% more for low-energy buildings, and 64% are prepared to pay a 5% premium. By comparison, 7% of participants living in conventional condominiums are prepared to pay 10% extra and 55% are willing to pay 5% extra for dwellings in low-energy buildings (figure 3).

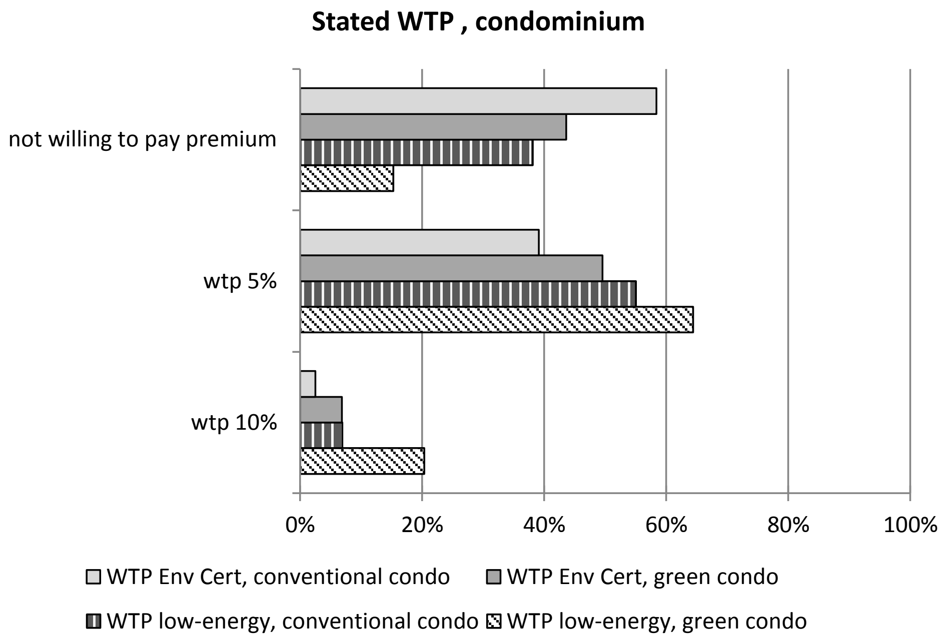

Figure 3. Willingness to pay premium at purchasing price for dwellings in buildings with low-energy and buildings with environmental certificate.

Interestingly, apartment owners indicated an environmental label as less value for money: only 7% respondents in green and 2% in conventional buildings were willing to pay 10% more (figure 3). Differences in responses were statistically significant (table 5).

Table 5. Difference in responses regarding stated willingness to pay, condominiums

	Mann-Whitney test for difference between rental and condominiums [p, probability]	Mann-Whitney test for difference between green and conventional condominiums
WTP		
WTP for low-energy building	0.0001*	0.0001*
WTP for building with environment certificate	0.0001*	0.075***

*** significant at p≤0.10; **significant at p≤0.05; * significant at p≤0.01

This is an interesting result, indicating that customers are willing to pay more for features they can understand. Customers can translate low-energy building features into lower requirement for energy and therefore lower operating costs. It may not as easy to find direct benefits from owning an apartment in a building with an environmental certificate.

3.2.2. Rental apartments

The majority of occupants of rental apartments (70%), regardless of whether they live in green or conventional buildings, were not willing to pay a premium for renting an apartment in an environmentally certified building (figure 5). However, 42% of the tenants in green buildings stated a WTP of 5% extra for renting an apartment in a low-energy building. Only one fourth (26%) of the respondents in conventional buildings agreed to the same premium. The difference in opinions was found to be not statistically significant (table 6). When interpreting these answers, we should note that respondents living in green rental apartments have a rental agreement that is somewhat unusual for Sweden, whereby space heating costs are related to the tenant's actual consumption and therefore not included in the rental fee. Commonly, space heating costs are included in the rental fee and actual consumption has no impact on rent. This may explain the difference in tenants' responses and stated willingness to pay.

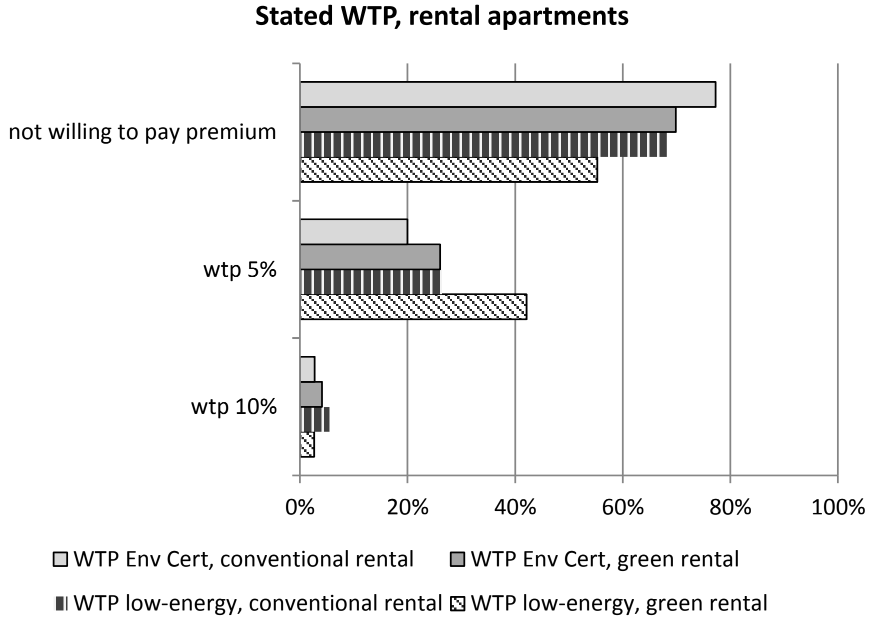

Figure 4. Willingness to pay rental premium for dwellings in buildings with low-energy and buildings with environmental certificate.

Table 6. Difference in responses regarding stated willingness to pay, rental apartments

	Mann-Whitney test for difference between rental and condominiums [p, probability]	Mann-Whitney test for difference between green and conventional buildings with rental apartments
WTP		
WTP for low-energy building	0.0001*	0.121
WTP for building with environment certificate	0.0001*	0.257

*** significant at p≤0.10; **significant at p≤0.05; * significant at p≤0.01

3.2.3. Environmental awareness and perceived importance of building certification

In contrast o the above, there might be a difference in the perceived value and the perceived significance of building environmental certification. When respondents were asked to indicate their opinion on the importance of environmental certification for buildings, a relative majority (45%) of respondents stated that environmental certification is important and that it may have a positive impact on building value or building attractiveness. Analysis indicated a statistically significant difference between responses received from occupants living in green and conventional condominiums (table 7). The majority of respondents living in green condominiums (53%) perceived that certification is important and that it may have a positive impact on building value, whereas only 34% of occupants in conventional condominiums had the same opinion.

