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Certification of Passive Houses: Lessons from Real Indoor Climate Systems

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ABSTRACT*:*
This paper examines if and how indoor climate systems are important for passive house certification. The research subjects are passive houses in Belgium, occupied by owner-clients. These have received a quality assurance certificate from an independent organization. Through interviews with the owners, and on-site analysis of indoor climate installations in passive houses, the selection of indoor climate systems for passive houses was analyzed and insights were obtained in changes occurring after certification. Also, two houses were analyzed during further visits, including interviews and measurements, to allow detailed performance evaluation of the indoor climate systems. The paper concludes that adaptation of certification procedures is recommended, by looking more closely at the practical implementation of indoor climate systems. The paper further questions the general validity of the scientific basis of the passive house definition.

1 Introduction

In this age of fluctuating energy prices, energy resources from unstable contracts, emission excesses, and dedicated regional and thematic development, efficient energy use is becoming more and more important. This is no longer solely an environmental consideration, but increasingly also a financial one. Many energy efficiency measures have a payback time from zero to twenty years, thus largely below the life span of a building. Energy efficiency also lowers the energy bills of households. And more energy savings lead to equivalent reductions in emissions of greenhouse gases. In general, promoting energy efficiency thus leads to a better follow-up of the Kyoto Protocol. For such reasons, more and more building professionals and governmental bodies are recognizing that the provision of radical energy demand savings during design is an essential part of sustainable construction and renovation.

To reduce the total primary energy consumption in the building sector, the European Commission has put forward the directive on Energy Performance of Buildings, the EPBD (2002/91/EC), which came into force 2002 and should have been implemented in the legislation of member states in 2006. The European Union will implement stricter regulations for the housing sector in the near future, as well as using financial incentives for environmentally friendly solutions. Further, the provision of a building energy label will be mandatory in Europe when selling or renting a house, and for display in public buildings. In most European countries the energy label for buildings is introduced in 2008-2009. This provides opportunities to include visibility of passive houses. Also, the European Commission wishes to include 'passive or low energy' houses in the future adaptation and strengthening of the EPBD.

According to the popular definition, passive houses have to reach a target energy demand for heating less than 15 kWh/ m^2a. This definition is physically based on the maximum amount of heating that can be transported by heating the inlet fresh air to 52 degrees C, without ventilation volumes exceeding hygienic ventilation requirements, nor recirculation of used air. Thus, in theory, the installed heating power is less than approximately 10 W/m^2.

Based on this definition, some European countries and regions have introduced voluntary passive house certification or in certain cases even a mandatory passive house standard. A western European overview of certification initiatives for passive houses has been given in [Mlecnik et al. 2008a]. This previous paper also illustrates why certification of passive houses is important. In Belgium a tax reduction is granted based on a passive house quality assurance form. Special grants for passive houses are given on a regional level. These financial benefits support market growth and seem to stimulate innovation by manufacturers of window frames, installations etc. Performance based contracting is thus being initiated for passive houses and low energy buildings. The energy performance has to be calculated and the air tightness of the building envelope usually has to be tested. In many countries including Germany and Belgium the certification is based on calculations with special passive house design software (PHPP).

Although the passive house standard guarantees a low energy use for heating, questions arise considering the indoor climate of passive houses. E.g. in the Netherlands health problems with balanced ventilation systems with heat recovery [Van Ginkel 2007] created quite some media attention recently. Quality assurance procedures of passive houses usually include a blower-door test, but do not yet systematically include the functioning of technical systems, and its effect on indoor climate.

What can we learn considering the importance of indoor climate systems for quality assurance of passive houses? The following questions are further addressed in different paragraphs. Are the indoor climate systems in practice chosen according to the passive house definition and background principles? Do they perform well considering comfort and health? Should certification procedures include a more detailed examination of indoor climate systems?

2 Selection of indoor climate systems

To understand the selection of indoor climate systems in Belgian passive houses, an inventory is made of these systems for heating, ventilation and domestic hot water production, as installed in Belgian passive houses. The research included on site inspection, interviews and comparison of the findings with calculation files and technical brochures submitted for receiving the quality assurance form. Further, winter heating and summer cooling strategies of different passive houses are discussed.

