Post-Occupancy Evaluation of Low-Energy and Passive House Apartments in the Løvåshagen Cooperative — Occupant Behavior and Satisfaction

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Abstract

Experience with low-energy and passive house buildings forms the basis for the further development of zero-emission buildings. A post-occupancy evaluation of the Løvåshagen cooperative is therefore conducted by means of user surveys and measurement of indoor climate parameters, energy use and window opening time.

The goal of the post-occupancy evaluation is to obtain information about how occupants use and experience low-energy and passive house dwellings, especially with regard to heating and ventilation. In addition, the impact of user behavior on the indoor climate and energy use will be assessed.

In this paper, the results of the user survey regarding user habits and occupant satisfaction are presented.

The results show that low-energy and passive house apartments are used in ways that have a substantial impact on the indoor climate and energy use. The assessed extent of window ventilation and use of floor heating throughout the year around definitely increase energy use substantially and therefore partially explain the difference between the calculated and measured energy use. This difference will be quantified by measurements and parametric simulation in the continuation of the study.

Most respondents are satisfied or very satisfied with living in a low-energy or passive house dwelling. Nevertheless, a clear need for improvement with respect to heating and ventilation systems is detected.

It can be concluded that increased attention to the interaction between the occupant, the building design and the technical installation is needed in the development of zero-emission buildings.

Keywords: indoor climate, energy use, post occupancy evaluation, occupant behavior, occupant satisfaction

Introduction

Experience with low-energy and passive house buildings forms the basis for the development of zero-emission buildings. It is therefore essential to conduct post-occupancy evaluations of existing low-energy and passive house buildings to see how they perform in practice, how they are used and, last but not least, how they are experienced by the occupants.

As part of the activities in *The Research Centre on Zero Emission Buildings* (ZEB), a post-occupancy evaluation (POE) of the Løvåshagen cooperative in Bergen, Norway is conducted. The objective of the ongoing evaluation is to obtain a deeper understanding of how the occupants use and experience low-energy and passive house buildings, especially with regard to heating and ventilation. In addition, the evaluation will provide insight into how occupant behavior influences the indoor climate and energy use.

The Løvåshagen cooperative in Bergen is a pilot project designed according to criteria established by Enova[1] and completed in 2008. The cooperative consists of 52 low-energy apartments and 28 passive house apartments.

Figure 1 Illustration of Løvåshagen cooperative [ByBo AS 2009], showing low-energy apartments in the blocks to the left and back and passive house apartments in the two blocks in front with solar thermal collectors on the roof.

[1] **Enova is a public enterprise owned by the Ministry of Petroleum and Energy that was established in 2001 to promote more environmentally friendly consumption and generation of energy in Norway.**

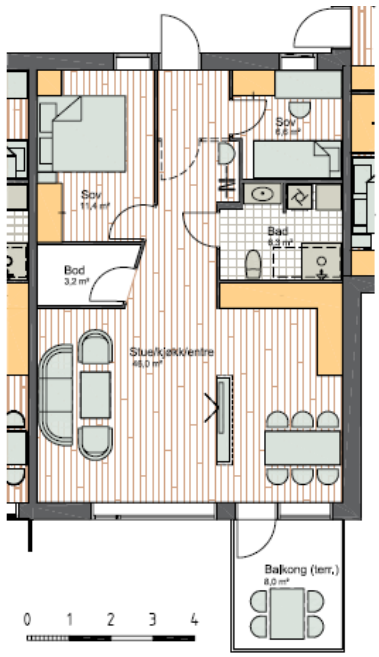

Figure 2 Typical apartment floor plan [ByBo AS 2009]

Each apartment is accessed via a gallery on the east or northeast side. The kitchens and living/dining rooms are oriented toward the west/southwest, whereas the bedrooms are mainly oriented towards the east/northeast. A floor plan of a typical apartment is shown in Figure 2.

The heating system in the passive house apartments consists of hydronic floor heating in the bathrooms and one radiator in the living room area. Each passive house apartment has a 200-liter water tank with a heat exchanger coil for the solar thermal collector. The ventilation unit is equipped with an electric heater battery that is used to increase the supply air temperature for thermal comfort reasons. Thus, the use of a traditional heating system separated from the ventilation system deviates from the original concept of passive house design, wherein the basic idea is to supply heat by post-heating the supply air and dispensing with a traditional heating system. The evaluation will therefore shed light on the occupants' experiences with the Norwegian adaptation of the passive house concept.

