KTH Architecture and the Built Environment

Low-energy residential buildings

Evaluation from investor and tenant perspectives

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Licentiate Thesis

Building & Real Estate Economics
Department of Real Estate and Construction Management
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An overview of concepts and results

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An overview of concepts and results

1. Introduction

The question of how to approach climate mitigation and human impact on environment has been a challenge but also a stimulus for the market to investigate and develop new and more environmentally progressive products and services. The focus on a product environmental impact initiated a new debate on how the environmental impact shall be measured and which are the critical factors in the environmental assessment. The complexity of building process and long life cycle that can span over 100 years adds to already difficult issue of the building environmental assessment. There is a very long list of potential factors which affect the total live cycle analysis; from construction material and energy needed in its production, transportation and construction to energy consumed during operation of the building.

In the studies that are presented in this thesis and summarized at the end of this paper the focus is on economic aspects of low-energy buildings, analysed both from a producer and consumer perspective. Those studies should answer following questions: Is it profitable to build low energy houses? Are there any special problems from a property developer's perspective? How is it to own such buildings in terms of special management problems? And what is the experience of consumers who have been living in low-energy houses? Are they e.g. more or less satisfied with the indoor climate than those who live in conventional houses of the same type and age.

Before these results are presented and discussed it is important to clarify the fundamental concepts used when the buildings are classified: What is really the meaning of green/sustainable/low energy building?

The paper is organized as follows: in section 2 definitions and concepts are presented; section 3 presents key findings and summarizes the conclusions from the research project, section 4 presents concluding comment.

2. Definitions and concepts

2.1. "Sustainable" or "green" building?

2.1.1. Sustainable building

High performance buildings, which aim to minimize environmental impact, are often referred to as "sustainable", "green" or "energy – efficient". Cole (1999) points out that the "green" issue may have different levels of "environmental involvement" or "shades of green" from so called "light green" to "deep green". The "light" way includes high-efficient choices like energy efficient lighting, whereas "deep green" refers to more demanding commitments (e.g. regarding design or financial inputs) like for instance choice of environmentally accepted materials or implementation of solar energy collectors.

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. This three-dimensional characteristic of sustainability is fundamental and, as Kohler (1999) clearly states, that the separation of those domains can lead to mistaken conclusions. Kohler (1999) explains that sustainability, if applied in the built environment, shall still be described in three unbreakable frameworks; where ecological sustainability aims to the protection of resources and ecosystem, economic sustainability is divided in investment and running costs, and social and cultural aspects refers to comfort, well being and human health protection. The global aspect and the three fundamental dimensions of sustainability lead to the question whether a building alone can be sustainable (Cole, 1999) or even construction industry (Cooper, 1999 and Pearce, 2005).

2.1.2. Green Building

Kibert (2008) defines "green building" as: "a healthy facility that is designed, built, operated and disposed of in a resource-efficient manner using ecologically sound approach". The term "green building" gained its popularity mostly due to efforts of various agencies, organisations and councils that are successfully promoting this concept. The U.S. Environmental Protection Agency (www.epa.gov) defines 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. The non profit organisation U.S. Green Building Council (www.usgbc.org) promotes green buildings concept in United States of America. The organisation defines parameters for new built or renovated green buildings through seven broad areas presented in table 1.

Table 1. Main assessment disciplines as according to LEED 2009 (U.S. Green Building Council - LEED 2009)

Main criteria	
Sustainable site	Promoting eco-concern choice of building's location for ex. locating construction there where urban infrastructure already exists; commuting to work using public transport
Water efficiency	Promoting efficient use of water resources
Energy and atmosphere	Promoting reduction of energy use of buildings below the level of standard building, promoting use of renewable energy source, reduced products emission
Materials and resources	Promoting reduction of construction disposal, use of eco-materials and reclaimed building materials
Indoor environmental quality	Promoting individual thermal comfort and increased healthy air
Innovation and design	Promoting design and exceptional performance in buildings
Regional	Promoting local initiative

Nowadays, there are many organisations and programmes which aim to promote "green" or "sustainable" building concepts, e.g., World Green Building Council (www.worldgbc.org), U.S. Green Building Council (www.usgbc.org), Swedish Green Building Council (www.sgbc.se) and the GreenBuilding Programme (GBP) initiated by European Commission (www.eu-greenbuilding.org).

2.1.3. Building environmental assessment methods

The fundamental objective for a "green" environmental assessment method is promoting designing, constructing and owning buildings with improved environmental performance (Cole, 1999). Moreover, Cole explains that the "green" assessment method is based on relating the building to a "typical" practice without defining an ultimate goal, whereas "sustainable" method should assess building against declared (locally and globally) sustainable conditions.

In practice the essential rule is that in order to be named 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 have introduced an environmental assessment method; either newly created methods, modified or adjusted versions of earlier established systems (e.g. LEED India). Building assessment and certification is a process.

Assessment is done against specified criteria and points are awarded for applying to specified standards. Finally summarized points indicate the level of building performance.

Environmental assessment promote environmental awareness, but also give a framework for professionals' work, and opportunities for buildings certification and labelling even in cooperation 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 the origin in reference to general rules, construction standards or climate conditions. Moreover, various assessment methods address different criteria or assign to them different weight. General characteristics of different assessment methods are presented in table 2.

Table 2. Comparison assessment methods (Reed et.al., 2009; Bonde, 2010)

Criteria/ assessment method	LEED (US)	BREEAM (UK)	Green Star (Australia)	CASABEE (Japan)	Miljöbyggnad* (Sweden)
Energy	X	X	X	X	X
CO2	X	X			
Ecology	X	X	X	X	
Indoor environment quality	X		X	X	X
Land use	X	X	X		
Innovation	X		X		
Management	X	X	X	X	
Material	x	X	X	X	X
Pollution	X	X	X	X	
Transport	X	X	X		
Waste	X	X			
Water	X	X	X	X	
Buildings type	All buildings	All buildings	All buildings	All buildings	All buildings
Residential buildings version	LEED for Homes	Code for Sustainable Homes			

** Previously known as Miljöklassad byggnad*

Some building environmental assessment methods tries to capture the complexity of a building and therefore tools include rather long list of criteria, making the assessment quite complex. And 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 like energy or material) may be left aside, however the final score may be high.

2.2. Energy effective building

Wither (1999) argues that among the many issues which must be addressed on the road to sustainable development, energy is the “single most important factor”. Building life cycle is counted for 50-100 years and during this time total energy associated with a building may be divided into energy that is directly connected with building itself: energy needed for building’s construction, operation, rehabilitation and demolition, and embodied energy, which is a sum of all energy needed to manufacture and transport goods (all material and technical installations) (Sartori and Hestnes, 2007). The question on how embodied energy and operating energy influence total energy used in buildings life cycle is a subject of discussion in the literature. Results differ depending on building type, production year, climate zone and finally energy measures used to analyse building’s performance. Energy used in buildings can be expressed in end-user energy or primary energy. The last one 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). The primary energy pays attention to energy resource 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 source (Gustavsson and Joelsson, 2010).

This paper and the studies presented in this thesis focus on end-user energy, the energy that is supplied to the building for its operation and to secure good indoor climate, also referred to as purchased energy. The primary source of energy supplied to the building or environmental consequences of different energy systems are not discussed.

2.2.1. 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 Swedish Building Regulations (Boverket, 2008), (Boverket, 2009) are considered here as benchmark for new building construction and referred to as conventional buildings.

Table 3. Brief description of new built dwellings standard according to Swedish Building Regulation BBBR 16 (Boverket, 2009)

Standard for different climate zones in Sweden	***Swedish Building Regulations, values not including household electricity use*** a - *For dwellings without electric heating systems* b - *For dwellings with electric heating systems*
Specific energy demand [1)] requirement for zone (I)	≤ 150 kWh/($m^2 A_{temp}$) a ≤ 95 kWh/($m^2 A_{temp}$) b
Specific energy demand requirement for zone (II)	≤ 130 kWh/($m^2 A_{temp}$) a ≤ 75 kWh/($m^2 A_{temp}$) b
Specific energy demand requirement for zone (III)	≤ 110 kWh/($m^2 A_{temp}$) a ≤ 55 kWh/($m^2 A_{temp}$) b
Heat loss	Quantitative values not specified
U-value [W/m^2K]	U (average for building envelope) ≤ 0,50 W/ m^2K, a U (average for building envelope) ≤ 0,40 W/ m^2K, b U value for windows is not specified
Annual heating load [2)] for climate zone (I)	Installed electrical power for heating of dwellings with electric heating ≤ 5,5 kW
Annual heating load for climate zone (II)	Installed electrical power for heating of dwellings with electric heating ≤ 5,0 kW
Annual heating load for climate zone (III)	Installed electrical power for heating of dwellings with electric heating ≤ 4,5 kW

1)Specific energy demand refers to amount of energy that must to be delivered to the building over a certain period of time (i.e. annually) in order 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 kWh/m^2; expressed in purchased energy i.e. end-use energy, measured at final level, purchased from distributor,

2)Annual heating load describes the maximum amount of energy that must be delivered to the building at a particular time (usually the coldest day) in order to achieve good indoor climate; expressed in W/ m^2

*A_{temp} refers to the area within the thermal envelope, where temperature should be kept over 10°C (http://www.boverket.se/Kontakta-oss/Fragor-och-svar/Bygg-och-konstruktionsregler/Om-avsnitt-9-i-BBR/Atemp)

2.2.2. Low energy building

It is generally understood that a low energy building should achieve better or significantly better performance values compared to 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 abating thermal bridges, including very good thermal isolation for the whole building envelope (very low heat transfer coefficient values for walls slab and roof), and energy efficient windows. In order to achieve good indoor comfort 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 being promoted by non-profit organisation 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).

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), recognize two types of low-energy houses: passive house and mini-energy house (Forum för energieffektiva byggnader, 2009a, Forum för energieffektiva byggnader, 2009b).

In Sweden passive house is recognised as 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). Mini-energy house, as low energy house, is expected to have "*better* building performance than defined in Swedish Building regulations BBR 16 (BFS 2008:20)" (Forum för energieffektiva byggnader, 2009b).

2.2.3. Low energy building and passive house concept

Low energy and passive house concept essentially builds on the same idea, that the heating energy in the building can be minimized through airtight and well insulated building shell. However, where the first one 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 in regard to the achievement of heating energy savings. Low-energy building and passive house comparison is illustrated in the Figure 1.

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

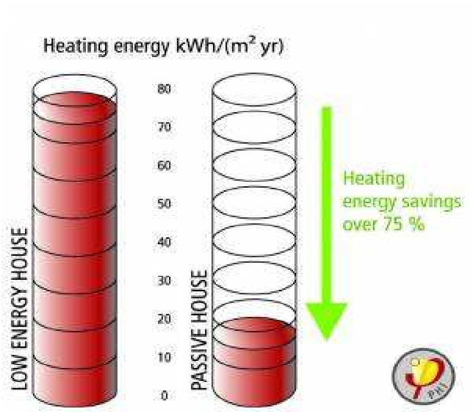

Figure 1. Heating energy comparison low energy house and Passive House (Passive House Institute, Darmstadt, Germany, http://passipedia.passiv.de/passipedia_en)

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

2.2.4. Passive House (PHI)

The concept of passive house has been popular especially in Germany, Austria and Switzerland, where many buildings – residential houses and schools have been built according to this concept. In Germany 300 dwellings have been recorded by 1999 and between 6 000 and 7 000 by the year 2006. (Feist, 2006)

In 1996 the Passive House Institute was established. Under leadership of Dr. Wolfgang Feist the independent research institute developed and promoted Passive House concept in Germany and worldwide (Passive House Institute, Darmstadt, Germany., What is passive House?)

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)

Passive House and conventional building heating system is illustrated in the Figure 2.

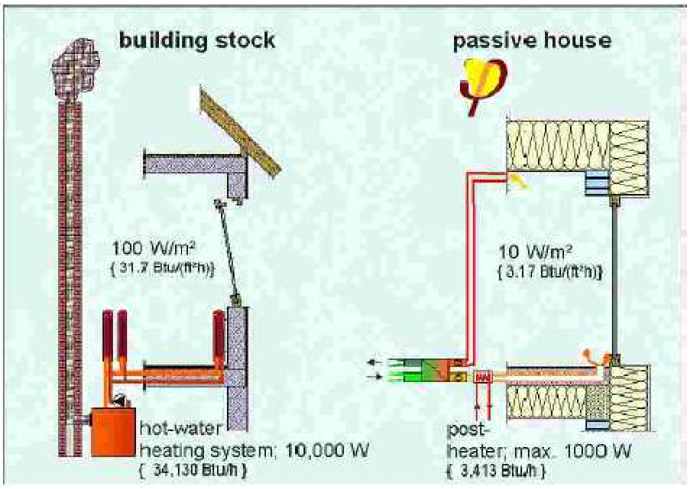

Figure 2. Concept comparison radiator heated house and Passive House (Feist, Cost-efficient Passive House in Central European Climate, PHI)

Wolfgang Feist explains that fundamental in the passive house concept is thermal comfort which is achieved by very good insulation of the buildings envelope and by minimization of thermal bridges, hence overall heat losses are very small. Airtight building construction and good thermal insulation allow that during winter season building retain warm air better and leakage of cold outdoor air is minimized. Due to those attributes requirement for heating is significantly reduced and therefore heating system may be simplified to complementary heating (e.g. heating with fresh air via 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 shall not be exceeded (Feist, Schnieders, Dorer, & Haas, 2005), Feist is explaining that those measures are consequence of concepts and energy-efficient design and not an aim by itself and that the difference in climate conditions calls for specific system solutions in regards 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).

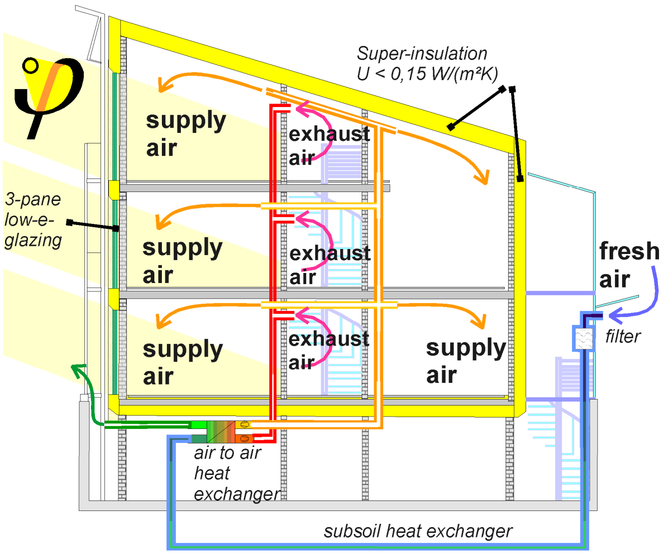

Figure 3. Illustration of Passive House concept and definition (Passive House Institute, Darmstadt, Germany., www.passipedia.org)

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

The air tight house requires ventilation system which can be also used for heating. The supplied air is fresh and unpolluted, however in order to achieve very low heating energy demand, the heat recovery from exhaust air must be utilized (Waltjen, et al., 2009). PHI recommends that ventilation aggregate units should have 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. The basic idea for air supply system in Passive House is presented in the Figure 3.

Table 4. 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	

2.2.5. Swedish passive house standard

Even though development of the industrial construction of passive houses in Sweden is relatively slow (see Figure 4), the first passive house that fulfils PHI standards was built already in 2001. Designed by Hans Eek, 20 terrace houses in Göteborg (Lindås) became a milestone in low energy buildings construction and showed that the Passive House concept can be successfully realised in Scandinavian climate.

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

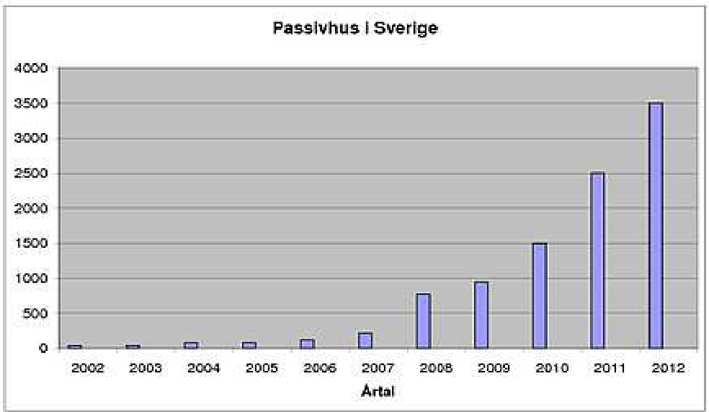

Figure 4. Passive house construction 2002-2012, estimated values, (www.passivehuscentrum.se)

Swedish definition ("FEBY Kravspecification för passivhus" 2007 and 2009) is based on German Passive House approach, however, calculations were adjusted to generally used standards in Sweden.

It is specified that passive house 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 conventional heating system.

The main requirements for the Swedish passive house (Forum för Energieffektiva Byggnader, 2009a) are summarized in tables 5, 6 and 7.

Table 5. Annual heating load criteria for passive house (Forum för Energieffektiva Byggnader, 2009a)

Standard for different climate zones	***Passive house standard 2009 for residential and non-residential buildings***	***Passive house standard 2009 for residential single and detached houses, <200 m²***
Annual heating load* for climate zone (I)	$\leq$12 W/($m^2 A_{temp**+garage***}$)	$\leq$14 W/($m^2 A_{temp+garage}$)
Annual heating load for climate zone (II)	$\leq$11 W/($m^2 A_{temp+garage}$)	$\leq$13 W/($m^2 A_{temp+garage}$)
Annual heating load for climate zone (III)	$\leq$10 W/($m^2 A_{temp+garage}$)	$\leq$ 12 W/($m^2 A_{temp+garage}$)

* Annual heating load describes the maximum amount of energy that must be delivered to the building at a particular time (usually the coldest day) in order to achieve good indoor climate; expressed in W/ m^2
** A_{temp} refers to the area within the thermal envelope, where temperature should be kept over 10°C (http://www.boverket.se/Kontakta-oss/Fragor-och-svar/Bygg-och-konstruktionsregler/Om-avsnitt-9-i-BBR/Atemp)
*** $A_{temp+garage}$ refers to the A_{temp} area and garage area included within the thermal envelope (Forum för Energieffektiva Byggnader, 2009a)

Table 6. Swedish passive house requirement (Forum för Energieffektiva Byggnader, 2009a)

Standard for different climate zones	***Passive house standard 2009 values not include household electricity use*** *For dwellings without electric heating systems*	***Passive house standard 2009 values not include household electricity use*** *For dwellings with electric heating systems*
purchased energy* requirement for zone (I) north	≤ 58 kWh/($m^2A_{temp+garage}$)	≤ 34 kWh/($m^2A_{temp+garage}$)
purchased energy requirement for zone (II) middle	≤ 54k kWh/($m^2A_{temp+garage}$)	≤ 32 kWh/($m^2A_{temp+garage}$)
purchased energy requirement for zone (III) south	≤ 50 kWh/($m^2A_{temp+garage}$)	≤ 30 kWh/($m^2A_{temp+garage}$)
n_{50}-leakage rate	≤ 0,30 l/s m² with +/- 50 Pa, according SS-EN 13829 standard	
windows' U-value	U ≤ 0,90 -0,80 according to standards SS-EN 12567-1 and SS-EN ISO 10077-1	
indoor comfort	sound from ventilation system should be better than class B temperature April - September should not exceed 26 C grade	
*purchased energy – end-use energy, measured at final level, purchased from distributor, energy from solar collector or wind power is not included		

Table 7. Swedish passive house requirement (Forum för Energieffektiva Byggnader, 2009a)

Standard for different climate zones	***Passive house standard 2009 values not include household electricity use***
Weighted energy* requirement for zone (I)	≤ 68 $kWh_{weighted}$ /($m^2A_{temp+garage}$)
Weighted energy* requirement for zone (II)	≤ 64 $kWh_{weighted}$/($m^2A_{temp+garage}$)
Weighted energy* requirement for zone (III)	≤ 60 $kWh_{weighted}$/($m^2A_{temp+garage}$)
Weighted energy* - energy adjusted with energy factors according to form: $Energy_{weighted} = \sum (e1*E1 + e2*E2 + e3*E3 + e4*E4) \le$ Energy (demand) E1, e1 – respective: purchased electricity and energy factor for electricity, e1=2 E2, e2 - respective: purchased district heating and energy factor for district heating, e2=1 E3, e3 - respective: purchased bio-fuel and energy factor for bio-fuel, e3=1 E4, e4 - respective: purchased solar/wind energy and energy factor for solar/wind energy, e4=0	

2.3. Overview of definitions

The aim of this paper was to present different concepts related to environmental qualities of buildings and discuss intentions behind those descriptions. Sustainable, "green" and energy efficient buildings aim at adopting resource efficient solutions, thought those terms not always can be safety used as synonyms. The sensible question is than how those different terms relate to each other.