Table 7. Difference in responses regarding perceived importance of building environment certificate

	Mann-Whitney test for difference between rental and condominiums [p, probability]	Mann-Whitney test for difference between green and conventional condominiums	Mann-Whitney test for difference between green and conventional buildings with rental apartments
certification	.09***	.0006*	.52

*** significant at p≤0.10; **significant at p≤0.05; * significant at p≤0.01

3.2.4. Importance of energy and environment factors for decision to purchase / rent apartment and stated WTP

Even though energy and environmental factors had, in general, a relatively minor impact on the decision to purchase or rent the apartments (Zalejska-Jonsson, 2013), the responses indicate that survey participants show a certain interest in those factors.

The majority of survey participants living in the condominiums indicated that the energy factor was decisive (15%) or very important (55%) while making the apartment purchase decision. In contrast, only 8% of tenants consider this factor to be decisive and 38% to be very important while making a decision on renting the apartment. The difference is also noticeable between green and conventional apartments as 70% of respondents living in green dwellings stated that energy factors were decisive or very important. This is comparable to 54% respondents living in conventional buildings.

The majority of respondents living in condominiums considered environmental factors (other than energy) as decisive (8%) or very important (50%); in comparison, 12% of tenants consider environmental factors as decisive and 36 as very important. Approximately 65% of the survey participants living in green apartments stated that environmental factors affected their decision to purchase the apartment (decisive and very important ranking) and approximately 45% of the tenants said the same.

3.2.5. Variables significantly effecting stated willingness to pay

The results (table 8 and table 9) indicate that respondents living in green buildings are more likely than those in conventional buildings (odds ratio 2.75) to pay a premium for low energy buildings and the occupants of condominiums are more likely than tenants to pay a premium to live in a green building (odds ratio for low-energy building 4.66; odds ratio for building with environmental certificate 2.04).

The results show that the oldest group of respondents (over 61 years) is less likely (odds ratio 0.31) to pay a premium for low-energy buildings than the youngest respondents group (21-30).

Table 8. Logistic regressions: stated willingness to pay for low-energy buildings

	model 1		
	odds ratio	p, probability	conf. interval (CI 95%)
older: 31-40	.58	.14	.28-1.19
older: 41-50	.42	.05**	.14-.70
older: 51-60	.38	.03**	.16-.91
older: over60	.31	.005*	.14-.70
woman	.86	.53	.54-2.46
family	1.17	.66	.56-2.46
rooms	.99	.97	.73-1.35
occupants	1.00	.96	.72-1.40
owned dwellings	4.66	.00*	2.80-7.77
green building	2.75	.00*	1.68-4.50
energy factor decisive	2.93	.02**	1.12-7.67
energy factor high importance	2.35	.01**	1.17-4.73
energy factor low importance	1.56	.23	.75-3.23
constant	.40	.11	.12-1.24
No of observations	389		
pseudo R2	.146		

**significant at p≤0.05, * significant at p≤0.01

Table 9. Logistic regressions: stated willingness to pay for buildings with environmental certificate

		model 2	
	odds ratio	p, probability	conf. interval (CI 95%)
older: 31-40	.53	.07***	.27-1.06
older: 41-50	.87	.74	.38-1.98
older: 51-60	.58	.21	.25-1.28
older: over60	.59	.18	.27-1.28
woman	1.08	.71	.69-1.71
family	1.96	.06***	
rooms	1.15	.34	.85-1.55
occupants	.80	.20	.58-1.12
owned dwellings	2.04	.005*	1.24-3.36
green building	1.41	.14	.88-2.24
environmental factor decisive	4.12	.005*	1.52-11.15
environmental factor very important	3.60	.001*	1.70-7.61
environmental factor very low importance important	1.30	.50	.59-2.83.
constant	.18	.005	.05-.60
No of observations	381		
R2	.09		

***significant at p≤0.1, **significant at p≤0.05, * significant at p≤0.01

The results indicate that interest in energy and environment factors affects stated willingness to pay. The survey participants who considered energy factors as decisive or important are more likely to pay a premium for low-energy buildings (odds ratio 2.93 and 2.35, respectively). Also, the respondents who considered environmental factors as decisive or important are more likely to pay a premium for dwellings in environmentally certified buildings (odds ratio 4.12 and 3.60, respectively).

Those findings may provide support to comments that (CV) respondents' familiarity with or interest in the subject under study may affect their stated willingness to pay (Diamond and Hausman, 1994). On the other hand, it is not surprising that respondents who perceive specific commodity aspects as important are ready to pay more for those features. Moreover, results (table 7 and 8) suggest that perception of those features may vary depending on individual characteristics (e. G. age) and life style (e. g.. family with children).

The arguments regarding the subjectivity of responses and the tendency to overstate values point to a potential bias in stated WTP studies and question the rationale of the respondents' decision. Recognising a potential bias in the results of the stated WTP, we adopted an investment viability approach to assess the rationale of stating willingness to pay a 5% premium for low-energy buildings.

3.3. Evaluating green building premium from an apartment owner perspective

In this section, we attempt to assess whether the WTP premium stated by the majority of respondents (5% premium) could be explained by the attractiveness of the investment. In order to test this hypothesis, we calculate the viability of this investment compared with a conventional building.

Energy assumptions

It is assumed that a conventional building constructed in Sweden between 2008- 2011 fulfills Swedish Building Regulations (Boverket, 2009) and therefore in southern Sweden, the expected energy consumption is 110 kWh/m2 in the case of buildings with district heating and 55 kwh/m2 in the case of buildings with electric heating. Comparably, very low-energy buildings built according to Swedish passive house standards (Swedish Forum för energieffektiva byggnader FEBY, 2009) were expected to achieve as low energy consumption for space heating as 50 kwh/m2 in the case of buildings with district heating and 30 kwh/m2 in the case of electrically heated buildings. Neither Swedish Building Regulations nor FEBY standards include domestic energy in their requirement for energy consumption. Hence, benefits associated with energy savings come from the difference between requirements for space heating in conventional and passive house buildings.

Holding period

Firstly, we would like to discuss what holding period is adequate for this calculation. It is possible to calculate the viability of a customer investment over a short or long period of time. We could assume that a customer purchases an apartment for his or her current needs, which may change in the future and therefore the calculation period should be relatively short, for example five years. In such a case, energy-saving costs during those five years are discounted and added tofuture energy savings (residual value). However, the computed results depend heavily on residual value (exit yield), which reflects a possible price increase per m2 for a very low-energy dwelling.

On the other hand, we can also foresee that time can have a negative impact on a building and some essential elements of the building envelope (e.g. windows) and installation (HVAC) might require renovation or replacement, which means that in order to draw further benefit from energy savings new investment might be needed. Therefore, in calculating energy-saving costs over a longer period (30 years), the residual value (exit yield) is considered to be equal to 0. Thus, the longer calculation period focuses only on potential cost/energy savings.

