

# User evaluations of energy efficient buildings: Literature review and further research

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2011

Published as: Åshild Lappegard Hauge , Judith Thomsen & Thomas Berker (2011) User evaluations of energy efficient buildings: Literature review and further research, *Advances in Building Energy Research*, 5:1, 109-127, DOI: 10.1080/17512549.2011.582350

## **Abstract**

This chapter gives an overview of research that describes user experiences with different types of energy-efficient buildings, focusing on indoor climate, technical operation, user attitudes and general satisfaction. Energy-efficient buildings are often rated better than conventional buildings on indoor climate, but on digging deeper, users have different concerns. The varying results from the user evaluations reflect that the quality of buildings differs. However, the complaints may also be a result of inappropriate use. The main aim of this chapter is to give guidelines for further research, based on existing user evaluations of energy-efficient buildings. Three important areas for further research on user evaluations could be identified. First, there is a shortage of research that takes into account the social context for evaluation; the social environment, the process of moving into an energy-efficient building and prior knowledge of environmental issues influence evaluation of the buildings. Energy-efficient buildings may also require specific architectural solutions and further research should consider architectural and aesthetic aspects in the evaluation. Research on the use and operation of energy-efficient buildings is increasing, but there is still a need to give more detailed attention to different ways of providing information and training in operation and use.

## Introduction

Ultimately, the performance of buildings depends on the users. This literature review focuses on users' experiences with different types of energy-efficient buildings. There is a well-known gap between predicted and actual performance in energy-efficient buildings. from predicted

In some cases, actual performance is quite different performance, especially during the first years (Hinge et al, 2008). A study by the New Building Institute (2008) found that 30 per cent of LEED1-rated buildings perform better than expected, 25 per cent worse than expected and a handful of LEED buildings have serious energy consumption problems. These problems may be caused by technical failures, expectations that are too high, or by inappropriate operation and use.

Bordass et al (2004, p1) suggest that gaps between a building's expected and actual energy consumption 'not so much arise because predictive techniques are wrong, but because the assumptions often used are not well enough informed by what really happens in practice because so few people who design buildings go on to monitor their performance'. Hinge et al (2008) also point to the use of buildings, and the role and active involvement of building operators and facility management to explain this gap. To achieve a building stock that has zero emission of greenhouse gases, it is crucial that building operation is comprehensible, that people get the information they need to operate the building, and also that they want to live and work in a zero-emission building. It is therefore essential to take into consideration the use and implementation of such buildings.

With regard to usability, there are many features common to all types of energy-efficient buildings. Evaluation of energy-efficient buildings from a user's light, perspective includes research on experiences of ventilation, in relation to experiences of housing quality in general. To investigate subjects for further research, we chose to look at some studies in more depth. A broader review of post-occupancy evaluation (POE) of sustainable buildings can be found in Meir et al (2009).

## Definitions

This literature review will include research on different types of energy-efficient buildings. Passive houses are buildings that, by incorporating high levels of insulation and airtightness, as well as effective heat recovery, achieve a very low energy demand. The German Passivhaus standard is the most widely used standard. To satisfy the passive house criteria, the total energy demand for heating and cooling must be less than 15kWh/m<sup>2</sup>/year, and the total primary energy consumption for all appliances, hot water, electricity, heating and cooling must not be more than 120kWh/m<sup>2</sup>/year ([www.passiv.de](http://www.passiv.de)). Low-energy buildings

generally consume less energy for space heating than average. However, they consume more energy than required by the standard for passive houses. According to Standards Norway (1998), the official requirement for total energy demand for heating in low-energy houses is a maximum of 30kWh/m<sup>2</sup>/year. Another term often used is green buildings. The goal of green buildings is to ‘use resources more efficiently and reduce a building’s negative impact on the environment’ (ECEEE, 2009, p7). The definition of green buildings therefore also includes aspects such as reducing waste or using recycled building materials. When using a very accurate definition, not all low-energy or passive buildings may be considered green buildings (ECEEE, 2009, p7).

In the following, the term ‘energy-efficient buildings’ is used as a collective term for different types of buildings designed to reduce energy consumption to different degrees. The research presented includes studies on low-energy buildings, passive houses, LEED buildings and green buildings.

#### Literature Review

Research on user evaluation of energy-efficient buildings can be thematically categorized into ‘thermal comfort’, ‘technical operation’ and ‘general satisfaction’. Most research conducted on user perspectives of energy-efficient buildings is naturally focused on thermal comfort, because aspects of heating, ventilation and indoor climate comprise the main differences between energy-efficient and conventional buildings. The category about thermal comfort is divided into residential and occupational buildings. After the literature review, we discuss missing aspects, followed by guidelines for further research.

### **Thermal comfort**

Are users satisfied with the indoor climate in energy-efficient buildings? In recent years, several user evaluations have been conducted on indoor climate in low-energy and passive buildings, both residential and occupational.

