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End-user experiences in nearly zero-energy houses

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ABSTRACT

High end-user satisfaction levels are key for the acceptance of nearly zero-energy housing. Post-occupancy evaluation research on highly energy-efficient dwellings can lead to recommendations which will influence their performance in the expected future large volume market of such houses. This study analysed mainly German, Austrian and Swiss post-occupancy evaluation research results on nearly zero-energy dwellings and undertook a survey of occupants of nearly zero-energy houses in the Netherlands. The study determined how various comfort parameters (such as winter thermal comfort, summer thermal comfort, indoor air quality and acoustics), information provision and control parameters are related to positive or negative end-user appraisal, finding that summer comfort design and the quality of – and information about – heating and ventilation systems are critical factors which must be addressed to improve user satisfaction in nearly zero-energy dwellings.

1. Introduction

From the end of 2020 all new buildings in the EU will have to be highly energy efficient and will be expected to consume 'nearly zero energy' [1]. The remaining energy demand will have to be covered 'to a very large extent' by renewable energy which is produced in and/or on the building or in the neighbourhood [1]. Today, most EU countries have already built some nearly zero-energy houses, at least as demonstration projects. It is expected that future supply and demand will be stimulated by promises of lower CO_2 emissions, lower energy bills and also comfort benefits. In the marketing framework of several European countries, different definitions and terminology for such housing have already been introduced [2]. Popular marketing terms include 'low-energy houses' (LEHs), 'passive houses' (PHs) or 'zero-energy houses' (ZEHs). 'Low energy' usually refers to buildings with the explicit intent of using less energy than standard buildings. However, often no specific requirements are stipulated. With respect to 'passive' houses, specified requirements usually have to be fulfilled, such as a maximum end-energy use for space heating and a limited primary energy demand for all end-uses. 'Zero energy' usually refers to net zero energy. This means a building where the net energy consumed over 1 year is matched by an equal amount of energy produced on site. In the Netherlands, for example, the national policy programme 'Clean and Efficient' ('Schoon en Zuinig'), as well as foundations such as the 'Stichting Experimenten Volkshuisvesting', 'Stichting Passiefbouwen.nl' and 'Stichting Passiefhuis Holland', aim to spread information about newly built LEHs, PHs and ZEHs in order to increase the market uptake of such buildings.

However, demonstration projects are often insufficiently or inadequately monitored, analysed and evaluated, meaning that the learning effect for future projects is generally poor and insufficient [3]. Amongst other suggestions, Preiser and Vischer [4] highlight the need for post-occupancy evaluation (POE) research. Poor demonstration projects risk leading to low credibility and investment for future projects should they not fulfil the expectations of and/or not be appreciated by the inhabitants [5]. End users are particularly important as multipliers and often act as peer-to-peer 'experience' experts for the acceptance or disapproval of advanced energy concepts [6]. In the Netherlands, for example, end users were found to be sceptical about mechanical ventilation systems

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[7]; however, it appears that mechanical ventilation in housing may have been negatively perceived due to problems related to poor installation [8].[2]

A key issue for the successful implementation of increased energy efficiency in the housing sector will be the user demand for nearly zero-energy building concepts – such as LEHs, PHs and ZEHs – which directly relates to the perceptions of users, their acceptance and satisfaction. On digging deeper, users can have different concerns, reflecting differences in the quality of different buildings [11]. Living conditions in the houses realised (particularly comfort and health criteria such as indoor temperature, humidity and noise level) and their operability (for example of mechanical ventilation systems) are important factors influencing occupants' perceptions of energy-efficient houses, and thus their further adoption. Therefore, this study investigates end-user satisfaction in nearly zero-energy dwellings and aims to provide recommendations for the improvement of quality and comfort.

2. Research strategy

The goal of the study is to detect barriers to and opportunities for the promotion of nearly zero-energy dwellings based on end-user experiences, by studying end-user satisfaction in current LEHs, PHs and ZEHs. The central research question is: *What are the experiences of end users with nearly zero-energy houses?* Based on the analysis and evaluation of end-user satisfaction with LEHs, PHs and ZEHs, suggestions for improvement can be made in order to establish the basic conditions for the widespread adoption of nearly zero-energy dwellings.

The first part of this paper introduces the theoretical framework (Section 3). It addresses the experiences in central European countries, particularly Germany and Austria where the development and market implementation of highly energy-efficient building concepts (such as the PH) is more advanced [12]. Many researchers in these countries have already contributed to our understanding, relating end-user satisfaction to parameters of highly energy-efficient building concepts. However, most of these studies have only been published in German. To obtain a better understanding of experiences in these countries, German, Austrian and Swiss literature on this subject is reviewed and discussed here. The findings drawn from the literature will be analysed in terms of key subjects addressed in end-user evaluation research.