Balanced ventilation units with heat recovery of type Flexit SL4 R are installed in each apartment. The units are placed above the ceiling in the bathroom. Exhaust vents are placed in the bathroom and kitchen. Inlet vents are placed above the doors to the living room and bedrooms. In addition, there is a kitchen hood where the exhaust bypasses the heat exchanger.

The volume and temperature of the inlet air are controlled via a display in the living room area. There are three positions for air volume and six positions for post-heating of the inlet air.

The space heating demand for the passive house apartments is calculated to be 12.8 kWh/m^{2}a [Dokka and Helland 2008]. The total heat demand, including domestic hot water, is calculated to be 42 kWh/m^{2}a [Dokka, et al. 2010]. The solar thermal collector is estimated to provide 22.6 kWh/m^{2}a or 47 % of the total heat demand. The total delivered energy demand (electricity) is calculated to be 74 kWh/m^{2}a [Enova SF 2008].

In the low-energy apartments, the heating system is based on electricity, comprising floor heating in the bathrooms and one electric stove in the living room area. The total delivered energy demand (electricity) is calculated to be 101 kWh/m^{2}a [Enova SF 2008].

Based on measurements by the electricity supplier [BKK 2013], the median[2] of the measured total temperature-corrected delivered energy (electricity) for the passive house apartments in 2011 and 2012 was 126 KWh/m^{2}a. The calculated demand for delivered energy is exceeded by approximately 70 %.

[2] The median value is used to describe the central tendency of the distribution of delivered energy to reduce the influence of extreme values because some apartments are unoccupied and at least one apartment is used as a home office.

The median of the measured total temperature-corrected delivered energy (electricity) for the low-energy apartments in 2011 and 2012 was 126.5 KWh/m^2a. The calculated demand for delivered energy is exceeded by approximately 25 %.

Thus, the measured energy use exceeds the calculated energy use considerably for both the low-energy apartments and the passive house apartments. Surprisingly, the median of the measured energy use is basically the same for the low-energy apartments and the passive house apartments. This constitutes a major deviation from the expectation of lower energy use in the passive house apartments due to increased insulation and energy supplied by solar thermal collectors.

In the ongoing study, the causes for the deviation between the calculated and measured energy use will be identified and evaluated by means of user surveys and long-term measurements of energy use, indoor climate parameters and window opening time. The focus of the evaluation will be on user habits and the interaction between the occupant, the building and the technical installation.

Regarding user habits, which strongly influence the indoor climate as well as energy use, the following parameters are identified in user surveys and measurements: indoor air temperature, window opening time, use and maintenance of the ventilation system, purchase and use of electrical equipment and lightening, use of hot water and the choice and use of solar shading.

In this paper, the results of the user survey regarding user habits and satisfaction are presented.

In the continuation of the study, the impact of behavioral factors on indoor climate quality and energy use will be quantified by means of long-term measurements and parametric simulations. In addition, measured indoor climate parameters will be compared with occupant feedback. The results will form the basis for characterizing the potential for behavioral change on the one hand and the need for further development and adaptation of the buildings and the technical installation to the needs of the occupants on the other hand.

Methods

Occupant Survey

An occupant survey was conducted using a net-based questionnaire. The link to the questionnaire was sent by email to all occupants that had their email addresses registered at the board of the housing cooperative.

Of the 86 occupants to whom the questionnaire was sent, 34 responded. Of these 34, 14 lived in passive house apartments and 20 lived in low-energy apartments.

The questionnaire consisted of two parts. The first part consisted of questions based on the standardized MM form of the Örebro Model [Andersson, et al. 1988], which is used to map perceptions, complaints and symptoms related to the indoor climate. The second part consisted of questions regarding user behavior and occupant satisfaction, especially with regard to the heating and ventilation system.

Measurements

A measurement concept is implemented to facilitate the analysis of the interactions between occupant behavior, indoor climate and energy use. The long-term measurements will provide data regarding energy use, energy contribution of the solar thermal collector, indoor climate parameters (room air temperature, relative humidity and CO_2) and window opening time. In addition, measurements of the ventilation air volume and the radiant and operative temperature are conducted.