#### **Residential buildings**

Isaksson and Karlsson (2006) have investigated the thermal environment and space heating in 20 low-energy terraced houses in Linda °s, south of Gothenburg. They conducted qualitative interviews with the occupants, as well as measurements of physical parameters. The heating system in these terraced houses is based on the emission of household appliances, occupants’ body heat and solar irradiation. Many agree that the heating system functions well. However, during the winter, when the heater is on, the indoor temperature varies. One resident states that ‘. . . the heating system alone is not able to maintain an acceptable indoor temperature but needs assistance from other sources of heat such as people, appliances or radiators. If no one is at home, the system will not be able to maintain the temperature set’ (Isaksson and Karlsson,

2006, p1684). The study shows that people experiment with warming up the house, for instance by leaving doors open and lighting candles. Temperature differences were also experienced between middle and gable houses. The gable houses had a lower average temperature than the middle houses. Also, the floor on the ground floor was reported to be cold by many residents, both in middle and gable houses. Improvements to increase the experienced comfort could be made by regulating the temperature dynamics better. When houses are empty for any time, it takes half a day to warm them up, and some of the residents therefore leave the heating on when they are away. A timer for the heating systems could solve these problems. A fireplace was desired by many. However, owing to the airtightness of the houses, fireplaces are not allowed. Interestingly, when comparing the residents' opinions with the measured parameters, there was a substantial difference between the measured indoor temperature and the occupants' perception of the thermal environment. The indoor temperature was often higher than experienced, indicating that subjective experience differs from person to person. Cold floor surfaces or draughts can also lead to the temperature being perceived as lower than it actually is.

A user evaluation of low-energy housing has been carried out in Stjørdal, Norway, at a housing complex with 56 flats called Husby Amfi (Kleiven, 2007). This study looked at user satisfaction with these dwellings both in winter and summer. The questionnaire included questions on comfort, indoor climate, the usability of the energy systems, and attitudes towards the environment and energy use. The residents were mostly very pleased with the flats. The thermal comfort was very high, both in winter and summer, but most of the residents reported that the flats got too hot on the warmest summer days.

Another study on indoor climate was carried out as a diploma project on passive houses (Samuelsson and Lu'ddeckens, 2009). They carried out a survey on three different passive houses, at Oxtorget, Frillesås and Gumslov in Sweden, in order to investigate residential satisfaction with the indoor climate. Questions were asked about experienced temperature and temperature variations, draughts and perceived indoor climate. Samuelsson and Lu'ddeckens (2009) have also calculated the energy consumption and simulated the indoor climate for two of the projects using the programs VIP3 (energy consumption) and IDA (indoor climate simulation). The results from the two models did not differ much, either in terms of energy consumption or heating. The models indicate that, in theory, the heating battery was enough to warm the houses during the winter. However, the results from the survey revealed perceived problems with the indoor temperature during the winter. In one of the three projects in particular, more than 50 per cent of residents reported that it was too hot in the summer and too cold in the winter. Similar discrepancies between the findings of the different methodologies were found by Isaksson and Karlsson (2006), also using two different methodologies. Samuelsson and Lu'ddeckens (2009) state that the problem with the simulation model is that it cannot simulate reality sufficiently well, and that it might not capture the problems experienced by the residents. The residents that were most satisfied with their dwelling lived in

Frillesa °s. The residents at Gumslov were least satisfied. They criticized the fact that they could not adjust the temperature, and that weather conditions influenced the indoor temperature. They also reported temperature differences of 3 – 4°C between rooms during the winter. The ventilation system did not function sufficiently well. They had to use additional heating during the winter, which affected their use of electricity. During the summer, the temperature was often too high. The survey revealed that residents of passive houses were not generally satisfied with the indoor climate. Samuelsson and Ludddeckens (2009) could not give a clear answer as to why residential satisfaction with indoor climate differed between cases. They proposed, for instance, that the heat recovery system might not have been as efficient as calculated. Another aspect considered was the location of the ventilation fans on top of the wall. If warm air was injected too slowly, there could be an accumulation of warm air under the roof, while the floor would get cold. The perceived indoor temperature would then be lower than the measured temperature. Their discussion shows how difficult it is to comprehensively predict indoor climate through simulations. Another challenge is the fact that people experience temperature and draughts differently.

Buber et al (2007) investigated the meaning of the terms comfort, well-being, cosiness and housing comfort in relation to experienced housing quality in passive houses. To understand how people experience living in passive houses, the personal opinions of residents were investigated in focus group interviews. The results show that the type of heating had a crucial influence on housing comfort, and thus on the well-being of its residents. None of the residents interviewed would have agreed to moving to a house that was heated just by the ventilation system. They wanted additional heating, such as wall heating or wood pellet ovens. The visual and sensible effects were of importance for perceived comfort. Regarding the fresh air supply, a ventilation system with frequent air exchange was seen as imperative for a high level of comfort.

