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Occupant Experiences and Satisfaction with New Low-Energy Houses

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Abstract
The development and the erection of low-energy buildings have been intensified in recent years. Still, there are only few studies on occupant experiences and satisfaction of living in low-energy houses. A questionnaire survey was therefore carried out in the autumn 2011 among occupants of low-energy houses that meet the future lower energy requirements of the planned Danish Building Regulations 2015. The purpose was to study experiences and satisfaction among occupants living in new low-energy houses. It included i.a. overall satisfaction, perceived indoor climate and experiences and satisfaction with technical installations for heating and ventilation, the ability of regulating the indoor climate, the availability and quality of information and the experienced heat consumption. The survey showed an overall satisfaction with new low-energy houses, but also that there were problems that should be addressed in order to make low-energy houses attractive to ordinary people. Occupants experienced among other things noise from the technical installations and that it was too hot in summer and too cold in winter, that there were a series of problems with the technical installations and that their use was difficult and that the energy consumption was higher than expected. A series of recommendations to increase occupant satisfaction in existing and future low-energy houses are given.

Keywords - Low-energy houses; indoor environment; perceived indoor climate; questionnaire survey; occupant satisfaction

1. Introduction

In 2006 the municipality of Egedal decided to make use of the option in the Danish Planning Law for a municipality to tighten the energy requirements in the local plan regarding the establishment of new settlements. During the years from 2007 to 2014, a total of 442 dwellings are to be designed and constructed with a heating demand corresponding to the low-energy standard in the Danish Building Regulations 2008 (BR08) [1] referred to as "low-energy class 1" in a new settlement called Stenløse Syd. This means that the energy consumption is to be 50% lower than the requirement in BR08 or what corresponds to “low-energy class 2015” in the present Danish Building Regulations 2010 (BR10) [2]. Sixty-six dwellings were to be designed and constructed with a yearly net space heating demand of 15 kWh/m². All the single-family houses were to be heated by a heat pump supported by a 3m² thermal solar system for domestic hot water. The dense low-rise housing was to be heated by a district heating network. All dwellings were to be equipped with a mechanical ventilation system with heat recovery and an electronic system for energy monitoring and control of the heating systems. The first houses were occupied in 2008. An EU-CONCERTO project “Cost-effective Low-energy Advanced Sustainable Solutions – Class1” [3] was developed around this planning initiative to support the demonstration activities through development, monitoring and evaluation. The CONCERTO community in the Class1 project includes additional the new construction of a kindergarten, an activity centre for elderly people and the energy renovation of two schools and five institutions of the municipality.

This paper presents the result of a questionnaire survey of occupant experiences and satisfaction in 35 single family houses which were completed at the time of the conductance of the survey. This was part of an evaluation of the settlement that also included an assessment of energy consumption of the houses and measurements of selected indoor climate parameters [4]. The objective of the questionnaire survey was to study the occupants’ experiences and satisfaction with various aspects of their new low-energy houses.

2. Methods

The questionnaire survey was conducted in November - December 2011 when the occupants had been living in their houses for a period ranging from 3 to 30 months. It was carried out by sending an e-mail with a brief description of the project and an invitation to participate in the study by filling in a questionnaire, using the online survey system SurveyXact [5]. The questionnaire was almost identical to the version used in a previous survey [6,7]. Sixty-one adults in 35 occupied houses were asked to participate in the survey. Up to three reminders were sent out with ten days’ intervals apart after the first invitation. Respondents were informed that they would get a gift certificate of 13 euros if they participated in the survey. The questionnaire was answered by 44 occupants corresponding to a response rate of 72.1%. Women constituted 45.5% (20) of the respondents. Responses (one, two or three) were received from 27 out of the 35 houses corresponding to a response rate of 77.1%. The questionnaire survey focused on the occupants’ overall satisfaction with their new low-energy houses; perceived indoor climate summer and winter; experiences and satisfaction with technical installations for heating and ventilation; the ability to regulate the indoor climate summer and winter; practice of opening windows; availability and quality of information and experienced heat consumption.