Discount rate and risk

The calculations were performed on real prices. The discount rate in the base-case scenario was based on a nominal ten-year fixed mortgage rate in 2011, which was approx. 4%, while the Swedish inflation target is 2% (www.riksbank.se). Consequently, the real discount rate for the household was assumed to be 2%. The base-case scenario assumes that the customer is risk-neutral; however, because the residual value reflects a potential price increase per m2 of a very low-energy building, we add a market risk factor calculated at 3% (Adair and Hutchison, 2005; Hutchison et al., 2005; Hordijk and Van de Ridder, 2005) and assume that the exit yield is 5%.

Price assumptions

The analysis focuses only on profitability of investment if purchasing a very-low-energy apartment, because, in the case of rental apartments in Sweden, the rental fee is a result of collective bargaining between municipal housing companies and local tenants' unions and does not reflect quality factors, but rather relates to building location, size and construction year (Lind, 2012).

The presumed price in this exercise is an approximation for the average square meter price for one square meter of apartment in a newly constructed building in Sweden. In reality, the property price may vary significantly depending on various factors such as size of the city, location (ex. suburbs, city center), building quality, dwelling size and apartment design. The main assumptions are presented in table 10.

Table 10. Calculation assumptions.

Dwelling price and WTP	
average price for m2 dwelling in newly constructed building (2011) [EUR/m2]	3300
willingness to pay for m2 low-energy building	5%
willingness to pay 5% purchase price [EUR/m2]	165
Energy requirement	
conventional building space heating (BBR18), Sweden-south [kWh/m2 per year] district heating	110
passive house building space heating (FEBY 2009), Sweden-south [kWh/m2 per year] district heating	50
conventional building space heating (BBR18), Sweden-south [kWh/m2 per year] electric heating	55
Passive house building space heating (FEBY 2009), Sweden-south [kWh/m2 per year] electric heating	30
Energy prices	
domestic heating prices (average 2011) [EUR/kWh]	0.11
electricity heating prices (average 2011) [EUR/kWh]	0.14
Investment assumptions	
calculation period	
short	5 years
long	30 years
real interest rate	2%

Results

Building regulations for electrically heated buildings are stricter than for those with district heating and consequently the difference between passive house standard and conventional building is relatively small, which reflects on the energy-saving costs. The results (table 11) indicate that energy savings in building with electric heating will not recoup an investment higher than 90 EUR/m2, which is 3% at assumed dwelling prices. On the other hand, the majority of dwellings in Sweden (approx. 70%) are heated by district heating, and in this case investing 5% seems to be a rational decision. The extra investment, 5% at assumed dwelling prices, which corresponds to 165 EUR/m2, is recouped by an energy-saving cost if district-heating prices were to increase annually by 1% over inflation. Annual energy savings for an average dwelling of 75m2 in a building with electric heating could reach about 250 EUR and in a building with district heating about 480 EUR.

Table 11. Present value of energy cost savings for short period of 5 years, including exit yield, for risk-neutral customer, discount rate 2%.

Annual energy increase*	0%	1%	2%	3%	4%	5%
Energy cost savings (PV) building with district heating EUR/m2	163	169	175	182	188	195
Energy cost savings (PV) building with electric heating EUR/m2	87	90	93	96	100	103
Stated willingness to pay 5%					165 EUR/m2	

Table 12. Present value of energy cost savings for long period of 30 years for risk-neutral customer, discount rate 2%

Annual energy increase	0%	1%	2%	3%	4%	5%
Energy cost savings (PV) building with district heating	148	169	194	224	261	305
Energy cost savings (PV) building with electric heating	78	90	103	119	138	162
Stated willingness to pay 5%					165 EUR/m2	

*increase in energy prices is calculated only for 5 years, the assumption being that there is no growth in energy prices for years 6 and onward

If the customer is risk-neutral, the energy-cost saving depends mainly on presumed energy prices (table 12); however, there are reasons to believe that the customer is risk-averse. The customer may feel unsure about environmental benefits, may need to increase the mortgage to cover extra cost or consider allocating the premium in alternative purchase, and therefore require a higher investment return. Tables 13 and 14 present sensitivity analyses, where the discount rate is composed of the sum of the mortgage rate (2%) and the individual risk factor, and the exit yield consists of the sum of the mortgage rate (2%), the market risk (3%), and the individual risk. Since the difference in space heating requirements for very-low-energy (passive house standard) and conventional buildings with electric heating is relatively small and energy cost savings are also relatively low, the sensitivity analyses focus on buildings with district heating (table 13 and 14).

Table 11. Sensitivity analysis of energy cost savings for short period of 5 years, inclusive exit yield, for risk-averse customer

District heated buildings
Relative energy price increase

	0%	1%	2%	3%	4%	5%
individual risk						
0%	162	168	174	181	187	194
1%	140	145	150	156	161	167
2%	124	128	133	137	142	147
3%	123	127	132	136	141	146
4%	100	104	107	111	115	119

Table 12. Sensitivity analysis of energy cost savings for long period of 30 years for risk-averse customer

District heated buildings
Relative energy price increase*

	0%	1%	2%	3%	4%	5%
individual risk						
0%	148	169	194	224	261	305
1%	129	147	167	192	222	258
2%	114	129	146	166	190	219
3%	101	114	128	145	165	189
4%	91	101	113	127	144	163

*increase in energy prices is calculated only for 5 years, the assumption being that there is no growth in energy prices for years 6 and onward

Even though the attractiveness of the investment in a very low-energy building decreases if the customer is risk-averse, the results suggest that the respondents' stated willingness to pay approximately 5% extra for low-energy buildings is a rational investment decision, particularly when the difference between the energy performance of conventional and low-energy buildings is relatively large. This applies to district-heated buildings, but if a customer chooses to live in an electrically heated building, the financial benefits from energy savings are not as high; therefore the 5% extra investment in low-energy building based only on potential energy-cost savings is not justified.

4. Conclusions

The results from a survey among 477 occupants of green and conventional buildings were used to study stated WTP for apartments in low-energy and environmentally labeled buildings. It was shown that occupants in green buildings are generally more willing to pay extra for such buildings; however, respondents stated different willingness to pay for low-energy buildings and buildings with environmental certification. Lower willingness to pay for buildings with an environmental certificate might be explained by the fact that occupants are not convinced that environmental certification translates into higher value. The results send an important signal to the industry, indicating that unless building environmental performance is taken into consideration in the valuation process, the value of certifying residential buildings can be questioned. Customers are willing to pay a premium for features they understand and can see the potential benefits of, in terms of low-energy consumption, for example. Additionally, since the environmental benefits are not observable directly and even questioned by earlier research, the customer may have reservations about environmentally profiled buildings. Customer sceptism may be reflected in the perception of a higher investment risk and lower willingness to pay.