In conclusion, in some energy-efficient houses, users complain about too high indoor temperatures on warm summer days and too cold temperature on cold winter days. Nicol and Roaf (2005) state that studies of thermal comfort show that the manner in which indoor thermal environment is evaluated by residents is context-dependent and varies over time. This can explain the difference between experienced comfort and simulated indoor climate found by Samuelsson and Ludddeckens (2009), with users living in passive houses declaring that they miss a fireplace on cold days. This reflects the feeling that a comfortable indoor climate is influenced by visual or sensible signs of heat. Cold surfaces and materials may decrease the perceived temperature from a user's point of view. Moreover, differences between reported and measured temperatures show that user satisfaction in domestic spheres includes subjective factors. Although this is true for most evaluations, homes may be considered to be special 'territories' (Morley, 2009) where demands for comfort are particularly high (Aune, 2007). However, a study by Coulter et al (2008) shows that when comparing three different categories of residences, users are most satisfied with thermal comfort,

temperature in the most energy-efficient residences. This study was a comparison between what they call ‘base-line’ residences, ‘energy star’ and ‘guaranteed performance’ (local building codes, USA). None of these are passive houses, but the best category of residences, ‘guaranteed performance’, saves 33 per cent in summer/cooling energy use when compared with base-line homes.

### **Occupational buildings**

Is the indoor climate experienced as better in energy-efficient occupational buildings than in conventional buildings? Leaman and Bordass (2007) have studied occupational buildings designed for lower environmental impact to determine whether they are better than conventional buildings from the occupants’ point of view. They compared user experiences through surveys in 177 conventional and green buildings. Buildings with natural or advanced natural ventilation were characterized as green buildings, and buildings with mixed modes or air-conditioning were characterized as conventional buildings. They found that green buildings scored better on ventilation/air, health, design, image, lighting, overall comfort and perceived productivity. Although the best green buildings ranked higher than the best conventional buildings, a few of the lowest scores were also attained by green buildings. Many of the green buildings were experienced as too hot in summer, and seemed to have more ambient noise. The experience of indoor climate may also be related to whether the occupants have single offices or an open-plan layout. In a single office an employee is more in control of the temperature, ventilation, lighting and noise than are occupants that are tied to their workplaces in open layouts. As already stated, Leaman and Bordass (2007) suggest that findings based on more general survey questions tend to give a more optimistic picture of indoor climate in green buildings than surveys that dig deeper.

Abbaszadeh et al (2006) also found that occupants in green buildings were more satisfied with thermal comfort, air quality, office furnishing, cleaning and maintenance than occupants in non-green buildings. However, overall, occupants in green buildings were more dissatisfied with lighting and acoustics. This study compared 21 LEED-rated buildings with 160 non-green buildings using the University of California, Berkeley Center for the Built Environment’s (CBE) Occupant Indoor Environmental Quality Survey. A chapter by Heerwagen and Zagreus (2005) evaluates the Philip Merrill Environmental Center in Annapolis, Maryland, which houses the Chesapeake Bay Foundation. The centre is an educational institution with a staff of about 90, and 35,000 students participate in the centre’s programmes each year. This aim of this chapter is to investigate whether sustainable buildings create improved indoor quality and improved occupant comfort, satisfaction, health and work performance when compared with conventional buildings. Four years after the completion of the building, a survey on indoor environmental quality was distributed. A series of interviews and discussion groups had already been conducted one year after moving into the new

building. The building has an open-plan solution, intended to foster interaction between employees. There is a natural ventilation system that uses environmental monitoring to decide when windows can be opened. The findings show that occupants are highly satisfied with the building. Air quality, day lighting and artificial lighting, as well as access to views, were rated positively by close to 90 per cent of the respondents. The evaluation also revealed critical aspects. Acoustic and temperature conditions, noise distractions due to the open landscape, insufficient provision of meeting rooms and glare from windows caused some concerns (Heerwagen and Zagreus, 2005).

Wagner et al (2007) carried out a four-week summer field study on thermal comfort with 50 subjects in a naturally ventilated office building in Karlsruhe, Germany. The study confirmed that there was a dependence between thermal comfort and outdoor temperature in naturally ventilated occupational buildings. However, the study showed that naturally ventilated and passively cooled buildings can be highly appreciated by occupants during the summer if they are designed properly in terms of indoor climate. Positive perceptions of thermal comfort can occur outside the temperature limits set in standards for air-conditioned buildings. Wagner et al (2007) have also carried out a survey on workplace occupant satisfaction in 16 office buildings in Germany. This survey revealed that the occupants' control of the indoor climate, and moreover the perceived effect of their intervention, strongly influenced their satisfaction with thermal indoor conditions.

A study by Barlow and Fiala (2007) also focused on the occupants' ability to control the indoor climate, and how this increases thermal comfort. They suggested that active adaptive opportunities should be made an important part of future refurbishment strategies for existing office buildings. In the study, opening windows was voted to be the most favoured adaptive opportunity, followed by controlling solar glare, turning lights off locally and controlling solar gain. Occupants also expressed desires to intervene with heating and ventilation, which at the time was operated centrally.

Studies presented on user evaluations of indoor climate in energy-efficient occupational buildings are in general positive, but when investigated in more depth, users have complaints and frustrations that it is important to notice. In contrast to residential buildings, control in occupational buildings is, at least in part, delegated to centralized control systems. Comfort experience varies greatly between individuals – what one person experiences as chilly may be too warm for another. This leads to individuals managing comfort in their work environment in many different ways, some of which may counteract entirely the designers' intentions (Heerwagen and Diamond, 1992; Hitchings, 2009). Therefore, users' perception about their ability to control the indoor climate is of great importance.