2.1 Research subjects

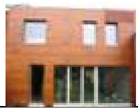
Six Belgian certified passive houses (documented in further detail in [Mlecnik et al. 2008b]) with varying architecture and building construction were selected for research. These projects received their quality assurance form in the period 2004-2005 and have been inhabited for at least two years by the owner-client. All houses have been designed for 4 to 5 persons. All projects fulfil the space heating energy demand requirement of maximum 15 kWh per m^2 per year. The U-values of non-transparent walls are below 0,15 W/m^2K, those of windows and glazing below 0,8 W/m^2K. Air tightness of all projects is below 0,6 ach^{-1}. In all cases air-to-air heat recovery is provided with a high efficiency heat exchanger on a mechanical ventilation system. All projects have an earth-air heat exchanger for preheating the incoming air in winter and for passive cooling in summer. Mechanical ventilation systems include a bypass of the air-to-air heat exchanger to be used in summer. In all cases, also some form of protection against overheating is provided, either through roof overhangs, louvers, window integrated sun shades or separate shading constructions. From comparison of the PHPP calculation with the actual project, we can conclude that the building skin of the passive houses is well designed according to passive house recommendations, although different types of architecture result. This should however have no direct impact on the selection of indoor climate systems. All projects, except number 3 (see Table 1: a single family row house), are free standing single family houses.

2.2 Observed indoor climate systems

2.2.1 Space heating and cooling

Table 1 gives an overview of the space heating and cooling strategies in the six projects. Although the scientific building skin characteristics like U-values and air tightness values do not differ much, it could be observed that the space heating strategy differs between different projects. Also, the dimensioning of the earth-air heat exchanger varies between projects.

Table 1 Space heating and cooling in six passive house projects with quality assurance

	Indoor Climate Systems as observed in Passive Houses (Belgium)		
Project number	Appearance	Space heating provided by:	Earth-air heat exchanger length (m); inside diameter (cm); medium depth (m)
1		Central air + convector in living room + radiator in bathroom	40; 20; 2
2		Central air + heater in bathroom	35; 20; 1,8
3		Central air	40; 11; 2
4		Pellet oven in living room	40; 20; 2
5		Central air	40; 20; 2
6		Pellet oven in living room + electric heater in bathroom	35; 20; 1,8

From Table 1, it can be observed that there is no preferential heating strategy. Preferred energy vectors include gas, electricity and biomass. Three projects prefer a slightly higher temperature in the bathroom and therefore have extra heating in the bathroom. Two projects have a pellet oven in the living room instead of central air heating. This oven is also used for heating sanitary hot water.

In project 1 it was observed that the inhabitant changed the original mode of heating via central air heating after certification. According to the inhabitant, a convector was installed in the living room. This item is now being used instead of the central air heating. The inhabitant did not find it logical that the incoming air in the bedrooms was heated and preferred ‘fresher’ air in the bedrooms. According to his experience this works fine now, since cooler air is coming into the bedrooms and air is heated in the living room according to occupancy and necessity.

In Belgium, an earth-air heat exchanger is often included in the system for reasons of excluding electric frost protection and for the contribution to passive cooling. From comparing the data of the earth-air heat exchangers with the required air volumes it can be observed that in project 3 the ground tube is under dimensioned. Also, the tubes in the other projects do not have optimal dimensions. For the projects no specific calculations were provided to dimension the earth-air heat exchanger. The diameter 20 cm is most commonly appearing because of easy market availability of PVC or PE tubes and not because of optimal dimensioning. The inhabitant of project 1 noted that pre-welding of the connections of the tubes was essential in his project to avoid leakage. This statement was confirmed by other passive house owners (not included in the table): in some cases leakage of ground water into the tubes occurred making the earth-air heat exchanger unfit for further use.

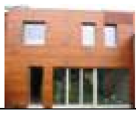
In theory passive houses only need a post-heating demand of approximately 10 Watts per square meter. But in reality we see that theory is deviating from practical implementation. The criterion of optimal heat distribution is observed to be more important than the exact passive house criterion, which only prevails in the design stage for optimizing the building skin.

The interviews also show that a good realization of (passive) cooling is an important issue for passive house clients.

2.2.2 Hot water production

In theory, the heating capacity of the main heat production should be dimensioned according to the domestic hot water needs. In Table 2, the strategy for the production of hot water in the researched projects is illustrated.

