A Comparative Evaluation of Low-Energy, Passive and Zero-Energy Houses in The Netherlands and Belgium

Erwin Mlecnik[1,2]
& Sylvia Jansen[1]
[1] OTB Research Institute for the Built Environment, TU Delft
The Netherlands &
[2] Passiefhuis-Platform vzw (PHP)
Belgium
E.mlecnik@tudelft.nl

Thorsten Schuetze
& Ger de Vries
Faculty of Architecture
TU Delft
The Netherlands
T.schuetze@tudelft.nl

Summary

The presented research aims to evaluate highly energy-efficient dwellings, in particular Passive Houses (PH), in Flanders and in The Netherlands, based on end-user experiences. In the introduction the definition of PH in the Benelux countries Belgium and The Netherlands is compared with the Nordic countries and certification and comfort issues are discussed. The research is based on the results of questionnaires directed to owner-occupants and inhabitants of so-called Low-Energy, Passive and Zero-Energy Houses including different types of dwellings, such as single-family houses and apartments. The satisfaction levels of inhabitants have been investigated and evaluated regarding different comfort criteria. The research results for both countries have been compared with each other. They indicate that PHs in Belgium and in The Netherlands are generally well accepted by the inhabitants and perceived as comfortable. However, the perceived comfort can vary and some deficiencies need to be addressed to achieve high levels of comfort and user satisfaction in future PH projects. Particularly, summer comfort as well as the installation quality and user friendliness of current indoor climate systems can be improved. Additionally, the development of quality assurance schemes for PHs is discussed in this paper. Based on a comparison between the Dutch and the Flemish criteria, recommendations are given on items that are currently missing in PH certification and can lead to further improvement of building processes and national policy.

Keywords: Passive House; Low-energy House; Indoor climate; Energy performance; End-user experiences

1. Introduction

Increasing awareness of the Passive House (PH) concept has stimulated the market development for so-called "nearly-zero energy houses" in the Benelux countries Belgium and The Netherlands. Like in the Nordic countries, motivated by promises of lower $C0_2$ emissions, lower energy bills and comfort benefits, some consumers have chosen to live either in Low-Energy, Passive or Zero-Energy Houses. The first PHs in the Benelux countries, designed according to the definition given by the Passivhaus Institut Darmstadt [1] are inhabited since 2001 in the Netherlands, and since 2003 in Belgium. Meanwhile, significant marketing efforts have been made – most notably in the Flemish and Brussels Capital Region -, leading to hundreds of regional companies promoting the PH concept and the required technologies. Dozens housing projects have been realised so far. This market development is now further stimulated by the recast of the European Energy Performance of Buildings Directive [2] that obliges all European member countries to introduce a regional definition and a follow-up of the development of nearly-zero energy houses.
With growing market share and popularity, living conditions in the realised PHs, particularly comfort criteria such as indoor temperature, humidity, noise level, and so on, are becoming important factors influencing the occupants' perception of the quality of such energy-efficient houses.

Furthermore, these factors possibly also influence the residents' operability and health conditions. It is for example known that overheating during the summer months should be avoided by appropriate design of PHs. Further, it is important that residents are able to avoid overheating, for example by operation of shading systems or free ventilation (such as open windows) to influence summer comfort conditions. Particularly in The Netherlands, there is also a strong debate on possible health problems related to poor installations of mechanical ventilation systems in Low-Energy Houses. Therefore, the presented research aims to evaluate highly energy-efficient dwellings, in particular PHs, in Belgium and in The Netherlands, based on end-user experiences, in order to provide recommendations for the future mass market.

2. Research approach

2.1 Research goal

The goal of the described research is the optimization of PHs by determination of current quality and requirements for future optimization. Based on the analysis and evaluation of end-user satisfaction levels of PHs in The Netherlands and in Belgium, as well as careful investigation of real performance and obtained quality, suggestions for the improvement in grant schemes or certification systems for PHs can be made. To gain a better understanding of the current state of PHs in Benelux countries, end-user experiences in Low-Energy, Zero-Energy and PH projects in the Flemish Region and The Netherlands have been analysed and evaluated. This study thus reveals factors that have to be addressed in the framework of the introduction of certification systems for built highly energy-efficient houses.