3. Results and Discussion

3.1 Occupant experiences and satisfaction

A high response rate was achieved in the questionnaire survey. This may be due to the occupants' involvement and the fact that every participant would receive a gift certificate as a reward.

3.2 Occupants' overall satisfaction

Occupants were generally satisfied with their new houses. To the broad question "Can you recommend others to live in a low-energy house?", 84% answered yes and 14% maybe. The occupants were also more satisfied with the temperature conditions and air quality in their new house compared with their earlier house, see next paragraph.

3.3 Perceived indoor climate summer and winter

To the broad question "Are there situations or times when you are not satisfied with the indoor climate in your home?", 26% answered yes. The main reasons given for the dissatisfaction were that it was either too warm in summer or too cold in winter.

The occupants were asked about the perceived indoor climate last summer and winter concerning the five parameters temperature, air movements, air quality, noise and daylight on a 5-point scale ranging from Unsatisfactory (1) to Satisfactory (5). One question was, for example, "What do you think about the indoor climate in your house, regarding the temperature last summer?". Table 1 shows the mean values for the five parameters and a general assessment of the indoor climate last summer and last winter.

Table 1. Mean values of assessments on a 5-point scale[1] of satisfaction with five indoor climate parameters and a general assessment of the indoor climate last summer and last winter

Parameter	Summer	Winter
Temperature	3.7	3.7
Air movements	4.2	4.2
Air quality	4.6	4.5
Noise	3.6	3.5
Daylight	4.7	4.7
General assessment of the indoor climate	4.3	4.1

[1]5-point scale ranging from Unsatisfactory (1) to Satisfactory (5)

During the summer the mean values of assessments of satisfaction on the 5-point scale varied from 3.6 (noise) and 3.7 (temperature) to 4.6 (air quality) and 4.7 (daylight). The mean value of the assessments of the 5 parameters and the general assessment of the indoor climate last summer was 4.3. This means that the occupants were most dissatisfied with the noise and temperature conditions and most satisfied with the daylight conditions and air quality. Nearly half (48%) of the occupants specified that they experienced noise from the technical installations, 14% experienced noise from activities inside the building and only 5% experienced noise from outside the building. From their written comments, it appears that the noise comes from several sources like ventilation system, heat pump and rainwater pump. One third (36%) of the occupants specified that they experienced that it was too warm during summer and 11.4% that the temperature varied too much. As expected, due to the general satisfaction with daylight conditions and air quality, only 20% (9) wanted more or less light in the living room, where 16% (7) would like less light and only 7% experienced stuffy air.

During winter the mean values of assessments of satisfaction on the 5-point scale varied from 3.5 (noise) and 3.7 (temperature) to 4.5 (air quality) and 4.7 (daylight). The mean value of the assessments of the 5 parameters and the mean value for the general assessment of indoor climate were 4.1. This means that during winter the occupants were most dissatisfied with noise and temperature conditions and most satisfied with daylight conditions and air quality. More than half (58%) of the occupants specified that they experienced noise from the technical installations, 15% experienced noise from activities inside the building and no one experienced noise from outside the building. Of the respondents, 30% (12) specified that they experienced that it was too cold, and 18% (7) found that the temperature varied too much. Some respondents explained that problems with temperature conditions were related to various technical problems, see below. Moreover, 20% (8) of the respondents indicated that they experienced problems with draught. The occupants generally expressed satisfaction with the daylight conditions and air quality, where only 5% (2) of respondents indicated that they experienced problems with too little daylight. Less than 20% (8) expressed that they would prefer to have more or less light in some rooms. No one experienced stuffy air and unpleasant smells.

Thus, some occupants experienced problems with the indoor climate. It is sometime stated that saving energy is a threat to good indoor climate and that living in a low-energy house is synonymous with living in a house with a poor indoor climate. Therefore, to put the problems in perspective, a comparison with the occupants' previous house was made by asking "How do you experience the air quality in your new home compared with your former home?" and similar for temperature conditions and noise. A majority (77%) of the occupants responded positively that the air quality was "better" in their new house. For the temperature conditions, nearly half (48%) of the occupants found it "better" and 25% found it to be "worse". One third (34%) found that the noise level was "better" now, whereas 39% found that it was "worse".