Can energy efficient building be "green"? Energy performance is only one of many assessment fields in the environmental assessment methods (BREEAM, LEED or Green Star) and therefore if the building environmental performance can be demonstrated in other assessment areas (e.g. material, water, waste) than the energy-efficient building can be named "green". On the other hand it is possible to reverse the question: is green building energy efficient? Report prepared by National Building Institute for U.S. Green Building Council (Turner and Frankel, 2008) indicates that on average LEED-buildings energy performance is better than national average, however in some cases the predicted performance of the LEED-buildings and the measured values differ significantly. Moreover, Newsham et. al (2009) studies 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 strengthen and BREEAM certificated buildings performance monitored. A pitfall of building assessment tools might be the complexity of evaluation and the factum that the weight of individual parameters may only to some extend affect the final result. On the other hand assessment methods allow highlighting the comprehensive environmental value of buildings.

It is possible to approach building evaluation using a three-dimensional framework: environmental, social and economic. Schnieders and Hermelink (2006) argumented for sustainable value of passive house, convincing that "user-oriented design" and focus on high quality of indoor environment contribute to social component and very low energy demand help on the path to fulfill environmental end economical conditions. Description of relationship between different concepts related to environmental qualities of buildings illustrates figure 5.

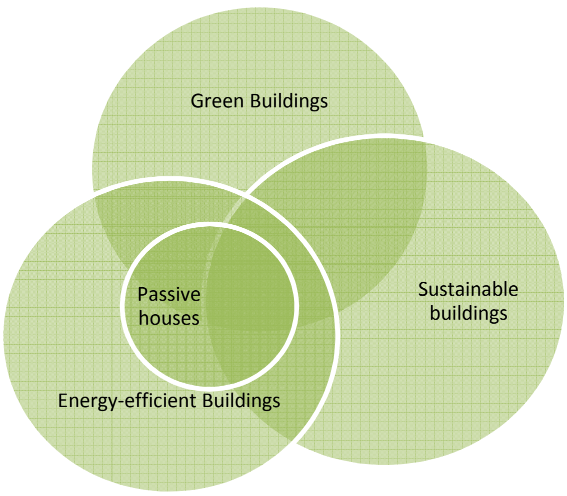

Figure 5. Overview of relationship between different concepts related to environmental qualities of buildings

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 on the course of design, production, management, operation and finally demolition which finally determine the resource efficiency and total environmental impact of the building.

3. Summary of the papers in the licentiate thesis

The study presented in this thesis aimed at investigating the comprehensive value of low-energy housing and its investment potential. The product value is from one side defined by investment inputs and from other by value delivered to the end-user; hence the assessment of energy-efficient buildings was approached from two perspectives: the investors and the user – occupant and housing managers.

3.1 Paper 1*: Low-energy versus conventional residential buildings: construction cost, operating cost, and return on investment*

Introduction

A good investment is measured by benefits it gives in return, and so financially viable investment is an elementary requirement for the stockholders. Cost and affordability have been often pointed as the greatest barrier in sustainable construction development (Pitt et al, 2008) and further often brought up in the discussion about the "sustainable" or "green" investment profitability. It is therefore important to collect market evidence to facilitate understanding and evaluation of environmentally conscious investments in real estate.

Purpose

The focus of this paper is to investigate the cost side of "green" building construction and if increased investment cost are profitable taking the reduction in operating cost into account. The investment viability is approached by comparing investment in conventional and "green" residential building, particularly low-energy building, using real construction and post-occupancy condition. Moreover, the paper investigates incentives needed to accelerate low-energy residential development in Sweden.

Method and data collection

The key information was obtained from private and public housing companies by surveys and personal interviews. The first survey was directed to the companies involved in constructing conventional and low-energy housing and the second survey to the housing companies that actively manage operation of low-energy houses. Personal interviews allowed for better understating of low-energy construction and access to more detail data.

The first survey was addressed to chief executives (i.e., those responsible for new projects and housing development) and project leaders. The notification of survey questionnaires were sent to 34 companies (93 people) that had participated in at least one low-energy housing project in Sweden. Answers were collected using an on-line questionnaire from February to March 2010; thirty-four completed questionnaires were collected for a response rate of 37%. Respondents represented 24 companies (i.e., 71% of the contacted companies), 16 public and 18 private.

The second survey questionnaire was sent to the person or people responsible for managing and operating low-energy residential buildings (30 recipients) in the 18 companies. Answers to an on-line questionnaire were collected from November to December 2010. Nine people, each representing a different housing company, completed the survey. Only multi-family residential buildings with rental apartments were subjects of study. The buildings meet or nearly meet the Swedish passive house standard (Forum för energieffektiva byggnader, 2009a).

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.

Key findings

The information received from investors and housing management companies indicate that low-energy buildings are considered as interesting and good business opportunity and the energy-efficient building investment are seen as strengthening company's market position.

At present the average extra cost in low-energy buildings construction is estimated to be approximately 6%. The cost of labour, material and more advanced mechanical ventilation systems with heat recovery add up to higher cost, but the at same time, accuracy of construction work and higher-quality material assure the achievement of qualitative objectives and future energy savings. The estimated operating cost is expected to be significantly lower thanks to reduced energy requirement, which according to housing managers reflects the actually metered energy consumption fairly well.

The calculated risk and uncertainty is not regarded to be higher in "green" buildings construction. The experience, however, is significant as it increased efficiency and profitability of low-energy residential projects. The study demonstrates that, at present energy prices and 6% extra investment cost for low-energy buildings, there is no significant difference between income return on low-energy and conventional residential buildings in the short term (i.e., up to five years), in the longer term, however, the savings and income return on energy-efficient are higher than on conventional housing. Low-energy housing investments generate better returns, as greater energy efficiency contributes to better cash flow, and since it is likely that energy prices will increase, so the profitability gap between low-energy and conventional buildings will grow to the greater benefit of energy-efficient buildings.

Low-energy buildings construction needs more experience and development of new technologies and building concepts can truly stimulate development of “green” construction. The change of Buildings Regulations appears to be a significant stimulant in accelerating energy-efficient buildings construction, which suggests that the present regulations are too low and not motivating industry. Additionally, the obligatory environmental assessment and certification system has been found to have insignificant effect on low energy housing development and even though companies believe in importance of environmental rating the practical implications are being questioned. The financial incentives, such as tax reductions or subsidies are generally considered as very important incitement for acceleration of energy-efficient buildings construction.

The paper shows that low-energy residential construction is a rational investment choice, even at higher initial cost. The investment offers better cash flow and higher rate of return and additionally reinforces company’s market position. At the same time, private and public housing companies points at government initiative and the construction regulations that can provide true motivation towards “green” buildings development.

The complexity and competitiveness of construction market requires that the investor should see beyond purely economical evaluation of a project and consider added values like learning value captured by construction experience and customers’ satisfaction, therefore the second paper presents results from a study of customer satisfaction in low energy versus conventional buildings.

3.2 Paper 2: *Assessing low-energy building performance from the perspective of residents and housing managers*

Introduction

Buildings fundamental goal is to deliver safe shelter and good indoor climate for the occupants. Creating the thermal comfort begins with modelling, which is based on mathematical descriptions of the designing building, its surroundings, and regional climate. The post-occupancy evaluation that includes occupant feedback can be use as a control measure to verify these calculations and an important link in closing the learning loop for investor, designer and builder. The evaluation and observations given by residents and housing managers are significant for designing and constructing good quality buildings, suited to occupant needs and expectations.

Purpose

Aim of the paper was to attempt buildings assessment based on occupant feedback and housing manager observations. Occupants survey from low energy and conventional houses were used to compare thermal comfort and to examine differences in comfort that may be related to living in low-energy houses. The paper explores the benefits and challenges related to managing and operating highly energy-efficient housing.

Method and data collection

To investigate indoor climate in energy-efficient housing, we carefully selected three low-energy multi-family residential buildings as our case study objects and a control group of three conventional multi-family buildings. The objective of this multi-case study was to capture the circumstances and conditions specific to passive multi-family housing.

The data was obtained by two surveys and personal interviews. The first survey questionnaire was sent to all registered tenants above age of 21 in chosen housing estate and the second survey was addressed to the housing companies that actively manage operation of low-energy houses. Only multi-family residential buildings with rental apartments were studied.

Key findings

The results indicate that the low-energy profile of a building had a limited influence on the decision to rent the apartment, however residents were generally proud to live in environmentally friendly buildings. Moreover, tenants also suggested that living in the energy-efficient buildings increased their environmental awareness, making their behaviour more environmentally friendly. Residents of low-energy houses gave better rating for indoor climate than that in conventional houses, which suggests higher satisfaction with the product; however, tenant feedback identified some problems with ventilation system and space heating.

Findings indicate that there no significant difference in operation and management of low-energy buildings, however information and communication activities are absolutely crucial in successful management of low-energy buildings. Moreover the low energy buildings requires the same amount or less adjustments than in conventional houses, which brings further evidence that in the life cycle perspective low energy houses are a better investment.

On the other hand the feedback from housing manages and occupants suggest that ventilation and heating system installed in low-energy buildings need to be carefully chosen since the biggest problems are insufficient auxiliary heating efficiency in air heating systems and adjustment difficulties with the air flow and temperature in those systems.

The results of the research study are valuable for a number of parties in the construction sector. The study provides valuable information for prospective investors and owners to take financial decisions on implications of building operation.

4. Concluding comment

This research proved that residents' feedback, as it represents end-user satisfaction with the product, should be used by developers and designers to learn about the consumer preferences, practical and preferable solutions. This knowledge is essential for consecutive progress in delivering quality housing and accelerating low-energy building development.

The European Council with latest directive regarding energy performance of buildings (2010/31/EU, 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 behind "nearly zero-energy building" combines two ideas: firstly that amount of energy which must be supplied to the building is very small and secondly that the source of this energy should come from renewable sources. This means that experience and expertise of building energy-efficient buildings are fundamental for achieving future goals and for further transfer of knowledge and future development.

The unique attributes of buildings, changing climate conditions, and the fact that energy balance calculations for low-energy buildings allow very little margin for error, advocate continuing and consecutive investigation of post-occupancy building performance and thermal comfort in low-energy buildings is essential.

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Low-energy versus conventional residential buildings: construction cost, operating cost, and return on investment

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Low-energy versus conventional residential buildings: construction cost, operating cost, and return on investment

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Abstract

Purpose - The focus of this paper is to investigate the cost side of "green" building construction and if increased investment cost are profitable taking the reduction in operating cost into account. The investment viability is approached by comparing investment in conventional and "green" residential building, particularly low-energy building, using real construction and post-occupancy condition.

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

Findings - Findings indicate that low-energy buildings are considered as interesting and good business opportunity and life cycle cost analysis suggests that low energy building (particularly passive house) is a better investment than conventional residential building. At the same time government initiative and the construction regulations are found to have strong motivation power towards development of "green" buildings.

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

Paper type – research paper

Key words – low-energy buildings, residential buildings, investment analysis

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., 2006; 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 regarding the extra cost of "green" buildings and the highly speculative return on investment and payback period (Issa et al., 2010).

In seeking empirical evidence, a few research studies have focused on the linkage between cost and income premium in energy-efficient and sustainable properties. Matthissen and Morris (2004) compared LEED 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% more than constructing a conventional house; on average, the specific extra investment was found to be 8% 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 (Echholtz et al., 2009) and that the relationship between green rating level (i.e., LEED) and effective rental premium is significant (Echholtz et al., 2010). Moreover, energy-efficiency apartments in Switzerland have sold at a 3.5% premium over the last ten years, while energy-efficient single-family homes commanded a premium of 7% (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 and measured values (Karlsson and Moshfegh, 2006; Wall, 2006). Although the general economic assessment of low-energy houses has been approached (Karlsson and Moshfegh, 2006; Karlsson and Moshfegh, 2007), the investment viability and life cycle costing analysis of low-energy buildings have 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 effect on investment feasibility. This paper therefore compares investments in conventional and "green" residential property (particularly low-energy housing) 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 low-energy housing market in Scandinavia.

Accordingly, this paper aims to:

a) investigate the difference in investment cost between low-energy and conventional housing
b) evaluate the profitability of low-energy versus conventional housing investments
c) investigate housing development companies' incentives to construct energy-efficient housing
d) 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 low-energy housing 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.

We particularly address the cost side of investment and explore if increased investment cost are profitable taking the reduction in operating cost into account. The investment costs have been defined here as design and production cost. Due to the fact that land prices may vary significantly depending on location, size, urban infrastructure etc., the land prices were not included in the evaluation.

Low-energy buildings requires better insulated envelope, which may increase width of walls, and reduce ratio between living space and total built area, which in its turn influence the amount of square maters available for sale and affect investment viability. This construction aspect of low-energy buildings was not discussed in this paper, but shall be explored in our further studies.

On the other hand, the complexity and competitiveness of construction market requires that the investor should see beyond such evaluation of a project and consider added values like learning value captured by construction experience and customer satisfaction. In a forthcoming paper results from a study of customer satisfaction in low energy versus conventional buildings will be presented.

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 (Figures 1 and 2).

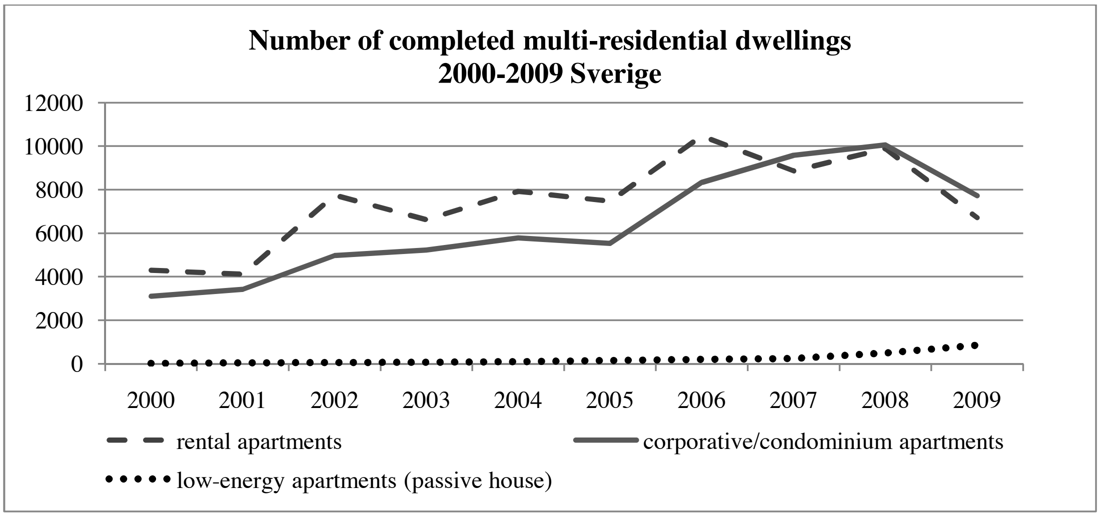


Figure 1. Housing construction in Sweden, 2001–2009 (SCB, Statistics Sweden, http://www.scb.se; Passivhuscentrum, http//www.passivehuscentrum.se)

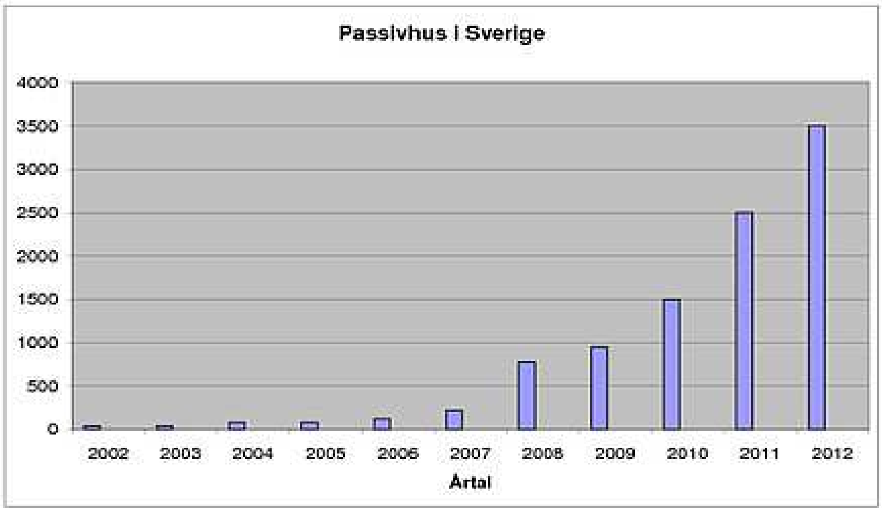


Figure 2. Number of passive housing units (total) in Sweden (Passivhuscentrum, http//www.passivehuscentrum.se)

1.4. Organization of the paper

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 and analysis in section 4 and 5 respectively; finally, the discussion and conclusions are presented in section 6.

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 1970s, the issue of energy used in buildings became a greater priority (Boverket, 2002).

The National Board of Housing, Building and Planning in Sweden gradually incorporated energy requirements into its building code. The latest changes in the Building Regulations (BBR 16) not only limit energy consumption in newly built buildings, but also include standards for the average U-value of the building envelope and further consider the energy source issue, by tightening rules for buildings using electric heating systems (Elmoroth, 2009). Stricter energy requirements and discouraging the installation of electric heating are part of the government's environmental strategy. The attention to energy used for space heating is understandable, as it is a potential area of energy savings and CO_2 emission reduction. In Sweden, approximately 650 million m^2 of indoor area requires heating, over half of which comprises residential buildings. Of total energy consumption in Sweden, one third, i.e., 160 TWh, is used in buildings, and almost 70% of this is used for space heating. Older building stock built before 1970 consumes on average approximately 250 kWh/m^2, while newer building stock consumes approximately 170 kWh/m^2 Boverket, 2002). The current BBR 16 Building Regulations (Boverket, 2009) requires that the specific energy demand (which includes heating/cooling, hot water, lighting, and electricity needed for operating building systems, such as pumps and ventilation; domestic electricity use is not included) for new buildings, located in the south climate zone of Sweden, should not exceed 110 kWh/m^2 of living area annually.

This regulation, 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 to 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 and passive house concept

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 buildings is energy-efficient design that allows the minimization of energy consumption throughout the building life cycle (Summerfield et al., 2009). Specifications that facilitate energy-efficiency gains include compact construction, minimum thermal bridge value, thermally insulated building envelope and windows (Figure 3), and adequate choice of heating and ventilation systems (Krope and Goricanec, 2009).