2.2 Data collection

End-user experiences from Low-Energy, Passive and Zero-Energy Houses in The Netherlands were collected by means of questionnaires and statistically investigated (see subsequently point 1). The findings were analysed and compared with research results from a limited amount of certified PH projects, particularly in the Flemish Region (see subsequently point 2). The results are based on the following approaches and questionnaires [3, 4]:

1. In The Netherlands, questionnaires with 108 different questions have been sent to 441 households of Low-Energy, Passive and Zero-Energy Houses and inhabited before 2010.

90 completed questionnaires were received back. This is similar to a response rate of 21%, which is quite common for paper questionnaires. The questionnaire contained both open and closed questions and addressed the following issues: General information including income and educational level as well as general satisfaction (13 items); Awareness and experiences regarding energy saving installations (6 items); buildings service engineering and energy (12 items), indoor climate (54 items), satisfaction (4 items), architecture (14 items), manual (5 items).
No accompanying study has been executed in addition to the questionnaire based research.

2. In the Flemish region, a questionnaire was sent to 51 owner-occupants of single-family Passive Houses, inhabited during at least one season before 2010.

16 answers were received back from certified Flemish PHs. The questionnaire contained both open and closed questions and addressed the following issues: background variables of the interviewees (4 items), inhabitant's age and presence in the house, income level, educational level; general satisfaction: environment (12 items), living (12 items), construction (11 items), installations (10 items); heating/ temperature (35 items); air humidity (18 items); ventilation/ air quality (71 items); health (11 items).
The accompanying study in the Flemish region [4, 5, 6] also included inspection of detailed PHPP calculations to assure that the PH standard is actually reached, interviews with occupants and indoor comfort measurements (temperature, relative humidity and CO_2 level in winter and in summer) in selected PHs in Belgium.

2.3 Structure of the paper

In the framework of this paper the definition, certification and comfort issues of PHs in Belgium and The Netherlands are summarized and comparisons with European and Nordic countries are discussed, before research results from the questionnaires are presented. In the conclusion, recommendations are given based on the research results. Finally, certification issues and developments , which are based on the research results, are discussed and recommendations are given.

3. Definition, certification and comfort issues

3.1 Definition

When comparing PH definitions, it can be observed that definitions can vary across different countries and regions [18]. Originally, after being introduced by Wolfgang Feist, Passivhaus Institut Darmstadt [1], the PH definition was reintroduced for residential units in European regions between 40-60 degrees Northern latitude [7]. The following conditions were specified in the calculation model of the PHPP (Passive House Projection Packet – Program for the calculation of energy demands of PHs):

• The total end-energy demand for space heating and cooling is limited to 15 kWh/m²a treated floor area;

• The total primary-energy use for all appliances, domestic hot water and space heating and cooling is limited to 120 kWh/m²a.

During the Intelligent Energy Europe Project "Promotion of European Passive Houses - PEP" [7], it was noted that for 60 degrees and higher latitudes as well as for existing buildings, it might be necessary to adjust the figures in order to be able to achieve an ambitious yet realistic solution. Also as a result of the PEP-project, countries were given room for national adjustment. For example, the Norwegian standard for PHs [8], approved in April 2010, has set the maximum end-energy demand for heating to 15 kWh/m^{2}a for sites where the annual mean temperature is at least 6.3 ℃. A bit higher heating demand is allowed for single-family homes below 250 m^2 and houses in the colder regions of the country.