To raise occupant satisfaction with the indoor climate in the actual houses, first priority is to reduce the noise level from the technical installations.

Since the noise level was not measured, it is not possible to evaluate whether requirements (BR10) are met. But the occupants' response show that it is relevant to perform control measurements and it is recommended to evaluate whether the existing requirements are sufficient. Secondly, more comfortable conditions of temperature should be provided, i.e. less warm conditions in summer, warmer conditions in winter, and a more stable temperature. Possible energy-efficient solutions could be external solar shading where it had not been established yet, smaller windows facing the sun, having a strategy related to the practices of ventilating by opening and closing windows (natural ventilation) and/or use of mechanical ventilation and a faster temperature regulation with sufficient heat capacity in all rooms.

3.4 Technical installations

The low-energy houses are relatively advanced, with several more or less complicated technical installations like for example a ventilation system, a heating system, a heat pump, photovoltaic and solar heating. It seems to be a challenge to make all installations run as intended from day one after occupants move into their new houses. There were a series of initial problems with the technical installations. More than half (55%) of the occupants experienced problems with technical installations in summer and 70% experienced problems in winter. This resulted in a number of critical comments from the occupants related to the heat pump, solar heating, ventilation system as well as geothermal heat. The complaints about heat pumps were twofold; they had too little capacity and used more energy than promised. Moreover, some installations were not functioning properly.

A higher degree of occupant satisfaction could be achieved by an improved commissioning process, ensuring that the technical installations run as intended from day one, and are able to provide the required indoor climate at a low noise level and at the required ventilation rate. This should be combined with a better follow-up on acute and periodic problems.

3.5 Availability and quality of information

The different technical installations in each house had their own user guide/manual (when available), their own user interface, with its own logic, terminology and symbols. Therefore, there is a risk that a house is complicated and difficult to use and therefore an optimal interplay between the different installations is not achieved. This can lead to energy consumption not being as low and indoor climate not being as good as it was intended. In some houses it was apparently forgotten that occupants feel more satisfied with the indoor climate if they can control it, e.g. by adjusting the temperature, the ventilation or the use of solar shading, see below.

In an attempt to clarify whether the occupants were prepared and capable of using their house as intended, four questions (Q1-Q4) were asked about the availability of information and their opinion about the information if they received it, see Table 2. It is seen that there were problems with the information both with respect to availability and quality. From this and a series of critical comments it is clear that there is a need for making it simpler to operate a low-energy house as intended. This may be achieved by more user friendly and robust installations that take into account normal peoples' competences and an informative and easy-to-understand guide to operating the technical installations of the house. A personal initial introduction by a pedagogic expert is recommended in order to improve the experiences of the hand-over process. It could also be a user manual or online support and an improved commissioning process, which would allow the occupants to be able to use their house from day one as intended. To achieve this, it is also recommended to involve occupants in innovative product development and to ensure that there is a follow-up that picks up the experience gained by occupants.

Table 2. The % of occupants who received written/orally information from the suppliers of the houses and the % of occupants who were dissatisfied with the information they received

Question	% who received written/oral information	% dissatisfied with information[2]
Q1Did you or others in the household receive a maintenance plan for the house?	43[1]	39
Q2 Did you or others in the household receive information on how the heating system works?	48/41	45
Q3 Did you or others in the household receive information on how the ventilation system works?	55/30	34
Q4 Did you or others in the household receive information on how to ensure a good indoor climate?	11/18	29

[1]No distinguishing between written/oral information was made for this question
[2]The % dissatisfied is determined as the % of occupants answering 1 or 2 on a 5-point scale ranging from Unsatisfactory (1) to Satisfactory (5) for the question "If "yes" - what is your opinion about the information?

3.6 User behaviour

User behaviour is important for both energy consumption and indoor climate. In the present study occupants were asked about behaviour in relation to regulation of their indoor climate and practice of opening windows.