Table 2 Hot water production in six passive house projects with quality assurance

	Hot Water Production Systems as observed in Passive Houses (Belgium)		
Project number	Appearance	Sanitary hot water provided by:	Hot water buffer content (dm^3)
1		Combined boiler (solar + gas fired) + hot water heat exchange system in shower	380
2		Combined boiler (solar + electrical heat pump)	180
3		Solar + gas fired assistance	200
4		Pellet oven in living room + solar assistance	500
5		Gas fired boiler	185
6		Pellet oven in living room + solar assistance	450

Although the use of renewable energy is not required for the passive house certification, owner-clients in Belgium tend to integrate solar collectors. Therefore the coupling with indoor climate systems tends to become more complex. Project 2 has the presence of a integrated combined compact heat pump unit. The combined indoor climate/ hot water production system consists of a compact heat exchanger unit, combining air-to-water heat pump, hot water production, pulsion and extraction fans, a high efficiency counter current heat recovery on the ventilation system, a backup electrical resistance heater and a connection to the solar collector and the hot water reservoir. This option is still considered to be an innovation on the Belgian market. Heat recovery from hot waste water has only been used in one case (project 1). The inhabitant reported several problems with the implementation: the legal issues considering the no-mixing with the drinking water system and some leakage problems. These problems were solved.

From the table it can be seen that differences occur in the design of the content of the hot water reservoir, although the hot water needs in the different passive houses are similar for 4 to 5 persons. Traditional solar assisted systems appear to need a larger buffer, making the total environmental benefit of this option questionable. Most projects could not provide dimensioning calculations for the hot water buffer and some inhabitants noticed that rules of thumb of the installer prevailed.

3 Performance of indoor climate systems

On the basis of the previous research, projects 1 and 2 were examined in detail with further inspection visits (see also [Mlecnik et al. 2008c]). During these visits measurements were performed, including logging of temperature and relative humidity, measurement of temperature gradient of hot water at the tap, occasional probing of formaldehyde content in the air in sleeping rooms, air flow measurement in all rooms in different ventilation settings. Further interviews with the occupants included their appreciation of thermal comfort, acoustical comfort, visual comfort, air quality, user friendliness, maintenance and health.

3.1 Ventilation system

Project 1 has a rectangular floor plan, two floors and a traditional double sloped roof. The carport, barn and cellar are located outside of the climate protected volume. Living spaces are oriented towards the south side (living room, kitchen, office) and provided with fresh ducted inlet air. Bathroom, sleeping rooms and entrance are located on the north side of the building with extraction of polluted air. The living space has an open connection to the upper floor level (see Figure 1). The exhaust hood in the kitchen is of a recirculation type with active coal filter, not connected to the ventilation system. The inhabitant notices that by using solar gains and a highly efficient counter flow heat recovery unit in the ventilation system, and an earth-air heat exchanger, the heating period for this building is limited to a few months.

Project 2 also has a square floor plan and two floors. The sloped roof slab is oriented towards the sun with extension on the south side. The living room has an open connection to the upper floor level as well. The cellar and garage are outside of the protected volume. Living spaces, working room and sleeping rooms are provided with fresh pulsion air. Bathroom, toilet, working room, kitchen and storage room have air extraction. To avoid unbalance in the ventilation system, the exhaust hood in the kitchen was not connected to the ventilation system: the cooking air is cleaned by means of a recirculation hood with active coal filter.

In both cases an unbalance was measured between incoming and outgoing air. According to PHPP calculations, both projects were designed for 30 m^3 fresh air per person per hour. Measurements reported too low ventilation rates with closed doors, especially in secondary sleeping rooms in the lowest ventilation setting (in both cases used as set point in winter). In Project 1 overheating was noticed in the installation/ boiler room, which influenced the temperature in neighbouring rooms. In Project 2 overheating was noticed in one room that changed its function to a permanent work space.