The stated willingness to pay for low-energy buildings was found to be a rational investment decision, particularly when the difference in energy performance between conventional and very low-energy buildings is relatively large. The changes in building regulations with regard to the energy performance of buildings reduce the performance gap between conventional and low-energy buildings and consequently decrease the attractiveness of investing in low-energy buildings. Furthermore, stricter energy performance requirements for buildings are expected to result in the conventional and low-energy building markets being merged. Consequently, environmental building assessment may become a more apparent way to communicate green benefits to the customer. This emphasizes the importance of environmental education, information quality and practical denotation of building environmental assessment for customers.

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[i] According to voluntary Swedish passive house standard (FEBY 2009) calculated space heating for residential buildings should not exceed 30 KWh/m2 annually for buildings with electric heating and 50 kWh/m2 annually for building with district heating. Space heating in comparable residential conventional building, understood here as building that fulfils current Swedish Building regulations, was 55 kWh/m2 annually for buildings with electric heating and 110 kWh/m2 annually for building with district heating.

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Article

Energy-Efficient Technologies and the Building's Saleable Floor Area: Bust or Boost for Highly-Efficient Green Construction?

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Abstract: When the external measurements of a building are fixed, an increase in external wall thickness caused by additional insulation, for example, will lead to loss of saleable floor area. This issue has to be taken into account in the evaluation of investment profitability. This paper examines how technologies used in energy-efficient residential building construction affect the available saleable floor area and how this impacts profitability of investment. Using a modeled building and an analysis of the average construction cost, we assessed losses and gains of saleable floor area in energy-efficient buildings. The analysis shows that the impact of potential losses or gains of saleable floor area should be taken into account when comparing investment alternatives: building energy-efficient green dwellings or building conventional ones. The results indicate that constructing energy-efficient buildings and introducing very energy-efficient technologies may be energy- and cost-effective even compared with conventional buildings. Employing new products in energy-efficient construction allows benefit to be drawn from lower energy consumption during the life cycle of the building, but also from the increase in saleable floor area.

Keywords: energy-efficiency; profitability; construction cost; green residential building; low energy building

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1. Introduction

There are ambitious goals in the EU to reduce energy consumption in the building stock and a crucial question is to what extent the investment in energy-efficient technologies is profitable and whether further political measures are necessary.

The process of decision-making in simple terms is based on valuing benefits against costs and against alternative solutions. In the case of investment in new property projects, initial and future costs are weighed against expected income. If we consider a scenario where a developer has the choice of constructing the same building as a conventional or as a high-performance green building, we can expect the decision to be dependent on investment viability. Research shows that initial construction costs for energy-efficient green building are generally higher than for conventional building. The difference can vary from 0% to as much as 20% [1–9]. The variation in investment cost depends on climate conditions, the developer's experience, environmental goals and the designed energy efficiency and is often related to higher material, labor and/or design costs.

On the other hand, the operation costs for a high-performance building are expected to be up to 40%–50% lower than for conventional buildings [9,10], where the predicted cost reduction depends mainly on the energy-efficiency of the building.

Finally, literature brings forward evidence that green buildings transact at 3%–12% higher prices than conventional buildings on the commercial [10–12] and the residential market [13–16,17].

This type of data can be used to calculate the profitability of the investment as is done in [9]. However, the reliability of an analysis depends on the accuracy of its assumptions. The literature has indicated a gap between the recorded and calculated maintenance and operation costs of green buildings (e.g., [18,19]). Moreover, the outcomes of the analysis have also proved to be highly sensitive to the expected rate of return [20–22] and presumed energy prices [23,24].

In this paper, we *first* show that these calculations can be misleading if they do not take into account that the choice of building with higher energy efficiency, e.g., a passive house, can reduce the saleable floor area. Thus, if the external measurements of the building are fixed, a building with thicker walls will entail less saleable floor area. *Secondly*, we show that technological development in recent years has reduced this loss and that this has contributed to the profitability of energy efficient buildings. This is shown by comparing technologies and prices from 2002 with those from 2012.

Specifications that facilitate energy-efficiency gains include compact construction, minimum thermal bridge value, a very well thermally insulated building envelope, energy-efficient windows and adequate choice of heating and ventilation systems [25,26]. For highly energy-efficient buildings, it is essential that the building envelope is airtight and very well insulated. The latter may have significant impact on the width of the external walls, roof and foundation. Consequently, external walls in energy-efficient buildings may require more floor area than those in conventional buildings. In the case of the scenario described above, where the external measurements of a building are fixed or limited, construction of an energy-efficient building has a direct effect on the amount of saleable floor area and consequently on the developer's potential income from rent or sale. Therefore, analyses that compare energy-efficient and conventional building projects should factor in the total floor area that is available for sale or rent. A significant difference in floor area availability may have an effect on potential income, but also on the potential customer segment. As far as the authors know, no earlier studies have quantified gains and loss related to saleable floor spaces in these buildings.

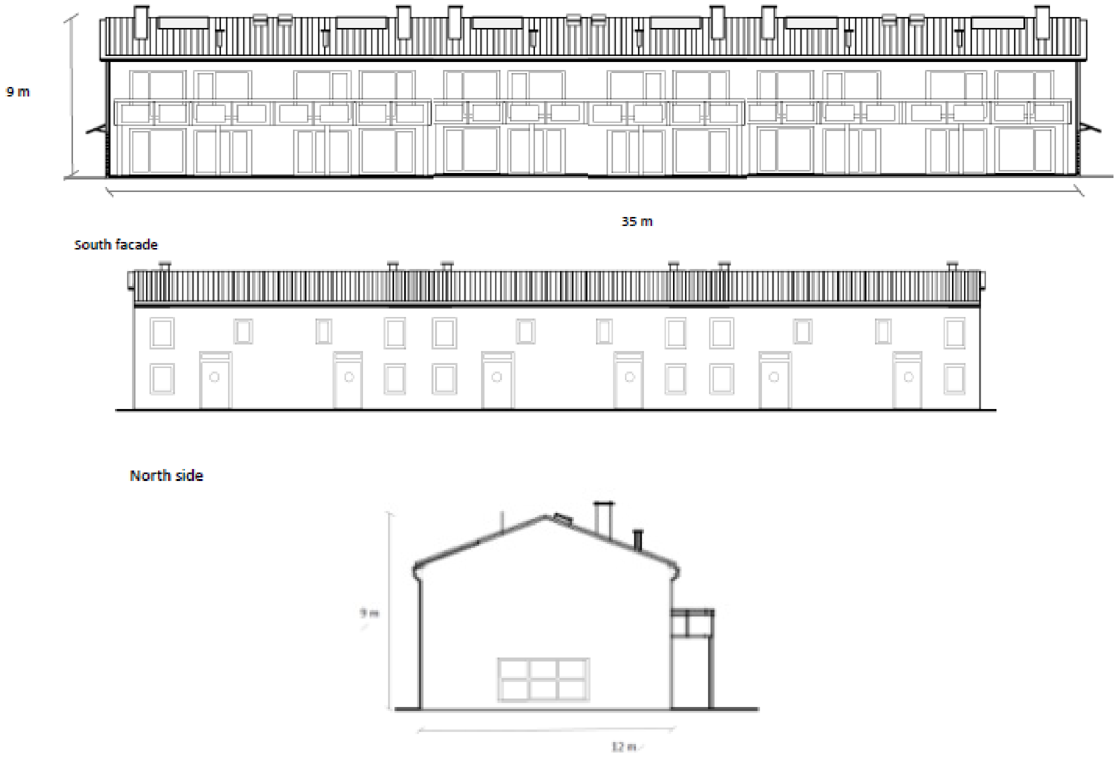
This paper contributes to the discussion on the profitability of energy-efficient solutions in green buildings [9,10,27,28] by investigating the possible impact of introducing more energy-efficient products on the economic attractiveness and profitability of constructing highly energy-efficient buildings.