## Technical operation

A study by Leaman and Bordass (2007) of the difference between user satisfaction in green and conventional occupational buildings shows that users tend to have a higher tolerance for deficiencies in green buildings than in more conventional buildings. People seem to tolerate more discomfort in a green building the more they know about how the building is supposed to operate, and how they can use thermostats and window controls, for example. Users are much less satisfied when they cannot understand how things work or how to control temperature and ventilation (Nicol and Roaf, 2005; Leaman and Bordass, 2007). Information on the use and operation of technical facilities is therefore crucial.

## Operating energy-efficient housing

As indicated above, the indoor climate in the apartments at Husby Amfi in Stjørdal was in general experienced as comfortable (Kleiven, 2007). In total, 70 per cent of residents used the energy operating panel in these flats, and most residents experienced them to be user-friendly, intuitive and simple. Most residents also put their flats into standby when they left, although a few residents found the energy operating panel difficult to understand. They wondered if it did not work, or said that they had not been well enough trained in operating it. The flats had a web-based follow-up system for energy use, but this system was barely used, as it was felt to be too advanced. Therefore, the web-based follow-up system did not contribute to lower energy use. This may be related to the high number of pensioners among the residents. A web-based follow-up energy system may have been easier to handle for younger residents that were more used to technological facilities.

In the investigations of Isaksson (2009) and Isaksson and Karlsson (2006) of the houses in Linda °s, interviews showed that knowledge about the heating system was an important issue for residents. Some told the authors that they did not have sufficient information about the heating system when moving in. Consequently, they tested the system during the first winter, something that resulted in varying indoor temperature and higher energy costs. The process of operating the energy system was a dynamic learning process. Isaksson (2009) emphasizes the importance of learning-by-doing in operating energy-efficient technology. The residents should have the opportunity to find a way to exploit the potential of the technology, and they have to experience that they can cope with it. Isaksson concludes that implementing energy-efficient buildings is not just a question of developing new technologies, but the great challenge is that ‘tools must be developed that support people to choose the sustainable ways to use the new technology’ (Isaksson, 2009, p195).

Real-life building performance often undermines design expectations, often because of users’ actual behaviour. A POE study of sustainable homes in the



UK by Gill et al (2010) showed that energy-efficient behaviour accounts for 15, 37 and 11 per cent of variance in heat, electricity and water consumption, respectively, between dwellings. This indicates that human factors need to be addressed to a greater extent in the design and use of energy-efficient buildings.

To summarize, the studies show that the operation and use of low-energy and passive houses may be difficult for users, and if the technological facilities are perceived as too advanced, they are not used or not entirely understood. The occupants' behaviour also has a significant impact on a building's energy performance. This may lead to an uncomfortable indoor climate. The research also shows, again, that perceived personal control and sufficient information on operation and use is crucial for an overall positive experience of such houses. These issues are explored in the next section.

## Information and feedback

Does the type of occupancy influence the motivation to deal with unfamiliar technologies in passive houses? Schnieders and Hermelink (2006) evaluated residential satisfaction with passive houses in two CEPHEUS projects (Cost Efficient Passive Houses as EUropean Standards), Hannover-Kronsberg and Kassel. In the project 'User-oriented design of passive houses', a study was conducted from spring 2000 to autumn 2002. The development of residents' opinions, attitudes, behaviour and satisfaction were recorded over time. Several studies have shown a high level of satisfaction with living in the passive houses in Hannover-Kronsberg. The building in Kassel is the world's first multistorey passive house. The main difference between the projects in Hannover and Kassel is the type of occupancy. The houses in Hannover-Kronsberg are owner-occupied and therefore represent typical passive houses. In contrast, the multistorey passive house has 40 flats for low-income tenants. The project was built at low cost by a social housing company. The Kassel project consists of two buildings with 23 and 17 flats, respectively, and a total living area of approximately 2900m<sup>2</sup> with a heating demand of about 15kWh/m<sup>2</sup>/year. The buildings are north-south oriented, which contradicts the common practice of southwards orientation. A hypothesis was that the demand for heating energy might be much higher in the Kassel project than in other owner-occupied cases, because 'Tenants usually do not identify themselves as much with their dwelling and its characteristics as owners do. Therefore the motivation to deal with unfamiliar technologies and the willingness to change customs might be lower' (Schnieders and Hermelink, 2006, p162). Energy consumption was measured and calculated, and the individual behaviour and strategies of energy use investigated by conducting three partly standardized interviews over a period of 2.5 years. The goal was to interview all residents several times. The study investigated the tenants' ventilation behaviour. Keeping the windows shut is an important factor in keeping the ventilation rate steady. The results showed that, in general, 'forbidden' ventilation