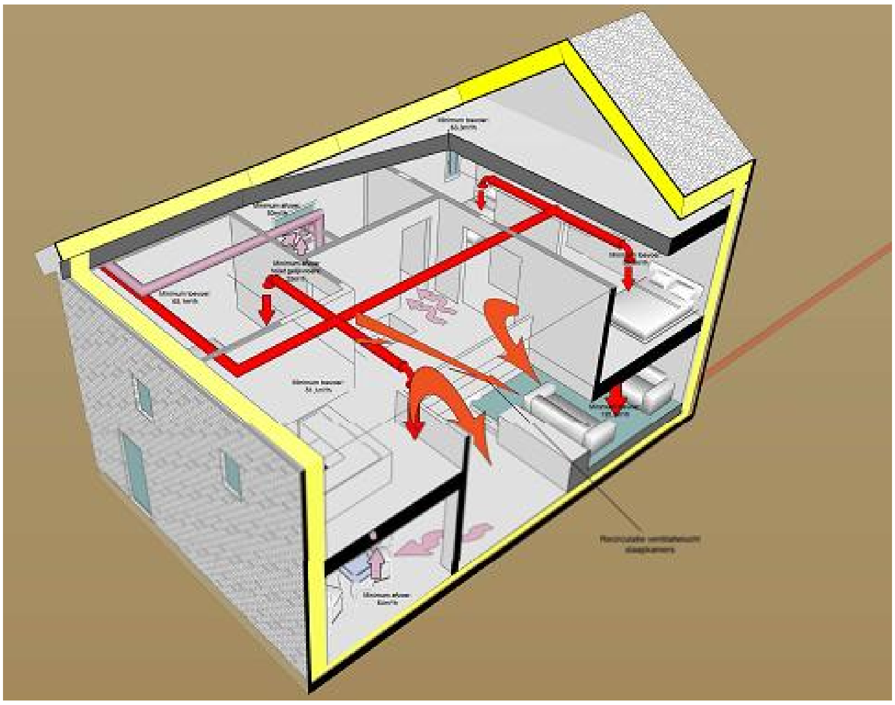


Figure 1. Ventilation system in Project 1.

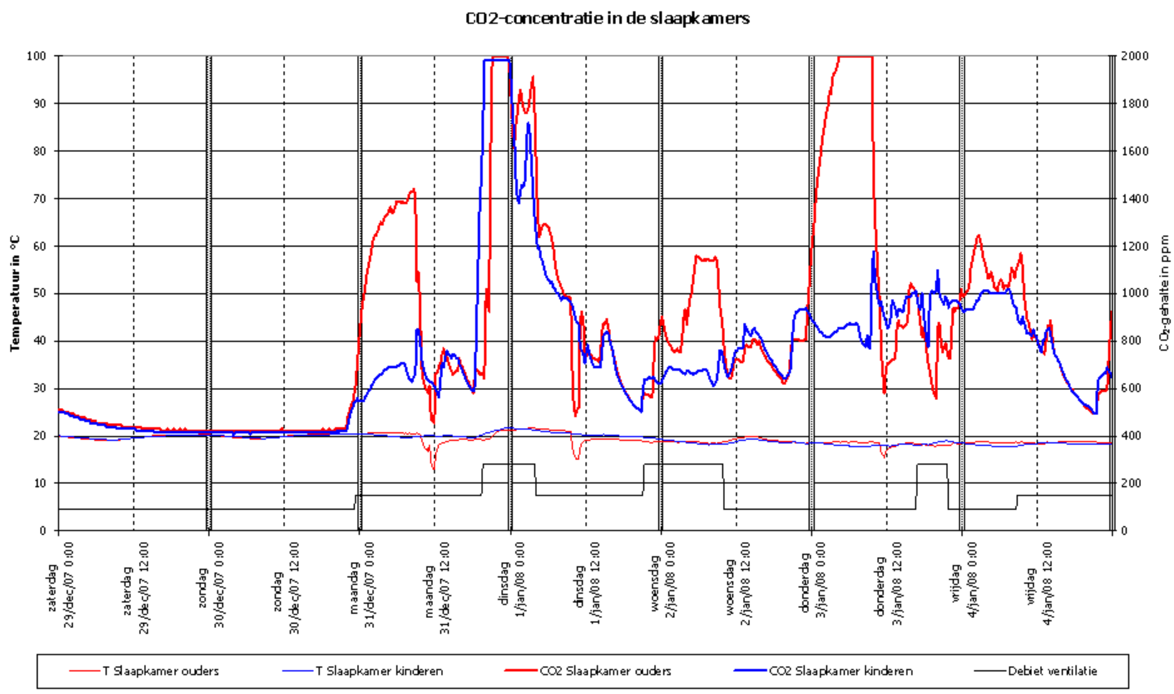


Figure 2. Measurements of indoor temperature and CO_2 concentration in Project 1 sleeping rooms (different scenarios during a winter period). Measurements by G. De bruyn, Cenergie cvba, presented on PassiveHouse 2008, Brussels. The lower curve represents the ventilation setting in three possible positions.

