House owners' experience and satisfaction with Danish low-energy houses - focus on ventilation

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Abstract. The purpose of this study was to evaluate house owners' experience and satisfaction with the first Danish detached low-energy single-family houses, built according to energy class 2015 before these supplementary requirements became standard for all new dwellings. A questionnaire survey was carried out among owners of newly built energy class 2015 houses. The paper presents the house owners answers to questions on their overall satisfaction, their heat consumption, and their satisfaction with the indoor environment (temperature, draught, air quality, noise and daylight). There is a focus on issues related to having a mechanical ventilation system, i.e. satisfaction with the air quality, does the air feel dry in winter, and does the ventilation system make noise and how the airing behaviour is in winter. As many as 370 out of 869 house owners, corresponding to a response rate of 43%, answered the questionnaire. There was an overall satisfaction with the new low-energy houses. More than 90% of the house owners perceived the indoor environment as satisfactory. The energy consumption was as low as expected by 59%, while only 7% answered that it was higher than expected. Compared with previous similar studies, problems with technical installations have decreased. However, there is a need for continued focus on the commissioning of new and not necessarily thoroughly tested, high-performance installations and new designs. Based on the survey a series of recommendations are given that might help to achieve both a low energy consumption and satisfied occupants of new low-energy dwellings.

1 Introduction

The current Danish Building Regulations (BR) defines the minimum requirements for the energy performance of buildings. In order to encourage the development of more energy-efficient buildings, the previous version of the regulations BR10 [1] included the supplementary and voluntary low-energy class 2015 and building class 2020. These more ambitious classes corresponded to the energy requirements suggested for the BRs forthcoming in 2015 and 2020, at the time when the requirements of BR10 were agreed. Low-energy class 2015 approximates the requirements of the present BR18. In 2012 and 2013, the proportion of low-energy class 2015 buildings was approximately one third of all newly constructed buildings in Denmark. Only very few buildings were built according to building class 2020 and therefore the survey in this paper refers primarily to low-energy class 2015. The yearly energy demand for heating, ventilation, cooling and hot water for a residential low-energy class 2015 house should be less than (30 + 1000 /Ae) kWh/m², where Ae is the heated floor area. The previous and new energy requirements in the Danish Building Regulations for detached single-family houses in Denmark are shown in Figure 1.

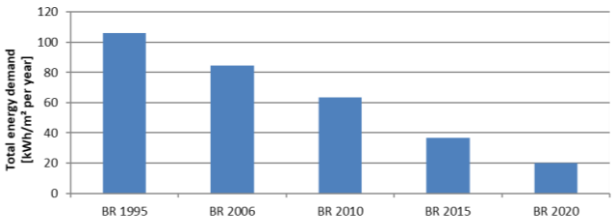

Fig. 1. The previous and new energy requirements for a new typical detached single-family house in Denmark. The requirements of BR2015 corresponds to the current BR2018 requirements.

Before the supplementary requirements for low-energy class 2015 became the new standard for all new buildings in Denmark, an evaluation was called for by the Danish Energy Agency. It should evaluate the experience gained among 1) house owners to identify possible negative consequences of living in detached low-energy single-family houses and 2) construction professionals to identify unforeseen consequences when designing and building to the class 2015 standard [2]. The intention was to let experience reveal the strengths of the low-energy class, but also to identify areas where changes were desirable, before making the low-energy class 2015 the new minimum requirement in the Danish Building Regulations.

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Earlier Danish studies have shown that previous generations of low-energy houses had some problems with the indoor climate e.g. high room temperatures in summer, so-called overheating, and noise from technical installations [3-5]. These earlier studies have also shown a need for more robust and easy-to-use technical installations that are operational at the time of moving into the house. The undesired "overheating" in low-energy houses was addressed in the revised BR10, by allowing the air temperature to be above 26 °C for only 100 hours and above 27 °C for only 25 hours per year.

On that background, the objective of this study was to carry out an evaluation of experience and satisfaction from the first low-energy single-family houses complying with the low-energy class 2015 requirements of the Danish Building Regulation 2010, in order to identify any need for adjustments, before low-energy class 2015 became the minimum requirement in the Danish Building Regulations 2015.