through windows stayed within a tolerable range that did not upset the energy balance as such. More interestingly, residents who admitted to a high level of window ventilation expressed a low opinion of the controlled ventilation, probably because they interfered with the system, which consequently did not work properly. The maximum ventilation switch is situated in the kitchen and the location leads to the misconception that it is dedicated only to kitchen odours, even though it affects the whole flat, including the toilet and bathroom. When an information letter was sent out, the use of maximum ventilation increased immediately. Before the first winter, many expressed worries that the ventilation system would not be enough to keep the flats warm. This scepticism was altered after the first winter. The average satisfaction with the ventilation system was 4.7 on a scale from 1 to 6. It was also assessed whether the residents were of the opinion that living in a passive house increased or decreased comfort. The results indicated a perceived increase of comfort. Most tenants adapted to the new building quickly and ‘very easy control of the ventilation, very high thermal comfort and air quality make the tenants feel very comfortable. In addition, they are realizing that costs for heating are extremely low’ (Schnieders and Hermelink, 2006, p162). This study indicates that the type of occupancy is not necessarily relevant for the motivation to operate energy-efficient buildings, or to identify with them, if good information on their operation is provided and the personal advantages are understood. The study also shows that user evaluations have to take into account what the occupants know and that their knowledge may be subject to change. Brown and Cole (2009) compared occupants in conventional and green buildings in British Columbia. They found that users in the green buildings were more interested in learning how the building and its controls work. However, while those who knew more about their building’s inner workings used the controls more extensively, they did not report higher degrees of perceived comfort.

So, even though cognitive aspects such as knowledge and learning are central for a well-functioning energy-efficient building, and should be improved through easy-to-use controls and appropriate guidance and feedback, there are other factors at play. Some have been explored already, such as the role of perceived control and special expectations have certain expectations regarding energy-efficient buildings, which are discussed in the next section.

## **General satisfaction in energy-efficient buildings**

There are a few studies of energy-efficient buildings that evaluate more than indoor climate and operational aspects. These studies cover general satisfaction, going beyond thermal comfort. This research is interested in whether the improved thermal comfort and the architectural qualities affect users’ performance and well-being. The concept ‘comfort’ in these studies is used in a wider sense than ‘thermal comfort’. It may for example include comfort in relation to light,

architecture and aesthetics.

## **User attitudes to energy-efficient housing**

Research shows that energy-efficient houses are mainly bought or chosen for reasons other than the energy profile. Isaksson and Karlsson's (2006) findings in the user evaluation of housing in Linda<sup>o</sup>s showed that the low-energy profile of the houses was positively evaluated, but the inhabitants' main reasons for moving there were the location and value for money. Residents were satisfied with living in low-energy houses. This was also due to architectural qualities such as the design and open-plan solution, which contributed to perceived housing satisfaction.

Buber et al (2007) state that passive houses are usually advertised as 'houses without heating' and not as 'comfortable houses', even though the comfort aspect is a crucial argument for potential passive house buyers. Housing comfort is a main issue, and the environmental effect might just be a side-effect for many. They refer to a study by Rohracher et al in 2001 (see Buber et al, 2007) that shows that potential passive house buyers are sceptical about buying a house without a sensible heating source. The residents also complained about a lack of information and knowledge when buying their passive house (Buber et al, 2007).

Schnieders and Hermelink's (2006) study of the Kassel project for low-income tenants also focuses on the residents' reasons for moving in. The first advertising campaign for flats in the Kassel project highlighted passive house characteristics and low-energy demand. The response to this campaign was weak, and only after advertising other characteristics such as attractive location, balcony and new buildings was there a great response. The findings from the study reflect the experience of the housing company. They show that the least important reason for moving in was the passive house aspect, whereas without a balcony hardly anybody would have chosen to move in.

In the study of the flats in Husby Amfi, Stjørdal, the low-energy concept of the flats was important for only one-third of the buyers. Interestingly, most residents answered that living in a low-energy building had made them more aware of energy use and environmentally friendly behaviour (Kleiven, 2007).

Haavik and Aabrekk (2007) have written a marketing guide on business opportunities in sustainable housing, based on success stories from ten countries. They argue that 'added values' should be the foundation for marketing. Added values are elements beyond the purely physical and technical aspects of the core product. Added values are, for example, 'none energy benefits' such as better air quality, better comfort, a sense of security, status, moral responsibility and aesthetics. Success stories in selling passive houses show that 'concept thinking' through the use of images is more successful than a pure focus on technical aspects.

In conclusion, energy-efficient buildings are seldom sold because of their energy profile, but because of other aspects such as location or having a balcony. Nonetheless, most residents seem to appreciate the environmental benefits over time, and become more aware of environmental issues. By the time positive aspects of energy-efficient buildings become more generally acknowledged, the energy profile of buildings may become a more relevant marketing factor.

Regarding the findings that aspects other than the environmental profile are important for marketing energy-efficient buildings, it is noteworthy that there are very few studies on aesthetic or architectural preference as perceived by users. It can be assumed that architecture and aesthetics are important factors when choosing a house (Thomsen, 2008). Architectural preferences in energy-efficient buildings are not the main focus of any of the studies reviewed, but architectural and aesthetic aspects are mentioned in some of them, for example in the study by Isaksson and Karlsson (2006). Their informants appreciated the architectural qualities in the low-energy houses, including the design and open-plan solution. The aesthetic aspects are also mentioned as a positive aspect in the evaluation of the Philip Merrill Environmental Center in Annapolis (Heerwagen and Zagreus, 2005), and in the evaluation of three university buildings in Australia (Paul and Taylor, 2008) (see next section).