3.7 Regulation of the indoor climate summer and winter

To the broad question "Are there typical situations or moments when you are not satisfied with the automatic regulation of the indoor climate in your home?", 36% of the occupants answered yes. They specified that they were dissatisfied due to a high temperature during the summer. On another broad question "Are there typical situations or moments when you are not satisfied with your personal regulation options?", 43% of respondents answered yes. Most occupants specified that they could not maintain a comfortable temperature (it was too warm) in the summer, and some were not satisfied with the slow temperature regulation, and that it was difficult/complicated to regulate the temperature and that they would like to have solar shading. The dissatisfaction was in some cases related to a floor heating system that reacted relatively slowly.

Occupants were asked two questions (Q1 and Q2) for a more detailed assessment of their experience of the regulation of the room temperature, ventilation and solar shading over the year, see Table 3.

Table 3. Mean values of assessments on 5-point scales of experiences with the regulation of room temperature, ventilation and solar shading

Question	Room temperature	Ventilation	Solar shading
Q1 To what extent do you feel that you personally have the ability to regulate and adjust the following?[1]	3.8	3.9	3.5
Q2 Do you feel that you need to be able to regulate the following? [2]	3.2	2.6	3.0

[1]5-point scale from "No possibility to personally regulate" (1) to "Full personal ability to regulate" (5)
[2]5-point scale from "No, never" (1) to "Yes, very often" (5)

For Q1, there was a big variation in occupant's perceived ability to regulate and adjust the three parameters, since there were answers at all 5 levels on the 5-point scale. Generally, the assessments were on the positive side, with the highest number of assessments (36, 48 and 31% respectively) answering "Full personal ability to regulate" (5) for all three parameters room temperature, ventilation and solar shading. For Q2, there were also answers at all 5 levels for all three parameters, which expressed a big variation in the occupants' perceived need to regulate the parameters.

3.8 User practice of opening windows

Occupants were asked about their practice with respect to opening windows day and night in summer and winter with the questions "Do you or others in the household, from time to time, open the windows during the day/night?". In the summer situation, 84% answered yes during the day and 48% during the night. It was justified by a desire to get fresh air, e.g. after a shower, or because it was (too) warm. In the winter situation, 57% answered yes during the day and 14% during the night. It was justified by a desire to get fresh air, e.g. after a shower or cooking. It is noteworthy that it was so relatively common to open windows to get fresh air even when all of the houses had mechanical ventilation. This practice could be initiated by a wish for increased comfort or be a practice learned during childhood or a practice relevant in a former home. In any case, it has consequences for the energy consumption during the heating season.

3.9 Heat consumption as experienced by occupants

The occupants experienced that the energy consumption was higher than expected. Of the occupants, 57% answered no to the question ”Is your heat consumption as low as you expected?”. According to the occupants, it was not because of high indoor temperatures. A review of the comments made about the energy consumption showed that many occupants were surprised at how high it was and that it was higher than expected and higher than promised. The big differences and the disappointed expectations may to some extent be explained by a higher than expected consumption of electricity due to some malfunctioning heat pumps. Behaviour, e.g. bathing habits of families normally also varies much, e.g. between 3 and 36 showers a week per family [6].

The behaviour of occupants is not necessarily rational in relation to energy consumption and indoor climate. This is due to many factors, but if more knowledge and information were available to users about how a particular behaviour affects energy consumption and the indoor climate, this might influence user behaviour in a positive direction. This knowledge could to some extent be contained in the technical installations and be made available as feedback to occupants through a user interface.

3.10 Comparison with other low-energy houses

Direct comparisons between new low-energy houses and older houses are not straight forward, among other things because evaluations using identical questionnaires are lacking. However, a comparison with the settlement “Fremtidens Parcelhuse” (Detached Houses of the Future) [6,7] is possible since a questionnaire survey were performed with questions identical to the ones used in this study. “Fremtidens Parcelhuse” closely matches meets the energy requirements as defined in the existing BR10, which allows an energy consumption that is approximately 33% higher than in the houses of the present study.

To the broad question "Are there situations or times when you are not satisfied with the indoor climate in your home?", more occupants were dissatisfied (44% answered yes) in “Fremtidens Parcelhuse” than in the present study (26% answered yes).