The measurement concept is implemented in two low-energy apartments and three passive house apartments, selected to represent low, average and high energy use.

Simulations

In the continuation of the study, parametric simulations of the indoor climate and energy use will be conducted for the apartments in which measurements are carried out. The simulations will be used to quantify the impact of the occupants' behavior on the indoor climate and energy use.

Results and discussion

In the following sections, the results of the occupant survey related to occupant behavior and satisfaction are presented. The results pertain to one housing project and therefore do not necessarily represent the general performance of low-energy and passive house buildings. Nevertheless, the results provide indications of tendencies, possible problems and potential improvements.

Window opening habits

The following figure shows the percentage of respondents that stated that they have the window in the bedroom open or tilted 8, 16 or 24 hours per day during the different seasons of the year.

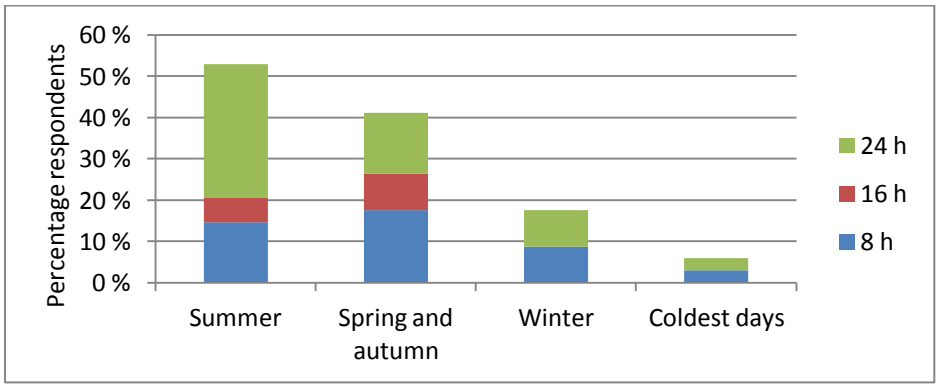

Figure 3 Percentage of respondents that stated that they have the window in the bedroom open or tilted 8, 16 or 24 hours per day

In the table below, the reasons for keeping the window open or closed are stated.

Table 1 Reasons for keeping the window open or closed

Reasons for keeping the window **closed**:	Reasons for keeping the window **open**:
Noise from outside (17 answers) Cold air from outside (11 answers) Dust/pollen from outside (2 answers) The ventilation system gives sufficient fresh air (12 answers) Reduction of heat loss/energy costs (6 answers)	Force of habit (3 answers) The ventilation system does not give sufficient fresh air (9 answers) Need for cooler air (2 answers)

The results show that the outdoor air temperatures during the different seasons of the year strongly influence the occupants regarding window opening time. At low outdoor air temperatures, the extent of window opening is considerably reduced. In the winter, more than 80 % of the respondents have the window open less than 8 hours per day, meaning that they most likely sleep with closed windows.

Approximately 40 % of the respondents open the window 8 hours or more per day during the spring and fall, which is expected to increase the heating energy use considerably.

There is a clear relation between outdoor air temperatures and window opening time for most occupants, even if there is a large variance. The majority of the respondents say that they keep the window closed to avoid annoyance by noise or cold air from outside. Thus, they rely on the ventilation system and consider it an advantage that they do not need to open windows to obtain fresh air.

Some respondents perceive the ventilation air volume supplied to be insufficient and therefore open the window. The ongoing measurements of the supply fresh air volume and CO_2 levels will be used to evaluate if the complaints concerning the perceived indoor air quality can be confirmed by deviations of measured from required values.

Heating habits in the bathroom

Regarding heating habits in the bathroom, 77 % of the respondents state that the floor heating is turned on all year, not only during the heating season.

Thirty-five percent of the respondents that stated that the floor heating is on all year would accept another floor material that would feel warmer, e.g., vinyl or water-resistant parquet, to reduce or even eliminate the need for floor heating solely for local comfort reasons. This reveals a potential for an optimized and integrated design solution for bathrooms.