## Performance and well-being

Most research on the correlation between energy-efficient buildings and users' performance and well-being has been carried out on occupational buildings. Some studies indicate that energy-efficient buildings have a positive impact on comfort, performance and well-being, but other studies do not. Heerwagen and Zagreus (2005) study on user evaluation of the Philip Merrill Environmental Center in Annapolis focused on the impact of the different passive-house features on the respondents' ability to work. Both temperature and acoustics were named as the conditions that can contribute positively but can also interfere with working abilities. Although acoustics was a concern, detailed assessment showed that most of the respondents seemed to be able to concentrate and achieve privacy when needed. Lighting (74 per cent) and air quality (61 per cent) conditions in the centre were rated as enhancing the ability to work.

For the Philip Merrill Environmental Center, the building's overall aesthetics were also institution has open-plan offices that identified as a positive aspect. The educational house a staff of about 90. Social benefits such as improved communication and sense of belonging were linked to the building's design, as well as perceived psychosocial benefits. About 80 per cent experienced a high level of morale, well-being and sense of belonging at work, and 97 per cent felt proud when showing the office to visitors (Heerwagen and Zagreus, 2005). Factors that influenced working ability negatively included distractions, interruptions, uncomfortable temperatures and glare from windows. Many said they preferred

to work at home when they needed to concentrate. Others tried to find some quiet space in the building. Noise was particularly an issue for those located close to circulation paths, with passers-by frequently stopping to chat. This might be a problem typical of large office buildings with open-plan layouts.

The authors also compared the results of the survey with results from evaluations of other LEED buildings that could be found in the database maintained by the CBE in 2005 at the University of California, Berkeley. Even though only a few LEED buildings are evaluated (10 from a total of 170), the results clearly show differences in user satisfaction with these LEED buildings. The Merrill Center is number 2 in the entire database (170 buildings) for overall satisfaction with the building. This is also a much higher score than any other LEED building achieves. A comparison of conventional buildings and LEED buildings also reveals that LEED buildings, in general, are not equated with high user satisfaction.

Another study by Heerwagen (2001) investigated whether green buildings enhance the well-being of workers in the Herman Miller SQA manufacturing building in The Netherlands. Heerwagen states that there is little knowledge on how and if sustainable building design influences working productivity. Key features of the case-study building are good energy efficiency, indoor air quality and daylight. Results from the company's evaluation of its performance show that, after moving from the old building to the new building, productivity, on-time delivery and product quality increased within the first nine months, whereas studies of buildings usually show a temporary productivity dip when moving companies to new buildings (Heerwagen, 2001). Heerwagen also found that shift workers were happier in the new building. In a survey, more than 20 per cent of daytime manufacture workers, on whom the study mainly focused, 'expressed an increased sense of being in good spirits while at work' (Heerwagen, 2001, p3). Data also show that daytime workers rated the environmental features of the new building as better, 80 per cent rated temperatures and daylight as better in the new building, 60 per cent perceived the new building as healthier, and more than 40 per cent stated that contact with nature, electric light and air quality was better than before. Almost 30 per cent also thought that their control over the environment was better in the new building (Heerwagen, 2001). The office workers perceived the new building as more healthy and were positive towards the overall experience of the environment. Also, 40 per cent felt that the new building was better for their work performance, privacy and overall work spirit. Social aspects were rated better, with 37 per cent stated that the new building was better for relationships with co-workers, and 28 per cent perceived that the sense of belonging was better. Although many responses were positive, it is worth noting that 40 per cent said there was no difference between the old and new buildings on the aspects mentioned above. The authors explained this by the spatial layout of the offices, which gives unequal access to daylight and views (Heerwagen, 2001).

Stemers and Manchanda (2009) studied the correlation between energy-efficient

design and occupant well-being in 12 case-study office buildings in the UK and India. The energy performances of the office buildings in use were compared with a detailed occupant survey on health, comfort and happiness. Some of the buildings had air-conditioning, some had a mixed mode and some were naturally ventilated/advanced naturally ventilated. Some of the office buildings had open-plan offices, and some were cellular. The results showed that increased energy use in the buildings is associated with increased mechanization (air-conditioning) and reduced occupant control. The reduced control is related to reduced occupant comfort and satisfaction. Energy use is inversely correlated with the well-being of the occupants. More energy use does not improve well-being. The authors conclude that there is growing evidence that perceptions of control, contact with nature and general pleasantness are important for the overall well-being of occupants in office buildings.

Overall, Heerwagen states that the SQA building in The Netherlands strengthens the ‘green building hypothesis’, which claims that ‘green buildings are better for people because they generate higher quality, healthier, more habitable space than comparable standard-practice buildings’ (Heerwagen, 2001, p6). Both studies by Heerwagen (2001) and Heerwagen and Zagreus (2005), and the study by Steemers and Manchanda (2009), indicate that energy-efficient buildings can have a positive impact on well-being and daily performance. Other studies do not confirm this. Paul and Taylor (2008), for instance, conclude that their study revealed insufficient evidence to support the hypothesis that green buildings are perceived as more comfortable than conventional buildings. They measured occupants’ perception of comfort and satisfaction in three university buildings in Australia, one green building and two conventional university buildings. The focus of the questionnaire was on aspects such as aesthetics, serenity, lighting, acoustics, ventilation, temperature, humidity and overall satisfaction of the users with their workplace. The survey found no evidence that green buildings are perceived as more comfortable than conventional buildings. The aspects of aesthetics, serenity, lighting, ventilation, acoustics and humidity were not perceived differently by the occupants of the two types of building, and the authors state that they were surprised by these findings (Paul and Taylor, 2008).