In The Netherlands, the non-profit organization "Stichting Passiefbouwen.nl" [9] originated from the PEP-project and promoted the same energy demand and energy use criteria since its foundation. For existing buildings the energy demand for heating was relaxed to 25 kWh/m²a. In Belgium, the PH was introduced by "Passiefhuis-Platform vzw (PHP)" [10] earlier in 2002 [11]: PHs had to reach a target end-energy demand for heating less than 15 kWh/m^{2}a, and a required air tightness level $n_{50} \leq 0{,}6$/h. It was reasoned that the exclusion of the total primary-energy demand criterion would simplify market uptake while the blower-door test would increase construction quality. For renovations, the relaxation of the end-energy demand for heating is under discussion, but not yet implemented [5]. Further - even amongst the Nordic countries - there are numerous differences in interpretation, for example regarding climate zone of the project, building dimensions, building use, criteria definitions for heat losses and included sources in the total or primary-energy demand [12]. But in general, the energy demand criteria for PHs are used both in the so-called Low Countries (middle European countries which can not be assigned to Nordic countries) and most of the Nordic Countries and are practically a link across borders [13].

3.2 Certification

A success factor of the above mentioned definition discussions has been the market uptake of related certification. In The Netherlands, the non-profit organization "Stichting PassiefBouwen.nl" [9] introduced a distinction of criteria for design and post-construction certification (see Table 1: the projects receiving a post-construction certificate also have a design certificate).

Belgium has known a market uptake of a voluntary PH label since 2005 ('quality assurance label'), also because of the widespread promotion activities of the non-profit organisation "Passiefhuis-Platform vzw" (PHP) [10] - and "Plate-forme Maison Passive" (PMP) in the French speaking part - and the introduction of grants related to this definition. Meanwhile, in Belgium, definitions for the Low-Energy, the Passive and the Zero-Energy House have been officialised in tax reduction law [14] at the end of 2009 (see Table 2). The income tax reduction during 10 years is respectively 300, 600 or 1200 EUR. We note that the tax administration relied on the two PH platforms (PHP/PMP) as controlling institutes, thus officialising the label in the format of a certificate by Royal Decree [14].

Table 1 Passive House certification in The Netherlands by Stichting Passiefbouwen.nl [9], and number of certificates for housing projects status May 2011.

Design only certificate	**Number of certificates (new / renovated)**
The design of the project has to comply with the Passive House standard defined in Table 1 (specific recommendations are given on www.passiefbouwen.nl), based on PHPP calculation and plans.	7 / 1
Design & Post-construction certificate	**Number of certificates (new / renovated)**
Additionally, a post-construction certificate can be obtained when • At least two inspections were performed during construction; • A blower-door test confirms the required air tightness; • Infrared thermography was used to evaluate the construction; • The air flow performance of the ventilation system was checked.	2 / 4
Total number of certified projects (new + renovated)	**14**

Table 2 Criteria for highly energy-efficient housing categories used in Belgian tax reduction law [14], and number of certificates provided by PHP status May 2011 (Flemish certificates only).

Low-Energy House certificate	**Number of certificates (new / renovated)**
The total energy demand for space heating and cooling should be limited to 30 kWh/m^2 conditioned floor surface;	2/ 0
Passive House certificate	
1° the total energy demand for space heating and cooling should be limited to 15 kWh/m^2 conditioned floor surface; 2° during a pressurization test (according to the norm NBN EN 13829) with a pressure difference between inside and outside of 50 Pascal, the air loss should not be more than 60 % of the volume of the house per hour ($n_{50} \leq 0{,}6$/h).	60/ 2
Zero-Energy House certificate	
1° comply to the conditions for a Passive House; 2° the remaining energy demand for space heating and cooling can be fully compensated by on site produced renewable energy. (The King defines in which way the production of renewable energy is taken into account for the compensation.)	16/ 0
Total number of certified projects (new + renovated)	**80**

Thus some market confusion exists concerning the selection of PHs for study. The market uptake of the post-construction certificate in The Netherlands has been very slow, resulting in many projects that carry a self-defined Low-Energy, Passive or Zero-Energy label or a design only certificate. And in Belgium, many projects are already inhabited but still applying for a certificate. The number of PH projects in Belgium is therefore significantly higher than stated in Table 2.