The second part of this study (Section 4), presents the results of a first end-user evaluation study of highly energy-efficient houses in the Netherlands. Issues such as the reasons for choosing such a house, general satisfaction and satisfaction with indoor climate and ventilation systems were addressed in our survey. These results are compared with the findings from the literature discussed in the first part of the study.

The recommendations at the end (Section 5) will discuss the opportunities for and barriers to the improvement of end-user satisfaction and reflect on the framework for the improvement of nearly zero-energy houses.

3. End-user experience research in Germany, Austria and Switzerland

3.1. The literature on nearly zero-energy housing

The post-occupancy evaluation (POE) of buildings is an established research approach in the social sciences [4,13–15]. POE methods are used for the systematic study of buildings once occupied, so that an assessment can be made, for example, through feedback from inhabitants and/or physical measurements made during the operation of buildings [11]. POE research has gained particular importance for nearly zero-energy housing, especially where the demand for PHs has increased, for example in Austria [16]. Regarding nearly zero-energy housing, various studies have also focused on onsite investigations and measurements evaluating indoor climate, energy and comfort, thereby assessing various aspects of the operation and performance of the occupied building (for example [17–24]).

Rohrmann [25] pioneered end-user satisfaction research into PHs by investigating experiences with the first PHs in Darmstadt. Subsequently, POE research focused on the characteristics of PH inhabitants as a special segment of the population with a specific lifestyle, appreciation patterns or user behaviour, possibly also related to environmental awareness [18,26–34].

POE analyses followed on larger, more or less identical, housing samples—such as the PH housing estate Hanover-Kronsberg in Germany [35,36]. In 2001 Keul [37] compared PHs with other types of houses – analysing 614 living units of which 15 were PHs, in the Salzburg region of Austria – while Stieldorf et al. [38] investigated 12 Austrian demonstration projects in the Austrian Vorarlberg Region, including one with 13 PH living units. In Germany, Hallmann [39] investigated end-user experiences in 22 PHs and 24 LEHs in the Lummerlund area in Wiesbaden and compared these experiences to those of a control group of users living in 11 conventional houses. A first Swiss study appeared when Gräppi et al. [40] surveyed and analysed 73 inhabitants of certified PHs in Germany, Austria and Switzerland. The largest study to date was undertaken by Treberspurg et al. [5], who monitored 1367 living units, of which 492 were PHs, in the Vienna area. This study compared the user appreciation of 225 PH households with 156 conventional ones. POE research has also been executed in the framework of social rental housing [41–43], student housing [44–46], renovation designed to achieve LEHs and PHs [47,48] and the evaluation of regional grant policy [21].

All of these studies identified innovation opportunities as well as problems and the reasons for unsatisfactory building performance. The following sub-sections will analyse the literature above, in order to obtain a better understanding of which factors are appreciated by end-users and which can lower user satisfaction. This study thematically investigates the conceptual terminology itself (for example 'passive house'), general satisfaction with the house (particularly thermal comfort), satisfaction with the indoor climate systems, the importance of user-friendliness and controllability issues, the relevance of information provision, and possible time-related changes in opinions and behaviour.

3.2. The concept of nearly zero energy as a reason for choosing a house

The literature revealed that for PH inhabitants, energy saving[3] was not a very important criterion when choosing a house [5,6,37]. It also showed that PH inhabitants are not politically 'greener' than mainstream customers [5]. While Treberspurg et al. [5] attributed a high marketing branding value to the PH concept, Keul [49] noted that the PH concept played a role in consumers' decision-making processes in only one out of six residential multifamily buildings. Schnieders and Hermelink [20] reported PH branding as least important from the viewpoint of marketing, whereas the presence

[2] Dutch scandals concerning the improper functioning of ventilation systems created quite a stir, leading to the recommendation to ensure better installation quality through effective commissioning and to better inform home buyers. The controversy was mainly focused on one specific LEH estate. See also [9,10].

[3] Keul [37] noted that 'conventional' residents generally have no interest in energy-saving lifestyles and are overconfident regarding their knowledge about energy saving.

of a balcony, for example, was a very important reason to move in. One study [39] showed that end users of conventional houses, LEHs and PHs, respectively, cited the importance of the neighbourhood in which the house is located (a control group of 11 inhabitants), the economic benefits (a group of 24 LEH users) and the importance of having their own property (a group of 22 PH users) most frequently.