2. Assumptions and Analysis

2.1. Modeled Buildings

The investigation started by modeling a building that was a typical terraced house in Northern Europe. The building consists of six dwellings, each of them two-level apartments, with total external measurements of approximately 12 m × 35 m (for details, see drawings in Figure 1 below). Initially, this building is based on drawings and information about the first passive house built in Sweden.

Figure 1. The model house.



Two building construction types are analyzed:

(A) A timber wall construction;

(B) A lightweight concrete brick wall construction.

For each of these two types of building, conventional and energy-efficient cases are modeled.

The conventional building follows the specified energy requirement in the current Swedish Building Regulations [29] for residential buildings with electrical heating, climate zone south, and therefore it is assumed that the maximum energy requirement (space heating) is 55 kWh/m^2. The basic notation for these is CVN-A (timber) and CVN-B (brick) (see Table 1).

The second building is an energy-efficient building for which the calculated annual space heating is 26 kWh/m^2. A building that fulfils this requirement is considered by current Swedish Building Regulations [29] to be a very low energy building. Additionally, it is assumed that the primary energy requirement inclusive of household electricity for the energy-efficient building is not expected to exceed 110 kW/m^2. During modeling, passive house principles were used [2,30]. The basic notation for these is EE-A (timber) and EE-B (brick) (see Table 1).

Table 1. Cases analyzed in this paper.

Notation	Explanation
CNV-A	conventional building, timber construction, insulation mineral wool, lambda 0.036 W/(mK)
CNV B	conventional building, brick construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-A1	energy-efficient building, timber construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-A2N	new technology, energy-efficient building, timber construction, insulation mineral wool, lambda 0.033 W/(mK)
EE-A3N	new technology, energy-efficient building, timber construction, insulation pir (polyisocyanurate), lambda 0.024 W/(mK)
EE-B1	energy-efficient building, brick construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-B2N	new technology, energy-efficient building, brick construction, insulation mineral wool, lambda 0.033 W/(mK)
EE-B3N	new technology, energy-efficient building, brick construction, insulation pir (polyisocyanurate), lambda 0.024 W/(mK)

In the course of the analysis, the energy-efficient building envelope is adjusted so that these values stay constant. No changes are made in the construction of roof and foundation, for which U-values are U(foundation) = 0.10 W/(m^{2}K) and U(roof) = 0.08 W/(m^{2}K). The airtightness of the building envelope is assumed to be the following for the conventional and the energy efficient building: 0.6 and 0.4 h^{-1}, at +/−50 Pa. It is further assumed possible to use air heating and heat recovery ventilation with an efficiency of 75% in both buildings. It is also assumed that, if necessary, the supplementary electric heating may be used in the buildings. The main assumptions are summarized in Table 2.

The energy-efficient building is modified step by step by applying new technology and using products with low thermal conductivity (described in the paper as lambda). It was essential that all the products used in the modeling were available on the market. Prototypes and early innovations were not considered. The reason for selecting innovative products that had already entered the market was to examine cost and potential benefits of using these products.

The important rule for this exercise was that, regardless of construction type and the novelty of the products, the building had to fulfill specified energy requirements. This premise allows for changes in the envelope (external wall), and consequently the benefits of using more energy-efficient products can be quantified. In the exercise, we have used the PHPP program (The Passive House Planning Package).

Table 2. Basic assumptions.

Assumed requirements	**Conventional building**	**Energy-efficient building**
Building dimensions (external)	12 m × 35 m	12 m × 35 m
Height (to the roof top)	9 m	9 m
Number of apartments	6	6
Number of levels	2	2
Basement	no	no
Annual space heating (kW/m^2) *	55	26
Annual primary energy including household electricity (kW/m^2)	not specified	110
Airtightness (at +/−50 Pa)	0.6 (h^{-1})	0.4 (h^{-1})
U-value (fundament) [$W/(m^2K)$]	0.14	0.10
U-value (roof) [$W/(m^2K)$]	0.14	0.08

Note: * calculated according to guidelines in Swedish Building Regulations.

2.2. Construction Cost

In this stage of the analysis, we calculated the average cost for producing our modeled buildings. All the prices used in the calculations are based on average market prices, which means that no special offers or discounts were considered. A price discount is possible to negotiate, but it is safe to assume that the same discount can be negotiated on all the products and therefore not relevant in the present analysis. The analysis excludes taxes and labor costs. The costs of constructing our model buildings were calculated using construction material prices from 2002/2003 and 2012/2013, as available in Sweden (sources: Sektionsfakta NYB 02/03 and NYB 12/13 [31,32]). All prices from 2002/2003 were adjusted for inflation. The cost assessment of new energy-efficient products was based on prices received from suppliers or sales representatives in 2013.

2.3. Difference in Floor Area

The next step of the analysis aimed at identifying losses and gains of saleable floor area caused by the difference in external wall measurements. The different technological improvements described in this paper may have an impact on energy requirement or on available living space. Considering that the energy requirement in our modeled buildings must be the same, regardless of the technology that has been applied, the building envelope was adjusted and this determines the effect that particular innovations may have on available living area. First, only the impact of different insulations was analyzed—see Table 3—and, secondly, the impact of better windows on possible adjustments to the building envelope was analyzed. In order to simplify the presentation, the second case is reported in Appendix 1–3 only. It is possible that some solutions may involve higher risks regarding such aspects as airtightness guarantee, mold issues or fire safety, and these problems are commented on in the discussion section below.

Table 3. (**a**) Loss in floor area between conventional and energy-efficient building, year 2002. (**b**) Loss in floor area between conventional and energy-efficient building, year 2013.