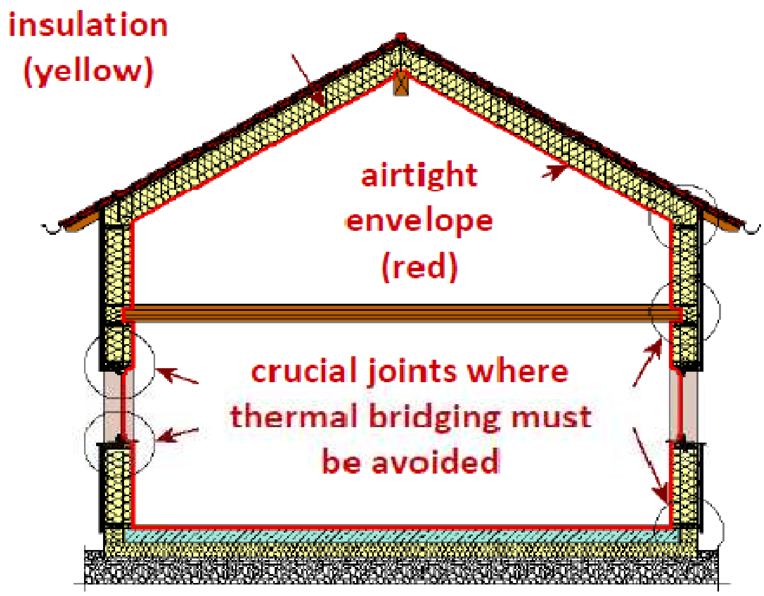


Figure 3. Passive house concept: airtight building envelope (original illustration: Passive House Institute, passipedia, www.passipedia.org; modified by author)

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. Definitions included in the Swedish standards for passive and mini-energy houses state that low-energy houses should aim to achieve better (Forum för Energieffektiva Byggnader, 2009b) or significantly better performance (Forum för Energieffektiva Byggnader, 2009a) than stated in the Swedish Building Regulations. FEBY passive house standards are fairly similar to international Passive House Institute standards (PHI, http://www.passiv.de), though the calculation principles were adjusted to suit those generally used in Sweden.

Table 1 compares Swedish Building Regulations BBR 16 (Boverket, 2009) and FEBY passive house standards (Forum för Energieffektiva Byggnader, 2009a).

Table 1. Brief comparison of passive house standards according to FEBY (Forum för Energieffektiva Byggnader 2009a) and the Swedish Building Regulations BBR 16 (Boverket, 2009)

Standard for various climate zones in Sweden	**FEBY Passive house standard, 2009** a) For dwellings without electric heating systems b) For dwellings with electric heating systems	**Swedish Building Regulation BBR16** a) For dwellings without electric heating systems b) For dwellings with electric heating systems
Specific energy demand [1)]requirement for zone (I) north	$\leq$58 kWh/($m^2 A_{temp+garage**}$) a $\leq$34 kWh/($m^2 A_{temp+garage}$)b	$\leq$150 kWh/($m^2 A_{temp*}$) a $\leq$95 kWh/($m^2 A_{temp}$) b
Specific energy demand requirement for zone (II) central	$\leq$54 kWh/($m^2 A_{temp+garage}$) a $\leq$32 kWh/($m^2 A_{temp+garage}$) b	$\leq$130 kWh/($m^2 A_{temp}$) a $\leq$75 kWh/($m^2 A_{temp}$) b
Specific energy demand requirement for zone (III) south	$\leq$50 kWh/($m^2 A_{temp+garage}$) a $\leq$30 kWh/($m^2 A_{temp+garage}$) b	$\leq$110 kWh/($m^2 A_{temp}$) a $\leq$55 kWh/($m^2 A_{temp}$) b
Heat loss	$\leq$0.30 l/s m² ±50 Pa, according to SS-EN 13829 standard	Quantitative values not specified
U-value [W/m^2 K]	U (for windows) $\leq$0.90–0.80 W/m^2 K according to standards SS-EN 12567-1 U (for building envelope elements) $\leq$0.15 W/m^2 K	U (average for building envelope) $\leq$0.50 W/m^2 K, a U (average for building envelope) $\leq$0.40 W/m^2 K, b U value for windows is not specified
Annual heating load [2)] for climate zone (I) north	$\leq$12 W/($m^2 A_{temp+garage}$) $\leq$14 W/($m^2 A_{temp+garage}$)	Installed electrical power for heating of dwellings with electric heating, $\leq$5.5 kW
Annual heating load for climate zone (II) central	$\leq$11 W/($m^2 A_{temp+garage}$) $\leq$13 W/($m^2 A_{temp+garage}$)	Installed electrical power for heating of dwellings with electric heating, $\leq$5.0kW
Annual heating load for climate zone (III) south	$\leq$10 W/($m^2 A_{temp+garage}$) $\leq$12 W/($m^2 A_{temp+garage}$)	Installed electrical power for heating of dwellings with electric heating, $\leq$4.5kW

1) 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 kWh/m2; expressed in purchased energy, i.e., end-use energy, measured at final level, purchased from distributor.
2) 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 W/m^2.
*A_{temp}: refers to the area within the thermal envelope where the temperature should be kept over 10°C (http://www.boverket.se/Kontakta-oss/Fragor-och-svar/Bygg-och-konstruktionsregler/Om-avsnitt-9-i-BBR/Atemp)
**$A_{temp+garage}$ refers to the A_{temp} area and garage area included within the thermal envelope (Forum för Energieffektiva Byggnader, 2009a)

2.3. Assessing project viability

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, internal rate of return, 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). Net present value (NPV) can be described by the following function:

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

(equation 1)

NPV: net present value of equity
NOI_i: net operating income through *i* periods
R: required rate of return
n: expected holding period
RV_n: residual value in the nth period TIC: total investment cost

Consequently, internal rate of return (IRR) can be described as:

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

(equation 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 a survey and personal interviews.

The survey

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 companies were chosen because they had experience of building low-energy housing. 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 leaders. The notification of survey questionnaires were sent to 34 companies (93 people) that had participated in at least one low-energy housing project in Sweden. Answers were collected using an on-line questionnaire from February to March 2010; thirty-four completed questionnaires were collected for a response rate of 37%. Respondents represented 24 companies (i.e., 71% of the contacted companies), 16 public and 18 private. 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).

The survey questionnaire and complete results appear in Appendix 1

Interviews

Twelve 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 low-energy housing 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 were obtained by survey and personal interviews. Survey questionnaire was sent to housing companies that were identified by market research as actively managing low-energy buildings. Only multi-family residential buildings with rental apartments were subjects of study.

The survey

Low-energy buildings were identified in the building stock of 18 public housing companies. The notification of survey questionnaire was sent to the person or people responsible for managing and operating indentified 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.

Most respondents were responsible for the management, operation, maintenance, and administration of low-energy multi-family residential buildings containing 30–60 dwellings each in production year 2008–2010. Energy requirement for most of these buildings 45–30 kWh/m^2 (including energy needed for space heating, hot water, and cooling as well as the electricity for building operation), meaning that the space heating values for those buildings meet or nearly meet the Swedish passive house standard (Forum för Energieffektiva Byggnader, 2009a).

The survey questionnaire and complete results appear in Appendix 2.

Interviews

Additionally 8 interviews were conducted with representatives of housing management companies in 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 aimed to acquire a deeper understanding of the different challenges of operating and managing low-energy versus conventional housing.

4. Results

4.1. Investment cost

Most respondents stated that the total investment cost of low-energy housing (LEH) was less than 10% 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% range, while only one quarter of the private companies gave this answer. Most of the private companies, i.e., approximately 60%, estimated that the extra investment cost of LEH was 5% or lower (Figure 5).

Public and private companies' opinions differ to some extent concerning the cost estimates. This difference may be because private companies tend 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.

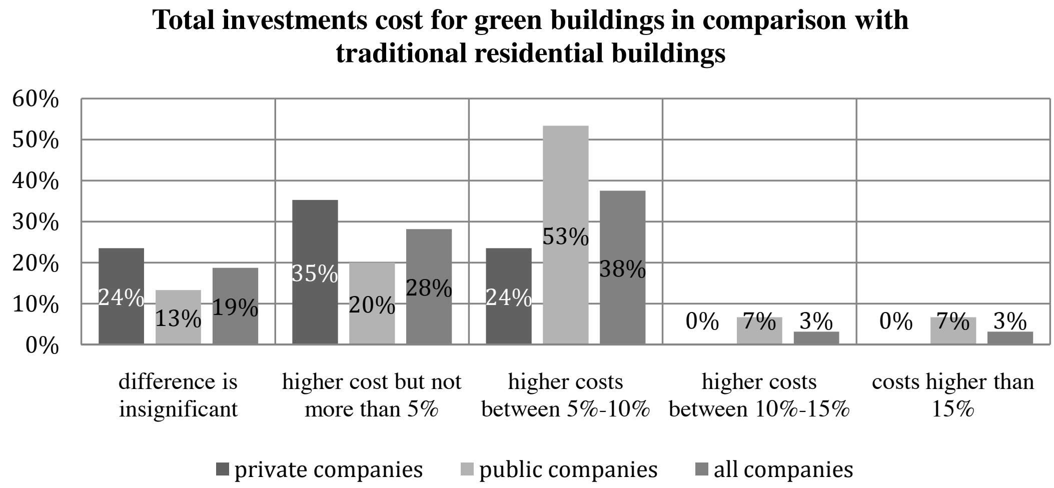
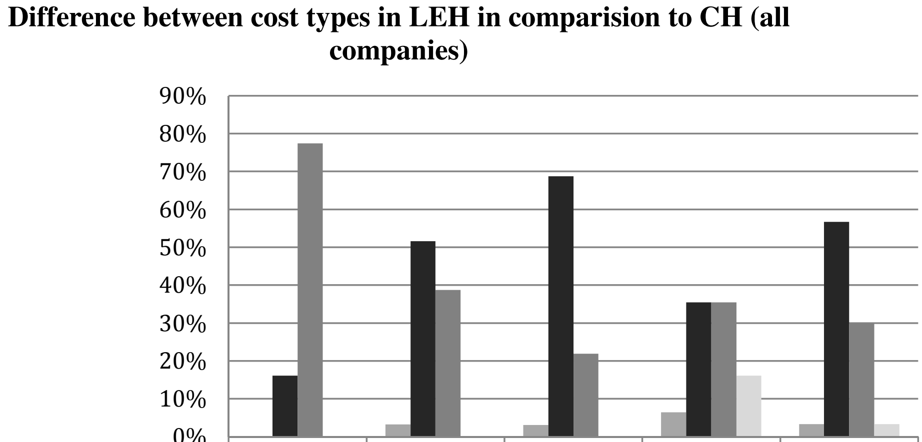


Figure 5. Total investment cost of green buildings compared with that of traditional residential buildings

Administration costs in LEH are no higher than in conventional housing (CH), except in the case of “reference projects”, where the increased costs often relate to organizing lectures and on-site visits. Nearly two-thirds of respondents said that LEH construction material was more expensive than CH material, which may relate to higher unit prices of more energy-efficient material (e.g., insulation and windows). Labour and design costs are also higher on LEH budgets (Figure 6). 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%) estimate that the design cost tends to be higher by approximately 10% in LEH projects; 40% of public companies agree with this estimate, though 50% of public companies consider the design cost to be about the same as in CH projects.



	administration and fees	design	construction material	installations	labor
significant cost difference (more than 20%)	0%	3%	3%	6%	3%
higher cost (about 10%)	16%	52%	69%	35%	57%
no or insignificant cost difference	77%	39%	22%	35%	30%
lower cost (about 10%)	0%	0%	0%	16%	3%

Figure 6. Cost type differences

Material

Materials are estimated to cost approximately 10% more for LEH construction and installation approximately 5% more. Investors said that, even though some installation costs (e.g., of the 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% more in LEH projects. One third of public companies estimated the insulation cost to be up to 20% 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% 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%) 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% 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 often do not assume that responsibility.

Energy cost

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 residents' 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. Financial calculations and profitability

Neither private nor public companies regarded calculated financial risk and uncertainty as higher in LEH than CH projects. Moreover, more private (60%) than public (30%) 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.

Private companies were convinced that constructing LEH is good business and that doing so will strengthen their market position (Figure 7). Public companies are not as clear in their plans regarding LEH construction, though 75% said that LEH has business potential.

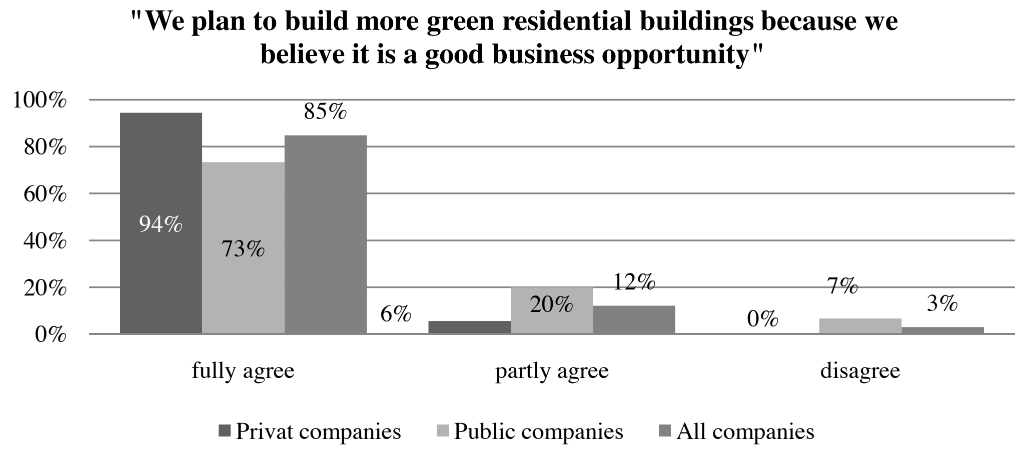


Figure 7a. Rationale for building low-energy buildings

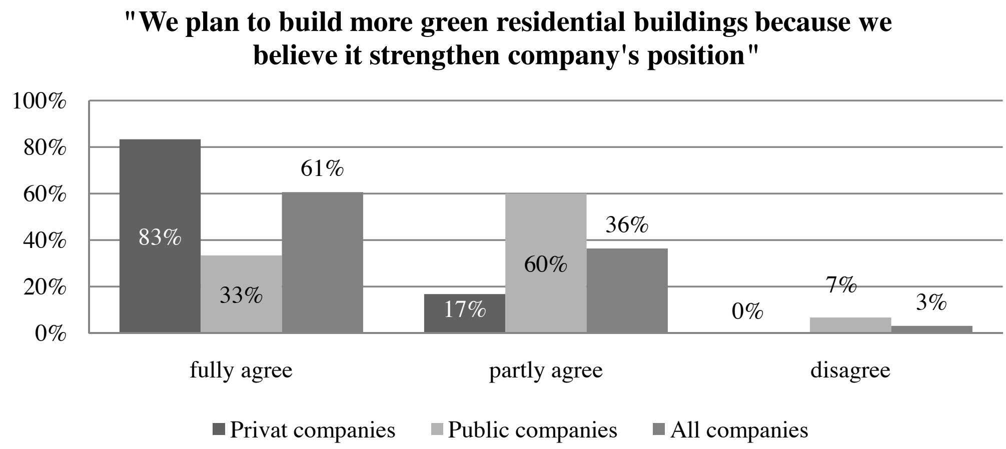


Figure 7b. Rationale for building low-energy buildings

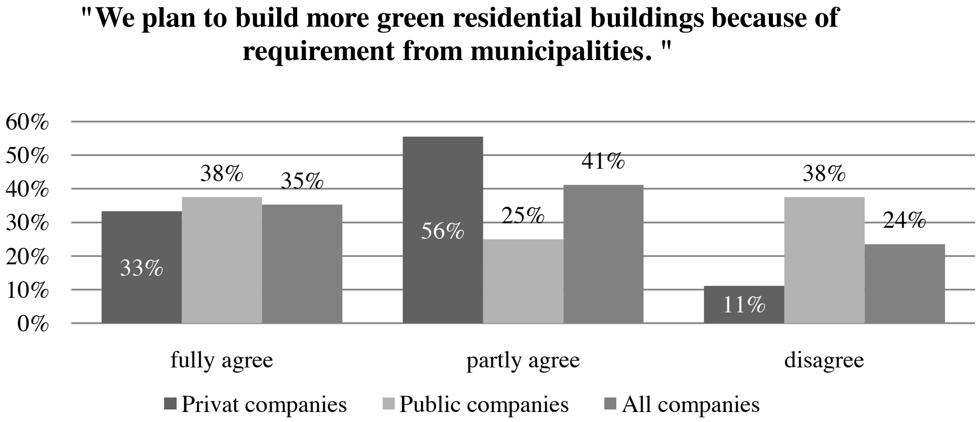


Figure 7c. Rationale for building low-energy buildings

Whereas private companies were looking into constructing various forms of low-energy dwellings (e.g., passive and near passive houses, zero-energy houses, and plus houses, public companies were concentrating their plans on passive and near passive houses (Figure 8). This finding illustrates private companies' long-term strategically competitive thinking, expectations of market development, and identification of future housing market demand.

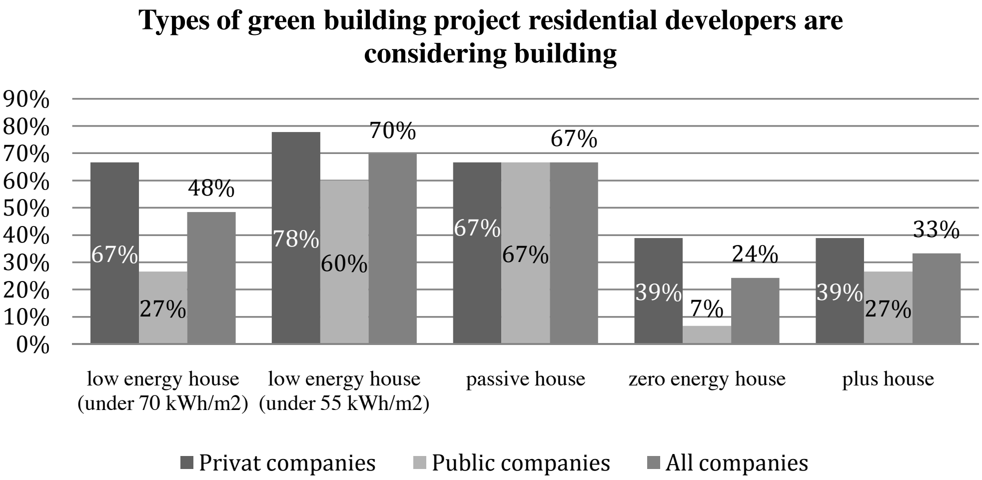


Figure 8. Types of green building projects residential developers are considering building

Opinions regarding the link between investment viability and energy efficiency are fairly evenly divided, though most private companies estimate that building housing with an annual energy requirement of 50–60kWh/m^2 constitutes the borderline for profitable investment (Figure 9).