2 Methodologies

The evaluation among owners of new detached low-energy houses was conducted as a questionnaire survey. It included 40 questions about i.a. their overall satisfaction, their heat consumption, and their satisfaction with the indoor environment (temperature, draught, air quality, noise and daylight). It also included questions on issues related to having a mechanical ventilation system, i.e. satisfaction with the air quality, does the air feel dry in winter, and does the ventilation system make noise and how the airing behaviour is in winter. A series of supplementing open questions allowed for individual comments.

It was desirable to investigate whether the indoor climate in the new low-energy houses were perceived to be worse or better than the indoor climate in the older dwelling that the house owners came from. More than 54% came from dwellings built before 1980. As it was not feasible to ask the house owners before they moved into their new house, they were asked retrospectively to compare the perceived indoor climate in their new house with the indoor climate in their former dwelling and to mark if it is worse, unchanged or better.

The survey was conducted in October 2013. It was carried out by sending a letter with a brief description of the project and an invitation to participate in the survey by filling in a questionnaire, using an online survey system SurveyXact [7]. It was assumed that all the involved households had access to computer and internet, since 93% of household in Denmark had this access. House owners were promised anonymity. To encourage the house owners to complete the questionnaire, they were offered to participate in the draw for a gift, value about 100 Euro, for every 100 replies. By deadline, 370 house owners of a total of 869 had answered, corresponding to a response rate of 43%. This relatively high response rate might be due to the occupants' involvement and interest in new low-energy housing. It should be mentioned that no reminders were sent out.

2.1 Houses in the survey

Since 1997, Danish law has stipulated that all property for sale should be inspected by a trained energy consultant. The inspection is mandatory for both new and existing buildings. The energy consultant shall prepare an energy certificate with an energy rating on a scale from A to G. The certificate is registered by the consultant and compiled in the Energy Performance Certificate Scheme database [6]. From this database, 869 low-energy class 2015 single-family houses erected in 2010 (1%), 2011 (7%), 2012 (55%) and 2013 (37%) were identified and used in the survey.

The houses were built by around 130 different companies. The average floor area of the houses was 186 m². The houses were mainly (94%) heated by floor heating and 76% had a mechanical ventilation system with heat recovery. The percentage of different types of technical installations in the houses is shown in Figure 2.

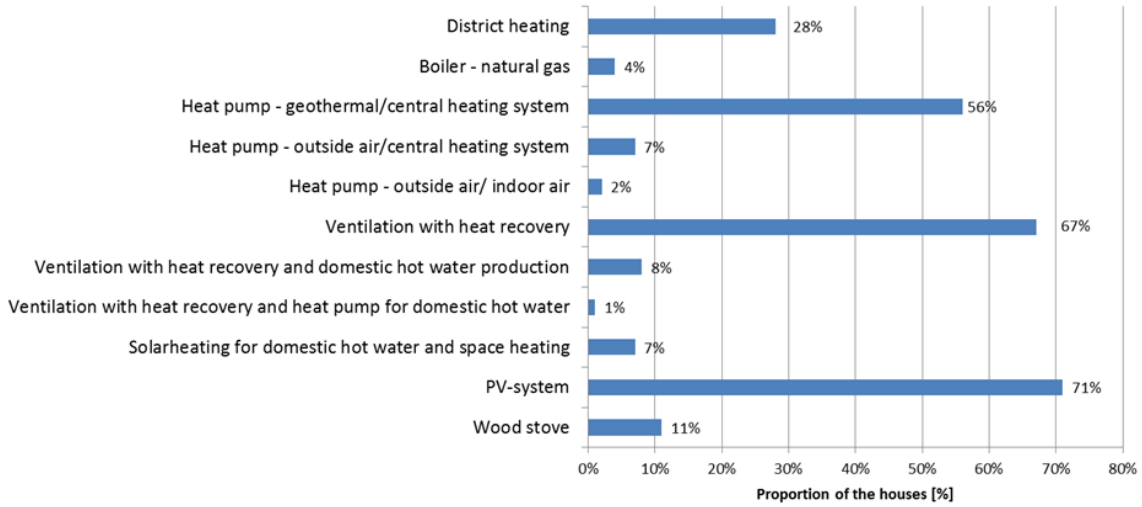

Fig. 2. Technical installations as reported by the house owners of the 370 detached low-energy single-family houses.