Year	Type	Loss in floor area building as a whole, m^2	Compared to
(**a**) 2002	EE-A1	−12.8	CVN-A
	EE-B1	−18.4	CVN-B
(**b**) 2013	EE-A1	−12.8	CVN-A
	EE-B1	−13.8	CVN-B

2.4. Appraising Economic Losses and Gains Based on Saleable Floor Area

In order to assess whether the living floor area gains can defray the costs of construction, it was assumed that the developer can sell or rent one square meter of floor area at a given price. Two different price levels are used: p_s1 represents the average price that the developer can sell a dwelling for in midsized cities or in the suburbs of large cities (p_r1—assumed rental fee); p2 represents the average price at which the developer can expect to sell a dwelling located in the city centre in major cities like Stockholm, Goteborg or Malmö (p_r2—assumed rental fee); see Table 4. The prices are based on the current situation but they are applied both for 2002 and 2012 in order not to introduce more aspects than necessary. The role of price changes is commented upon in the discussion. The assessed income losses or gains in relation to difference in saleable living area are presented as a total value, *i.e.*, as a result of multiplying the difference in saleable area and price per square-meter.

Table 4. Assumed selling and renting prices for new residential construction in the city centre and in the suburbs.

Location	Assumed selling and renting prices
Sale price of m^2 in the suburbs (p_s1)	2500 (Euro/m^2)
Sale price of m^2 in the city centre (p_s2)	6000 (Euro/m^2)
Rent price per year of m^2 in the suburbs (p_r1)	100 (Euro/m^2)
Rent price per year of m^2 in the city centre (p_r2)	150 (Euro/m^2)

There are reasons to believe that the square-meter price of an energy-efficient building may be higher than that of a conventional building [16,17,33]; however, for better comparability, the price of one square meter is the same regardless of building type or energy-efficiency level. It is assumed that there is no extra willingness to pay for the energy-efficient building.

3. Study Results and Discussion

It is possible to make calculations for an almost infinite number of cases based on the assumptions above, therefore only the cases that seem most interesting are reported below. Results for cases where we also take into account the effect of window quality are reported in Appendix 1–3 (Tables A1–A5), but they are also included in the discussion.

3.1. *Conventional* versus *Energy-Efficient Building with Standard Products—Difference in Floor Area*

The floor area benefits or losses are presented in the form of difference in total living floor area (m^2) calculated for the whole building. The comparison is made between a conventional building (CNV-A or CVN-B1) and an energy-efficient building with old techniques (EE-A1 and EE-B1). The results are reported in Table 3 below and in Table A1 for different assumptions about windows.

In the case of timber construction, floor area lost to external walls in energy-efficient buildings in 2002 was 12.8 m^2, but for brick construction, the difference was 18.4 m^2 (Table 3a). In the ten-year period, new dimensions of lightweight concrete bricks became available on the market. The greater range of products affected prices and allowed adjustments in brick wall construction. With products available on the market in 2012/2013, we were able to reduce the latter gap to 13.8 m^2 (Table 3b).

3.1.1. The Situation in 2002

3.1.1.1. Timber Houses

Table 5 below reports the cost difference between conventional and energy-efficient timber houses in 2002, indicating that cost difference in construction was approximately 14,000 Euro (as calculated for the whole building, with prices adjusted for inflation to year 2013). The assessed income losses in relation to difference in saleable living area indicate that for the house constructed in the suburbs, where m^2 prices are relatively lower, the anticipated income loss is approximately 32,000 Euro, but the income decrement is even higher in the city centre 76,800 Euro.

Table 5. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2002, timber house.

Difference in cost, living floor area and income	**CVN A-EE-A1 2002**
Construction cost difference *	
Cost difference (Euro/m^2 wall section)	−6.56
Cost difference (Euro, total wall construction)	−3,256
Cost difference windows (Euro)	−10,997
Total cost difference (windows + wall) (Euro)	−14,253
Gains/losses in living floor area (m^2)	−12.8
Assessed income losses/gains due to area difference *	
$p_s1 = 2{,}500$ Euro/m^2	−32,000
$p_s2 = 6{,}000$ Euro/m^2	−76,800
$p_r1 = 150$ Euro/m^2	−1,920
$p_r2 = 100$ Euro/m^2	−1,280

Note: * Cost difference and assessed income loss/gains are presented as a total value for a modeled building.

3.1.1.2. Brick Houses

Table 6 below summarizes the result from conventional and energy-efficient brick houses in 2002 and the result shows that, taking into account loss of saleable area, the cost for the energy-efficient building was 110,400 Euro higher in the central location and nearly 46,000 Euro higher in the suburban location.

Table 6. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2002, brick house.

Difference in cost, living floor area and income	**CVN B-EE-B1 2002**
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−26.25
Cost difference (Euro, total wall construction)	−13,025
Cost difference windows (Euro)	−10,997
Total cost difference (windows + wall) (Euro)	−24,022
Gains/losses in living floor area (m^2)	−18.4
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−46,000
p_s2 = 6,000 Euro/m^2	−110,400
p_r1 = 150 Euro/m^2	−2,760
p_r2 = 100 Euro/m^2	−1,840

3.1.2. The Situation in 2012

3.1.2.1. Timber Houses

Table 7 below reports a cost difference between conventional and energy-efficient timber houses in 2012 of 5500 Euro, indicating that the construction cost difference are lower than that in 2002. The relative price of the more energy-efficient products had fallen. The optimal envelope for the modeled building in 2002 and in 2012 was the same; therefore, the difference in living floor area between conventional and energy-efficient building was the same (12.8 m^2). Consequently, the result shows that when taking into account loss of saleable area, the cost for the energy-efficient building was 76,800 Euro higher in the central location and 32,000 Euro higher in the suburban location. Results for different assumptions about windows are reported in Tables A2 and A3.

Table 7. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, timber house.

Difference in cost, living floor area and income	**CVN A-EE-A1 2013**
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−7.66
Cost difference (Euro, total wall construction)	−3,801
Cost difference windows (Euro)	−1,746
Total cost difference (windows + wall) (Euro)	−5,547
Gains/losses in living floor area (m^2)	−12.8
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−32,000
p_s2 = 6,000 Euro/m^2	−76,800
p_r1 = 150 Euro/m^2	−1,920
p_r2 = 100 Euro/m^2	−1,280

3.1.2.2. Brick Houses

The relative costs for the energy-efficient building in 2012 are lower than in 2002 due to greater product availability. Considering cost efficiency and product range, we were able to reduce the gap in saleable living floor area between conventional and energy-efficient building from 18.4 m^2 in 2002 to 13.8 m^2 in 2012. Table 8 below reports the result from conventional and energy-efficient brick houses in 2012 and the result shows that, taking into account loss of saleable area, the cost for the energy-efficient building was 82,800 Euro higher in the central location and 34,500 Euro higher in the suburban location.

Table 8. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, brick house.