To date, very few studies have been carried out on windows and daylight in energy-efficient buildings; however, the positive effects of daylight are well documented in earlier research (Boyce et al, 2003). This topic is especially relevant in passive houses, where the size and placing of windows are crucial for energy efficiency, and the architectural expression will be influenced by it. Menzies and Wherrett (2005) focused on the meaning of windows in the workplace for both environmental sustainability and psychological reasons. Windows are important for the provision of daylight and a view. However, glare and passive solar gain can be problematic. Both sustainability and issues of comfort regarding a number of different types of multiglazed windows were of importance when investigating four office buildings in Edinburgh. A survey examined the level of comfort in the projects with respect to the effect of windows on their work environment. The thermal performance of the double-glazed windows in each build-

ing was also assessed. Levels of daylight were rated acceptable in all buildings, with little difference between those with low-emittance coating windows and those without. There was no clear difference in perceived comfort between occupants of the buildings with higher-specification glazing and the buildings with lower-specification glazing. However, the percentage of glazed facades played a role in perceived comfort. Occupants in the two buildings with lower percentages of glazing (below 30 per cent) wished for more windows, whereas those in the higher-percentage buildings were happier with the size of their windows. Despite that, the lighting level was rated acceptable in all buildings. Discomfort from glare was perceived to be on an acceptable level in the buildings where the glazed percentage facade was less than 40 per cent. All buildings also had blinds installed, which, according to the respondents, helped to reduce glare (Menzies and Wherrett, 2005). The building with the most energy-efficient windows was also perceived to be the most comfortable. However, the findings related to the other buildings did not support the hypothesis that environmental sustainability necessarily leads to improved comfort and productivity. The authors point out that a building with energy-efficient windows may contribute to high levels of comfort and productivity, but it is not the windows alone that create a better working environment. The key for creating a comfortable environment lies in the building design, orientation and window designs working together (Menzies and Wherrett, 2005).

In conclusion, these studies, which are based on more comprehensive accounts of comfort, show how the overall level of user satisfaction is influenced by a broad variety of factors. Floor plans, design, noise levels and many other parameters determine how occupants experience a building. The important finding of these studies, therefore, may be that there is no determinism in the relation between energy efficiency and user satisfaction: energy-efficient buildings can be experienced very positively, but this depends on many other factors.

## Discussion

General surveys often conclude that energy-efficient buildings are experienced as being better than conventional buildings, but on digging deeper, complaints and frustrations emerge among the users and it is important that these are considered. Some buildings function very well and have a positive impact on well-being and performance; others do not. Some buildings have operational systems that are difficult to understand, or users have not received sufficiently good information about how to operate them. These partly contradictory results of the connection between energy efficiency and user satisfaction in buildings is more complex than is usually assumed. Concluding this literature review, we propose three ways of improving the evaluation of energy-efficient buildings:

- inclusion of the buildings' social context in the analysis;

- extension of evaluations to include architectural and aesthetic qualities; and
- an in-depth study of training and information in the daily operation of energy-efficient buildings.

## Social context

Heerwagen (2001) and Paul and Taylor (2008) state that, in order to test the hypothesis that green buildings are perceived as more comfortable, and contribute to a healthier and better living and working environment, several case studies have to be conducted. The findings by Heerwagen (2001) and Heerwagen and Zagreus (2005) differ from the findings of Paul and Taylor (2008). The chapters of Heerwagen indicate that green buildings increase comfort, well-being and work performance, but Paul and Taylor (2008) could find no differences in perceived comfort in a green building and two conventional buildings. The differences in findings may be due to the features of the buildings, but also the attitudes and preferences of the users, such as whether they can identify with the concept of an energy-efficient building. When comparing energy-efficient buildings with conventional buildings, it is therefore important to consider the social context of the users, and the process behind the building.

The research presented often lacks focus on the meaning of the social context, or it lacks focus on the attitudes and meanings the users associate with the building. Leaman and Bordass (2007) state that users tend to have a higher tolerance of deficiencies in green buildings than they do in more conventional buildings. This implies that image and process mean something in the evaluation of a building. According to Vischer (2008), it is important to conduct user evaluations of buildings on more than one level. Contextual variables cannot be ignored. Users in a new occupational building may be happy about having a completely new building, whether it is energy efficient or not. A new building signals that employees are worth something, and it may contribute to a company's positive image. It is then easier to evaluate a building as positive, and ignore frustrations with ventilation and comfort. In the same way, evaluations of occupational buildings may also be coloured by conflicts with leaders, colleagues and a difficult organizational environment. Residential buildings are also evaluated taking into account the background of the residents' knowledge of the building they live in. If the building has received attention in the media and among researchers, this will affect evaluations.