3 Results

3.1. House owners' overall satisfaction

Overall, the house owners rated it to have been a positive experience to move into and live in their new low-energy houses, since 93% of the house owners would recommend others to stay in a low-energy house. The important reasons formulated by the house owners themselves were good indoor climate and low energy and operating costs.

3.2 Heat consumption as experienced by house owners

Over half (59%) of the house owners experienced that their heat consumption was as low as they expected before they moved into the house, while 7% found their heat consumption not to be as low as expected. One-third (34%) did not know, presumably because they had not yet lived so long in their houses.

3.3 Perceived indoor climate in the low-energy house compared with former dwelling

A majority of the house owners perceived the various indoor climate parameters temperature, draught, air quality, noise and daylight to be better (84, 85, 84, 67 and 77% respectively) in their new low-energy house compared with the conditions in their former dwelling, see Figure 3. A minority of house owners perceived the individual indoor climate factors temperature, draught, air quality, noise, daylight to have become worse (4, 2, 2, 8 and 2% respectively) in their new low-energy house.

3.4 Perceived indoor climate in the low-energy houses

After defining the perceived indoor climate by the five parameters temperature, draught, air quality, noise and daylight, the house owners were asked to make an overall assessment of the indoor climate. More than 90% of the house owners found that the indoor climate was generally satisfactory in summer (93%) and in winter (94%) with only 4% and 2% expressing dissatisfaction in summer and winter.

In the following the house owners' assessments of the five specific indoor climate parameters are presented.

The temperature conditions were perceived as satisfactory by 84% in winter, while 73% experienced satisfactory temperature conditions in summer. The temperature was found to be unsatisfactory by 4% in winter, compared with 12% in summer. As in previous studies of low-energy houses, dissatisfaction was caused by temperature conditions that were too hot in summer. It was indicated by 19% and 32% that this was the case, daily and weekly, respectively. Large windows facing south were mentioned as the reason for the high summer temperatures. Some house owners commented that they had also experienced that it was hot in summer in their former house. Some house owners mentioned that their floor heating system was "slow" and could be difficult to use, but it was emphasised that there was a more constant temperature in the house. About half of the house owners indicated that the temperature in their new house was higher in summer (52%) and winter (48%) compared with their former house, while 19% indicated that the temperature had been lower in summer, and 6% indicated that the temperature had been lower in winter, see Figure 4. Large windows were mentioned as the reason for the high summer temperatures. The fact that nearly half of the house owners expressed that the temperature in winter in their new house was higher than in their former dwelling, might indicate that some of the potential energy saving form moving to a low-energy house has been transformed into better thermal comfort.

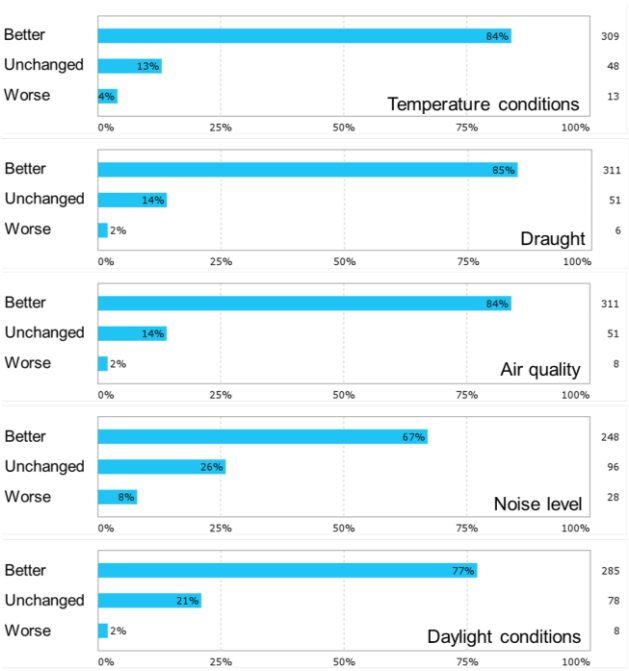

Fig. 3. Answers to the question "How do you perceive the temperature conditions, draught, air quality, noise level and daylight conditions in your new house compared with your previous dwelling?".