3.3 Comfort issues

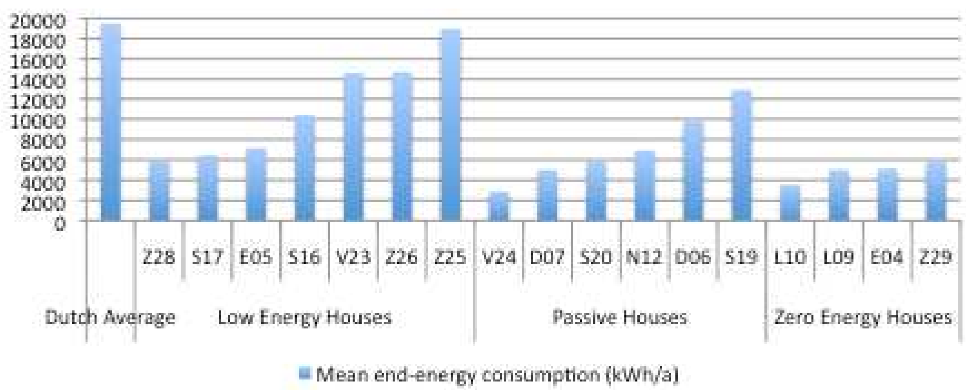
The comfort discussion in the Benelux Countries has a specific policy context, focusing on comfort perceived by end-users, additionally to the general discussion on differences in calculation values for reference area, indoor temperature, internal heat gains, appliances and persons [12, 13]. Dutch scandals on improper working of ventilation systems created quite a stir leading to the recommendation to enforce better installation quality through effective commissioning and to better inform home buyers [15, 16]. Also, previous Belgian research showed that in some PHs the air volumes in sleeping rooms might be on the low side, although inhabitants do not complain [6]. Some barriers and possible solutions considering the functioning of the indoor climate systems have been addressed, resulting in recommendations to provide specific designs, or to improve summer comfort and the indoor climate systems for PHs. Also in Belgium, the implementation of the Energy Performance of Buildings Directive is highly connected to providing good indoor comfort. For example, if (fictitious) summer overheating is detected in the energy performance calculation, it is penalized with a fee. However this does of course not solve the physical problem of possible uncomfortable indoor climates.

4. Analysis of the questionnaires

4.1 General results

In Figure 1 the average end-energy consumption of the investigated Dutch dwellings is illustrated, based on end-user statements in the survey of the total gas and electricity consumption of the household. The results show that the average end-energy consumption of all investigated projects is lower than the average of Dutch households in 2008. However, there are single households in the category "Low-Energy Houses", which have a total consumption that is higher than the Dutch average. The average end energy consumption of the categories "Low-Energy", "Passive Houses" and "Zero-Energy" was 10050, 7233 and 5119 kWh/a, respectively. The non-parametric Kruskal Wallis test showed that the end energy consumption differs between the three groups ($p < 0.01$).

Figure 1: Mean end-energy consumption in kWh/a per household of Dutch projects, assigned to three different building categories, and in comparison with the average end-energy consumption of Dutch households in 2008.



There were also differences between the groups with regard to the average primary energy consumption, but this could not be tested statistically due to the small sample size. While the mean end-energy consumption of the analysed households is only 43% of Dutch average, the mean primary-energy consumption is with 62% much higher. This can be explained with the high portion of electric energy consumption of the total energy consumption in the investigated households and accordingly the higher primary-energy factor for electricity (2.56) in comparison with gas (1.0).
The investigated PHs In The Netherlands are not officially certified. The U-values of non-transparent walls are generally below 0,15 W/m^{2}K, those of windows and glazing usually below 0,8 W/m^{2}K in Belgium, and below 1,1 W/m^{2}K in The Netherlands. For most of the Dutch projects data regarding air tightness levels could not be provided. In comparison, all Belgian projects with a certificate met the calculated space heating energy demand of maximum 15 kWh/m^{2}a by verified PHPP calculation. The air tightness of the Belgian projects certified until the end of 2009 was always below the threshold of 0,65 ach-1, with an average of 0,4 ach-1 on 31 projects.
A more detailed analysis of the questionnaires has been provided in previous papers [3, 4, 5]. In this paper we focus on compiling the data regarding the appreciation of indoor comfort.
The Dutch households were asked to give a grade for the satisfaction level for living in their own dwelling, between 1 (lowest satisfaction level) and 10 (highest level). An analysis of variance showed that the mean satisfaction level differs between the three categories (p=0.01). "Passive House" has the highest mean (8.93) and differs statistically significantly from the "Low-Energy"