Figure 2 illustrates some of the critical points in the dimensioning of the ventilation system in Project 1. E.g. the ventilation system can not cope with a large amount of people (New Year's Eve party) and with three persons sleeping in one bedroom at the lowest ventilation rate with doors closed. On the other hand the system performs well with standard occupation as designed according to PHPP.

3.2 User experiences

The following table (Table 3) illustrates some of the positive and negative occupant experiences that were registered from the detailed interviews, considering the indoor climate:

Table 3 User experiences in two passive house projects with quality assurance

	User experiences as observed in Passive Houses (Belgium)		
Project number	Issue	Positive Experience (cumulated)	Negative experience (cumulated)
1, 2	Thermal comfort	No cold airstreams although architectural features like large open spaces. Small temperature differences. Perceived good functioning of earth-air heat exchanger in winter and summer.	Too warm in bedrooms (changes implemented). Too cold in bathroom (changes implemented).
1, 2	Acoustical comfort	Prevention of outside noise (airplanes)	Less contact with outdoor noise. Noise from ventilation system more noticeable (dampers missing), stimulating lower setpoints for ventilation.
1, 2	Visual comfort	Satisfying design.	-
1, 2	Air quality	Good functioning in conditions as designed.	Perceived low ventilation rate in highly equipped room (permanent work space) Dry air in winter (Mobile humidification installed in sleeping rooms, in one case also in living room).
1, 2	Maintenance/ user friendliness	Simple change of filter.	Summer by-pass needs manual operation. Difficult cleaning of ducts.
1, 2	Health	Less health complaints in one case (compared to previous house).	Sore throat and respiratory irritation in one case.

3.3 Recommendations

The evaluation of the two passive houses leads to preliminary recommendations. The indoor air quality depends, with the assessed critical ventilation capacity, on the emission, and related heating and moisture effects, by household activities such as washing and laundry drying, from equipment in a working room and even from the central equipment for heating and ventilation. To prevent pollution, a place for such activities and installations outside the protecting envelope could be designed.

The design of the air duct system is crucial for reducing noise production and for energy efficient function of fans: the heat exchanger and fan unit require a central position in the dwelling, with air ducts designed for low pressure losses. Inlet openings should be far enough from outlet if one can not depend on induction or coanda effect of inlet dampers. More careful attention to inspection and cleaning of ducts is recommended. Pollution from deposited dirt on filters and fan blades and from construction activities can become a health risk after some years. In both cases maintenance of ducts was not sufficiently considered in the design stage.

Air volume and temperature control per room is sometimes wished for. Application of different zones supports different heating levels through ventilation air. The bathroom may require a heat source to provide instant higher temperatures: a radiator, a heated mirror or other (electrical resistance) heaters. In exceptional cases it is necessary to be able to open windows, e.g. with high occupancy.

4 Adapting certification procedures

4.1 Conclusions

Passive houses should be produced with much attention for quality in all stages of the building process. Certification and guidance result in quality that is generally higher than resulting from traditional construction processes. The current certification procedure in Belgium seems to ensure that the building envelope has good overall performance quality. This is also partly because the necessary practical testing of the building air tightness leads to a high involvement of the building skin contractor.

Indoor climate systems require special attention during certification. Performance guarantees and procedures for indoor climate systems are not yet fully developed in Belgium. Because the hot water demand largely outweighs the space heating demand, it is a challenge to optimize hot water systems to include renewable energy, heat recovery from waste water and maybe even visible ‘fire’.

The exact passive house definition has its origin in providing space heating by the central ventilation system. This paper has questioned this basis, since in practice consumers tend to include heating in the living room and in the bath room and tend to prefer a lower set point temperature in sleeping rooms.

From the case studies it is recommended to adapt certification procedures of passive houses to include quality assurance of the proper working of installed indoor climate systems. A practical test for installations (like the air tightness test for building skins) can motivate installers to perform a better job and to provide higher quality than business as usual. The user friendliness of indoor climate systems for passive houses can be improved by evaluating the innovations, and also by involving the users in the selection of concepts and techniques.

4.2 Further research

Further research includes the evaluation of user experiences of more passive houses and low energy houses in Belgium. This should provide insights if certified passive houses perform better than non-certified houses and if passive houses have a perceived better performance than low energy buildings.

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