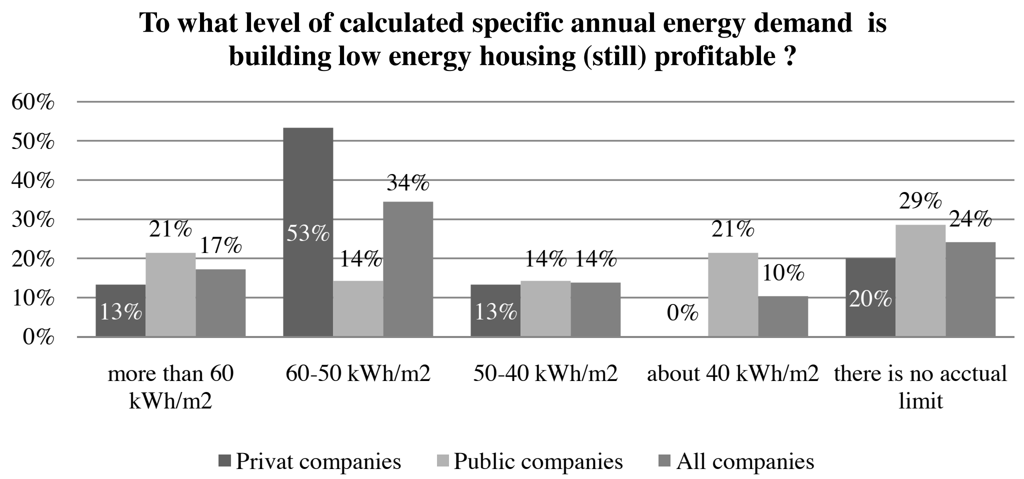


Figure 9. Specific annual energy demand reflects profitability limit for low-energy dwellings

4.4. Stimulants and outlook in the future

Generally private companies recognise factors which can be controlled by the company as ex. industrialization or construction components standardization as the factors that have the greatest effect on LEH market development. Public companies on the other hand identified external factors as subsidies and obligatory certification to influencing low energy building construction to a larger extent. All respondents assigned high importance to the Building Regulations and suggested that strengthening the Building Regulations have a strong influence (50%) on acceleration of low energy buildings construction (Figure 10).

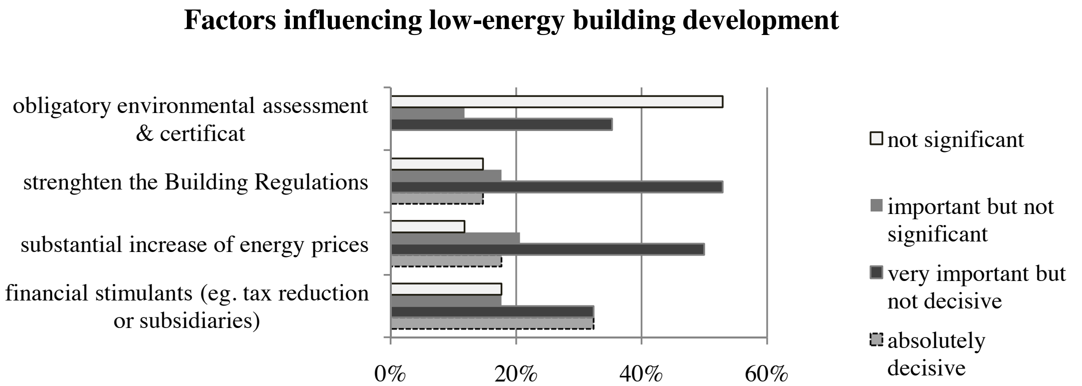


Figure 10 Factors influencing low-energy building development

Interestingly, according to majority of survey respondents obligatory environmental assessment and certification system has an insignificant effect on low energy housing development. Only 30% of private and 45% of public companies acknowledge obligatory environmental assessment to be an important factor. On the other hand majority of housing management companies believe in importance of environmental rating and stating their interest in participation in environmental assessment of their building stock.

Additionally, decrease of prices for environmentally friendly material was found to be an important factor, but it is rather development of construction new technologies and building concepts that can truly stimulate development of "green" construction (Figure 11).

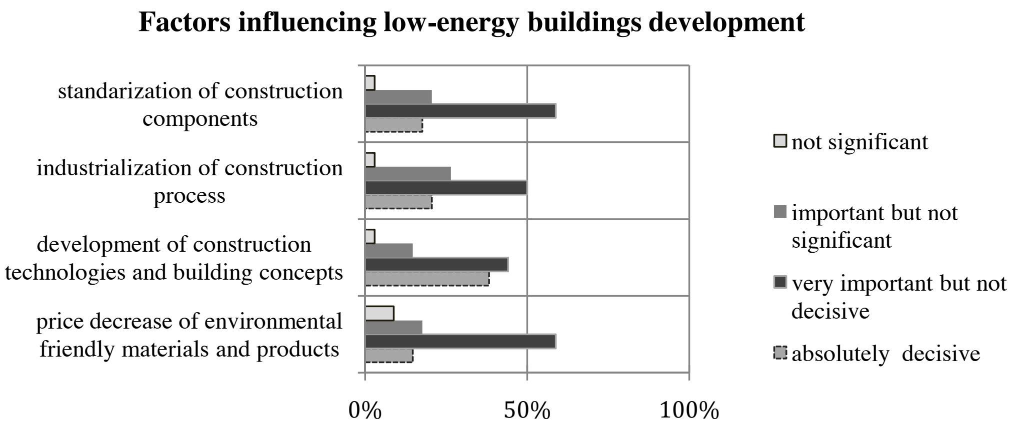


Figure 11 Factors influencing low-energy building development

5. Economic analysis

5.1. Data and elementary assumptions

Using feedback from investors and housing managers, we can attempt to assess LEH and CH investments and build a life cycle costing (LCC) model that allows for differentiation analysis. The main variables in investment analysis are extra investment cost, expected rate of return, and energy cost (specifically, heating cost). The results of the study indicate that low-energy buildings do not cost over 10% more to construct than do conventional buildings, and the average investment premium is estimated to be 6%. The average construction cost of new multi-family buildings in Sweden in 2009 was EUR 2663 per m^2 (SCB, Statistics Sweden, http://www.scb.se); in the following analysis, the total investment cost of a conventional dwelling is taken to be EUR 2660 per square metre of living area.

Investors do not account for higher risks in LEH calculations and indicate that prior experience of LEH projects significantly increases efficiency and profitability in ensuing LEH projects, so the discount rate, R, is the same for LEH and CH and can be expressed:

$$R = government\ bonds\ rate + risk\ premium$$

$$R = 2{,}3\ \%^{*} + r \qquad \text{(equation 3)}$$

(Sveriges Riksbank, Central Bank in Sweden, http://www.riksbank.com)

District heating is relatively common for new housing construction in Sweden and is used for both space and water heating. The space heating installed in LEH buildings in Sweden uses a heat recovery ventilation system with auxiliary heating, with electricity, district heating or hot-water heating as energy source and in some cases solar panels for hot water (up to 40% water heating savings). We assume that CH and LEH use the same heating source, i.e., district heating. Housing managers report that the operating cost of LEH is generally as projected, whereas the maintenance cost is comparable to that of CH. Hence, the annual specific energy demand is estimated as 110 kWh/m^2 reference area for CH, according to the Swedish BBR 16 Building Regulations (Boverket, 2009), and 50 kWh/m^2 for LEH, according to the Swedish passive house standard (Forum för Energieffektiva Byggnader, 2009a). Energy costs are assumed to increase 2% annually. In LCC, we omit maintenance cost, though we deduct EUR 10 per m^2 annually from the operating income for management cost. Building management cost here refers to activities the housing management company must undertake to ensure good building operation; activities include administration and planning, building performance optimizing, communication with tenants, and technical help in case of problems.

Net cash flow or net operating income (NOI) consist of income from rents, less operating and management costs. Potential income was estimated based on the average rent for new build public buildings in Sweden in 2009, which was approximately EUR 144 per m^2 (SCB, Statistics Sweden, http://www.scb.se); rent is assumed to be the same in both types of housing.

In assessing LEH and CH investment projects, the NPV (equation 1) and IRR (equation 2) equity investment models are used. Residual value, which captures a building's value at a given time, is intentionally omitted from calculations, which means that the net income from an investment at a time when NPV = 0 covers the total investment cost. In other words, we assume that the investor is unwilling to sell the building at any time. This allows the investor to eliminate uncertainty from future property valuation and focus on net present value, rate of return, and payback period.

5.2. LEH and CH investment analysis

The analysis indicates that the net present value of both types of projects is very similar and that the rate of return is fairly low, as the IRR (30 years) for LEH was 2.05% and for CH 2%, magnifying the importance of energy cost. If the energy cost increases, then the LEH investment is more profitable, as the difference between the IRR for LEH and CH increases at an annual rate of 5%; IRR CH (30) = 1.8% and IRR LEH (30) = 1.5%.

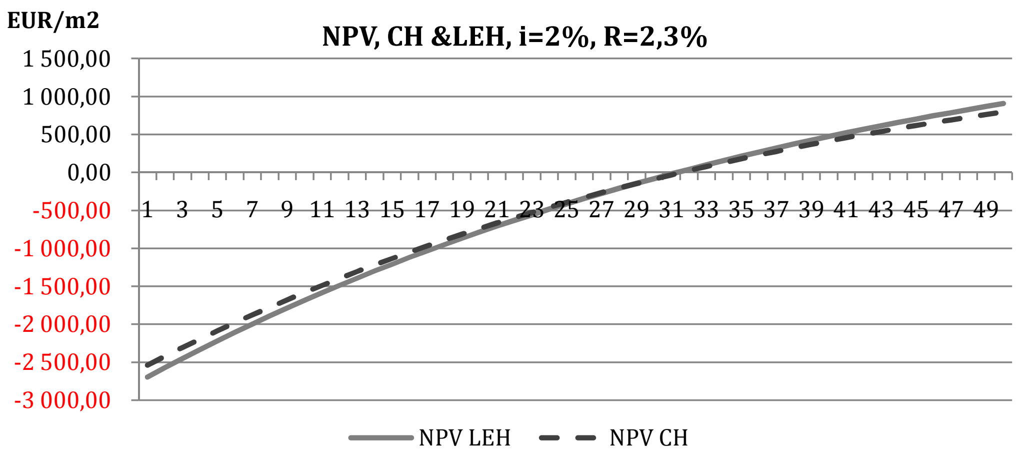


Figure 12. NPV for LEH and CH investments at *i* = 2% annual price increase for heating energy

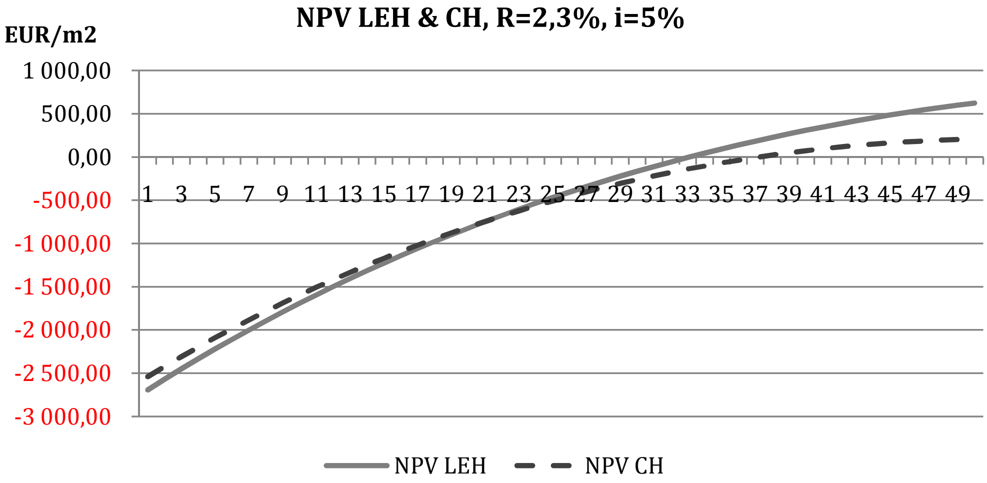


Figure 13. NPV for LEH and CH investments at *i* = 5% annual price increase for heating energy

Savings on energy allow for better cash flow in LEH projects, which is important from a financing perspective and a positive factor in relation to risk assessments.

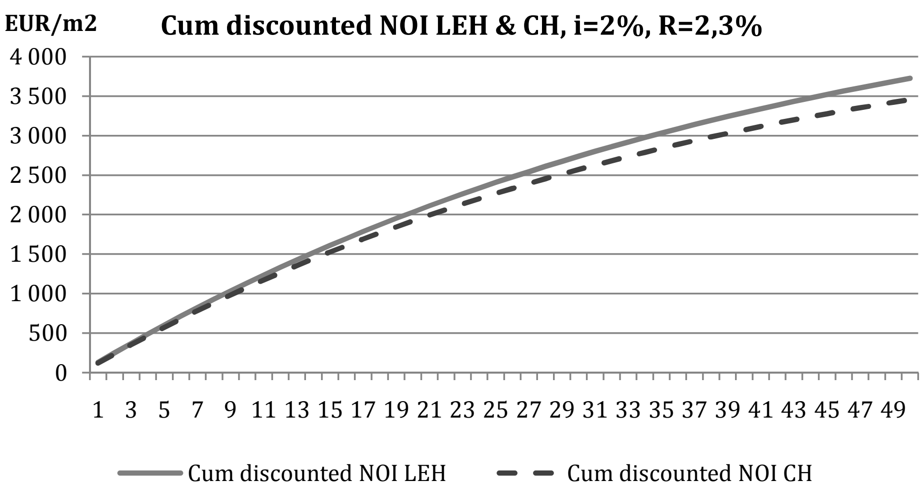


Figure 14 . Cumulative discounted net operating income at present values, at *i* = 2% annual price increase for heating energy and a discount rate of 2.3%

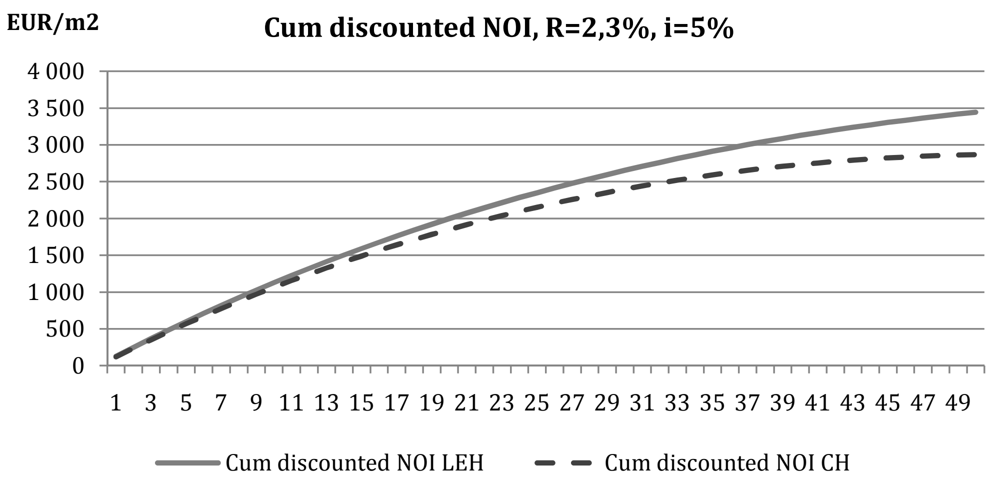


Figure 15 . Cumulative discounted net operating income at present values, at i = 5% annual price increase for heating energy and at a discount rate of 2.3%

To concentrate on variables that influence by investment types, we have undertaken LCC analysis for DNOI, which was difference between net operating income for LEH and CH. Concentrating on DNOI allows us to evaluate how the extra investment needed for LEH influences investment viability. The variables that can influence outcome of the analysis are the discount rate, extra cost of investment, and energy price change. The operating costs are elementary, reflecting only difference in heating cost, because hot water consumption and energy used for general building operation (e.g., energy needed for aggregate units, fans, and public lighting) is assumed to be equal in LEH and CH buildings.

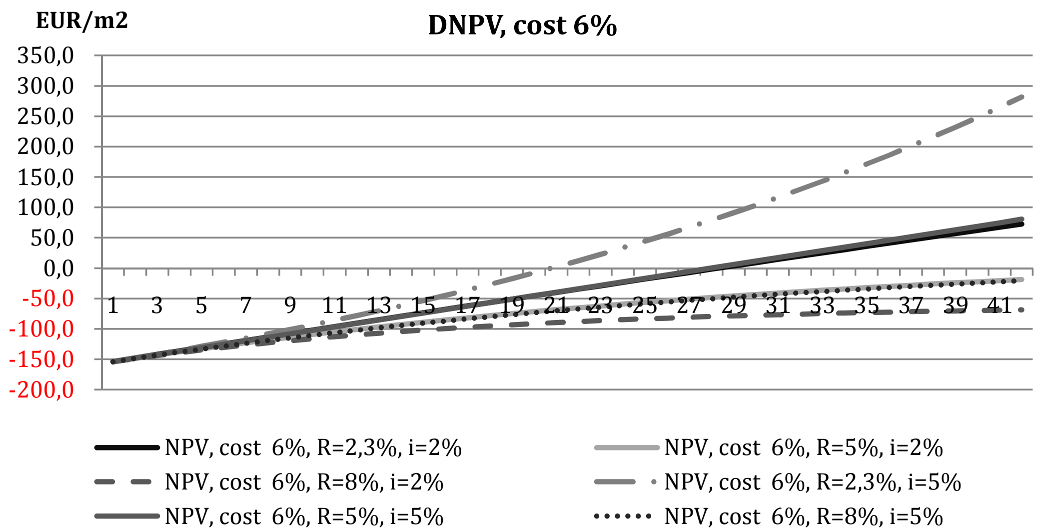


Figure 16. Net present value for DNOI; extra cost = 6%, i = 2%, annual energy price increase = 5%, and R = 2.3% and 5%

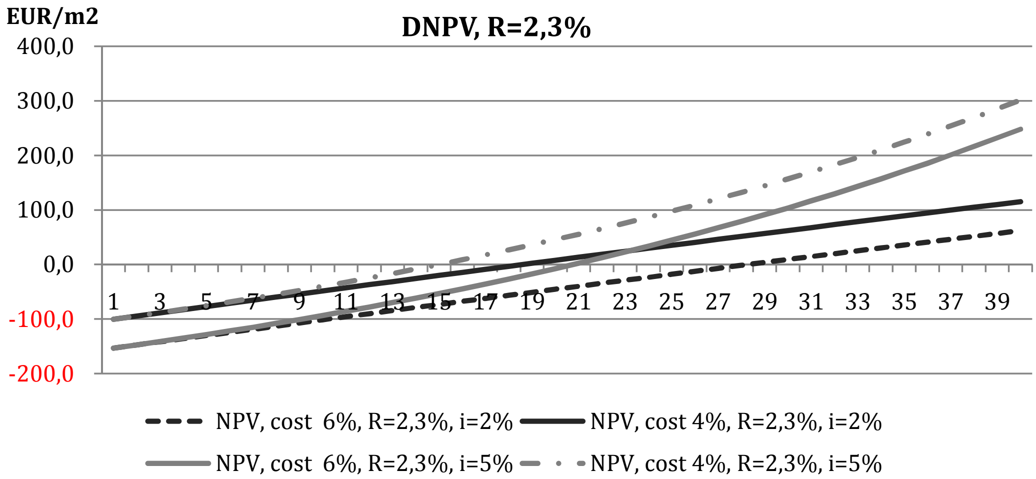


Figure 17 . Net present value for DNOI; extra cost = 4% and 6%, annual energy price increase = 2% and 5%, and *R* = 2.3%

Analysis indicated that:

a) The cumulative discounted NOI for LEH is better than for CH, which means that the cash flow for LEH is better even with an estimated 6% extra investment cost.

b) The greater the energy price increase, the better the cash flow of an LEH investment.

c) At a 2% annual energy price increase, the IRR (30) for LEH = 2.05% and for CH = 2.00%; at a 5% annual energy price increase, the IRR (30) for LEH = 1.8% and for CH = 1.5%.

d) At 2%, 5%, and 10% annual energy price increases, DIRR (30) = 2.6%, 5.4%, and 10.1%, respectively, DIRR- IRR for difference in net operating income between LEH and CH

e) Decrease in initial extra investment cost significantly influences the DNPV and payback period; the function is parallel and the difference in payback period for *i* = 2%, *R* = 2.3%, and extra investment cost = 6%, 4%, and 2% is 29, 19 and 9 years respectively which means that lowering the extra investment cost for LEH by two percentage points shortens the payback period with nine years.

f) Reducing the extra investment cost, of all the variables, exerts the greatest influence on DNPV; notably, this variable is somewhat under investor control.