3.3. General satisfaction according to end users

In general, nearly zero-energy houses are appreciated by the inhabitants [5,6,19–21,35,39,40,43,49,50]. Various studies have noted that inhabitants of PHs would generally recommend a PH to other clients [6,19,21]. Keul [49] noted that satisfaction levels related to new PH dwellings were higher than those related to average Viennese housing. Although the average sample showed some distortion towards single-family housing, the study found that there was no correlation between the satisfaction of inhabitants and parameters such as age, gender, household size or number of children in the household.

Comfort was revealed to be an important parameter with regard to positive appreciation. A number of studies have found that occupants perceive their living conditions to improve after moving into PHs [20,43], particularly with regard to winter thermal comfort and indoor air quality. In some studies, not one occupant gave a negative rating on the perceived indoor climate during winter [19,20]. One of the important beneficial parameters experienced by the inhabitants was, for example, fresh air in bedrooms in the morning [51]. Different research reports based on indoor air quality measurements confirmed that the air quality in PHs was indeed better than that of conventional buildings (for example [22,23,52]).

Users of PHs often feel more comfortable during the winter than during the summer [21–23,39]. Thus, summer thermal comfort requires specific attention. For example, in the Hanover-Kronsberg estate, 40% of end users invested in additional solar shading [35]. Additionally, Ebel and Feist [33] stressed the importance of reducing internal heat gains – heat coming from, for example, household equipment and lighting – in order to avoid overheating in summer. In contrast to these findings, some studies [19,20,50] reported high levels of summer comfort satisfaction.

3.4. Satisfaction with indoor climate systems

Perceived comfort levels can also be influenced by the level of satisfaction with indoor climate systems, such as those associated with heating and ventilation. A correct dimensioning of the heating system is needed to facilitate sufficient heating during the winter, especially in houses which are only equipped with air-heating [33]. Technical deficiencies in the heating system were discovered in the first demonstration buildings investigated by Danner [6], Ebel et al. [18] and Flade et al. [28]. Hübner [51] argued that in the first large-scale PH dwellings the quality of components such as ventilators, heat exchangers and control elements did not meet the expected standards, with the breakdown of ventilators or control elements and air leakage in exchangers possibly resulting in low user satisfaction. In addition to the general quality of design and execution, specific attention to air humidity, noise and odour is also needed, as is apparent below.

Different studies [6,40,51] reported cases in which the air quality during winter was perceived to be too low. The dimensioning of air exchange rates is usually the key to solving this problem [43,53]. End users of PHs mentioned problems with insufficient noise control related to either the ventilation system or noise originating inside the building, for example, from neighbours or other floors (see, for example [54]). Noise caused by ventilation equipment functioning during the night is less tolerated than during the day [40]. Amongst other reasons, noise problems can be caused by insufficient noise reduction measures, such as inadequate sound absorbers in the ventilation ducts. Schnieders and Hermelink [20] reported that a problem with noise pollution could be solved by small technical enhancements and providing better information to tenants—for example, explaining that ventilators become noisier when filters are not cleaned or changed.

Furthermore, some studies identified odour as a potential nuisance that was possibly related to the performance of the ventilation system [39]. Some possible causes were found to be exhaust air mixing with fresh air when there is insufficient distance between the air inlet and exhaust, and a lack of sufficient ventilation in some spaces, such as common stairwells [20,43]. There may also be a relationship between odour complaints and exposure to volatile organic compounds from materials, especially formaldehydes [55], but this has not yet been thoroughly investigated.

3.5. The influence of control parameters on satisfaction levels

Users might be dissatisfied with building services such as heating and ventilation systems when they cannot control them sufficiently. In general, end users wish to control temperatures in different rooms (see for example [35,50]). Ebel and Feist [33] recommended the simplification of control devices for heating and ventilation in order to avoid confusion as well as incorrect use and poor performance. For example, Hübner [51] noted complaints about unreadable control devices and a lack of information regarding the status of operation. A study [20] noted possible conditions other than the set temperature due the slow change in room temperature inherent to PHs. In later PH projects, the initial correct setting of the heating and ventilation system was discovered to be a crucial parameter related to positive user satisfaction [5].

Studies [20,43] have reported a relationship between an increased level of user-driven free ventilation (opening windows) and a negative perception of controlled ventilation systems. Ventilation systems need to be correctly dimensioned in order to avoid the opening of windows by residents in winter [32], as this contributes to heat and energy losses. However, various studies (for example [19,20,22–24,34,56,57]) have acknowledged that the influence of end users on the absolute values of energy consumption in nearly zero-energy houses is rather limited. Using energy measurements and comparing PHs and LEHs, Feist [34] showed that careless end users in PHs still use less energy than careful end users in LEHs.