Difference in cost, living floor area and income	**CVN B-EE-B1 2012**
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−28.98
Cost difference (Euro, total wall construction)	−14,380
Cost difference windows (Euro)	−1,746
Total cost difference (windows + wall) (Euro)	−16,127
Gains/losses in living floor area (m^2)	−13.8
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−34,500
p_s2 = 6,000 Euro/m^2	−82,800
p_r1 = 150 Euro/m^2	−2,070
p_r2 = 100 Euro/m^2	−1,380

At this point, it is important to discuss how the initial assumptions could have affected building envelope construction in 2002. First, it was assumed quite strictly that buildings must be airtight, delivering 0.4 h^{-1} at +/−50 Pa. A decade of learning and sharing the experience of energy-efficient building construction resulted in a significant improvement in the airtightness of new buildings in the Nordic countries. Ten years of experience translate into a reduction of labor hours to perform highly accurate work. Secondly, for convenience of analysis, it was assumed that products like tapes, foil or thermal-free bridge connections are available and commonly used. It is possible that the construction cost of an energy-efficient airtight building could have been much higher in 2002 due to the higher cost and lower availability of those products on the market.

3.2. Energy-Efficient Building with New Products—Difference in Floor Area

The floor area benefits or losses are presented in the form of difference in total living floor area (m^2) calculated for the whole building. The comparison is made between a conventional building (CNV-A or CVN-B) and an energy-efficient building with old techniques (EE-A1 and EE-B1), as well as an energy-efficient building with newly developed products (EE-A2N, EE-A3N, EE-B2N, EE-B3N). The results are reported in Table 9 below and in Appendix 2 and 3 for different assumptions about windows.

Table 9. Loss in floor area for different energy-efficient technologies, only changes in wall construction, 2013.

Type	Loss in floor area building as a whole, m^2	Compared to
EE-A1 *	−12.8	CVN-A
EE-A2N	−9.1	CVN-A
EE-A3N	3.9	CVN-A
EE-B1	−13.8	CVN-B
EE-B2N	−9.2	CVN-B
EE-B3N	20.3	CVN-B

Note: * Area loss/gains calculated as a difference in total living area between conventional and energy-efficient building.

3.2.1. Timber Houses

The analysis shows that applying new energy-efficient solutions in the construction helps achieve energy goals and may also be more profitable for the developer. By applying more energy-efficient components in constructing the building envelope, it was possible to adjust external wall width so that the very low space heating level was maintained and the gap in living floor area between conventional and energy-efficient building decreased to approximately 9 m^2 in the case of EE-A2N (insulation at lambda = 0.033). In the case of EE-A3N (insulation at lambda = 0.024), the saleable floor area increase was almost 4 m^2 more than in a conventional building (Table 9).

If account is taken of the gain in saleable area, the energy-efficient building with new products (EE-A3N) can generate 23,700 Euro more income in the central location than the conventional building (Table 10), which is enough to defray the extra cost. The income generated from the gain of saleable area (EE-A3N) in the suburban location was calculated at 9700 Euro (Table 10).

Table 10. Cost difference and assessed living area lost between conventional and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	CNV A-EE-A2N	CNV A-EE-A3N
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−7.3	−38.5
Cost difference (Euro, total wall construction)	−3,635	−19,084
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−5,381	−20,831
Gains/losses in living floor area (m^2)	−9.1	3.9
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	−22,750	9,750
p_s2 = 6,000 Euro/m^2	−54,600	23,400
p_r1 = 150 Euro/m^2	−1,365	585
p_r2 = 100 Euro/m^2	−910	390

When highly energy-efficient windows were also applied in the buildings, the increase in living floor area was 3.9 m^2 for EE-A2N and 7.4 for EE-A3N more than that in conventional building (CVN-A) (Table A1) and was sufficient to defray the higher cost of highly energy-efficient windows and new insulation in the case of EE-A3N (Table A2, Appendix 2). Taking into account loss of saleable area, the income for the energy-efficient building (EE-A3N) was approximately 44,000 Euro higher in the central location and 18,500 Euro higher in the suburban location (Table A2). The results imply that constructing energy-efficient buildings with highly energy-efficient components may be more attractive than producing conventional buildings.

The analysis shows that using highly energy-efficient new components in the construction of energy-efficient timber houses results in an increase in saleable floor area and is often more profitable (Table 11). Furthermore, according to the results (Tables A2 and A3, Appendix 2), by applying both highly-energy efficient windows and new insulation, a developer can build an energy-efficient instead of a conventional building, which allows more living space to be sold and consequently increases income. This is even before considering potential energy and environmental savings.

Table 11. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	**EE-A1-EE-A2N**	**EE-A1-EE-A3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	0.3	−34.8
Cost difference (Euro, total wall construction)	166	−17,268
Cost difference windows (Euro)	−1,746	−1,7464
Total cost difference (windows + wall) (Euro)	−1,580	−19,014
Gains/losses in living floor area (m^2)	3.7	16.7
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	9,250	41,750
p_s2 = 6,000 Euro/m^2	22,200	100,200
p_r1 = 150 Euro/m^2	555	2,505
p_r2 = 100 Euro/m^2	370	1,670

3.2.2. Brick Houses

In the case of a brick wall construction, potential saleable floor area increases when highly energy-efficient products are employed in the building envelope construction. Applying the new technological solutions enables the developer to increase income by as much as 50,000 Euro in the suburbs and approx. 121,000 Euro in the city centre (Table 12). Using the new products in energy-efficient building construction increases saleable floor area, which in the case of EE-B2N was 4.6 m^2 and in EE-B3N 34 m^2, compared with energy-efficient building using old technologies (Table 13).

Adopting more energy-efficient windows and new insulation also encouraged favorable changes in light-concrete wall construction. In the case of EE-B3N (light-concrete brick construction with PIR insulation at lambda 0.024), by adopting windows with average U = 0.7 W/(m^2K), it was possible to re-design the external wall so that gains in living floor area could defray the additional cost of the new component. The benefit is 30 m^2 greater living floor area compared with a conventional building (Table A3).

Table 12. Cost difference and assessed living area lost between conventional and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	**CNV B-EE-B2N**	**CNV B-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−30.4	−62.1
Cost difference (Euro, total wall construction)	−15,100	−30,802
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−16,846	−32,548
Gains/losses in living floor area (m^2)	−9.2	20.3
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	−23,000	50,750
p_s2 = 6,000 Euro/m^2	−55,200	121,800
p_r1 = 150 Euro/m^2	−1,380	3,045
p_r2 = 100 Euro/m^2	−920	2,030

Table 13. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	**EE-B1-EE-A2N**	**EE-A1-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−1.5	−33.1
Cost difference (Euro, total wall construction)	−720	−16,422
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−720	−16,422
Gains/losses in living floor area (m^2)	4.6	34.0
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	11,500	85,000
p_s2 = 6,000 Euro/m^2	27,760	204,000
p_r1 = 150 Euro/m^2	690	5,100
p_r2 = 100 Euro/m^2	460	3,400

The advantage of applying new highly energy-efficient components might also be qualitative: for example, more advanced window solutions help to minimize the thermal bridges, which reduces heat loss and the risk of draughts, and consequently delivers better indoor comfort for occupants. However, there are certain risks which should be discussed, for example, risks related to density of insulation material, airtightness of the building envelope and the moisture level of other components used in the construction, particularly organic material like timber. Checking for moisture level is as important as ensuring that the building envelope is airtight. One of the consequences of failure to produce an airtight building is heat loss and therefore an increase in energy consumption; however, sealing a building envelope with a high moisture level may also lead to problems with moisture and even mould. Ensuring that the moisture level in a building construction does not exceed safe parameters is essential for occupants' well-being and a healthy indoor environment.