The desire for an environmentally friendly image or the wish to be ordinary may also colour building evaluations. The intention of the different stakeholders at Linda's Park was to build housing that appealed to environmentally conscious people, as well as to 'ordinary' people (Isaksson and Karlsson, 2006). Indeed, there were only a few residents who regarded themselves as environmentally engaged persons, who found the environmental aspects important when choosing



the house. They expected to use less energy than in a conventional house, and wanted to reduce their impact on the environment, which they perceived as an important contribution to their family and to nature (Isaksson and Karlsson, 2006). Most of residents characterized themselves as being average when it came to environmentally friendly living. This also corresponds with the image that the stakeholders wanted to promote when marketing the houses. However, Isaksson (2009) emphasizes that both constructing and buying a passive house is something beyond the prevalent norm. It is most likely that people buying passive houses are aware of that. Going beyond the norm can also be viewed as extreme by outside observers. This might be appreciated by some residents, but not others, who would rather choose to characterize themselves as the ‘norm’. Even though the majority of residents named reasons other than the low-energy profile as reasons for choosing a house at Linda’s Park, they were aware of the concept in advance, and they have to handle it the people who look upon themselves as ‘average’ also have to develop an attitude towards it. Maybe they even feel they have to justify their choice to outsiders. This may be one reason why people seem more likely to tolerate deficiencies in low-energy buildings than in conventional buildings. It is therefore crucial to map the context of the building evaluation, users’ attitudes and their knowledge of the building.

## Architecture and aesthetics

It has been mentioned in this review that the architecture and aesthetics of energy-efficient buildings may have meaning for users (under the category ‘general satisfaction’). There is little research on this topic, so there is little available knowledge. Very few studies have focused on evaluating the architectural and aesthetic aspects of energy-efficient buildings. An energy-efficient approach influences the design and layout of a building, for in limitations on window area, material use and example in its orientation, or construction. It is commonly acknowledged that the appearance of a building provides information about its purpose and use, and that architectural aspects can have a significant influence on user satisfaction (Thomsen, 2008). It should therefore be of interest to determine whether the premise of an energy-efficient building results in specific architectural expression, and how the aesthetics of energy-efficient buildings are perceived by users. Do users find energy-efficient architecture aesthetically appealing? Can they identify with it? What role does the aspect of aesthetics play when choosing to live in an energy-efficient house? Further research should investigate these questions as they are important aspects of the realization of successful and comprehensive architectural concepts.

The focus on architectural aspects of energy-efficient buildings includes light and windows, and one study on this topic has been mentioned (Menzies and Wherrett, 2005). There is, however, a lack of research on window size and light in low-energy and passive houses, and according to Menzies and Wherrett

(2005), these aspects have to be seen in relation to other aspects of comfort and indoor climate in an energy-efficient building.

## Information and Training

Difficult energy operation systems are a common theme in the research, and should be a to make the operation of buildings focus in future constructions. understandable to users in order the work or home environment, as well as to ensure optimum performance of the building.

The lack of instructions on the adequate use of the building is a typical reason that people mention when having problems with the operation of their house or at their workplace (Kleiven, 2007). In the study by Schnieders and Hermelink (2006), it was found that operating the ventilation system was not entirely understood. The maximum ventilation switch was located in the kitchen, and this location led to the misconception that it was dedicated only to dealing with kitchen odours. Other problems they observed could be solved by providing more information to the residents, for example about the requirement to change filters more often in order to avoid noise from the ventilation system.

Schnieders and Hermelink (2006) also state that the results of informing people are often better if a qualified person explains and demonstrates the handling of the system as soon as a tenant moves in, rather than providing written information. Isaksson (2009) points out that complicated technical descriptions are seldom read by users, especially if they are not interested in technical innovations. Only if the users can operate the building will its performance be close to the calculations carried out in the planning phase. There is little research providing detailed evaluations of operation systems, and how information and training on use and operation should be given. How should energy operating panels be designed? Should there be differences according to resident groups and system operators? In what ways should information on use and operation be provided? How much information is needed, and should there be feedback on the operation of energy-efficient buildings over time?

Buildings and their users change over time (Brand, 1995). Longitudinal studies focusing on operation and maintenance over years are significant in planning better and more usable energy-efficient buildings.

## Further research

We see the following aspects as important areas of focus for future research:

- User evaluation must include a focus on social context, process and image for a better understanding of why a building is evaluated the way it is.

This also implies the significance of being aware of the gap between the outcome of simulations and experienced reality in indoor climate in energy-efficient buildings.

- User evaluation must include a detailed focus on different types of user-friendly operating systems.
- User evaluation must include a detailed focus on different ways of providing information and training for the users and system operators in energy-efficient buildings.
- User evaluations should be longitudinal, and focus on operation and maintenance over time.
- – Evaluations should include more than indoor climate, temperature, air quality and operational aspects. Other important aspects include perceived architectural quality and aesthetics, as well as light conditions.
- Evaluations should focus on users' reasons for choosing to live in energy-efficient buildings, to be able to give input on how to market energy-efficient buildings.

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