3.6. The influence of information and communication on satisfaction levels

Various studies stress the need for specific user instructions regarding building services such as heating and ventilation systems in PHs, including information about their properties, operation and maintenance [5,6,32,33,40,43,47,49]. For example, Treberspurg et al. [5] found that inhabitants had uninformed opinions about PHs which resulted in less positive appreciation. According to various studies [5,20,43,51,54], the perceived barrier of 'poor controllability of indoor climate' can be partially removed by providing specific information to the end users. Some of these studies [51,54] have also proposed using more effective communication methods to increase satisfaction, for example, during meetings of owners and/or tenants. Moreover, the early communication of technical problems by end users can be very useful, since solving such problems can lead to increased satisfaction [5].

Wagner et al. [54] confirmed the need for specific information regarding the ventilation system. In particular, establishing the correct settings for the heating and ventilation systems on first use requires the provision of specific information, beyond the usual oral communication of instructions and the availability of a manual [5]. Moreover, the importance of explaining specifics such as reducing the air-exchange rate of ventilation systems during the winter in order to avoid dry air (by switching the control to a low position) was highlighted [20]. Furthermore, it was found that some user groups, for example those in social housing, might not be aware of whether a ventilation system is functioning or not, or whether a filter needs to be replaced. To enhance awareness regarding these issues Hübner and Hermelink [43] recommended clear instructions be given on components and control panels. Additional assistance, for example by the landlord or building manager, as well as guidance and proper introduction to the systems were also suggested. In addition, system control and maintenance issues, for example demonstrating how to change the filters, should be addressed. One factor in a tenant's appreciation of extremely low heating costs might also be an easily understandable energy consumption bill [20].

3.7. Influence of the time factor on satisfaction levels

Various studies have argued that the period of investigation plays an important role in POE research [5,20,28,39,51]. For example, Hübner [51] showed that residents tend to forget information provided when they moved into their new dwellings, which can lead to less satisfaction over time. However, the trend is also often positive. For example, Treberspurg et al. [5] showed that the number of PH residents with high levels of appreciation for the dwelling increased from 84% to 94% in 1 year. It has been suggested that this might be related to the fact that it takes some time before inhabitants gain an overview of their energy costs and become aware of lower energy prices in PHs compared with their previous home [20]. Some studies showed that originally sceptical users later related ventilation systems to comfort improvement [20,28]. Various studies [39,51] have shown that the time factor plays an important role with respect to the positive appreciation of aspects such as not having to open windows in winter in LEHs and PHs.

3.8. Conclusion

The studies generally confirm that the decision to choose a nearly zero-energy house is usually based on a combination of different criteria, such as reflection on architectural layout, economic costs or benefits, various environmental arguments, interest in PH technology, the site of the house and the influence of consultants (see also [6]). Energy efficiency and the branding of the dwellings as nearly zero energy – currently often regarded as essential to their promotion – are in themselves not enough to convince customers to choose this type of house.

General user satisfaction and comfort satisfaction is very much dependent on the properties of specific projects and positive or negative appreciation cannot be generalised. End users appreciate comfort in PHs mainly because of better winter thermal comfort and better indoor air quality. However, indoor climate systems need to be carefully planned and checked regarding heating provision, ventilation capacity, indoor air humidity control, noise protection and odour removal. Satisfaction is found to be lowered by deficiencies in heating and ventilation technologies, caused either by insufficient product quality, or poor design and/or poor construction of the climate system.

The controllability of the indoor climate is a relevant evaluation parameter in satisfaction research on nearly zero-energy houses. While the energy efficiency of PHs appears to be robust with regard to the influence of occupant behaviour, the design and provision of user-friendly heating and ventilation controls require specific attention. Especially for end users not involved in the design or building process, specific information provision, particularly regarding heating and ventilation, is considered crucial to facilitate the proper operation of systems and thereby achieve higher levels of user satisfaction and better energy performance. Furthermore, it is important to be aware that time changes experiences and influences satisfaction levels. The satisfaction of inhabitants can increase over time as end users become aware of the energy savings and grow familiar with the indoor climate systems. These results confirm the importance of information provision regarding building related energy savings and indoor climate systems in order to satisfy end users.