6. Conclusion

The study demonstrates that, at present energy prices and 6% extra investment cost for LEH, there is no significant difference between income return on LEH and CH in the short term (i.e., up to five years), though the savings and income return on LEH are higher than on CH in the longer term. Moreover, if energy prices increase, the savings and income gap will increase, and LEH is expected to deliver higher value. The findings indicate that LEH is an attractive investment, especially in view of increasing energy prices; investors are recognizing this potential and are interested in developing LEH projects. What, then, is preventing an increase in LEH construction?

First, qualitative and quantitative aspects of LEH projects may differ from each other. Quantitatively, the costs of labour (e.g., training, hours worked, and required work accuracy) and of higher-quality materials, such as insulation, windows, and more advanced mechanical ventilation systems with heat recovery, add up to a higher investment cost. At the same time, accuracy of construction work and higher-quality material assure the achievement of qualitative objectives and future energy savings.

Second, high work accuracy is absolutely necessary for constructing air-tight, well-insulated, and energy-efficient buildings. Achieving this requires transforming conventional 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.

Nevertheless, most respondents agreed that experience gained during prior low-energy housing projects improves the efficiency and profitability of ensuing projects. Moreover, improvements in construction processes due to experience, competence, and ongoing monitoring (Turner, 1999) as well as improvements in cost position, for example, due to better procurement, strategic partnerships, and cost driver control (Porter, 1985), allow the investor and developer to control investment costs and improve the market position. One can observe this phenomenon in LEH construction only if such projects are *not* considered experimental attempts but rather standard production.

If the return on investment for LEH is better than for CH, why has conventional construction not yet been replaced by more promising energy-efficient construction? The current Building Regulations appears to discourage the development of energy-efficient buildings and the extra initial cost of low-energy buildings seems to overshadow future savings, particular in the case of investors who sell directly to the market and who have little incentive to consider reduced future operating costs (Nässen et al., 2008). The presented results indicate that practitioners see a need for change in the Building Regulations. The public housing companies are in some ways limited by other regulations, such as the Public Companies Procurement Law – Lag (2007:1091) om offentlig upphandling, and may be less willing to take on such projects, which are considered to harbour more uncertainty (Lind and Lundström, 2007). This might explain certain reservations towards involvement in LEH projects, especially if low-energy construction principles are unfamiliar to the investor.

Most investors recognized the business value of low-energy buildings and expressed willingness and readiness to invest in low-energy projects. This suggests that 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. On the other hand, LCC analysis indicates that low-energy dwellings are a better investment, even given their 6% extra investment cost. LEH investments generate better returns, as greater energy efficiency contributes to better cash flow. It is likely that energy prices will increase, so the profitability gap between low-energy and conventional buildings will grow to the greater benefit of energy-efficient buildings.

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Assessing low-energy building performance from the perspective of residents and housing managers

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Assessing low-energy building performance from the perspective of residents and housing managers

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Abstract

A fundamental goal for buildings is to deliver safe shelter and good indoor climate for the occupants. Creating the thermal comfort begins with modelling, which is based on mathematical descriptions of the designing building, its surroundings, and regional climate. The post-occupancy evaluation that includes occupant feedback can be used as a control measure to verify these calculations and an important link in closing the learning loop for investor, designer and builder. The evaluation and observations given by residents and housing managers are significant for designing and constructing good quality buildings, suited to occupant needs and expectations.

The aim of the paper was to attempt a buildings assessment based on occupant feedback and housing manager observations. To investigate indoor climate in energy-efficient housing, three low-energy multi-family residential buildings and a control group of three conventional multi-family buildings were carefully selected. The objective of this multi-case study was to investigate thermal comfort and capture the circumstances and conditions specific to passive multi-family housing.

The results indicate that the low-energy profile of a building had a limited influence on the decision to rent the apartment, however residents were generally proud to live in environmentally friendly buildings. Moreover, tenants also suggested that living in the energy-efficient buildings increased their environmental awareness, making their behaviour more environmentally friendly. Residents of low-energy houses gave better rating for indoor climate than that in conventional houses, which suggests higher satisfaction with the product; however, tenant feedback identified some problems with ventilation system and space heating.

Findings indicate that there no significant difference in operation and management of low-energy buildings, however information and communication activities are absolutely crucial in successful management of low-energy buildings. Moreover the low energy buildings requires the same amount or less adjustments than in conventional houses, which brings further evidence that in the life cycle perspective low energy houses are a better investment.

Key words: low-energy buildings, residential buildings, post-occupancy evaluation, indoor comfort

1.Introduction

1.1. Background

Today's buildings are expected to excel in performance, require minimum energy, and leave a minimal environmental footprint while being affordable and profitable investments. The troubling issue is whether the construction industry can achieve all these ambitious goals and still deliver good indoor comfort for building occupants. Various calculations and simulations indicate that low-energy buildings can deliver indoor comfort that equals or exceeds that of conventional buildings, though the results of field studies and post-occupancy evaluations have yet to verify these theoretical results.

Post-occupancy studies of building performance address questions of building efficiency by measuring building technical performance, investigating environmental performance (e.g. energy and water consumption) and occupant satisfaction (Leaman et al., 2010).

Post-occupancy studies of low-energy houses have concentrated mainly on quantitatively describing indoor climate and rarely use occupant surveys as a method of observing building efficiency. Studies of low-energy buildings in Sweden have focused mainly on calculated and monitored energy data (Wall, 2006), simulated and measured thermal performance (Karlsson and Moshfegh, 2006), and life cycle energy performance (Gustavsson and Joelsson, 2010).

1.2. Purpose and significance of the study

This paper addresses this research gap and investigates low-energy housing performance under Swedish conditions by surveying occupant satisfaction and housing manager experience. Surveys of occupants of low-energy and conventional houses are used to compare thermal comfort and examine differences in comfort that may be related to living in low-energy houses. We also try to understand challenges related to managing, operating, and maintaining highly energy-efficient housing.

This paper specifically aims to:

a) investigate the weighting of environmental factors when making apartment rental decisions
b) investigate thermal comfort in low-energy houses
c) explore possible differences between living in low-energy and conventional housing
d) explore the benefits and challenges of managing and operating low-energy housing

Thermal comfort modelling is based on mathematical descriptions of the building, its surroundings, and regional climate; occupant feedback is used as a control measure to verify these calculations and as an important link in closing the learning loop. Occupant feedback as part of post-occupancy evaluation can be used in formulating guidelines for developing successful low-energy housing. Furthermore, the study and findings should also interest policymakers and advisors for the national strategy for nearly zero-energy buildings, which is in line with European Council Directive 2010/31/EU (European Parliament and Council, 2010).

1.3. Scope and limitations

This paper approaches building evaluation from the end-user perspective; in other words, we attempt to assess buildings based on occupant feedback and housing manager observations. This stage of building assessment excludes measured energy or water consumption and is limited by the number of observations and access to information.

The response rate and the quality of responses might be determined by occupants motivation (Oppenheim, 2005), which in the studied cases might be related for example to strong disappointment or dissatisfaction with apartment. On the other hand, the reason for non-respondents unwillingness to take part in the study might be unrelated to studied topic and be coincidental (Oppenheim, 2005). There is, however, no indication that respondents were more motivated to express their dissatisfaction or satisfaction with apartment. The demographic characteristics of respondents in the presented study do not suggest disproportion in collected responses.

1.4. Organization of this paper

The paper is organized as follows: section 2 briefly reviews the theoretical background and relevant literature; section 3 discusses methodological considerations and the data collection; section 4 presents the results and analysis; while section 5 summarizes the discussion and conclusions.

2. Theoretical background and literature overview

2.1. Low-energy housing and the Passive House concept

A common understanding is that the performance of low-energy buildings exceeds that specified in the building code and regulations. Low-energy construction requires compact construction, minimum thermal bridges, a thermally insulated building envelope, energy-efficient windows, and adequate heating and ventilation (Krope and Goricanec, 2009). Years of study and experience of designing and building low-energy housing contributed to what is called the 'Passive House' concept (Feist et al., 2005). The Passive House Institute (PHI) of Darmstadt, Germany, 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' (PHI, http://passipedia.passiv.de). The Passive House concept is illustrated in Figure 1.

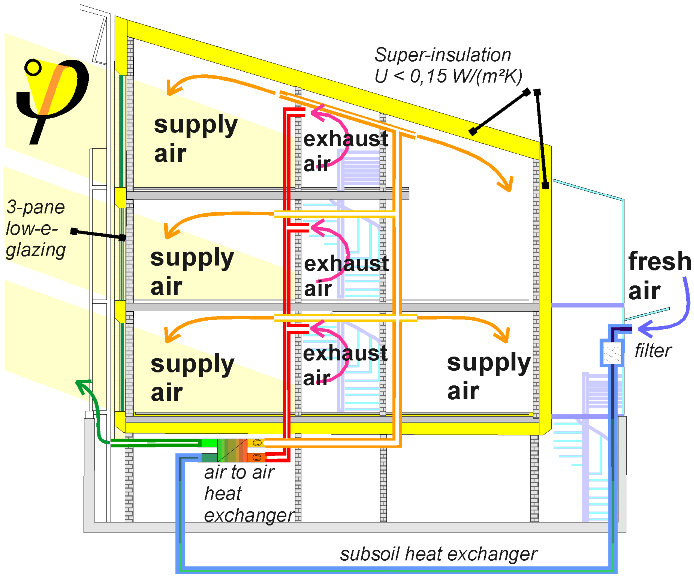

Figure 1 Passive house concept as described by PHI (Feist, W. First Step; What can be a Passive House in your region with your climate?)

It is crucial that the building envelope is well insulated and constructed with minimal thermal bridges. It is recommended that annual space heating (i.e. energy for heating and electricity for operating the ventilation system) should not exceed 15 kWh/m^2 (Feist et al., 2005), and/or that the peak heating load should not exceed 10 W/m^2 of reference area. Further PHI standards emphasize the importance of the energy source and require that the annual primary energy demand (i.e. sum of energy used for heating, domestic water heating, and auxiliary and household electricity) should not exceed 120 kWh/ m^2 of net floor area within the thermal envelope (Feist et al., 2007). Wolfgang Feist, the PHI founder, points out that, while the Passive House principle remains the same in different climates and regions, achieving thermal comfort entails the application of specifically adapted design and construction solutions (Feist, W. First Step; What can be a Passive House in your region with your climate?)

The Passive House concept has proved especially popular in Germany, Austria, and Switzerland, where many passive residential and non-residential buildings (including schools) have been built. Sweden is no stranger to the concept, though the passive house market is taking time to develop. According to a market report (Forum for Energieffektiva Byggnader, 2009b), approximately 400 dwellings using passive house technique have had been built in Sweden as of March 2009. In Germany, 300 dwellings meeting Passive House standard had been built by 1999 and between 6 000– and 7 000 by the year 2006. (Feist W., 2006).

Forum för energieffektiva byggnader (FEBY, the Forum for Energy-efficient Buildings), the organization that promotes building and renovation to energy-efficient standards in Sweden, formulated standards for passive houses based on PHI requirements, but adapted the values and calculation methods to Swedish practice, therefore FEBY's passive house criteria differ somewhat from PHI standards.

Most low-energy buildings described in this paper meet or nearly meet FEBY passive house standards; however, to avoid confusion between the FEBY and PHI standards, the studied Swedish buildings are referred to as low-energy housing.

2.2. Thermal comfort

Buildings primarily provide shelter for their occupants, but it is also important that they provide a healthy indoor environment. the Swedish Building Regulations (Boverket, 2006, 2008) establishes general standards for air quality, water quality, lighting, temperature, and hygiene and makes recommendations for indoor temperature calculations, air quality, ventilation design, and lighting. The Swedish passive house standard (Forum for Energieffektiva Byggnader, 2009a) complements these requirements and additionally sets expected minimum values for sound quality, thermal comfort, and building envelope performance (Table 1).

Table 1 Indoor climate requirements and recommendations of Swedish passive house standard for residential dwellings (Forum for Energieffektiva Byggnader, 2009a)

Sound quality	Minimum standard B, according SS 02 52 67 for bedrooms
Thermal quality	Recommended windows U<0,90 W/m^2K For other building envelope elements U<15 W/m^2K Air leakage at 50Pa, n_{50}<0,3l/(s, m^2) Overheating precautions: marginal temperature in April–September period maximum 10% over 26°C in most critical rooms
Ventilation	Heat recovery aggregate unit η>70%, maximum temp 52°C, minimum air flow 0,35 l/(s,m^2)

Energy calculations, modelling, and simulations allow for designing a building, but post-occupancy evaluation allows for assessment of created indoor climate. On the other hand the thermal comfort is a mental condition that expresses satisfaction with the thermal environment (International Organization for Standardization, 2005); it is a subjective opinion that varies depending on various psychological, sociological, cultural, and physical factors. Moreover, the perception of comfort can change over time and is not always predictable (Nicol and Roaf, 2005). Studies have produced two mainstream thermal comfort models: static and adaptive. The static model is based on the heat balance model and assumes that people cannot influence, or have very limited possibilities of influencing, their thermal environment (Kwok and Rajkovich, 2010). The adaptive model of thermal comfort takes account of occupants' behavioural adjustments (de Dear and Brager, 1998a), which can be defined in three ways: personal adjustment (e.g. changing clothing and activities), technological or environmental adjustment (e.g. opening windows and switching on fans or heating), and cultural adjustment (de Dear and Brager, 1998b). The principle of the adaptive approach is that, when change occurs and an occupant experiences thermal discomfort, he or she will seek ways to find optimum thermal conditions again, i.e. to experience thermal comfort (Nicol and Humphreys, 2002). Nicol and Roaf (2005) and Nicol and Humphreys (2002) emphasize that comfort results from dynamic interaction between occupant and building, which means that occupant satisfaction reflects on how well the building and occupant interact.

One way to learn about building performance and occupant–building interaction is via post-occupancy evaluation (POE). Interest in POE has recently increased due to concerns relating to climate change and human impact on the environment, and to construction regulations and standards imposing more efficient building performance and its effect on indoor environmental quality. Although the performance of energy-efficient buildings has attracted considerable interest, relatively little attention has been paid to post-occupancy evaluation (Bordass et al., 2001c). This neglect is partly due to inconsistent incentives for owners, developers, and designers to undertake or even get involved in post-occupancy building evaluation (Zimmerman and Martin, 2001). POE entails a certain risk, as it may deliver both good and bad news at the same time, for example, demonstrating good building performance but also identifying problems (Bordass et al., 2001c), which raises questions of who should take responsibility for any shortcomings. Furthermore, it is unclear who should initiate, manage, and pay for POE: the client, developer, or designer. In light of the risks and possible liabilities connected to POE results, all parties involved require convincing evidence of its value to become involved in a POE (Cooper, 2001).

The Probe project (Bordass et al., 2001a, 2001b, 2001c; Cohen et al., 2001; Leaman and Bordass, 2001) and other studies employing feedback techniques (Bordass and Leaman, 2005; Bordass and Way, 2005) demonstrate the value of POE for all parties involved in building design, construction, and operation. The feedback received from the occupant survey was particularly valuable, as the results provided better understanding of building and installation performance and of occupant preferences.

Post-occupancy studies of low-energy and passive apartment housing have typically concentrated on evaluating building performance based on measured data rather than on occupant survey results, though a few such studies have investigated resident satisfaction with low-energy or passive houses. The most comprehensive post-occupancy field study was part of the CEPHEUS project (Schnieders and Hermelink, 2006), and the results indicated that occupants of the investigated passive housing were generally very satisfied with the indoor climate, though occupant feedback also revealed some shortcomings in ventilation system design and operation. The latest comparative study (Mahdavi and Doppelbauer, 2010) of low-energy and passive apartments in Austria suggests that buildings deliver good thermal conditions and that occupants are generally satisfied with indoor climate. The passive house occupants' acceptance of the ventilation system was quite high, though some problems regarding low humidity in winter were reported.

The uniqueness of individual building projects requires that project-specific construction and system solutions be devised depending on location, regional climate, and comprehensively understood design. Because of the unique attributes of buildings, changing climate conditions, and the fact that energy balance calculations for low-energy buildings allow very little margin for error, consecutive investigation of thermal comfort in low-energy buildings is essential. Bearing in mind that thermal comfort 'expresses satisfaction with the thermal environment', it is imperative to study the satisfaction of residents of low-energy buildings.

3. Method and data collection

3.1. General research design

To investigate indoor climate in energy-efficient housing, we carefully selected three low-energy multi-family residential buildings as our case study objects. The cases were evaluated using a control group of three conventional multi-family buildings. The objective of this multi-case study was to capture the circumstances and conditions specific to passive multi-family housing. The studied low-energy residential buildings were selected according to the following criteria:

- multi-family residential buildings meeting or nearly 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. elderly and student housing was not considered)
- publicly or privately owned rental apartment buildings

Conventional housing (CH) was not selected at random but carefully chosen, so that comparison with the low-energy housing (LEH) could be done in the best manner. It was decisive that the CH control buildings be located in the same region (and preferably municipality), have the same number of apartments, be of similar ages, and preferably be owned and managed by the same housing companies.

3.2. Overview of the buildings

The buildings are divided into three groups (pairs) according to their locations.

The first pair of buildings is in location A, one of Sweden's biggest cities on the west coast, with approximately 500,000 inhabitants. The low-energy and the conventional buildings here are close neighbours, located just outside the city centre (accessed with public transit in approximately 10 minutes), in a popular area near the harbour. The surveyed tenants occupied both the CH A and LEH A buildings at approximately the same time, i.e. summer–autumn 2008.

The second pair of buildings is also located on the west coast of Sweden, in a city with approximately 40,000 habitants. The low-energy house is located in a newly developed area just outside the city, accessible from the city in approximately 10 minutes by public transit, surrounded by forest and overlooking a nearby lake. The conventional house is centrally situated near a park and recreation area. The surveyed tenants occupied both the CH B and LEH B buildings in period from September to December 2009.

The third pair of buildings is located in a small city on the west coast of Sweden with approximately 22,000 habitants. The low-energy building was occupied in 2007 and is situated near forest and 2 km from a local beach. The city centre is just few kilometres away. The conventional building is located in the city centre and was occupied in 2004.

3.3. Technical overview

All studied LEH was built using passive house technologies, i.e. the buildings are very well insulated and highly energy-efficient windows were installed. All buildings were 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 an auxiliary heating supported by electricity, hot water heating or district heating to distribute warm air of the desired 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 heating system, as each apartment in LEH C has in-floor heating in the hall and bathroom. In the LEH buildings, water is mostly heated by district heating. In LEH A and LEH C approximately 30% of total hot water demand comes from renewable energy generated from e.g. solar panels.

Individual metering systems for domestic electricity and water were installed in all LEH units. Residents of LEH buildings pay a base 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.

3.4. Tenants

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 a link indicated in the cover letter. Respondents were asked closed-ended questions, but could comment on each question as well.

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 housing; CH – conventional housing

The residents of the selected buildings varied widely, from single people, families with young children, a families with teenaged children, to elderly 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, as can be seen in Table 3.

Table 3 Respondent characteristics

Gender	LEH	CH
man	43%	45%
woman	57%	55%

Age	LEH	CH
20-30	20%	20%
31-40	19%	22%
41-50	12%	11%
51-60	18%	15%
60-65	6%	6%
>65	25%	24%

LEH – low-energy housing; CH – conventional housing

The survey questionnaire and complete results appear in Appendix 3.

3.5. Housing management companies

Data about the operation and management of low-energy houses were obtained by survey and personal interview. A survey was sent to housing companies that market research identified as actively managing and operating rental low-energy buildings. Only multi-family residential buildings with rental apartments were studied.