For decades, nearly all bathrooms in Norway have been equipped with floor heating. The use of tiles has increased the need for floor heating for local comfort reasons. It has, in a way, become an indispensable user demand in Norway that bathrooms have to be equipped with tiles and floor heating. This also leads to a heat demand based on local thermal comfort reasons in periods during which there actually is no need for heating with regard to comfort for the whole body. The need for heating for the feet can even lead to a need for room air cooling, which typically is accomplished by opening the window. In low-energy and passive house buildings, the heating period is intended to be much shorter than in traditional buildings. Consequently, the supply of heat outside the heating

season will increase the deviation between the calculated heat demand and the heat supply in low-energy and passive house buildings. The impact on energy use will be quantified in the further long-term evaluation.

In other countries, where floor heating is less common, the heat supply in bathroom is also based on the room air temperature demand. For passive houses with centralized air-based heating systems, a supplementary local heat source is usually used in bathrooms to facilitate a higher room air temperature than in other parts of the building. Feist, et al. [2004] recommend the use of local heat sources with fast response times, such as radiators, radiant heaters or convection heaters. Another recommended possibility is to make use of the heat losses from the heating system by placing non-insulated supply ventilation ducts over the ceilings in bathrooms. According to Feist, et al. [2004], a time-controlled supplementary local heat source will produce a negligible increase in energy use because heat losses from a warmer bathroom will reduce the heating demand in other parts of the building. This might even justify the use of electric heating for local supplementary heaters, provided that the central air heating system is based on an environmentally friendly energy source [Feist 2004]. Measurements in the passive house project Stuttgart Feuerbach revealed that supplementary direct electric heating increased energy use by just 0.5 kWh/m^{2}a [Feist 2004].

Consciousness of energy use

The user survey contained a question concerning how conscious the occupant is of issues that influence energy use. The three possible answers were “Not conscious,” “Somewhat conscious” and “Very conscious.” The figure below shows the answers with respect to the different issues.

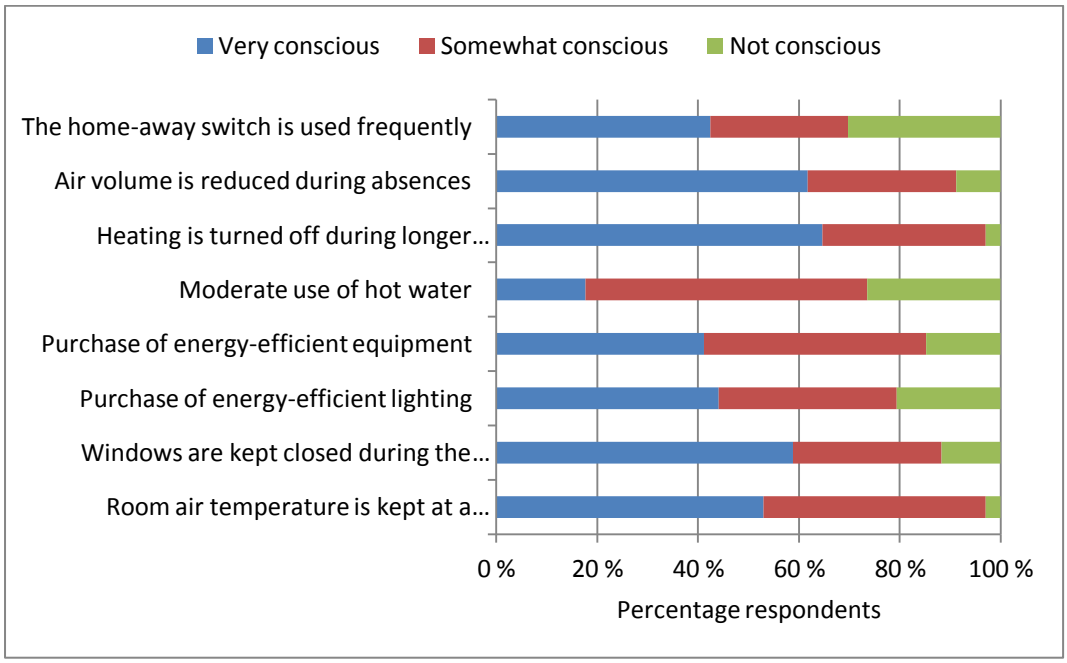

Figure 4 Consciousness of occupants regarding issues that have an influence on energy use Comment on the home–away switch: A switch is placed next to the entrance door, where the occupants can switch off circuits for all lighting and some wall outlets.