4. End-user experience research in the Netherlands

4.1. Advancing end-user experience research

The findings described above are generally based on satisfaction research on LEHs and PHs in Germany and Austria, and reveal the importance of design, execution, information and time as research parameters when investigating satisfaction with nearly zero-energy houses. A focus on evaluating experiences with indoor climate systems, particularly satisfaction with winter and summer thermal comfort, air quality, noise, controllability and information issues is required. To address these issues, a Dutch questionnaire was developed to undertake POE research on frontrunner projects in the Netherlands.

In June 2010, the questionnaire was sent to 441 known LEH, PH and ZEH households. The dwellings chosen had to have been occupied before June 2009 to guarantee that the users had experience living in their dwellings for at least 1 year. The questionnaire contained open-ended as well as multiple-choice questions addressing the following topics: sociodemographic characteristics, satisfaction with the house (13 questions); awareness and experiences regarding energy saving installations (6 questions); building services and energy (12 questions), indoor climate (58 questions), design issues (14 questions) and information issues (5 questions). Out of 441 questionnaires, 90 were completed and returned (a response rate of 21%), a good result for paper-based questionnaires. The results concern 63 LEHs, 7 PHs and 20 ZEHs.[4] These projects were newly built single-family dwellings and varied in typology from single detached houses to terrace and town houses and apartment buildings.

4.2. Motives for choosing a house

Fig. 1 shows the percentage of respondents who indicated that a particular aspect was an important factor in choosing their particular dwelling (multiple answers possible).

Fig. 1 shows that the dwelling size and direct dwelling environment were the most important reasons for choosing the house. However, Fig. 1 also shows low energy costs was the third most important reason. For about one-third of the respondents, the

[4] See also [58] for an analysis of end-user energy consumption data and more detailed information. A comparison with conventional houses was not included. It should be noted that the energy data were submitted by the end-user and were not affirmed by onsite inspections or energy measurements and that the projects chosen were initially provided with a marketing name by regional players. In this research the choice of the term PH was not directly related to the German definition or to the availability of a PH certificate. The categorisation of the buildings as LEH, PH and ZEH was based on the occupants' reported average end-user energy consumption: 10050, 7233 and 5119 kWh/a, respectively. The non-parametric Kruskal-Wallis test showed that the end-user energy consumption differed between the three groups ($p < 0.01$). There were also differences between the groups with respect to average primary energy consumption, but this could not be tested statistically due to the small sample size. Note that in the ZEH category the primary energy balance of most households indicates that they consume more energy than they produce, and are therefore in reality not 'zero energy' buildings.

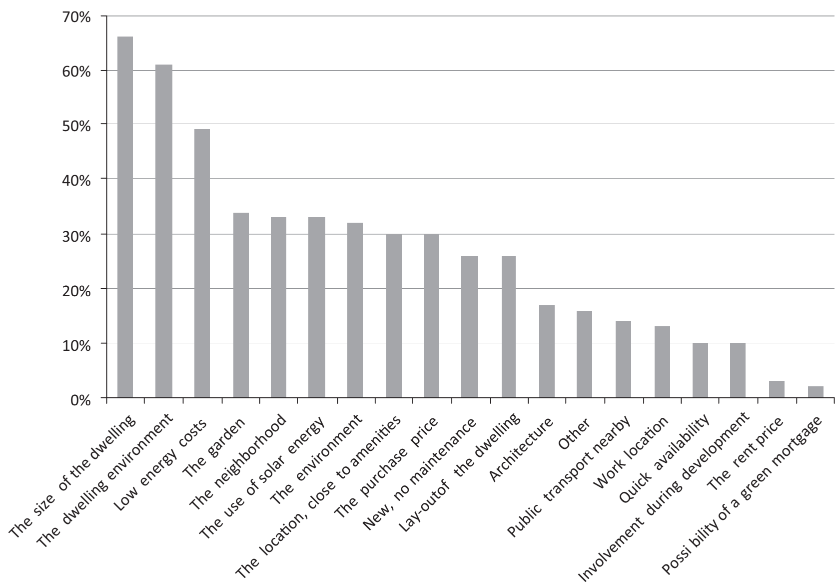

Fig. 1. Percentage of respondents who indicated that a particular aspect was an important factor in choosing their LEH, PH or ZEH (multiple answers possible).

environment, the neighbourhood, a location close to amenities, the garden, the use of solar energy and/or the purchase price were important. When asked specifically, about half of the respondents stated that architectural design was important to them, but for most this was not one of the most important reasons for choosing the house.