3.3. Limitations

This paper has shown the effect of employing new technologies on the profitability of producing energy-efficient buildings; however, the analysis has certain limitations. During the investigation, it became clear that the innovative products are still in the prototype phase. Their use and availability on the market is relatively low. The standard energy-efficient products available on the market and used in this exercise as new technology were launched as few as 8–10 years ago. Unfortunately, solutions presented at building fairs or in manufacturers' catalogues were so new that detailed descriptions of the product or prices were sometimes not available. Detailed technical information was obtainable only on request, often directed or re-directed to the manufacturer.

It is unclear what total impact new energy-efficient technologies may have on the environment and peoples' health, as life cycle analysis and toxicity analysis of the presented solutions are outside the scope of this paper, but we hope that future studies will address those issues. Furthermore, the presented results are based on a simulation exercise, where certain assumptions had to be made, for example, regarding building positioning or installation system. It should be pointed out that there are virtually endless design alternatives among which we have presented only a few. The differences in saleable floor gains or losses depend on comparable design alternatives. Finally, prices used in the cost assessment are only based on purchasing material prices; costs of logistics, labor and external works were not considered.

4. Concluding Comments

The intention of this paper was to investigate how new energy-efficient products affect construction cost and profit. As noted in the literature (see extensive literature on economics of energy efficiency, innovation and technological development for example [34–37]), one of the greatest barriers to diffusion and commercialization of new environmental technologies is that benefits are spread out over time (e.g., energy savings) or not observable directly (e.g., environmental impact). It is thus important to demonstrate that implementing new energy-efficient technologies in the construction of buildings can have a more direct effect, which may positively impact on the profitability of highly energy-efficient buildings in the form of saleable floor area.

The impact of potential losses or gains of saleable floor area should be taken into account when comparing investment alternatives: building energy-efficient green dwellings or building conventional ones. The paper shows that constructing energy-efficient buildings and introducing very energy-efficient technologies may be both energy- and cost-effective when compared with conventional buildings. Employing new products in energy-efficient construction allows not only for benefits to be drawn from lower energy consumption during the life cycle of the building, but also from the increase in saleable floor area. This may have a significant effect on investment appraisal, particularly for projects in the city centre and other areas with high prices.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix 1. Loss in Floor Area in Relation to Windows of Different Quality

The calculations are made in the same way as in the main text. The table below presenting results for EE-A2N, EE-A3N, EE-B2N and EE-B3N include changes in insulation and highly energy-efficient windows. No changes were made to CNV A, CVN B and EE-A1 and EE-A2.

An average energy-efficiency (U) value for windows used in conventional buildings CVN-A and CVN-B was approximately 1.1 W/(m^2K); an average energy-efficiency (U) value for windows used in energy-efficient houses was 0.9 W/(m^2K); In this stage windows of 0.9 W/(m^2K) in cases EE-A2N, EE-A3N, EE-B2N and EE-B3N were replaced with more energy-efficient windows where average U value was 0.7 W/(m^2K). The average energy-efficiency value (U) for EE-A1 and EE-B1 were kept the same, *i.e.*, 0.9 W/(m^2K). The simulation is done only for 2013 construction.

Table A1. Loss in floor area between conventional and energy-efficient building and between energy-efficient building with different technologies, year 2013.

Type	Loss in floor area building as a whole, m^2	Compared to
EE-A1	−12.8	CVN-A
EE-A2N, $U_{windows}$ = 0.7 W/(m^2K)	3.9	CVN-A
EE-A3N, $U_{windows}$ = 0.7 W/(m^2K)	7.4	CVN-A
EE-B1	−13.8	CVN-B
EE-B2N, $U_{windows}$ = 0.7 W/(m^2K)	25.8	CVN-B
EE-B3N, $U_{windows}$ = 0.7 W/(m^2K)	29.5	CVN-B
EE-A2N, $U_{windows}$ = 0.7 W/(m^2K)	16.7	EE-A1
EE-A3N, $U_{windows}$ = 0.7 W/(m^2K)	24.1	EE-A1
EE-B2N, $U_{windows}$ = 0.7 W/(m^2K)	39.6	EE-B1
EE-B3N, $U_{windows}$ = 0.7 W/(m^2K)	43.3	EE-B1

Appendix 2. Results When Taking Window Quality into Account

The Situation in 2002

Highly energy-efficient windows are considered as new products; therefore, simulation could not be performed.

The Situation in 2013

Timber Houses

Table A2. Cost difference and assessed living area lost between conventional and energy-efficient building with new products constructed in 2013, timber house.

Difference in cost, living floor area and income	**CNV A-EE-A2N**	**CNV A-EE-A3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−0.3	−38.5
Cost difference (Euro, total wall construction)	−146	−19,084
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−7,380	−26,317
Gains/losses in living floor area (m^2)	3.9	7.4
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	9,750	18,500
p_s2 = 6,000 Euro/m^2	23,400	44,400
p_r1 = 150 Euro/m^2	585	1,110
p_r2 = 100 Euro/m^2	390	740

Brick Houses

Table A3. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, brick house.

Difference in cost, living floor area and income	**CNV B-EE-B2N**	**CNV B-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−4.6	−27.3
Cost difference (Euro, total wall construction)	−2,267	−13,558
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−9,500	−20,792
Gains/losses in living floor area (m^2)	25.8	29.5
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	64,500	73,750
p_s2 = 6,000 Euro/m^2	154,800	177,000
p_r1 = 150 Euro/m^2	3,870	4,425
p_r2 = 100 Euro/m^2	2,580	2,950

Appendix 3. Comparison of Energy-Efficient Buildings with Different Technology

Table A4. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	**EE-A1-EE-A2N**	**EE-A1-EE-A3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	7.4	−30.8
Cost difference (Euro, total wall construction)	3,654	−15,283
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−3,578	−22,516
Gains/losses in living floor area (m^2)	16.7	24.1
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	41,750	60,250
p_s2 = 6,000 Euro/m^2	100,200	144,600
p_r1 = 150 Euro/m^2	2,505	3,615
p_r2 = 100 Euro/m^2	1,670	2,410

Table A5. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	**EE-A1-EE-B2N**	**EE-A1-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	24.4	1.7
Cost difference (Euro, total wall construction)	12,113	821
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	4,879	−6,411
Gains/losses in living floor area (m^2)	39.6	43.3
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	99,000	108,250
p_s2 = 6,000 Euro/m^2	237,600	259,800
p_r1 = 150 Euro/m^2	5,949	6,495
p_r2 = 100 Euro/m^2	3,960	4,330

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