The results show that about half of the respondents consider themselves to be very conscious about all issues except the use of hot water, of which only 20 % consider themselves to be very conscious. Almost all the respondents are at least somewhat conscious of issues that influence energy use.

Approximately 80 % of the respondents state that they would like to learn more about indoor climate and energy use, preferably from a short flyer or on a website. This indicates a potential for behavioral change by means of information that leads to increased awareness of issues related to indoor climate and energy use.

Summer overheating

In all of the passive house apartments and some of the low-energy apartments, the living room and kitchen are oriented toward the west. In the rest of the low-energy apartments, the living room and kitchen are oriented toward the southwest. All of the apartments have relatively large window areas and therefore are exposed to unwanted solar gains during the summer. Apartments oriented toward the west are especially prone to overheating due to the low solar angle in the afternoon.

No solar shading was installed by the project developer, but an opening in the facade for the mounting of exterior shading was provided. Exterior shading has been installed by 18 % of the respondents, and 70 % of the respondents use interior shading, such as curtains or blinds. Twelve percent of the respondents state that they have no shading at all.

The figure below shows the proportions of the respondents who stated that they were never, sometimes or often are bothered by overheating during the three months preceding the survey. The figure also shows the distribution of installed solar shading.

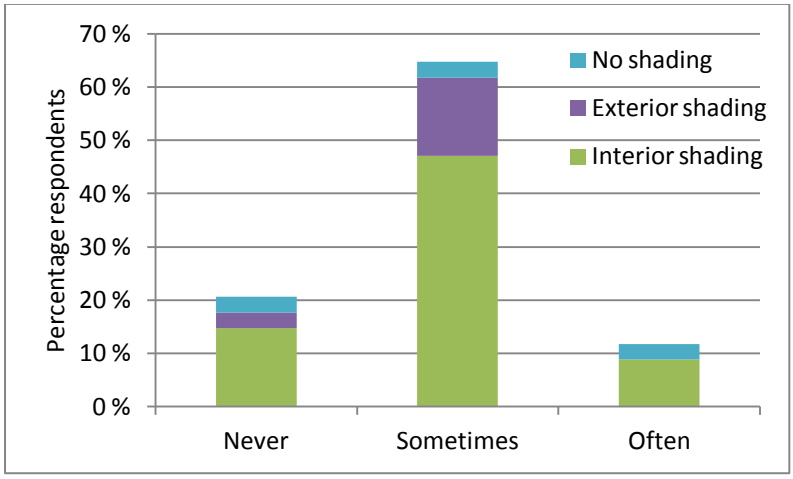

Figure 5 Percentage of respondents that stated that they never, sometimes or often were bothered by overheating in the 3 months preceding the evaluation

All the respondents that stated that they were often bothered by overheating (4 respondents) live in passive house apartments oriented toward the west.

Despite a quite high percentage of respondents that reported that they are sometimes bothered by overheating, there is a generally high level of satisfaction with the room temperatures, which 77 % of the respondents consider to be good or very good.

In the continuation of the study, the relationship between perceived thermal comfort and measured indoor climate parameters will be evaluated.

Satisfaction with the heating system

Despite a generally high level of satisfaction regarding the room temperatures, there are clear differences in the satisfaction with the heating systems in the different rooms.

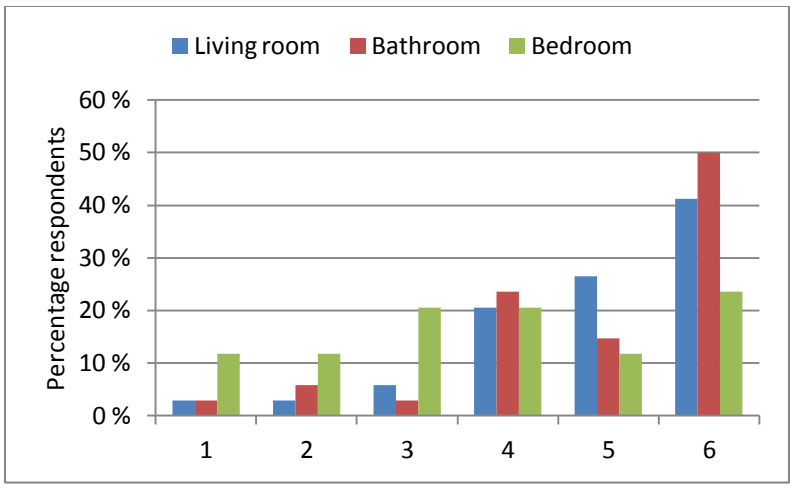

Figure 6 Satisfaction with the heating system in the different rooms on a scale from 1 to 6, where 1 is "very dissatisfied" and 6 is "very satisfied"