4.3. General satisfaction according to end users

Almost all residents (87 of 90 responses, 97%) indicated that they were satisfied with their house (yes/no). Only one respondent was dissatisfied with the indoor temperature during winter and complained that their heating system was not able to provide sufficient heating for a comfortable indoor temperature on the upper floor of their building during winter. The respondents were also asked to provide an indication of the level of satisfaction with their dwelling on a scale of 1–10, where 1 was the lowest satisfaction level and 10 the highest. The overall satisfaction rate was 8.0 (std = 0.9, $n = 90$), which can be considered 'good'. In the Netherlands a rating of 6 is often perceived as 'sufficient'. Only two residents provided a score lower than 6, both giving a 4.

The study then examined whether the mean satisfaction score differed between energy types (PH, LEH and ZEH) using non-parametric tests [59]. The results revealed that the mean satisfaction level did vary between the three categories (non-parametric Kruskal–Wallis test; $p < 0.01$).[5] Further analyses using the non-parametric Mann–Whitney U-test showed that the mean satisfaction score of residents living in PHs (mean = 8.93, $n = 7$) was statistically significantly higher than the mean satisfaction score for LEHs (mean = 7.93, $n = 63$) and for ZEHs (mean = 7.80, $n = 20$). It should be noted, however, that despite the non-parametric tests, the number of respondents for the PH and ZEH groups was too low to provide reliable results.

4.4. Satisfaction with indoor climate

The results with regard to satisfaction with the indoor climate are summarised in Table 1. An analysis of additional results showed that the specific systems for ventilation, heating and hot water as well as the presence of PV generators did not statistically significantly influence the general satisfaction levels of the inhabitants.

Four respondents (4% of 89) were not satisfied with the indoor climate in the living room during winter. Eight respondents (9% of 88) were not satisfied with the indoor climate in the bedrooms during winter. For both findings there was no statistically significant difference between the three different types of dwellings ($p = 0.72$ and $p = 0.09$, respectively, Fisher's exact test [FET]).

Six respondents (7%) indicated that they were not satisfied with the climate in the living room during summer and 14 respondents (16%) were not satisfied with the climate in the bedroom during summer. Twenty-nine respondents (34% of 86) experienced the summer indoor temperature in the living room as too hot (at least sometimes) and 49% (of 88 respondents) found the bedroom too hot in summer. There were no statistically significant differences between the three energy categories with regard to satisfaction with indoor climate in the living room ($p = 0.47$, FET) or bedrooms ($p = 0.22$, FET).

In this study the reason for the relatively high proportion of dissatisfied respondents with regard to the indoor climate in the bedrooms in summer can probably be attributed to architectural design aspects such as south orientation of the bedrooms and a lack of shading systems.[6] Also, in some cases it can be assumed that problems with ventilation systems, such as an improperly functioning bypass, led to high indoor temperatures.

Of 88 respondents, 12 (14%) were not satisfied with their level of control of their heating system. There was no statistically significant difference between the three types of dwellings ($p = 0.18$, FET). Many respondents who were less satisfied with the temperature control in their dwelling were also less satisfied with the indoor cli-

[5] $p < 0.01$ means that the chance (p = probability) that the zero hypothesis of 'no difference' is unjustifiably rejected, is less than 1%.

[6] The availability of external shading systems was investigated using various questions. Seventy-one percent of 88 households had an external shading system, 14% had a structural horizontal shading element and 16% had no external shading system at all for the windows in their living rooms. Fifty-five percent of 85 households had an external shading system, 9% had a structural horizontal shading element and 35% had no external shading system at all for their bedroom windows. Regarding the availability and the use of internal shading systems, 40% of 86 households had such a system in their living rooms and it was used in 83% of these cases. Forty-eight percent of 85 households had an internal shading system in their bedrooms and used it in 90% of the case.

Table 1
Frequencies of responses with regard to satisfaction with the indoor climate.

Indoor climate	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied
Living room in winter	1 (1%)	3 (3%)	11 (12%)	48 (54%)	26 (29%)
Living room in summer	–	6 (7%)	12 (13%)	47 (53%)	24 (27%)
Bedrooms in winter	1 (1%)	7 (8%)	12 (13%)	51 (58%)	17 (19%)
Bedrooms in summer	1 (1%)	13 (15%)	17 (19%)	47 (53%)	11 (12%)

mate during winter. This relationship was statistically significant, for both the living room and bedrooms ($p < 0.01$, FET). In addition, many respondents who were less satisfied with the temperature control in their dwelling were also less satisfied with the indoor climate during summer. This relationship was statistically significant for the living room ($p = 0.05$, FET) but not for the bedroom ($p = 0.08$, FET).