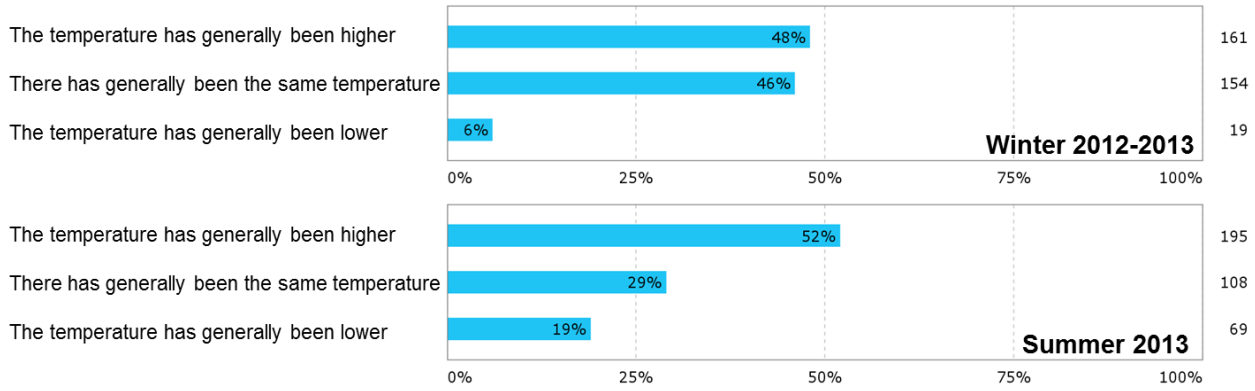

Fig. 4. Answers to the question "How was the temperature indoors in your new house in the winter 2012-2013/summer 2013 compared with your previous dwelling?".

Only few house owners experienced problems with draught as 94% and 96% never experienced problems with draught in winter or summer. Only 3% found the draught conditions unsatisfactory in winter and 2% in summer. Draught was only mentioned in connection with the opening of windows and near the inlet of the ventilation system.

The air quality was perceived as satisfactory by 88% in winter, and by 90% in summer, see Figure 5. Only 4% found the air quality unsatisfactory in winter and in summer. The house owners reported almost no problem in relation to the perceived air quality. Only to a modest extent, it gave rise to dissatisfaction with the air quality that the air felt dry in winter, see Figure 6. Problems with dry air were reported by 7% to be daily and 11% to be weekly or monthly. Some house owners emphasised dry air and odours from a neighbour's wood stove in connection with the question of air quality.

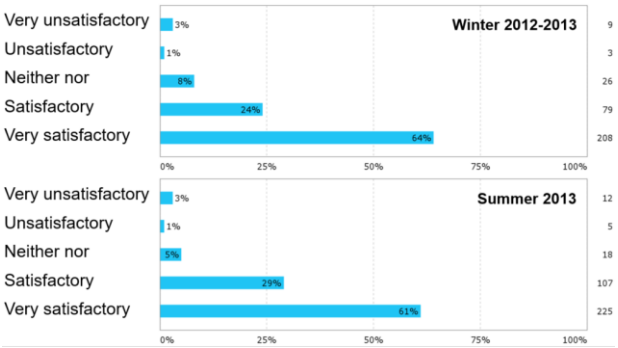

Fig. 5. Answers to the question "How did you find the air quality in your house?".

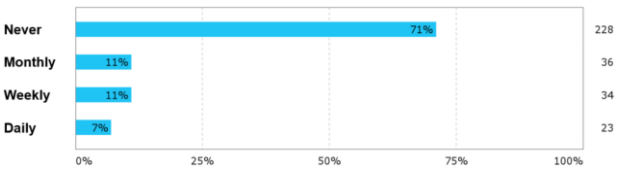

Fig. 6. Answers to the question "How often have you perceived problems with dry air in the winter?"