There is a high level of satisfaction with the heating system in the living room area and the bathroom, whereas quite a high percentage of respondents are less satisfied with the heating system in the bedroom.

The dominant reason for discontent with the heating system in the living room area and the bathroom is the difficulty of adjusting the temperature.

The following causes are specified regarding the discontent with the heating system in the bedroom:

- Difficulty of adjusting the temperature (4 answers)
- Lack of a local heat source (2 answers)
- The inlet air should be cooler (10 answers)

Thus, the dominant reason for discontent with the heating system in the bedroom is that the inlet air is perceived to be too warm. As mentioned earlier, there is generally a high level of satisfaction with the temperature conditions in the apartment, and only a few respondents states that they open the window to cool down the sleeping room. This indicates that the occupants have adapted to the concept of fresh air supply through a ventilation system but nevertheless would prefer cooler air in the bedroom.

It is obviously a waste of energy to heat a bedroom when actually a cooler bedroom is desired, especially if it leads to supplementary window ventilation. One technical solution for this issue would be to bypass the supply air to the bedrooms around the heater battery after the heat exchanger. This would, however, necessitate a local supplementary heat source in case of a higher temperature being desired at times, e.g., when the bedroom is used as a children's room in the daytime. As mentioned earlier, studies show a negligible increase in energy use by supplementary local heat sources, and therefore, even the installation of simple electric heaters could be justified [Feist 2004].

Satisfaction with the ventilation system

The figure below shows the stated satisfaction with the ventilation system on a scale from 1 to 6, where 1 is "very dissatisfied" and 6 is "very satisfied." Eighty percent of the responses are on the upper half of the scale, and 62 % of the respondents state that they are "satisfied" or "very satisfied."

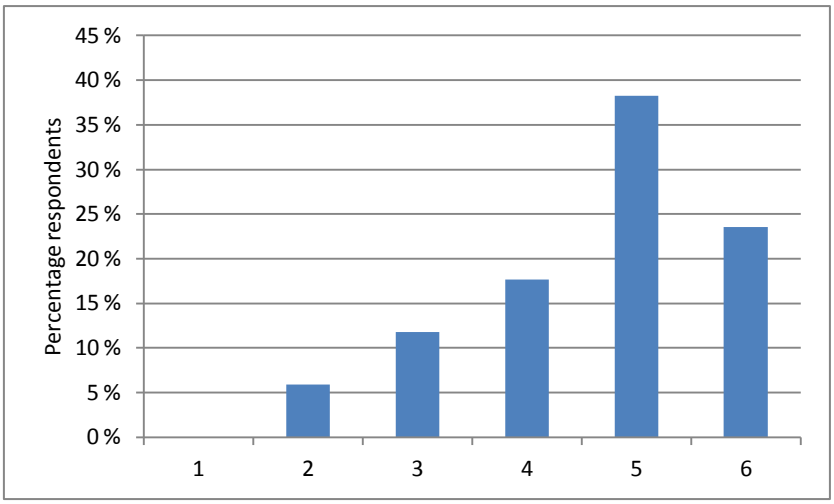

Figure 7 Satisfaction with the ventilation system on a scale from 1 to 6, where 1 is "very dissatisfied" and 6 is "very satisfied"

The reasons for discontent are the following: noise (1 answer), perception of dry air (2 answers), too little fresh air (2 answers), difficulty of controlling the air volume/temperature (1 answer) and difficulty of changing the filter (2 answers).

The respondents were asked to assess the degree of difficulty of the initial use of the ventilation on a scale from 1 to 6, where 1 is "very difficult" and 6 is "very easy." No one considered the initial use to be "very difficult." However, the answers were evenly distributed from "difficult" to "very easy," which indicates that there is potential for improvement regarding the user-friendliness of and/or instructions for the use and maintenance of the ventilation system.