4.5. Satisfaction with ventilation systems

The results with regard to satisfaction with air quality and amount of ventilation are summarised in Fig. 2. Of 86 respondents, 74% experienced the indoor air quality as good, 21% as average and 4% as bad. Of 88 residents, 81% regarded their dwelling as sufficiently ventilated and 17 (19%) reported that their dwelling was not ventilated well enough. These residents were also more frequently dissatisfied with the air quality in their dwelling ($p < 0.01$, FET). Most of the 71 residents who reported that their dwelling was ventilated well enough indicated that it had good air quality (89%). In contrast, of the seventeen respondents who reported that their ventilation was not good enough, only two (13%) reported good air quality.

The levels of smoking were not statistically significantly different between those who reported that their dwelling was well ventilated and those who did not ($p = 0.65$, FET; $n = 88$). Moreover, there was no statistically significant difference between LEHs, PHs and ZEHs regarding the perceived air quality ($p = 0.26$, FET) and the perceived amount of ventilation in the dwelling ($p = 0.21$, FET).

The vast majority of the respondents were satisfied with the levels of humidity in the living room (83% of 82 respondents) and in the bedroom (83% of 87 respondents) during winter, as shown in Table 2. A small percentage, 16% and 14% (for living room and bedrooms, respectively) experienced the air as too dry, and 1% and 2% (living room and bedrooms, respectively) as too humid. There were no statistically significant differences regarding the perception of the levels of humidity in the living room ($p = 1.00$, FET) or the bedroom ($p = 0.53$, FET) during winter between the three different types of dwellings.

The results for humidity levels during summer are quite similar. Only a small percentage (9% of 87) of respondents experienced the air as too dry in the living room, and only 6% of 87 respondents reported that the air was too dry in the bedroom, while 3% experienced the living room as too humid, and 6% found this to be the case in the bedroom. There were no statistically significant differences between the three categories regarding the perception of humidity in the living room ($p = 0.13$, FET) or the bedroom in summer ($p = 0.41$, FET).

Fifty-seven respondents (63%) indicated that they used a mechanical ventilation system with heat recovery for the ventilation of their living room and 62% for the ventilation of the bedrooms. The presence of a mechanical ventilation system with heat recovery in the living room could not be related to satisfaction with the indoor climate in the living room in winter/summer, or air quality and humidity in the living room in summer. However, it could be related to perceived humidity in the living room in winter. Residents with a mechanical ventilation system with heat recovery in the living room indicated more often that it was too dry in the living room (too dry: $n = 12$ of 51, 23%) than residents without this type of ventilation (too dry: $n = 1$ of 31, 3%). The presence of a mechanical ventilation system with heat recovery in the bedrooms could not be related to satisfaction with indoor climate in the bedrooms – neither in winter nor in summer – or air quality and humidity in the living room in summer or winter.

Table 2
Frequencies of responses with regard to the evaluation of air humidity.

Humidity	Too dry	Good	Too high	Invalid
Living room in winter	13 (16%)	68 (83%)	1 (1%)	–
Living room in summer	8 (9%)	74 (85%)	3 (3%)	2 (2%)
Bedrooms in winter	12 (14%)	72 (83%)	2 (2%)	1 (1%)
Bedrooms in summer	5 (6%)	76 (87%)	5 (6%)	1 (1%)

4.6. Conclusion

The literature study showed that a promotion strategy emphasising concept branding or energy efficiency might not be very useful (see also [5,6,20,37,39]). The Dutch study shows that, if people are to choose to live in a nearly zero-energy house, the size and the environment of the dwelling are obviously important, but an emphasis on the energy costs of the dwelling can also attract interest. This study confirms that, like in other countries, the perceived comfort levels of residents of nearly zero-energy housing in the Netherlands are generally high, and an awareness of this might be an additional attraction for potential customers. However, perceived comfort levels are generally independent of energy category and further research is needed in order to confirm whether the level of appreciation of PHs is different, because the sample here was very small.

Like in other countries, this study shows that, while end users show high levels of acceptance and satisfaction with nearly zero-energy houses, the technical equipment (ventilation/heating) is sometimes criticised on the basis of perceived comfort deficiencies. The results highlight that more attention to the problems of overheating in summer and the provision of good air quality (particularly air humidity) and temperature control in winter is required. The high satisfaction levels of occupants could not be correlated with the presence of certain equipment and/or building services installations (ventilation, PV, heating, etc.). Apart from possible dry air in living rooms, the presence of a mechanical ventilation system with heat recovery could not be related to indoor climate satisfaction parameters. A limitation of the present study was that no control group of Dutch houses was available.