LEH buildings were identified in the building stock of 18 public housing companies. Survey were sent to the person or people responsible for managing and operating identified LEH buildings, for a total of 30 recipients. The number of survey recipients per company varied depending on the size of the housing company and number of LEH buildings managed. Answers to on-line questionnaire were collected from November to December 2010. Nine people, each representing a different housing company, responded to the survey.

The survey questionnaire and complete results appear in Appendix 2.

In period of approximately one year, i.e. December 2009–February 2010 seven interviews were conducted with representatives of housing management companies, which actively managing and operating rental low-energy buildings. Three interviews were face-to-face, open-ended interviews and four were scheduled telephone interviews. The interviewees represented one private and four public companies. The goal of the interviews was aimed to acquire a deeper understanding of the different challenges of operating and managing low-energy versus conventional housing.

4. Results

4.1. Environmental factors: their importance

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 changed health or financial circumstances. A central location, good surroundings, neighbourhood safety, ample apartment size, and good apartment design were the indisputably decisive factors. Those factors were so highly valued that they could outweigh dissatisfaction with other factors, such as building quality. Generally, the same factors influenced the decision making for residents of both low-energy and conventional buildings (Figures 2 and 3).

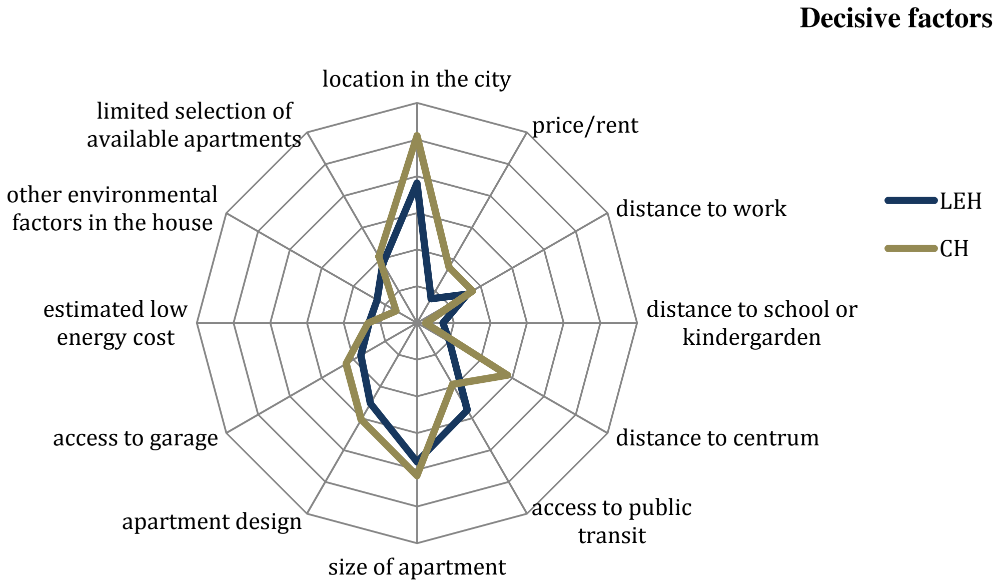

Figure 2 Decisive factors influencing apartment rental decisions

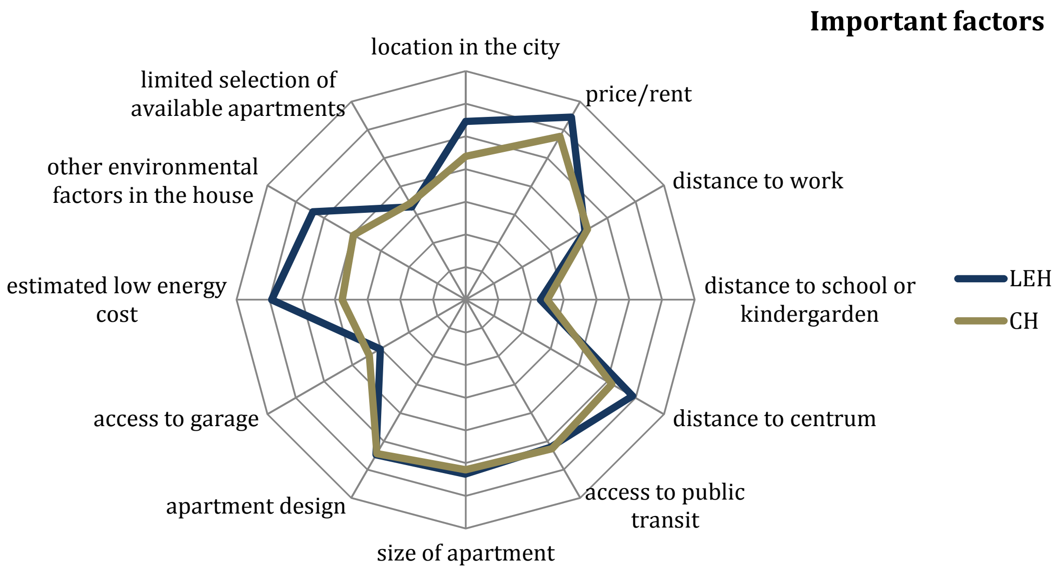

Figure 3 Important factors influencing apartment rental decisions

For most respondents who live in LEH, the fact that their buildings were constructed as low energy building had no impact on the decision to rent the apartment (75%). On the other hand, 25% of LEH residents admitted that the expected low energy consumption of the building was an important factor influencing their decision making. It was mainly LEH residents in locations A and C who took the buildings' low-energy profile into consideration, whereas LEH residents in location B ignored this factor (Figure 4). This difference may be related to the limitations of the housing market and the insufficient quantity of newly built rental apartments.

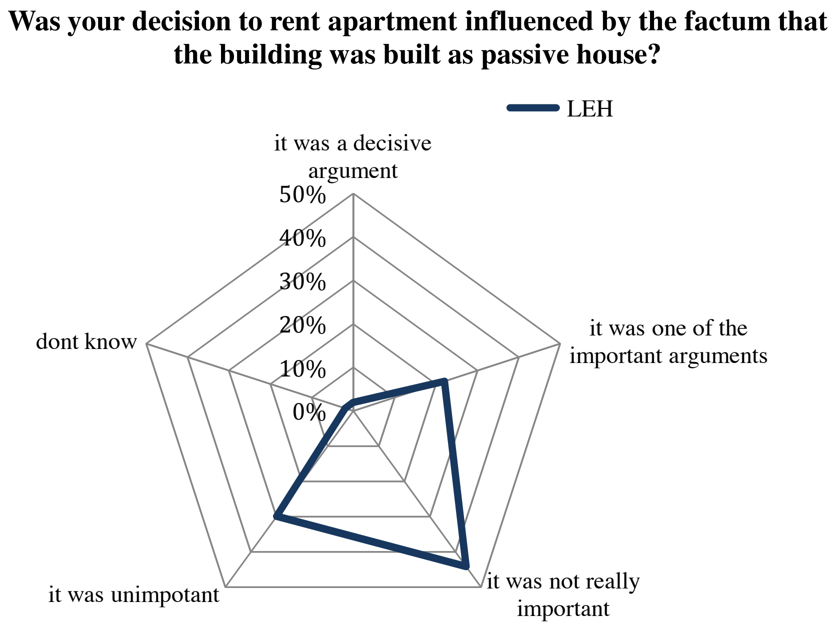

Figure 4 Influence of LEH features on prospective tenants' decision making

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, making their behaviour more environmentally friendly.

Respondents generally supported the environmental assessment of buildings and acknowledged the importance of such ratings, although almost 50% doubted that the results of the buildings' environmental evaluations would have practical implications for them. The housing management companies also believed in the importance of environmental assessment of buildings, and many expressed interest in assessing their building stock; however, a few housing managers were concerned that results of the environmental evaluation would have few concrete implications for the housing company.

4.2. Indoor thermal climate

More LEH residents than CH residents found the indoor temperature too cold in winter. On the other hand, CH tenants were more likely than LEH tenants to find the indoor temperature too warm in summer (Figure 5) and were consequently more likely to use supplementary cooling.

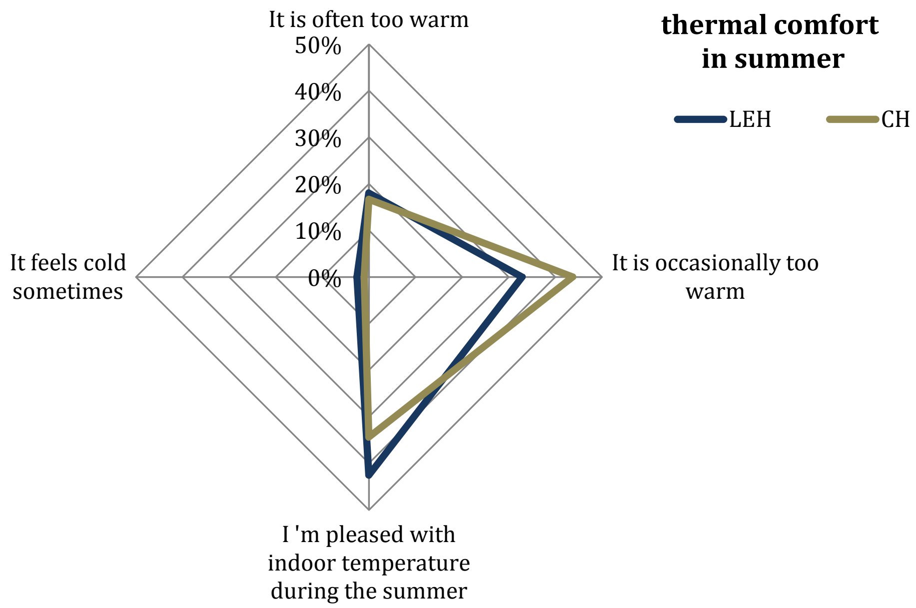

Figure 5 Indoor temperature in summer

Detailed evaluation demonstrated that residents of LEH B experienced the most problems with thermal comfort. Their difficulties with indoor temperatures in winter may be related to construction and design factors or to a faulty or insufficient heating system. At this stage, it is difficult to identify the source of these thermal problems; further research is needed to determine at what design or building stage this problem could have been prevented. The company managing LEH B is currently assessing various solutions to this problem that ensure good thermal comfort in the affected dwellings.

Tenants would usually try to influence indoor temperature by using building features (e.g. adjusting the heating system or opening windows) or by adapting their behaviour (e.g. choosing different clothing) (de Dear and Brager, 1998b). However, if those actions were insufficient and residents still experienced thermal discomfort, they sometimes took a more ‘radical’ approach, actively deciding to purchase electric heating or cooling equipment. This had three consequences. First, the use of supplementary heating and cooling is recorded on the electricity bill, but is not reflected in the building performance record. Second, such devices may affect the quality of indoor climate; for example, using electric heating contributes to very dry air and may unbalance the ventilation. Third, since these residents felt a need to take ‘radical’ action, this may influence their perceived environmental control and hence their satisfaction (Leaman and Bordass, 1999).

One fifth of LEH residents admitted to using supplementary heating either often or occasionally (Figure 6). However, closer analysis reveals that two thirds of those who used supplementary heating were occupants of LEH B.

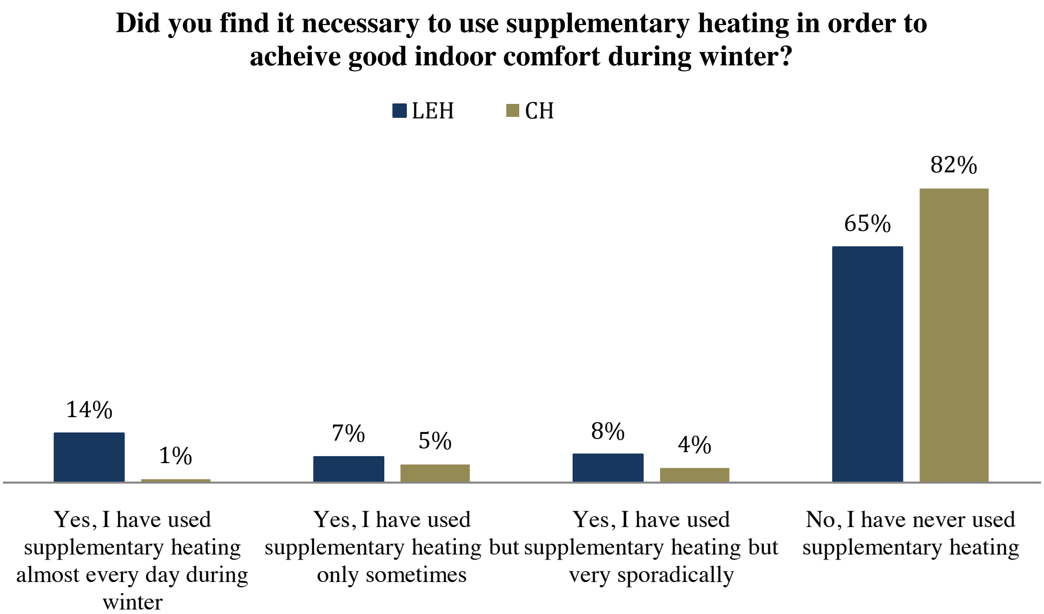

Figure 6 Use of supplementary heating in winter

Residents of LEH A were generally pleased with the indoor temperature year round; 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 in each dwelling.

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 dwelling’s location in the building.

Many CH residents (40%) said that they sometimes found their apartments too cool. No unusual problems were reported with heating system (i.e. radiators), though the heating system in CH A was fine tuned relatively late in the season, and tenants sometimes found indoor temperature too high in the first winter.

More common problems reported in conventional buildings referred to window quality and drafts, especially in CH C. Those problems were not reported by the occupants of the LEH buildings. This problem could be because CH C was built in 2004 when windows were not as energy efficient as those used in later projects.

Ensuring good thermal comfort in summer can also be a challenge. However, the LEH occupants are more satisfied with indoor temperature in summer than are the CH tenants (Figure 5), who were more likely to use supplementary cooling in summer (Figure 7).

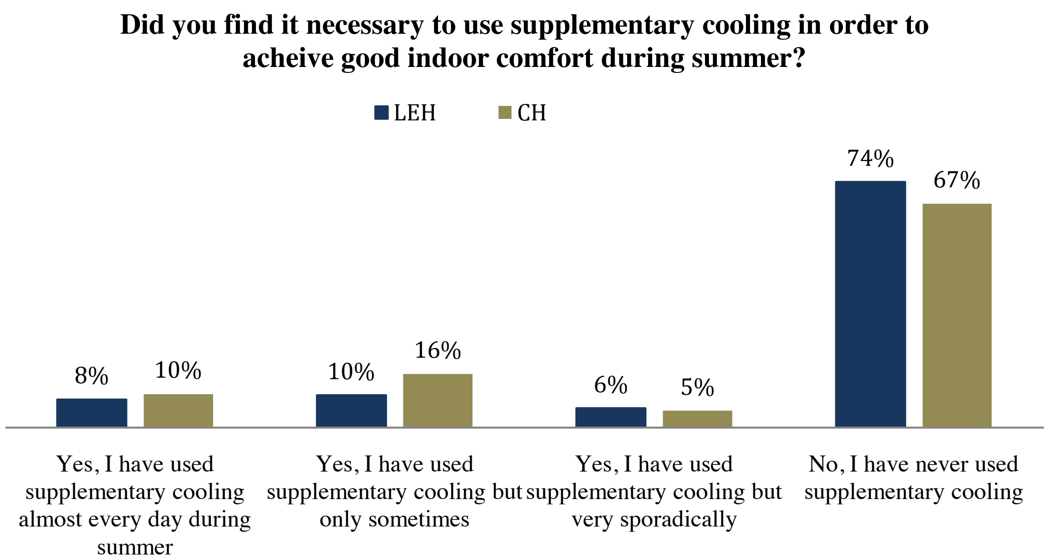

Figure 7 Use of supplementary cooling in summer

Simulating the energy balance for the whole building and for the most critical dwelling units in a building (e.g. top-floor and corner apartments) is important in LEH, as low-energy buildings are very sensitive to energy balance miscalculations. Underestimated heat losses can result in a need for supplementary heating, whereas underestimated heat gains can result in overheating, especially in summer. 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.

4.3. Building quality and indoor climate

LEH residents assigned much higher assessment scores, hence expressed higher satisfaction, with sound insulation (Figure 8a) and air quality (Figure 8b) than CH residents.

LEH tenants appreciated the sound insulation from neighbours and outside noise, which is largely related to the thick, well-insulated walls and high-quality windows used in LEH construction. Furthermore, they highly value the fact that the apartments are filled with sunlight, often describing their apartments as light and airy.

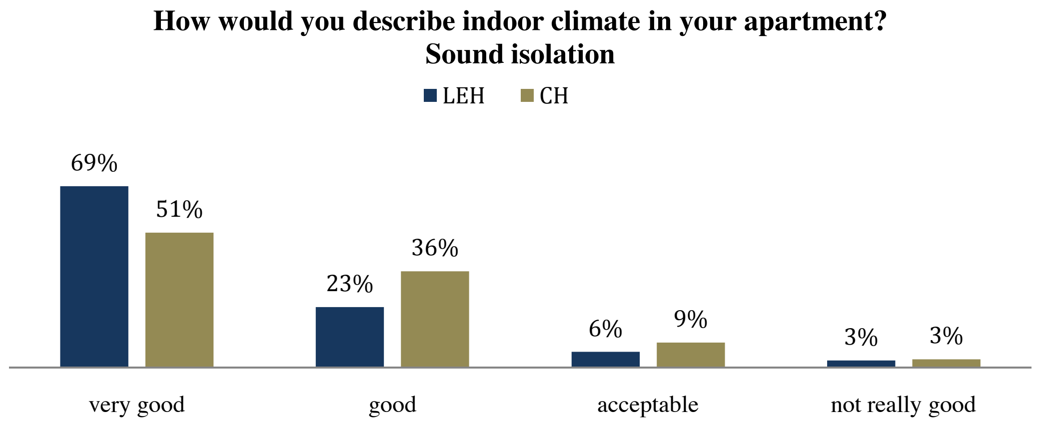

Figure 8a Satisfaction with indoor climate, quality of sound insulation

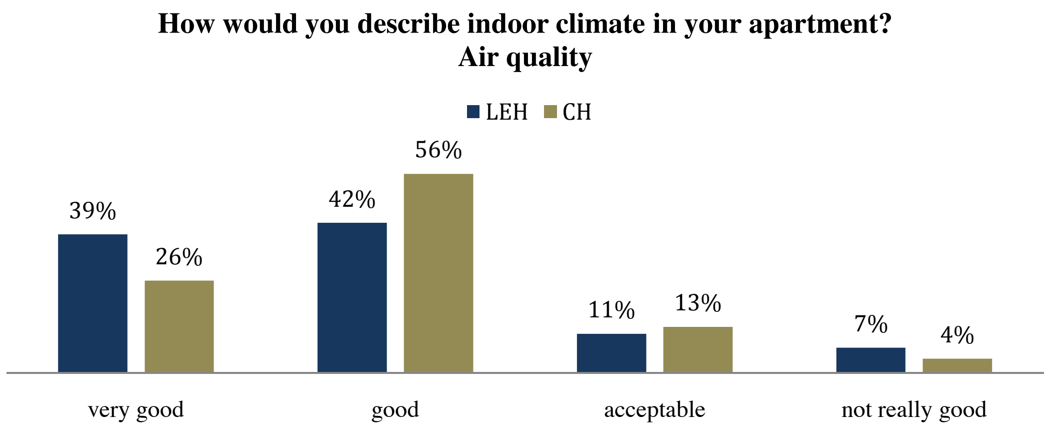

Figure 8b Satisfaction with indoor climate, air quality assessment

Ventilation systems can cause problems in both low-energy and conventional buildings. The most troublesome was the spread of cooking smells through the ventilation system into other apartments. LEH occupants, in general, were happier with the ventilation system than were CH occupants. Mechanical ventilation systems equipped with heat exchangers can reduce air humidity, and LEH tenants often described the indoor air as dry. 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 and over-pressure in parts of the dwellings.