Noise conditions were perceived as satisfactory by 84% in winter, and 86% perceived the noise conditions as satisfactory in summer. 6% found the noise conditions to be unsatisfactory in winter compared with 4% in summer. In winter most people (74%) have never perceived problems with noise from the ventilation system, see Figure 7. To a minor extent, the ventilation system gave rise to dissatisfaction with noise conditions. Problems with noise from the ventilation system were reported by 9% to be daily and 6% to be weekly in winter against 12% and 7% respectively in summer. In summer, it can be useful to use night ventilation (by-pass heat recovery) to cool down the house. Therefore, it is important to focus on noise reduction in the ventilation system and especially at inlets (and outlets) in bedrooms and children's rooms. The house owners' comments included the ventilation system and heat pump as sources of noise, but in most cases, it was not considered as a big problem, but something "you could live with in light of the perceived advantages". It was stated by 57% that there was no nuisance from noise in any room. Other technical installations than the ventilation system caused problems with noise for 6% daily and 4% weekly in winter and 6% and 3% respectively in summer. As expected, annoying noise was found to come from the utility room, which was reported by 18%. Notably the results also showed that 13% perceived annoying noise in the bedroom.

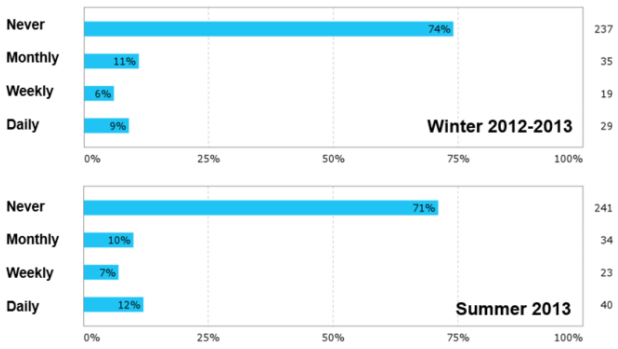

Fig. 7. Answers to the question "How often have you perceived problems with noise from the ventilation system?".

Daylight conditions were perceived as satisfactory by 91% in winter, and by 94% in summer. Daylight conditions were found to be unsatisfactory by 2% in winter and in summer. To a modest extent, glare in summer gave rise to dissatisfaction with daylight conditions. It was indicated by 4% daily and 11% weekly that this was the case. A few house owners, 3% daily and 8% weekly, perceived that there was too much daylight. In their comments, the house owners suggested possible building solutions, including roof overhangs and exterior solar shading; some explained that they had retrofitted their house with marquees, curtains and blinds to overcome problems.

3.5 Technical installations

House owners were asked whether they had received sufficient information on how the house's various technical installations worked. Nearly two thirds found that they had enough information, while about one third (38%) did not find that they had received sufficient information. For the latter group, see Figure 8, 83% lacked information on the ventilation system, 49% lacked information on the heating system, 47% lacked information on the heat pump and 31% lacked information on solar cell systems for power generation.

House owners were also asked whether they had perceived small or big problems with the technical installations. Big problems had been experienced by 9% in winter and 6% had experienced big problems in summer. Small problems were experienced by 31% in winter and by 24% in summer. The house owners' comments elaborated the problems and the recurrent problems were related to commissioning of the ventilation system, heating system and heat pump immediately upon moving into their new house. Compared with previous similar studies, problems with technical installations and design have decreased. However, there is a need for continued focus on the commissioning of new, and not necessarily thoroughly tested, high-performance installations and new designs to achieve both low energy consumption and satisfied house owners. It is also worth mentioning that some house owners mentioned that their floor heating system was "slow" and could be difficult to use, but it was emphasised that there was a more constant temperature in the house.