5. Discussion and recommendations

The goal of this study was to detect barriers to and opportunities for promoting nearly zero-energy dwellings on the basis of end-user experiences, by studying end-user satisfaction with nearly zero-energy houses. Developments in Germany and Austria (mainly the building of passive houses) are related to the European requirement for the market development of nearly zero-energy houses. POE research from these countries already provides lessons from the projects realised and the Dutch study contributes to this.

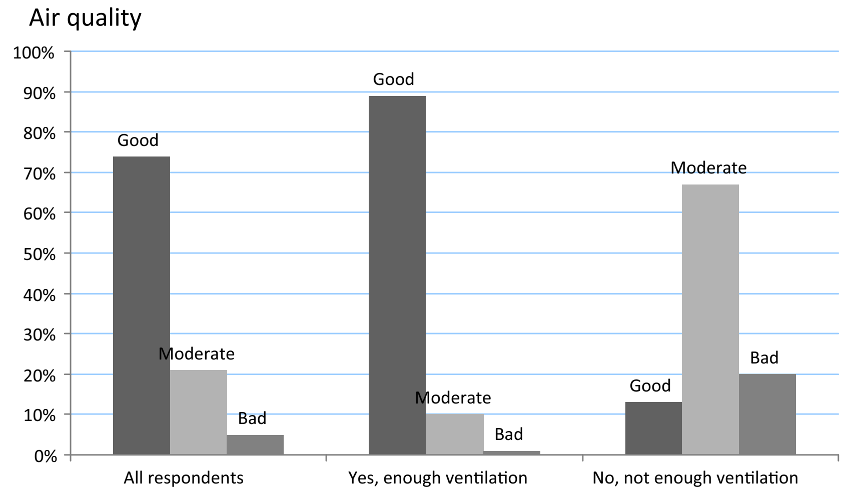

Fig. 2. Frequencies of responses with regard to the evaluation of air quality and amount of ventilation.

The study indicates that energy costs associated with a dwelling might be an important aspect, alongside other factors (for example, size, location, neighbourhood and purchase price), which encourage potential residents to choose a nearly zero-energy dwelling. However, the relevance of emphasising energy efficiency or concept branding is limited. End users living in highly energy-efficient houses are quite satisfied with their dwellings and indicate a high comfort level, findings which could be used as additional arguments in the promotion of such dwellings.

A barrier to the adoption of nearly zero-energy houses might be a perception of insufficient summer comfort and/or air quality, independent of energy category. Some respondents were less satisfied with comfort levels related to the indoor temperature during summer, particularly in the bedrooms, as well as the indoor air quality. Sometimes a less comfortable indoor climate can be directly linked to design deficiency (for example, lack of shading or ventilation bypass) or technical deficiencies in the heating and ventilation systems. This illustrates the importance of quality assurance regarding design and execution, alongside requiring the high energy performance of nearly zero-energy houses.

End users relate perceived comfort levels directly to heating and ventilation systems. Careful design and execution, including noise protection, sufficient air humidity control and odour removal strategies, are critical points for attention in relation to possible improvements in all housing categories. In addition, simplicity and the user-friendliness of control systems are of utmost importance. Detailed information provision – including, but not limited to, initial oral instructions and providing written manuals – is of critical importance and should not be neglected. For example, the perception of poor levels of control, dry air in winter, as well as noise or odour problems, can sometimes be eliminated by providing specialised information. In particular, in relation to first-time occupancy, the importance of the start-up phase for the operation of heating, ventilation and control systems can be critical for optimising performance, with feedback from occupants' effectively contributing to detecting and eliminating deficiencies. It is recommended that inhabitants be given additional information to that provided in the standard short introduction to the house, including, at the very least, operation manuals, but preferably also detailed instructions concerning the specific advanced housing concepts they will encounter in the dwelling.

POE research itself has the potential to become a valuable instrument for eliminating adoption and communication barriers. Questionnaires can detect the apparently small percentage of unsatisfied end users, who can then be assisted by eliminating deficiencies in quality and providing the necessary information. Particularly for end users who are not involved in the building process, for example in rental housing, it is recommended that user-oriented technical information and/or training by qualified persons be provided.

In conclusion, it is apparent that there is a specific need to provide quality assurance and improve information transfer to the end users of nearly zero-energy houses. Quality assurance should include the evaluation of comfort in relation to aspects such as indoor climate and thermal comfort during winter and summer, air quality and noise protection, as well as social parameters such as information transfer to and communication with end users. To maintain high levels of comfort and user satisfaction in future projects, the further development of quality assurance schemes for nearly zero-energy houses using POE research methods to detect deficiencies is recommended.

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