Indoor climate systems in passive houses

E. Mlecnik[1,2] and S.Van Loon[1]
(1) Passiefhuis-Platform vzw, Belgium

E. Hasselaar[2]
(2) OTB, Delft University of Technology, the Netherlands

ABSTRACT

According to the definition, passive houses in Europe meet a target energy demand for heating of less than 15 kWh per square meter and per year. This low level for the heating demand is based on heating by a small post-heater in the hygienic ventilation system at 52 ^{0}C maximum, while the ventilation system can be dimensioned purely for ventilation purposes. In theory thus the installed heating power is less than approximately 10 Watts/m^2.

But what happens in practice? The practical realization can be different from the definition and user experiences with indoor climate systems for passive houses may require further adaptations. Belgian example projects and the indoor climate systems in winter and in summer were studied. The study includes inspection of technical details and interviews with occupants of some passive houses in Belgium.

The results illustrate the concerns of occupants considering winter and summer comfort in especially bedrooms, low air humidity creating respiratory problems and complex control of installations including temperature control. The research shows that occupants tend to prefer new adapted types of post-heating. Also, a good realization of (passive) cooling techniques is a very important issue in passive houses.

The paper gives recommendations on how to improve the user friendliness of indoor climate systems for passive houses.

1. INTRODUCTION

Promoting energy efficiency is a consequence of the Kyoto Protocol. The European building sector is responsible for about 40% of the total primary energy consumption. To reduce this share, the European Commission (EC) has put forward a directive on Energy Performance of Buildings, the EPBD (2002/91/EC). A building energy label will be mandatory in Europe when selling or renting a house. In most European countries the energy label for buildings is introduced in 2007-2009.

According to the popular definition (PEP, 2008), passive houses have to reach a target energy demand for heating less than 15 kWh/m^{2}a. This definition is based on meeting the heating demand by heating the inlet fresh air to 52 ^{0}C, without recirculation or ventilation volumes that exceed hygienic ventilation requirements. In theory thus the installed heating power is less than approximately 10 W/m^2.

Some European countries and regions have introduced voluntary passive house certification or in certain circumstance a mandatory passive house standard. In Belgium a tax reduction is granted based on a passive house quality assurance form. Special grants for passive house 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 being initiated for passive houses and low energy buildings. The energy performance has to be calculated and the airtightness of the building envelope has to be tested. In Germany the certification is based on calculations with special passive house design software (PHPP) and the results support the provision of green mortgages for passive houses. In Switzerland the 'Minergie-P' (for passive houses) label offers financial benefits. In Frankfurt (Germany) and in the Vorarlberg Region (Austria) the passive house standard is required for the construction of public buildings. Although the passive house standard guarantees a low energy use for heating, questions arise considering the indoor climate of passive houses. Quality assurance procedures of passive houses usually include a blower-door test, but do not include the functioning of technical systems and its effect on indoor climate yet. Such a check is for example required in Germany (Passive House Institute Darmstadt).

To understand and address potential indoor climate problems, an inventory is made of climatic installations for heating, ventilation and domestic hot water production that are installed in Belgian passive houses. Winter and summer comfort strategies of different passive houses are discussed.

2. COMPARISON OF CLIMATE SYSTEMS

Six certified passive houses were compared and two of the houses inspected in detail. The projects meet the space heating energy demand 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. Airtightness is below 0,6 ach. In all cases air-to-air heat recovery is provided with a high efficiency heat exchanger on a mechanical ventilation system. Some form of protection against overheating is provided, either through roof overhangs, louvers, window integrated sun shades or separate shading constructions. Mechanical ventilation systems include a bypass of the air-to-air heat exchanger to be used in summer. All houses have been designed for 4 to 5 persons. Although U-values and airtightness and characteristics of the earth-air heat exchanger do not differ much, the climate systems can be very different.

Project name	*Space heating*	*Hot water Buffer [dm^3]*	*Domestic hot water production*	*Earth-air heat exchanger length [m] diam. [cm, depth [m]*
Heusden-Zolder	Heated ventilation air, extra convector in living, radiator in bathroom	380	Solar and gas-fired boiler, heat recovery on hot waste water	40/20/2
Bocholt	Heated ventilation air	180	Solar and electrical assisted compact heat pump	35/20/1,8
Heusden-Destel-bergen	Heated ventilation air	200	Solar assisted gas-fired boiler	40/11/2
Torhout	Pellet oven in living room	500	Solar assisted pellet oven	40/20/2
Wijtschate	Heated ventilation air (2)	185	Gas-fired boiler	40/20/ 2
Ename	Pellet oven in living room	450	Solar assisted pellet oven	35/20/1,8

Table 1: Indoor climate strategies in passive houses in Belgium, projects described in (Mlecnik et al., 2008)

Since passive houses only have a post-heating demand of approximately 10 Watts per square meter, the indoor climate systems should be dimensioned according to the domestic hot water needs. For now it is unclear why such 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. Until now, post-heating of the ventilation air with a water-to-air heat exchanger is a popular option in Belgium, although direct electrical post-heating begins to occur. Owner-occupants who prefer the radiant heat of a stove tend to opt for pellet ovens that provide for hot water at the same time. 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. Although the use of renewable energy is not required for the passive house standard, owners-occupants often integrate solar collectors. Therefore the coupling with indoor climate systems tends to become more complex. Innovations are present that combine ventilation, heat recovery from ventilation air, hot water production and solar thermal collectors in compact (heat pump) units. Heat recovery from hot waste water has only been used in one case.