Table 4 shows a comparison between mean values of assessments on a 5-point scale of satisfaction with the five indoor climate parameters and a general assessment of the indoor climate summer and winter of the present study (complying with BR15) and “Fremtidens Parcelhuse” (complying with BR10). All assessments, except the assessment of noise, were more positive in the houses of the present study. Around half (48%/58%) of the occupants specified that they experienced noise from the technical installations during summer respectively winter, whereas these numbers were 33/35% in “Fremtidens Parcelhuse”.

In “Fremtidens Parcelhuse”, the occupants were most dissatisfied with the temperature conditions and a majority (68%) specified that they experienced that it was too warm during summer. In the present study, only one third (36%) had this experience. In both studies occupants were most satisfied with the daylight conditions. Therefore, although the low-energy houses of the present study were more energy-efficient (class 2015) than "Fremtidens Parcelhuse" (complying with BR10) the indoor climate was perceived as being better, except with respect to noise from the technical installations.

Table 4. Comparison between mean values of assessments on a 5-point scale[1] of satisfaction with five indoor climate parameters and a general assessment of the indoor climate summer/winter of the present study in Stenløse Syd (energy class 2015) and "Fremtidens Parcelhuse" [2] (complying with BR10)

Settlement	Stenløse Syd	Fremtidens Parcelhuse[2]
Season	Summer/Winter	Summer/Winter
Temperature	3.7/3.7	3.3/3.5
Air movements	4.2/4.2	3.6/3.7
Air quality	4.6/4.5	3.9/4.1
Noise	3.6/3.5	3.8/3.7
Daylight	4.7/4.7	4.4/4.4
General assessment of the indoor climate	4.3/4.1	3.8/3.6

[1]5-point scale ranging from Unsatisfactory (1) to Satisfactory (5)
[2] [6,7]

In both the present study and in "Fremtidens Parcelhuse", there were a series of initial problems with the technical installations. In both settlements, more than half (55/60%) of the occupants experienced problems with technical installations in summer and 70/67% experienced problems in the winter.

The occupants experienced that the energy consumption was higher than expected. Of the occupants, 57% answered no to the question "Is your heat consumption as low as you expected?". In "Fremtidens Parcelhuse" this number was 50%.

It seems, that some of the occupants had received a monetary estimate of what energy consumption they could expect when they bought their new house. This figure was probably estimated on a standard calculation not taking into account the actual behaviour of the family, e.g. their use of technical installations, preferred temperature level or habits of airing out. The expectations of the occupants may therefore not be realistic and this leads to dissatisfaction, even though the house may be complying with requirements. To avoid such misunderstandings, occupants should be informed about the assumptions for the predictions and how their family situation and behaviour may affect energy consumption.

4. Conclusions and Recommendations

There was overall satisfaction with the new low-energy houses, and there is no basis for a general conclusion that low-energy buildings are synonymous with poor perceived indoor climate. However, there are challenges that need to be addressed to make low-energy houses more attractive to ordinary people. Occupants experienced among other things noise from technical installations and that it was too hot in summer and too cold in winter, that there were a series of problems with the technical installations and that their use was difficult and that the energy consumption was higher than expected.

A series of recommendations to increase occupant satisfaction in present and future low-energy houses can be given:

- Avoid uncomfortable noise from technical installations.
- Avoid uncomfortably high temperatures during summer by some kind of external solar shading, consider the size of the windows facing the sun and facilitate effective use of natural (and/or mechanical) ventilation.
- Develop more robust and easy-to-use technical installations enabling ordinary occupants to control the indoor climate and energy consumption as intended in their new relatively technically advanced house, e.g. by a single/one user-friendly user interface that can communicate with all relevant technical installations.
- Provide good information and communication on how to operate the technical installations, e.g. in the form of an informative and easy-to-understand user manual and/or support on the internet.
- Ensure that occupants can use their house as intended by technical installations being fully operational from day one, i.a. through quality control during a commissioning process.
- Communicate about the houses' energy consumption so that occupants get realistic expectations in accordance with their family situation and behaviour.

5. Acknowledgment

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