3.6 Airing behaviour

Even though the majority of the houses have a mechanical ventilation system, it is seen that people are still airing out in the winter by opening windows on the clamp or completely open in the winter, especially in the daytime, see Figure 9. About two-thirds of the house owners open windows during the day, while one-third open windows at night. Nearly a third never opens windows at daytime, while about two thirds never open windows in the night. Half of the occupants open and close windows occasionally during the day. As reasons for opening windows, the occupants mention that it is to ventilate, to get fresh air and to cool down especially the bedroom and for airing out the bathroom.

3.7 Able to regulate?

House owners were asked whether they had found that they were be able to regulate, and whether they had used the option to regulate the room temperature, the ventilation and the solar shading. It was found by 97% that they had the option to regulate the room temperature, and 78% were using the option to regulate the temperature. It was experienced by 90% that they had the option to regulate ventilation, 55% used the option to regulate the ventilation. It was experienced by 41% that they had the option to regulate solar shading and nearly all (40%) used the option of adjusting the solar shading. Several house owners noted that solar shading was needed; several had established internal shading in the form of curtains and blinds.

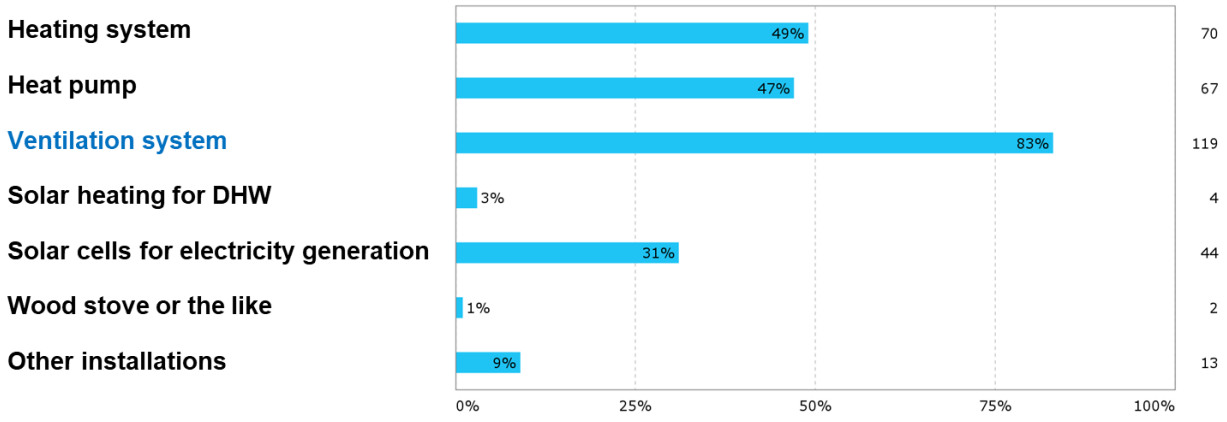

Fig. 8. About one third of the house owners did not find that they had received enough information on how the technical installations work. The figure show their answers to the question “Which of the following installations are you lacking information about?”