The research shows that clients often prefer different types of post-heating and that a good realization of (passive) cooling is an important issue for passive house clients.

3. INDOOR CLIMATE SYSTEMS

The construction of Belgian passive houses with attention to the building envelope and climate systems has been described in different publications (PHP, 2008). Two projects are described in detail on the basis of an inspection visit, measurements and interview with the occupants.

3.1 Passive House Heusden-Zolder

Architect Eric Ubachs designed a freestanding passive house with a rectangular floor plan, two floors and a traditional double sloped roof (see figure 1). The carport, barn and cellar are located outside of the climate protected volume. Technical details of the building envelope are documented in the Belgian national brochure on passive houses, available for download on (PEP, 2008). The building was constructed in 2003-2004 and has been occupied since September 2004. Thermal insulation with U-values below 0,15 W/m^{2}K for the opaque parts of the envelope and below 0,8 W/m^{2}K for windows and frames, airtightness with n_{50}-value of 0,20 air change rate per hour (ach) of the building skin, and high-efficiency heat recovery ventilation reduce the heat losses and make a traditional heating system obsolete. 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 2). The exhaust hood in the kitchen is not connected to the ventilation system: the cooking air is cleaned by means of an active coal filter in a recirculation hood.

Figure 1: Passive house in Heusden-Zolder (mind the shade on the walls: in mid summer the windows do not receive direct sunlight)

By using solar gains and a highly efficient counter flow heat recovery unit in the ventilation system, and an earth-air heat exchanger, this building does not need heating for the longest part of the year. Post heating of the fresh air is possible by means of a hot water circuit located in the inlet air system after the heat recovery unit; inlet air can be heated by a water-air heat exchanger, heated by a gas-fired solar-combi condensation boiler. In the bathroom an extra radiator is provided to secure an increased room temperature. Because the inlet air distribution provided relatively much heat to the bedrooms and too little to the living room, a convector was added to the living room, to re-arrange and improve the heat distribution in the living room.

Domestic hot water is produced by the same 380 litre high efficiency solar-combi boiler. The boiler is dimensioned for hot water production and not for space heating and is fed with heat from a 5,5 m^2 solar collector. Waste heat from the shower water is recovered with a heat recovery system in the sewer system, so that waste heat is used for preheating cold water during a shower. A thermostatic water tap ensures a constant shower water temperature.

Figure 2: Interior in Passive house in Heusden-Zolder

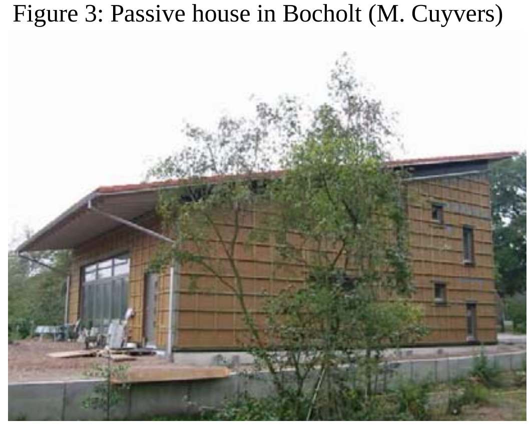
To avoid overheating in warm periods, the roof has an extension on the south side. A balcony protects the ground floor windows from direct summer sun (see Figure 1). The architectural shades give a minor reduction of the diffuse solar irradiation, however. On the east and west side louvers are provided as sun shades. Strategically placed windows can be opened to provide cooling during the evening and in the morning. Also, the 40 m earth-air heat exchanger (diameter 20 cm) at a medium depth of 2 m provides for a lower temperature of the inlet air. In the summer situation the air to air heat recovery in the ventilation system is bypassed and the ventilation system can contribute to some extent to cooling during the night.

3.2 Passive House Bocholt

The passive house in Bocholt is a free standing wood frame construction with 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. The cellar and garage are outside of the protected volume. Through its design and orientation of windows the house benefits from solar gains to reach the passive house standard.

Extreme thermal insulation properties with U-values < 0,1 W/m^2K for opaque parts and < 0,8 W/m^2K for windows and frames, and airtightness (n_{50} value 0,34 ach) of the building envelope reduce the heat losses and make a traditional heating system obsolete. Living spaces, working room and sleeping rooms are provided with fresh pulsion air. Bathroom, toilet, working room, kitchen and storage room have air extraction. 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 a 5 m^2 solar collector and a 180 litre hot water reservoir. Also an earth-air heat exchanger is connected to the ventilation system, which preheats the ventilation air in winter and provides passive cooling in hot periods. Extra heating is provided by a hot water circuit in the main ventilation pulsion pipe. This hot water circuit is connected to the reservoir of the combined compact heating unit. Sanitary hot water is tapped from the same reservoir. The reservoir is heated by combining efforts of the air-to-water heat pump, the solar collector and possibly extra heating by means of electrical resistance. To avoid overheating by the sun, the roof has an extension on the south side to protect the ground floor from the summer sun (see Figure 3).