Regarding control of air volume, approximately 50 % of the respondents state that the air volume is controlled according to the current demand, and 33 % state that the air volume is usually set to level II.

Regarding post-heating of the air, 24 % of the respondents state that the temperature level is always set to level I or II, i.e., the lowest levels. Sixty-seven percent of the respondents state that the temperature is controlled according to the current demand. One respondent does not know how to control the temperature.

In the further evaluation, the relationship between the use of the ventilation system and window opening habits will be analyzed. In addition, the impact on the indoor climate and energy use will be quantified.

Satisfaction with indoor air quality

The figure below show the responses regarding satisfaction with the indoor air quality, which 76 % of the respondents consider to be "good" or "very good."

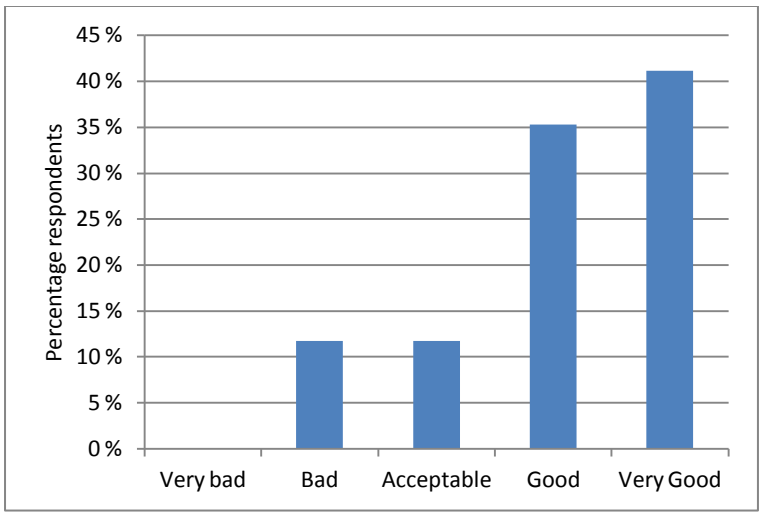

Figure 8 Assessment of perceived indoor air quality

The following reasons for discontent are specified: air feels sticky (3 answers), smell from cooking spreads within the apartment (1 answer), tobacco smoke or other odor from other apartments (1 answer) and little ability to control the ventilation (1 answer).

In the further evaluation, the perceived indoor air quality will be compared with the measured indoor air quality.

Changes in indoor climate-related symptoms

The respondents were asked to rate to what degree they have noticed change in indoor climate-related symptoms after moving to the Løvåshagen cooperative.

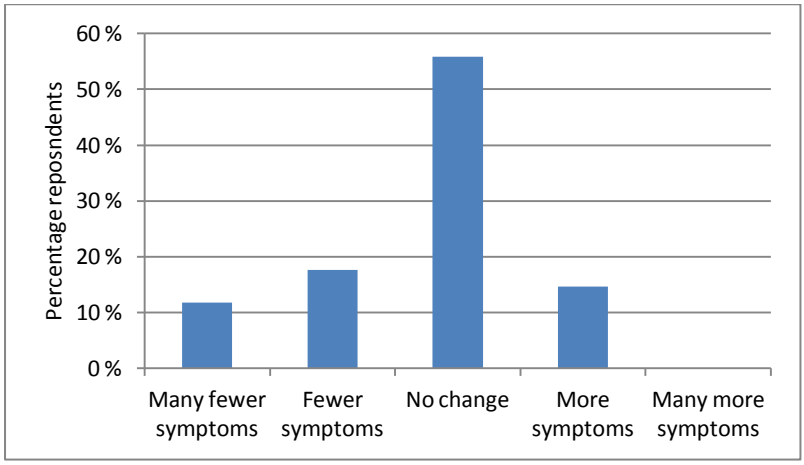

Figure 9 Change in indoor climate-related symptoms

Most of the respondents stated that they have not noticed any change in indoor climate-related symptoms. Approximately 30 % of the respondents stated that they now have fewer or even many fewer symptoms. Some respondents state that they now have more symptoms.

Additional results from the user survey regarding the indoor climate and its impact on health and comparisons with other studies are published in[Klinski, et al. 2012].