(7.93) and "Zero-Energy" (with a mean of 7.80 the lowest). The specific ventilation system was shown to have no statistically significant influence on the general satisfaction level.

4.2 Appreciation of indoor comfort

Table 3 shows the questionnaire results considering indoor climate appreciation of the Dutch self-proclaimed PHs. Although most occupants are generally satisfied, there are possible comfort problems in one case. 6 out of 7 respondents replied that they experience the temperature during the summer in their living room as 'generally good', and 1 as 'sometimes too warm'.

Table 3 Residents' appreciation of indoor climate in Dutch PHs (not certified), (number of answers per item, results 2011, inhabited).

Satisfaction level with the indoor climate (numbers indicate amount of households per level)						
	Very satisfied	Satisfied	Neutral	Unsat-isfied	Very un-satisfied	Total number
Living room (winter)	3	4	0	0	0	7
Sleeping room (winter)	4	2	0	1	0	7
Living room (summer)	3	4	0	0	0	7
Sleeping room (summer)	3	4	0	0	0	7

For the Flemish projects more detailed results were obtained. Table 4 shows the questionnaire results considering room temperature appreciation of the certified Belgian PHs (all owner-occupants). Although most occupants are generally pleased, we remark possible comfort problems in a few cases. Particularly, perception of room temperature in summer could be improved.

Table 4 Residents' appreciation of room temperatures in Belgian certified PHs, certified or intention to certify (number of answers per item, results 2009-10, inhabited > 9 months).

How do you experience the mean room temperature during the heating period?						
	too warm	***warm***	***pleasant***	***hale***	***too cold***	***total no.***
in the living room		1	17,5	1,5	1	21
in the bedroom	1		15	5		21
in the bathroom			18	2	1	21
in the kitchen		1	17,5	1,5	1	21
in hobby rooms/ play rooms		1	16			17
How do you experience the mean room temperature in summer?						
	too warm	***warm***	***pleasant***	***hale***	***too cold***	***total no.***
in the living room		6	5			11
in the bedroom		5,5	5,5			11
in the bathroom		3	8			11
in the kitchen		6	5			11
in hobby rooms/ play rooms		3	5			8

Measured winter temperature measurements (9 projects) varied between 18,2 and 21,6 degrees C with an average of 19,8 degrees C. Measured summer temperature (6 Flemish projects) varied between 20,2 and 25,8 degrees C with an average of 22,4. 2 out of 12 respondents found the temperature in summer usually too high and 2 out of 11 respondents experienced draft on windows and doors. 2 out of 11 interviewees stated that they sometimes have the impression of getting insufficient fresh air. 5 out of 12 respondents thought that the air in winter in bedrooms is 'dry'.
With 3 exceptions, owner-occupants of Belgian certified PHs are generally satisfied with the quality of installations. One respondent mentioned excessive energy use, noise and heat production of a converter. One respondent regularly disabled the integrated heat pump/ventilation unit during the night to avoid the noise production in the master bedroom. Some reserves should be taken into

account. For example, in many cases mobile humidifiers were found in the bedrooms. Also, noise from the ventilation system is often mentioned.
8 out of 12 respondents mentioned that the ventilation system only worked well after control or adaptation, only 3 respondents stated to have no problems with the ventilation system from the beginning, and one respondent was still not pleased. 2 out of 12 find the control of the ventilation complicated. 2 out of 12 state that ventilation grills have not yet been adjusted. Although most respondents stated to have a general manual in their possession, only 4 out of 11 received a room airflow report. 5 out of 10 did not know the airflows that are necessary in each room.