Figure 3: Passive house in Bocholt (M. Cuyvers)



Strategically placed windows can be opened to provide cooling during the evening and the morning. Also, the 35 m earth-air heat exchanger (diameter 20 cm) at a medium depth of 1,8 m will provide for a lower temperature of the pulsion air. In the summer situation the air to air heat recovery in the ventilation system is bypassed and the ventilation system can also be used for night or passive cooling.

To avoid unbalance in the ventilation system, the exhaust hood in the kitchen is not connected to the ventilation system: the cooking air is cleaned by means of a recirculation hood with active coal filter.

Precaution against overheating by windows on the east and west side is through the design of small windows and the application of external shading devices.

4. PRACTICE

Consumers tend to value the energy and, more so (Skumatz, 2000 & 2004), the non-energy benefits of low energy and passive houses. The claimed advantages of passive houses other than energy savings are (IEA SHC Task 28, 2006): better air quality, reducing the risk of asthma, higher comfort levels and a higher market value. Research at TU Delft illustrates the concerns of occupants considering noise of equipment, maintenance problems, summer comfort, air quality and lack of climate control (Hasselaar 2006) (Van Ginkel, 2007). For this reason a project is started to evaluate the climatic conditions and user aspects of passive houses. Inspections, interviews and measurements have been performed on the indoor climate systems in two passive houses: Heusden-Zolder and Bocholt.

Positive occupant experiences are:

The dwelling acts as a well stirred bowl, with small temperature differences, and this allows for architectural features such as open staircases, a vide or high windows, without the associated cold airstreams.

The ground-air heat exchanger and the heat recovery unit reduce the influence of variations in outdoor temperatures.

The ground-air heat exchanger prevents freezing of the heat recovery unit, but the summer by-pass needs manual operation now.

The insulated envelope functions as an acoustic shield against outside, however, contact with wind, rain, the birds and all kinds of events.

Negative experiences were also reported. The heated ventilation air provides enough heat for the house, but the heat flux to the bedrooms tends to be too much and to the living and bathroom too little: in one of the cases an extra convector was added in the living, while the second case has an extra heater in the bathroom;

The acoustically insulated envelope makes indoor noise more noticeable, and noise from fans or airflow in dampers is more likely to cause nuisance, stimulating lower setpoints than may be needed for healthy indoor air, especially in smaller houses with many occupants.

The measurements show poor ventilation volumes in (mostly) bedrooms and working rooms, while the circulation is experienced as poor, caused by the (wrong) type and location of air inlet dampers;

The installations are novel and unfamiliarity creates potential control and maintenance problems or unpredicted costs.

The evaluation of the passive houses brings up some interesting new questions. In both cases mobile air humidifiers were noticed. In one of the cases the occupant complains about “dry”air, especially in winter periods, the perceived cause of a sore throat or respiratory irritation. In another case the occupant notices less health complaints compared to a previous house. It is unclear, whether the effects are caused by low relative humidity or by air pollutants in poorly ventilated rooms. In one of the cases the laundry was dried in the living area: this increases humidity, but the dust level from fabrics and soaps increases as well.

Moisture in the warm and humid summer air condensates in the ground-air heat exchanger. It is not clear whether the pipe should be tilted towards the house or the inlet point, in other words: should produced water be collected near and removed from the inlet or down flow near the entrance to the dwelling? In one of the cases the condensation process stopped after a short period; when adaptation of the ground temperature to the inlet air temperature is the cause, then this would point at efficiency loss.

Architectural built-in solar shading works well to stop direct sunlight, but the level of diffuse light in Belgium and other Nordic countries can be more that 60%, asking for a secondary shading device to prevent overheating.

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 installations for heating and ventilation. To prevent pollution, a place 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. The two inspected cases reveal poor attention to inspection and cleaning of ducts. Pollution from deposited dirt on filters and fan blades in the system ask for cover-capacity in the design stage and can become a health risk after some years.

Air volume 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.

5. CONCLUSIONS

Passive houses are produced with much attention for quality in all stages of the building process. Certification and guidance result in quality that is generally higher than a result of traditional construction processes. The envelope has good overall performance quality. The performance guarantees for climate installations are not fully developed yet. The market may need more time to adapt products to passive designs, for instance integration of space heating, domestic hot water production and ventilation in compact appliances. Solar energy or biomass fired boilers provide a heat storage that also feeds a simple post-heating system. Modelling the intermittent operation of a gas boiler to provide small heat pulses is feasible. There is debate about the feasibility of electric post-heating systems that require no boiler or chimney. 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’.

It is recommended to adapt certification procedures of passive houses to include quality assurance of the proper working of installed indoor climate systems. The user friendliness of indoor climate systems for passive houses can be improved by evaluation of practical experiences, also by involving the users in the selection of concepts and techniques.

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