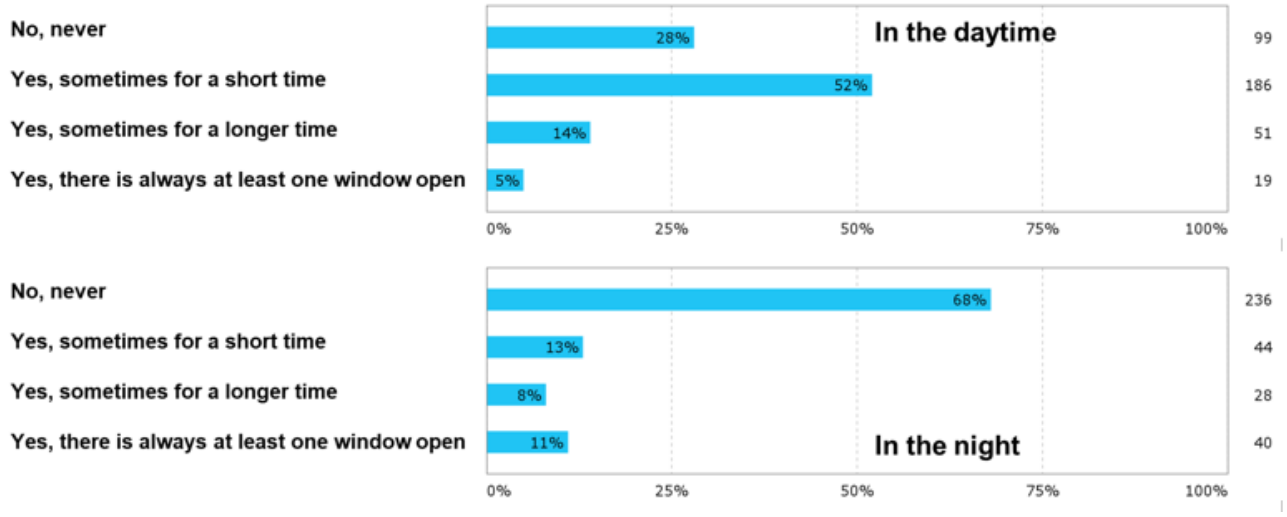

Fig. 9. Answers to the question "Do you open windows in winter?"

4 Discussion

Overall, the house owners had a positive experience of moving into and staying in their new low-energy houses and they would recommend others to live in a low-energy house. They explained it by their experience of good indoor climate and low energy consumption and consequently low running costs. A majority were more satisfied with the indoor climate in their new house compared with their former dwelling.

Earlier studies have found that prerequisites for ensuring that occupants are satisfied with the indoor climate in low-energy houses, are, among other things, a strong focus on preventing uncomfortably high temperatures during summer and uncomfortable noise from technical installations [3, 4]. Solutions are available, e.g. by combining external solar shading, appropriate window design and orientation and facilitating effective use of natural and mechanical ventilation and noise reduction at ventilation inlets. Compared with previous similar studies on earlier generations of low-energy houses [4, 5], the satisfaction with the perceived indoor climate have improved.

Earlier studies have also called for robust and easy-to-use technical installations that are fully operational at the time of moving into the house. Comparing the results of this study with similar studies on earlier generations of low-energy houses [4, 5], it is found that problems with the technical installations had decreased. However, there is a need for continued focus on the commissioning of new and more or less thoroughly tested high performance installations and new designs to achieve both the desired low energy consumption and satisfied house owners.

To a greater extent than previously, the house owners in this study experienced that their heat consumption was as low as they had expected before they moved into the new house. This might be due to improved communication with house owners giving a more realistic expectation of their energy consumption in accordance with their family situation and behaviour than before.

5 Conclusions

The majority of house owners were satisfied with their low-energy houses, and they can recommend others to live in such houses.

Generally, house owners perceived the indoor climate as satisfactory and as better than in their former older and not low-energy dwelling.

To help ensure satisfaction among owners of new modern low-energy dwellings it is recommended to:

- Avoid launching new installations and new designs in dwellings to achieve a low energy consumption, without first thoroughly testing them for unwanted side effects. Focus on e.g. annoying noise from ventilation systems and heat pumps especially in bedrooms and children's rooms is recommended.
- Apply robust and easy-to-use technical installations that are operational at the time of moving into the house.
- Minimise problems with high indoor temperatures during summer, by e.g. considering the effect of large windows facing the sun, use of solar shading and bypassing heat recovery in the ventilation system. Provide documentation at the design stage of the indoor temperature in summer by a simulation tool.

- Give a thoroughly introduction on how it is intended to operate and maintain the technical installations. This will help occupants to understand how their behaviour can support the automatic regulation for the benefit of both the indoor environment and energy consumption.
- Consider bedrooms/children's rooms as critical rooms because they are occupied for long time and because e.g. noise as well as the temperature are critical parameters for assuring a good sleep quality.

The paper is a reanalysis of data from a previously reported project, initiated by the need for relevant case studies for Subtask 4 on "Strategies for design and control of buildings" under IEA-EBC Annex 68 Indoor Air Quality Design and Control in Low Energy Residential Buildings. All occupants who took time to answer the questionnaire are gratefully acknowledged, and so are the Danish Energy Agency for supporting the study.

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