LEH tenants positively described the minimal system adjustments that were necessary; rather, it was in the CH buildings that more intrusive adjustments were needed (Figure 9).

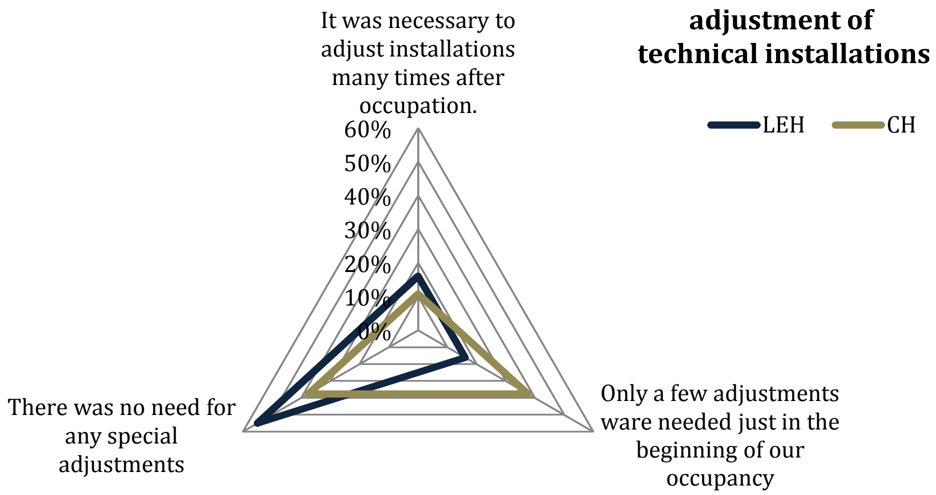

Figure 9 Required system adjustments

4.4. Is low-energy housing any different from conventional housing?

4.4.1. The occupant perspective

In general, most LEH residents stated that there is some difference between low energy building and conventional building (Figure 10). This difference has not been directly related to difference in tenants' behaviour (Figure 11) or technical solutions in the building (Figure9).

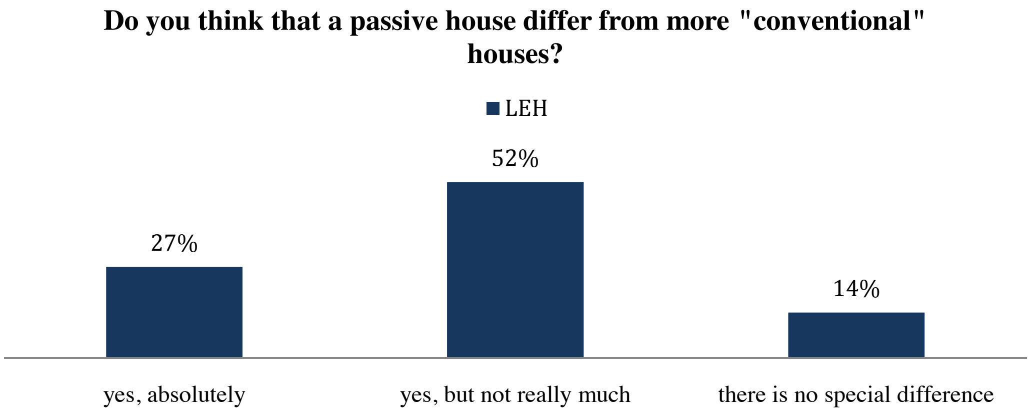

Figure 10 General difference between LEH and CH

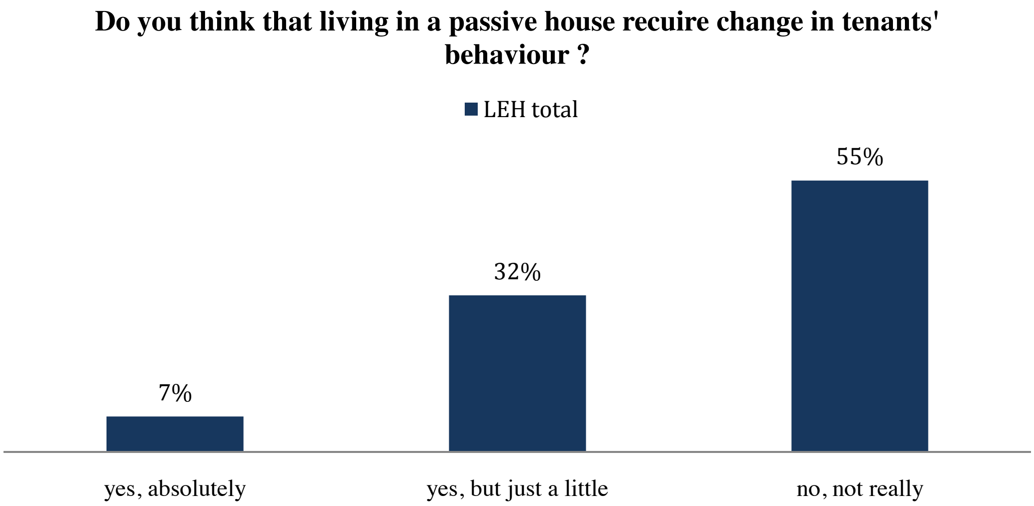

Figure 11 Tenants behavioural change in LEH

Approximately one third of LEH residents said that the difference in regard to occupant behaviour is rather small between low-energy and conventional houses (Figure 11). Two main differences have been mentioned: clothing habits and awareness of energy and water consumption. LEH residents often wore jumpers, slippers, and use blankets, especially when sitting still for longer times. For most respondents, this behavioural change was not 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, LEH residents believed they generally spent less on energy and water than they would otherwise, a belief supported by the data (Figure 12).

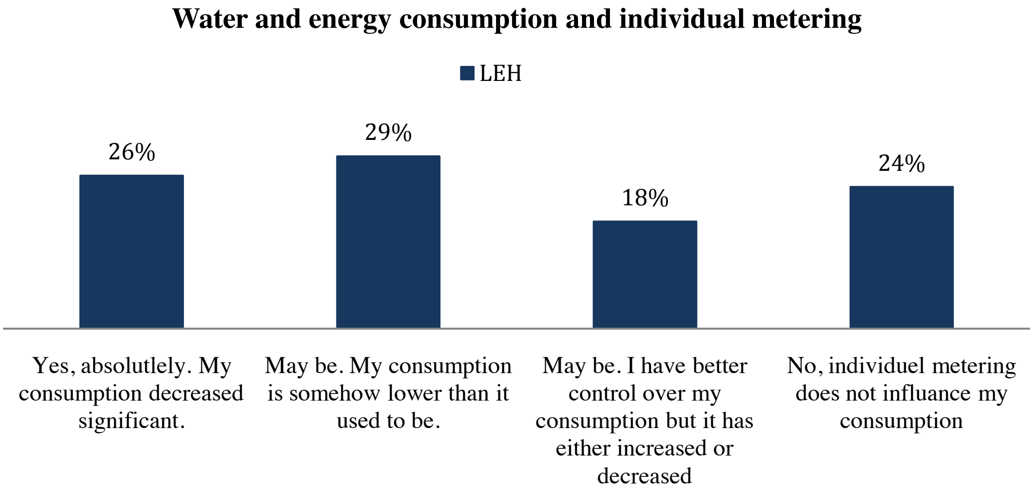

Figure 12 Effect of individual metering on energy and water consumption in LEH

4.4.2. The housing manager perspective

Housing management companies estimated that LEH operation costs, for energy and water consumption, are at least 40% lower than those of CH. Some companies stated that overall water consumption in LEH houses tends to be lower than the template consumption values generally used is Sweden.

According to housing management companies, LEH buildings required no more system adjustments and gave no more problems with technical systems than did conventional buildings. On the contrary, when all mechanical systems were in operation and appropriately adjusted, LEH buildings required minimal attention

Housing management companies clearly stated that information and communication activities had to be emphasized in the case of LEH. It is crucial for successful operation that LEH residents be informed of any special technical systems in the building that may affect their comfort. This includes information about building construction (e.g. external wall construction and installation wall placement), ventilation, the heating system, and available control options. Seventy per cent of residents received written manuals, and in some cases general information meetings were organized for tenants; personal help was available in the event of questions and problems.

5. 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 good and bad solutions. The findings indicate that that the indoor environment in energy-efficient buildings was rated higher than that in conventional buildings, which suggests higher satisfaction with the product; however, tenant feedback identified problems with ventilation system and space heating. Resident feedback, as it represents end-user satisfaction with the product, should be used by developers and designers to learn about the consumer preferences, practical and preferable solutions. This knowledge is essential for consecutive progress in delivering quality housing.

The results of the study provide further support for adaptive model theory, as LEH occupants sought adaptive opportunities and applied behaviour adaptation strategies, such as changing clothes, using window blinds, or opening windows. The study captured an issue raised by de Dear and Brager (1998a) regarding adaptation limits in buildings where occupants have little or no individual thermal control. In the analysed cases, the LEH tenants had limited individual control over their indoor environment (i.e. limited individual control of apartment temperature); the results indicate that, when indoor temperature did not fulfil expectations, occupants considered or even used supplemental heating/cooling equipment to achieve thermal comfort.

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. Actual costs were observed to be in line with estimates, and were at least 40% lower than in conventional houses. Moreover, low-energy residential buildings required the same or less system adjustment than did conventional ones, which suggests that, from a lifecycle perspective, the low-energy buildings are a better investment.

Recognizing the importance of national environmental goals and in view of European building performance policy (European Parliament and Council, 2010), 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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Appendix 1

Housing developers view on "green"[i] multi-residential buildings – questionnaire & results

Questionnaire was sent to 93 people, who represented 34 companies. Companies participated in at least one low energy housing project in Sweden. 34 responses ware collected which results in response rate of 37%; 16 responses from public companies and 18 responses from private companies.

Respondents represented total 24 companies (respondents rate 71%).

1. ***Company's name***

	private companies	public companies
Number of respondents	18	16

2. ***Respondents name and position (open question)***

3. ***Have your company undertaken environmental goals in regard to construction of residential buildings***

	private companies	public companies	all companies
Yes	100%	97%	97%
No, but works are ongoing	0%	0%	0%
No, not at present	0%	6%	3%
Don't know	0%	0%	0%

4. ***If your company have undertaken environmental goals in regard to construction of residential buildings, what are they focusing on?***

	private companies	public companies	all companies
energy requirement	100%	100%	100%
CO2 emissions	71%	20%	47%
environmental friendly material	82%	80%	81%
energy source	53%	53%	53%
other	18%	13%	16%

5. ***Which of following individual components of green buildings is your company focusing on?(multiple answers)***

PRIVATE COMPANIES	decisive	important but not decisive	fairly important	not really important
very good isolation and good air tight building envelope	61%	39%	0%	0%
very low energy requirement	61%	39%	0%	0%
usage of only renewable energy source	33%	50%	17%	0%
minimum CO2 emission	44%	50%	6%	0%
environmental friendly material	39%	50%	6%	6%
minimal space heating requirement	18%	53%	24%	6%
other	0%	67%	17%	17%

PUBLIC COMPANIES	decisive	important but not decisive	fairly important	not really important
very good isolation and good air tight building envelope	75%	25%	0%	0%
very low energy requirement	73%	27%	0%	0%
usage of only renewable energy source	33%	53%	7%	7%
minimum CO2 emission	15%	54%	31%	0%
environmental friendly material	33%	60%	7%	0%
minimal space heating requirement	60%	40%	0%	0%
other	0%	33%	33%	33%

ALL COMPANIES	decisive	important but not decisive	fairly important	not really important
very good isolation and good air tight building envelope	68%	32%	0%	0%
very low energy requirement	67%	33%	0%	0%
usage of only renewable energy source	33%	52%	12%	3%
minimum CO2 emission	32%	52%	16%	0%
environmental friendly material	36%	55%	6%	3%
minimal space heating requirement	38%	47%	13%	3%
other	0%	56%	22%	22%

6. How many green multi residential building projects have your company carried out?

	private companies	public companies	all companies
1 project	18%	31%	24%
2 project	18%	31%	24%
3 project	0%	13%	6%
4 project	0%	6%	3%
more than 4	65%	19%	42%

7. Please indicate projects name or production year ...(open question)

8. Would you describe project as (multiple answers)

PUBLIC COMPANIES	Standard production	Pilot project
project 1	13%	80%
project 2	33%	40%
project 3	20%	20%
project 4	13%	7%

PRIVATE COMPANIES	Standard production	Pilot project
project 1	53%	53%
project 2	47%	35%
project 3	41%	29%
project 4	41%	12%

ALL COMPANIES	Standard production	Pilot project
project 1	34%	66%
project 2	41%	38%
project 3	31%	25%
project 4	28%	9%

9. According to your estimation what is the total investment cost of green multi-residential buildings in reference to a traditional multi-residential project?
Total investment cost for green multi-residential buildings is:

	private companies	public companies	all companies
lower cost	0%	0%	0%
difference is insignificant	24%	13%	19%
higher cost but not more than 5%	35%	20%	28%
higher cost between 5%-10%	24%	53%	38%
higher cost between 10%-15%	0%	7%	3%
higher cost than 15%	0%	7%	3%
don't know	18%	0%	9%

10. According to your estimation what is the relationship between cost types in green residential buildings in comparison to traditional residential buildings?

ADMINISTRATION AND FEES	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	0%	0%
higher cost (about 10%)	18%	14%	16%
no or insignificant cost difference	71%	86%	77%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	12%	0%	6%

DESIGN	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	7%	3%
higher cost (about 10%)	59%	43%	52%
no or insignificant cost difference	29%	50%	39%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	12%	0%	6%

MATERIAL COST	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	7%	3%
higher cost (about 10%)	59%	80%	69%
no or insignificant cost difference	29%	13%	22%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	12%	0%	6%

INSTALLATION COST	private companies	public companies	all companies
significantly higher cost (more than 20%)	6%	7%	6%
higher cost (about 10%)	35%	36%	35%
no or insignificant cost difference	24%	50%	35%
lower cost (about 10%)	24%	7%	16%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	12%	0%	6%

LABOR COST	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	7%	3%
higher cost (about 10%)	50%	64%	57%
no or insignificant cost difference	31%	29%	30%
lower cost (about 10%)	6%	0%	3%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	13%	0%	7%

11. ***According to your estimation what is the relationship between following construction material components in green residential buildings in comparison to conventional residential buildings?***

OUTSIDE DOORS	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	14%	6%
higher cost (about 10%)	12%	36%	23%
no or insignificant cost difference	59%	43%	52%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	29%	7%	19%

WINDOWS	private companies	public companies	all companies
significantly higher cost (more than 20%)	6%	20%	13%
higher cost (about 10%)	41%	73%	56%
no or insignificant cost difference	24%	0%	13%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	29%	7%	19%

ISOLATION	private companies	public companies	all companies
significantly higher cost (more than 20%)	0%	33%	17%
higher cost (about 10%)	60%	60%	60%
no or insignificant cost difference	7%	0%	3%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	33%	7%	20%

12. ***According to your estimation what is the relationship between following installation components in green residential buildings in comparison to traditional residential buildings?***

HEATING SYSTEM	private companies	public companies	all companies
significantly higher cost (more than 20%)	6%	0%	3%
higher cost (about 10%)	12%	7%	10%
no or insignificant cost difference	24%	50%	35%
lower cost (about 10%)	29%	29%	29%
significantly lower cost (more than 20%)	12%	14%	13%
don't know	18%	0%	10%

VENTILATION SYSTEM	private companies	public companies	all companies
significantly higher cost (more than 20%)	24%	8%	17%
higher cost (about 10%)	35%	31%	33%
no or insignificant cost difference	24%	62%	40%
lower cost (about 10%)	0%	0%	0%
significantly lower cost (more than 20%)	0%	0%	0%
don't know	18%	0%	10%

13. ***According to your estimation what is the expected operating costs for green multi-residential buildings in comparison to conventional residential buildings?***
    Operating cost for green buildings is expected to be:

	private companies	public companies	all companies
significantly higher (more than 20%)	0%	0%	0%
no or insignificant cost difference	0%	0%	0%
not less than 5%	6%	7%	6%
lower cost (about 5%-10%)	6%	7%	6%
lower cost (about 10%-20%)	24%	27%	25%
significantly lower cost (more than 20%)	59%	60%	59%
don't know	6%	0%	3%

14. What measures have your company installed in green buildings in order to help tenants minimizing energy consumption?

	private companies	public companies	all companies
energy efficient equipment	88%	94%	91%
individual metering of warm water	88%	81%	85%
individual metering of electricity	71%	81%	76%
individual metering of heating	35%	31%	33%
clear information about energy consumption	53%	50%	52%
timer	29%	31%	30%
don't know	6%	6%	6%

15. According to your estimations up to what level of energy demand (exclusive domestic electricity) are energy saving measures still profitable?

	private companies	public companies	all companies
up to 60 kWh/m2	13%	21%	17%
60-50 kWh/m2	53%	14%	34%
50-40 kWh/m2	13%	14%	14%
about 40 kWh/m2	0%	21%	10%
there is no particular limit	20%	29%	24%

16. What energy savings measures are you considering as particularly profitable? (open question)

17. Do you agree with a statement that "green residential buildings require higher quality of works"?

	private companies	public companies	all companies
fully agree	53%	94%	73%
partly agree	47%	6%	27%
disagree	0%	0%	0%
don't know	0%	0%	0%

18. Do you agree with a statement that "green residential buildings require higher quality of material and products"?

	private companies	public companies	all companies
fully agree	35%	38%	36%
partly agree	47%	63%	55%
disagree	18%	0%	9%
don't know	0%	0%	0%

19. Do you agree with a statement that "construction technique requires generally more knowledge"?

	private companies	public companies	all companies
fully agree	29%	63%	45%
partly agree	65%	38%	52%
disagree	6%	0%	3%
don't know	0%	0%	0%

20. Do you agree with a statement that "there is higher risk for performing mistakes in construction of green buildings"?

	private companies	public companies	all companies
fully agree	0%	19%	9%
partly agree	35%	50%	42%
disagree	65%	31%	48%
don't know	0%	0%	0%

21. Do you agree with a statement that "there is greater uncertainty in calculations done for green buildings"?

	private companies	public companies	all companies
fully agree	0%	6%	3%
partly agree	35%	38%	36%
disagree	65%	56%	61%
don't know	0%	0%	0%

22. Do you agree with a statement that "experience from previous green building projects improve substantially profitability of the subsequent green building projects"?

	private companies	public companies	all companies
fully agree	59%	31%	45%
partly agree	24%	50%	36%
disagree	0%	6%	3%
don't know	18%	13%	15%

23. Do you agree with a statement that "green buildings require more technical adjustment (e.g. ventilation system) in order to achieve designed efficiency"?

	private companies	public companies	all companies
fully agree	24%	31%	27%
partly agree	47%	44%	45%
disagree	18%	19%	18%
don't know	12%	6%	9%

24. Do you agree with a statement that "green buildings demonstrate bigger challenges for property management companies"?

	private companies	public companies	all companies
fully agree	38%	38%	38%
partly agree	38%	50%	44%
disagree	19%	6%	13%
don't know	6%	6%	6%

25. Do you agree with a statement that "green buildings require less maintenance in the longer perspective"?

	private companies	public companies	all companies
fully agree	12%	19%	15%
partly agree	53%	38%	45%
disagree	18%	31%	24%
don't know	18%	13%	15%

26. Does your company offer (build) green multi-residential buildings according to the own concept?

	private companies	public companies	all companies
Yes, residential buildings according to our concept are already on the market/ are under construction	82%	56%	70%
We are presently working on our own “green building concept”	12%	0%	6%
No, not at the present time	6%	44%	24%