5. Conclusion

Based on the presented findings it can be concluded that households living in PHs in The Netherlands and in Belgium are quite satisfied with their dwellings and indicate a high comfort level. However, some households are less satisfied with too high indoor temperatures during the summer particularly in the sleeping rooms, as well as insufficient indoor air quality. Although the general PH criteria basically guarantee a low end-energy use for heating, the current criteria do not necessarily lead to quality end products with good comfort conditions. The research results show that especially summer comfort conditions and the proper working and user friendliness of current indoor climate systems can be improved. Therefore the following suggestions should be taken into account in the framework of future PH planning and certification:
- Making a summer comfort criterion obligatory for PH certification is crucial for the enhancement of the overall indoor comfort;
- The proper operation of ventilation systems is of such great importance for the user satisfaction of PH inhabitants that – compared to standard construction - more attention has to be given to quality control regarding the planning, installation, operation and maintenance of those systems;
- Strongly recommended are the control of the implementation of standards and acoustical criteria (such as maximum noise levels) for ventilation systems, and especially ventilation units, to avoid disapproval of ventilation systems and possible indoor climate problems;
- It should be regarded as standard practice to provide residents with relevant information (more than only user manuals) about the operation and maintenance of ventilation systems (including unit and system control, required room air flows, maintenance of outlets, inlets and filters, practical tips and tricks for improving comfort), which is currently poorly addressed.

6. Discussion

Based on the described research, the main concerns regarding PHs in the Benelux countries are insufficient indoor climate systems, as well as overheating during the summer months. When targeting the mass market these concerns have to be smoothed and the quality of PHs has to be assured. The current PH certification systems have the benefit that they imply that PHs should be produced with special attention to construction quality, which is for example reflected in the requirement for air tightness. Especially in the Belgian certificate, the specific construction requirement considering air tightness motivates contractors to achieve a predetermined quality already during the design phase. Nevertheless, the air leakage control of the building after construction remains an important issue. Furthermore the absence of thermal bridges should be checked also during the construction phase. A control after construction, for example by thermo graphic analysis, which is an item in the Dutch post-construction certificate, may be relevant for certification but is often too late, because the building phase is over and mistakes can’t be resolved any more with acceptable effort.
Also issues that imply a relationship with comfort conditions need to be addressed in the certification. User experiences show that summer overheating remains an important issue, not to be neglected in general PH criteria. The research also finds that including performance criteria for indoor climate installations in PH certification is a path to explore, in particular regarding the proper working and user friendliness of ventilation systems. For example, in the current Belgian tax criteria performance guarantees for indoor climate installations are not specified. Specific web tools (for example www.beterventileren.be) can set examples for designers.
Additionally, a control report for ventilation might be essential in the near future. The Flemish quality assurance procedures currently still do not ask for checking the proper function of technical

systems: such a check is for example required in the Dutch post-construction certificate where minimum airflow rates need to be achieved in practice. The PHP/PMP certification system has been refined in several stages according to practical experiences to address comfort issues [17], and further improvement might be needed.

The separation of design and post-construction certificates, as in the Netherlands, might be an opportunity to increase market penetration of certificates, but also a barrier for achieving quality when the market is not effectively convinced to aim for a post-construction certificate. Companies might opt to achieve only a design certificate in order to call their projects a 'Passive House', but in the end this might lead to market confusion and poor comfort conditions. Also, poor real energy performances of PHs, as well as Low-Energy and Zero-Energy Houses, are an item for concern, as visible in the results of the Dutch research. Also, the Dutch certificate that only considers the design currently allows for a cooling demand in PHs. Both in The Netherlands and in Belgium, confusion might occur when certificates are issued that do not include an evaluation of for example summer overheating, thus leading to projects with possibly poorer comfort conditions. The user experiences also open the debate towards required or recommended certification of PH technologies. Development or inclusion of related product and system criteria for certification could be an issue for future research.

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