General satisfaction with living in a low-energy or passive house dwelling

The figure below shows the general satisfaction with living in a low-energy or passive house dwelling on a scale from 1 to 6, where 1 is “very dissatisfied” and 6 is “very satisfied.”

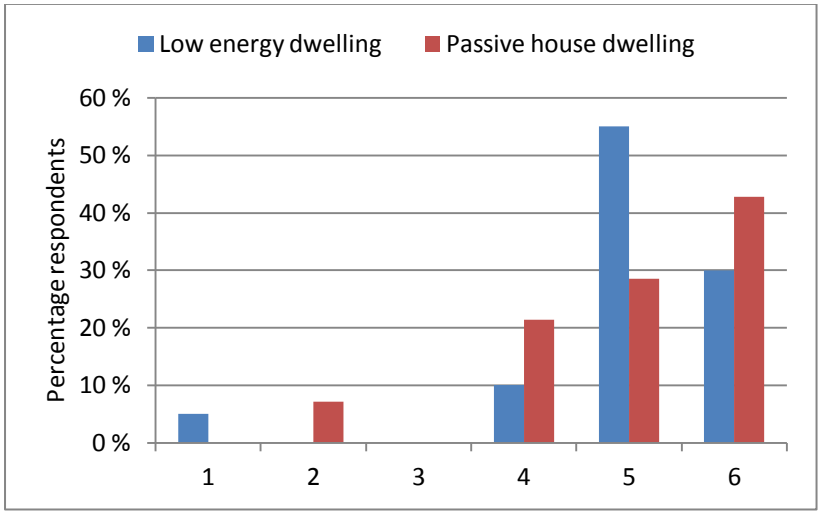

Figure 10 General satisfaction on a scale from 1 to 6, where 1 is “very dissatisfied” and 6 is “very satisfied”

The results show a generally high level of satisfaction: 85 % of the respondents living in low-energy apartments and 72 % of the respondents living in passive house apartments are satisfied or very satisfied.

A few respondents are dissatisfied or even very dissatisfied and indicate that their expectations concerning energy use, thermal comfort and indoor air quality are not met.

Conclusions

The results from a user survey concerning user habits show that low-energy and passive house apartments are used in ways that have a substantial impact on the indoor climate and energy use. The assessed extent of window ventilation and use of floor heating throughout the year definitely increase energy use substantially and therefore partially explain the difference between the calculated and measured energy use. This difference will be quantified by measurements and parametric simulation in the continuation of the study.

The clearly dominant specified reason for window ventilation is that the ventilation is perceived to not provide enough fresh air. The ongoing measurements of indoor climate parameters and air volume will be used to evaluate whether the discontent with the indoor climate can be confirmed by measured values.

Even if there is a generally high level of satisfaction with the thermal conditions in the dwellings, many respondents would prefer cooler bedrooms. Thus, solutions for temperature differentiation within dwellings should be considered and further developed.

The results indicate that window ventilation use is not due to the force of habit but rather a real need to change the perceived indoor climate, either with regard to thermal comfort or air quality. Thus, a crucial precondition for a reduction or elimination of window ventilation during the heating season is the faultless performance of the heating and ventilation system in providing satisfying thermal comfort and indoor air quality.

Nearly 80 % of the respondents stated that the floor heating is on all year, which obviously has a substantial impact on energy use. Because the intended heating season in low-energy and passive house dwellings is considerably shorter than in traditional dwellings, continuous heating in low-energy or passive house dwellings will increase the difference between heat demand and supply. This indicates a need for the implementation and further development of local heating solutions for bathrooms, where the interactions between the material use, the heating system and the occupant are taken into account to a greater extent.

Regarding summer overheating, only respondents living in passive house apartments oriented toward the west reported that they were often bothered by overheating. No respondents living in apartments with exterior shading reported that they were often bothered by overheating.

Most respondents are satisfied with the ventilation system. Nevertheless, the results indicate a potential for further improvement regarding user-friendliness and instructions for use and maintenance of the ventilation system.

Most respondents are satisfied or very satisfied with living in a low-energy or passive house dwelling. Nevertheless, a clear need for improvement is detected with respect to the heating and ventilation systems.

It can be concluded that increased attention to the interactions between the occupant, the building design and the technical installation is needed in the further development of zero-emission buildings.

Acknowledgement

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