27. Is building method for your green buildings standardized?

	private companies	public companies	all companies
Yes, generally it is	67%	56%	62%
Yes, but only to certain extend	33%	19%	26%
No, we adjust method to each project	0%	25%	12%

28. Is your company going to carry out green building projects in the future?

	private companies	public companies	all companies
Yes, absolutely	100%	0%	53%
Yes, that is possible	0%	81%	38%
No	0%	19%	9%

29. Which green residential building project is your company planning to build? (multiple answers)

	private companies	public companies	all companies
low energy house (under 70 kWh/m2)	67%	27%	48%
low energy house (under 55 kWh/m2)	78%	60%	70%
passive house	67%	67%	67%
zero energy house	39%	7%	24%
plus house	39%	27%	33%
other	6%	7%	6%

30. "We plan to build more green residential buildings in the future because we believe it is a good business opportunity"

	private companies	public companies	all companies
fully agree	94%	73%	85%
partly agree	6%	20%	12%
disagree	0%	7%	3%
don't know	0%	0%	0%

31. "We plan to build more green residential buildings in the future because we believe it strengthen company's position "

	private companies	public companies	all companies
fully agree	83%	33%	61%
partly agree	17%	60%	36%
disagree	0%	7%	3%
don't know	0%	0%	0%

32. "We plan to build more green residential buildings in the future because of requirements from construction municipalities"

	private companies	public companies	all companies
fully agree	33%	38%	35%
partly agree	56%	25%	41%
disagree	11%	38%	24%
don't know	0%	0%	0%

33. Do you agree with a statement that "construction industry is ready to build green residential buildings required with quality and precision"?

	private companies	public companies	all companies
fully agree	17%	6%	12%
partly agree	78%	63%	71%
disagree	6%	31%	18%
don't know	0%	0%	0%

34. Which of followings factors have greatest impact on development and growth of green building construction? (multiple answers)

PRICE DECREASE OF ENVIRONMENTAL FRIENDLY MATERIALS AND PRODUCTS	private companies	public companies	all companies
absolutely decisive	6%	25%	15%
very important but not decisive	61%	56%	59%
important but not significant	17%	19%	18%
not significant	17%	0%	9%

DEVELOPMENT OF CONSTRUCTION TECHNOLOGIES AND BUILDING CONCEPTS	private companies	public companies	all companies
absolutely decisive	33%	44%	38%
very important but not decisive	44%	44%	44%
important but not significant	17%	13%	15%
not significant	6%	0%	3%

INDUSTRIALIZATION OF CONSTRUCTION PROCESS	private companies	public companies	all companies
absolutely decisive	28%	13%	21%
very important but not decisive	56%	44%	50%
important but not significant	17%	38%	26%
not significant	0%	6%	3%

STANDARDIZATION OF CONSTRUCTION COMPONENTS	private companies	public companies	all companies
absolutely decisive	22%	13%	18%
very important but not decisive	35%	24%	59%
important but not significant	6%	15%	21%
not significant	0%	3%	3%

35. Which of followings factors have greatest impact on development and growth of green building construction? (multiple answers)

FINANCIAL STIMULANTS (EX. TAX REDUCTION OR SUBSIDIARIES)	private companies	public companies	all companies
ABSOLUTELY decisive	28%	38%	32%
very important but not decisive	28%	38%	32%
important but not significant	28%	6%	18%
not significant	17%	19%	18%

Appendix 1

SUBSTANTIAL INCREASE OF ENERGY PRICES	private companies	public companies	all companies
absolutely decisive	17%	19%	18%
very important but not decisive	50%	50%	50%
important but not significant	28%	13%	21%
not significant	6%	19%	12%

STRENGTHEN CONSTRICTION STANDARDS	private companies	public companies	all companies
absolutely decisive	22%	6%	15%
very important but not decisive	56%	50%	53%
important but not significant	17%	19%	18%
not significant	6%	25%	15%

OBLIGATORY ENVIRONMENTAL ASSESSMENT & CERTIFICATE	private companies	public companies	all companies
absolutely decisive	0%	0%	0%
very important but not decisive	28%	44%	35%
important but not significant	22%	0%	12%
not significant	50%	56%	53%

[i] Survey focuses particularly on low energy houses among broadly understood concept of “green” buildings

Appendix 2

The appendix 2 presents questions included in questionnaire which was sent to housing management companies, which actively manage operation of low energy houses.

Questionnaire was addressed to 25 persons, who represented 17 companies; 9 persons answered and each respondent represented different company.

1. ***What is the housing for of the low energy building?***

	form of low energy houses (number of mgmt companies)
detached housing	1
multi-family house	8

2. ***How many dwellings are in the low energy housing estate?***

	number of dwellings in estate
30 apartments and less	4
31-60 apartments	4
61-80 apartments	0
81-100 apartments	0
more than 100 apartments	1

3. ***How many buildings are included in the low energy housing estate?***

	number of buildings
1-2 buildings	5
3-4 buildings	1
5 or more buildings	3

4. ***In which year was the low energy housing constructed (occupied)?***

	construction year
2004 or earlier	0
2005-2007	1
2008-2009	5
2010	3

5. ***Swedish Construction Code (BBR 16) distinguishes two heating forms for houses: electric heating and other heating sources; which heating form was installed in the low energy building?***

	heating source
electric heating	3
other than electric heating	5

6. ***What was the calculated specific energy demand in your low energy housing?***
****specific energy demand is understood as purchased (delivered) energy to the building for heating/cooling, hot water and building operation, during normal year***

	calculated specific energy demand
90-71 kWh/m2	0
70-56 kWh/m2	3
55-46 kWh/m2	0
45-30 kWh/m2	6
don't know	0

7. ***Which of following ventilation system was installed in the law energy building***

	Installed ventilation system
heat recovery aggregate individual each apartment (FTX)	5
central heat recovery aggregate (FTX)	4
FX	0

8. ***Which of following heating systems was installed in the low energy building? (multiple answers possible***)

	heating system
air heating connected to ventilation system with supporting battery (auxiliary heating)- hot water heating	2
air heating connected to ventilation system with supporting battery (auxiliary heating)- district heating	5
air heating connected to ventilation system with supporting battery (auxiliary heating)– electric battery	3
domestic heating (as separate system)	1
electric heating (as separate system)	1
hot water radiators (ex. floor heating)	1
solar panels	2
don't know auxiliary heating	0

9. What is your general opinion about technical installations (like ventilation, heating etc.)?

	general opinion about technical installations
The technical installations are too complicated for user	2
The technical installations are complicated but only in the beginning	2
The technical installations have not been a problem	5
Don't know	0

10. Did technical installations (like ventilation, heating etc.) need a lot of adjustment?

	adjustment in technical installations
It was necessary to adjust installations many times during seasons	1
It was necessary to adjust installations many times but only during the first year (after occupation)	2
Adjustments of installations was needed only in the beginning	3
There was no need for special adjustments	3
don't know	0

11. How would you describe need of adjustment and of fine-tuning of the technical installations in low energy house in comparison with conventional building?

	need of adjustments in low energy house
low energy house required *significantly more* adjustments than conventional building	2
low energy house required *some more* adjustments than conventional building	0
low energy house required *as much* adjustments as conventional building	5
low energy house required some less adjustments than conventional building	0
low energy house required *significantly less* adjustments than conventional building	1

12. What is your forecast regarding operation costs for low energy buildings?

	operation cost forecast
significant higher than in conventional houses (more than 20%)	0
fairly higher cost (about 10%)	0
no or insignificant cost difference	0
fairly lower cost (about 20%)	3
significant lower cost than in conventional houses	
(more than 40%)	6
don't know	0

13. What is the real energy consumption (space heating) for low energy houses with reference to calculated consumption?

	real energy consumption
much higher than calculated	1
somewhat higher than calculated	1
about as calculated	2
lower than calculated	1
much lower than calculated	1
don't know	2

14. Do you agree with the statement that:
"Green buildings demonstrate bigger challenges for property management companies"

	management companies
fully agree	3
partly agree	4
disagree	2
don't know	0

15. Do you agree with the statement that:
"We estimate that green buildings require less maintenance in the future in comparison with conventional houses"

	management companies
fully agree	2
partly agree	4
disagree	3
don't know	0

16. Do you agree with the statement that:
"Experience from earlier low energy housing projects allows us to increase efficiency and decrease operation and maintenance cost."

	management companies
fully agree	3
partly agree	3
disagree	1
don't know	1

17. Do you agree with the statement that:
"Experience from earlier low energy housing projects allows us to increase efficiency in the existing housing stock."

	management companies
fully agree	3
partly agree	2
disagree	2
don't know	2

18. What is the tenants' opinion about indoor temperature during winter?

	management companies
It is often too cold	0
It is occasionally too cold	3
Tenants are generally pleased with indoor temperature during the winter	3
It feels occasionally too warm	0
Don't know	2

19. What is the tenants' opinion about indoor temperature during summer?

	management companies
It is often too warm	0
It is occasionally too warm	3
Tenants are generally pleased with indoor temperature during the summer	3
It feels occasionally too cold	0
Don't know	2

20. How would you describe tenants' satisfaction in low energy houses (in comparison with conventional houses)?

	management companies
tenants are significantly more satisfied	2
tenants are somewhat more satisfied	3
there is no noticeable difference	1
tenants are somewhat less satisfied	1
tenants are significantly less satisfied	0
don't know	2

21. Do you agree with the statement that:
"The communication and information given to tenants in low energy houses is more crucial than in conventional houses"

	management companies
fully agree	6
partly agree	2
disagree	1
don't know	0

22. Do you agree with the statement that:
"Residents of low energy houses use often supplementary heating in order to achieve good indoor comfort during winter"

	management companies
fully agree	0
partly agree	2
disagree	4
don't know	2

23. Do you agree with the statement that:
"Residents of low energy houses use often supplementary cooling in order to achieve good indoor comfort during summer."

	management companies
fully agree	0
partly agree	0
disagree	5
don't know	4

24. What form of information about your housing have tenants received? (multiple answers)

	management companies
Written manual when moving in	7
Information meeting with housing management company close to occupation date	8
Information meeting with housing management company 6 mc after occupation date	1
Personal help when we had questions or problems	6
There was no need for special information or help	1

25. According to your experience, what are the greatest challenges in operation and management of low energy housing?

	significant problem	big problem	occasionally problem	no problem	don't know	total
adjustment of air flow in ventilation/air-heating system	0	3	3	3	0	9
adjustment of temperature in ventilation/air-heated system	0	4	2	2	0	8
insufficient efficiency of battery	1	1	3	3	0	8
to achieve optimal energy consumption	0	1	2	3	1	7
tenants' behaviour and "old" habits	0	2	4	1	1	8
insufficient engagement of construction entrepreneur in building operation face	2	1	1	4	0	8
insufficient knowledge about construction and installations	0	1	3	4	0	8

26. What is your opinion about environmental rating of buildings and if it has any consequences for you?

	management companies
The environmental rating for buildings is very important and we will be happy to environmentally assess buildings in our stock	5
The environmental rating for buildings is important but it has no practical implications for housing management companies	2
It doesn't matter if building is environmentally rated or not	2

Appendix 3

The appendix 3 presents questions included in questionnaire which was sent to low energy houses (LEH) and conventional houses (CH). The questionnaire addressed to residents in low energy buildings included extra questions, which are marked here as questions: 19,20, 21, 22.

The questionnaire was first sent to buildings in location A. The questionnaire was later slightly modified. The change refers to questions: 17 and 18.

The questionnaire was sent to all registered tenants above age of 21 years in chosen housing estate.

	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%

1. ***Which of following factors determined your decision about renting the apartment? Please indicate the weight in which factors influence your final decision.***

	decisive factors		**important factors**	
	LEH	CH	LEH	CH
location in the city	38%	51%	55%	44%
price/rent	8%	18%	65%	58%
distance to work	16%	17%	42%	43%
distance to school or kindergarten	7%	2%	23%	25%
distance to Centrum	10%	28%	59%	52%
access to public transit	27%	19%	52%	53%
size of apartment	38%	42%	53%	52%
apartment design	25%	30%	55%	54%
access to garage	18%	22%	30%	34%
estimated low energy cost	13%	13%	59%	38%
other environmental factors in the house	13%	7%	54%	40%
limited selection of available apartments	19%	21%	33%	34%
other	18%	16%	20%	16%

	not so important factors		unimportant factors	
	LEH	CH	LEH	CH
location in the city	5%	3%	2%	2%
price/rent	24%	19%	4%	6%
distance to work	23%	15%	19%	24%
distance to school or kindergarten	11%	12%	59%	61%
distance to Centrum	23%	12%	8%	8%
access to public transit	14%	15%	6%	13%
size of apartment	9%	5%	0%	1%
apartment design	17%	12%	3%	3%
access to garage	25%	18%	27%	26%
estimated low energy cost	21%	32%	7%	17%
other environmental factors in the house	28%	33%	6%	21%
limited selection of available apartments	27%	23%	22%	22%
other	4%	20%	57%	47%

2. *What is your general opinion about your estate?*

	LEH	CH
I enjoy living in my apartment very much	67%	69%
I quite enjoy living in my apartment	24%	22%
I don't enjoy the place at all	8%	6%
I enjoy living in my apartment but it could have been better	1%	2%
don't know	0%	0%

3. *"I estimate that temperature in my apartment during winter was .... and during summer was .... "(open question)*

4. *Did you find it necessary to use supplementary heating in order to achieve good indoor comfort during winter?*

	LEH	CH
Yes, I have used supplementary heating almost every day during winter	14%	1%
Yes, I have used supplementary heating but only sometimes	7%	5%
Yes, I have used supplementary heating but very sporadically	8%	4%
No, I have never used supplementary heating	65%	82%
don't know	6%	8%

5. How would you describe indoor temperature in your apartment during summer?

	LEH	CH
It is often too warm	18%	17%
It is occasionally too warm	33%	44%
I 'm pleased with indoor temperature during the summer	43%	34%
It feels cold sometimes	3%	1%
Don't know	4%	4%

6. Did you find it necessary to use supplementary cooling in order to achieve good indoor comfort during summer?

	LEH	CH
Yes, I have used supplementary cooling almost every day during summer	8%	10%
Yes, I have used supplementary cooling but only sometimes	10%	16%
Yes, I have used supplementary cooling but very sporadically	6%	5%
No, I have never used supplementary cooling	74%	67%
Don't know	3%	2%

7. How would you describe indoor climate in your apartment?

AIR QUALITY	LEH	CH
very good	39%	26%
good	42%	56%
acceptable	11%	13%
not really good	7%	4%
Don't know	1%	1%

SOUND INSULATION QUALITY	LEH	CH
very good	69%	51%
good	23%	36%
acceptable	6%	9%
not really good	3%	3%
Don't know	0%	0%

LIGHT QUALITY	LEH	CH
very good	64%	59%
good	27%	32%
acceptable	5%	7%
not really good	4%	2%
Don't know	1%	0%

8. What is your general opinion about technical installations (like ventilation, heating etc.)?

	LEH	CH
The technical installations are too complicated and difficult to use.	13%	4%
The technical installations are complicated but only in the beginning	13%	15%
The technical installations have not been a problem	60%	65%
Don't know	15%	16%

9. Did technical installations (like ventilation, heating etc.) need a lot of adjustment?

	LEH	CH
It was necessary to adjust installations many times after occupation.	16%	11%
Only a few adjustments ware needed just in the beginning of our occupancy	16%	38%
There was no need for any special adjustments	55%	38%
Don't know	13%	14%

10. What form of information about your housing have you received?

	LEH	CH
Written manual when we moved in	68%	45%
Information meeting with real estate management company	15%	14%
Personal help when we had questions or problems	29%	39%
No information at all	13%	30%

11. Do you think that individual metering of hot water and electricity influence your consumption?

	LEH A	LEH B	LEH C	LEH total
Yes, absolutely. My consumption decreased significant.	22%	11%	40%	26%
May be. My consumption is somehow lower than it used to be.	31%	21%	29%	29%
May be. I have better control over my consumption but it has either increased or decreased	19%	26%	12%	18%
No, individual metering does not influence my consumption	26%	32%	17%	24%
Don't know	2%	11%	2%	3%

	CH A	CH B	CH C	CH total
Yes, absolutely. My consumption could decrease significant.	14%	32%	5%	16%
May be. My consumption might get somehow lower	50%	32%	40%	44%
No, individual metering would not influence my consumption	30%	23%	50%	33%
Don't know	5%	14%	5%	7%

12. What is your opinion about environmental rating of buildings and if it has any consequences for you?

	LEH	CH
The environmental rating for buildings is very important and I am/would be proud that my building is environmentally assessed	41%	34%
The environmental rating for buildings is important but it has no practical implications for me	47%	48%
It doesn't matter if building is environmentally rated or not	12%	17%

13. Respondents

	LEH	CH
man	43%	45%
woman	57%	55%

14. Number of persons living in the apartment (open question)

15. Age

Age	LEH	CH
20-30	20%	20%
31-40	19%	22%
41-50	12%	11%
51-60	18%	15%
60-65	6%	6%
>65	25%	24%

16. Number of room s in the apartment (excluding kitchen)

Number of rooms	LEH	CH
1 room	3%	1%
2 rooms	31%	31%
3 rooms	41%	55%
4 rooms	25%	13%

The survey questionnaire was first sent to buildings in location A. The questionnaire was later slightly modified. Question 12 was included in questionnaire sent to LEH A and CH A, modified and replaced by question 13, which was included in questionnaire sent to LEH B, LEH C, CH B AND CH C

17. How would you describe the indoor temperature in your apartment? (multiple answers)

	LEH A	CH A
It is too hot during summer	22%	32%
It is too cold during winter	34%	11%
I 'm pleased with indoor temperature	52%	58%

18. How would you describe indoor temperature in your apartment during winter?

	LEH B	LEH C	CH B	CH C
It is often too cold	58%	18%	0%	5%
It is occasionally too cold	37%	15%	39%	38%
I 'm pleased with indoor temperature during the winter	0%	51%	44%	38%
It feels warm sometimes	0%	5%	0%	5%
Don't know	5%	10%	17%	14%

Following questions was sent *ONLY* to LEH A, LEH B, LEH C, i.e. to low energy houses only

19. Was your decision to rent apartment influenced by the factum that the building was built as passive house/low energy building?

	LEH A	LEH B	LEH C	LEH total
it was a decisive argument	3%	0%	0%	2%
it was one of the important arguments	27%	5%	20%	22%
it was not really important	38%	53%	54%	44%
it was unimportant	30%	42%	24%	30%
don’t know	2%	0%	2%	2%

20. Do you think that a passive house differ from more "conventional" houses?

	LEH A	LEH B	LEH C	LEH total
yes, absolutely	20%	37%	38%	27%
yes, but not really much	60%	42%	40%	52%
there is no special difference	18%	11%	5%	14%
don’t know	2%	11%	17%	7%

21. Do you think that living in a passive house require change in tenants' behaviour?

	LEH A	LEH B	LEH C	LEH total
yes, absolutely	3%	33%	5%	7%
yes, but just a little	32%	22%	36%	32%
no, not really	60%	33%	55%	55%
Don't know	5%	11%	5%	6%

22. How would you describe your current housing costs (for heat, hot water, electricity) in comparison with a "conventional" housing?

	LEH A	LEH B	LEH C	LEH total
My current housing (running) costs are much lower than I used to have	11%	0%	19%	12%
My current housing (running) costs are in some way lower than I used to have	28%	17%	24%	26%
There is no difference between my current and previous housing (running) costs	31%	56%	43%	37%
My current housing (running) costs are in some way higher than I used to have	20%	22%	14%	19%
My current housing (running) costs are much higher than I used to have	9%	6%	0%	6%