Health risk associated with passive houses: An exploration

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SUMMARY
The passive house standard of northern European countries functions as an inspiration for home owners and project developers for building or retrofitting with high energy ambitions. Passive houses typically involve high insulation levels and heat recovery ventilation. Residual heating is based on heating of the inlet airflow, but other solutions (stove etc.) are applied as well. The development of energy-efficient building is technology driven. The feedback from the consumers is low and there have been complaints by occupants about perceived health effects of heat recovery ventilation. Examples of passive houses are analyzed to find indicators of "emerging" health risks. Potential problems are overheating, noise from installations, legionella contamination of domestic water buffers, low ventilation volumes, complex control mechanisms and lack of flexibility of ventilation services. Recommendations are given for the improvement of the user friendliness of indoor climate systems for passive houses.

KEYWORDS
Energy performance, Passive house, Health, User influence

INTRODUCTION

In the Netherlands the energy use of new buildings is subject to performance based legislation. The energy consumption is calculated on the basis of a physical model and results in a dimensionless Energy Performance Coefficient (EPC). Since its introduction in 1996 the EPC-value has become stricter and was reduced from 1.4 in 1996 to 0.8 in 2006, which is an improvement of 43%. Each step supported the market growth of certain products or systems. Since 1998 the application of heat recovery balanced ventilation systems in newly constructed dwellings grew from 5% to about 40% (Hasselaar, 2006). Heat recovery ventilation represents a cost-effective way to reduce the EPC-value, because of the highly efficient heat exchanger (>80% thermal efficiency) and improved motorized fans that save approximately 50% electrical energy compared to conventional fans.

The ambition to reach high energy performance has led to the development of the Passive house standard, where the strategy to reduce the energy demand is followed to such extremes, that a central heating system is not required. The energy demand for space heating and cooling of passive houses is limited to maximum 15 kWh/m^2y of treated floor area (in Western European climate regions). The primary energy use of all appliances including domestic hot water, space heating and cooling, lighting and domestic appliances must not exceed 120 kWh/m^2y. Many passive houses have been built in Austria and Germany and other countries follow: Sweden, Belgium, while the interest in passive houses and passive renovation is increasing in the Netherlands as well (Mlecnik, 2005). Because innovative concepts are often driven by top-down energy policy and the most economic way to meet regulations, the building sector tends to focus on the reduction of the Energy Performance

Coefficient rather than the actual energy performance. The technology driven approach creates the risk of poor user orientation or conflicts with indoor environmental quality.

In energy efficient designs, a three step strategy is followed: reduce the demand for energy, supply energy through sustainable sources and finally apply systems with high energy efficiency. The leading paradigm of achieving energy quality is to apply improved technology without change of behavior required, but occupants of collectively self-built projects have the opinion that behavior does matter in reaching the maximum energy effect (Ornetzeder, 2001). User friendly technological solutions will provide control functions to make performance behavior dependent and with flexibility to allow individual adaptations. This requirement turns the “trias energetica” into a four step strategy, the fourth step being: provide control systems in support of energy conscious handling of processes by the users. Direct involvement of occupants in the design process of dwellings and climate systems is one way of promoting the user friendliness, allowing occupants to "learn" behavior that is more adapted to the needs of sustainable housing (Ornetzeder, 2001). The question is how to organize participation in the design of new buildings and of renovation projects.

Passive house designs typically involve very high insulation levels, triple glazed windows in frames with thermal barrier and perfect sealing. The envelope is without thermal bridges. Heat recovery ventilation is standard. Often, solar thermal and photovoltaic systems are applied. Because of overheating risk in the summer, services for night time cooling (ventilation) are provided, in certain cases by applying ground-to-air heat exchangers. Residual heating can be a simple electrical heat resistance radiator or wood burning stove. Often, however, floor or wall heating are applied, which are systems based on low temperatures and large surfaces. Low temperature systems increase the efficiency of solar systems and heat pumps. Passive houses require space for a thick layer of insulation materials in the envelope and space for equipment such as a buffer for the solar domestic system, ducts and unit for HRV or a heater/hot water back-up for the solar system. Sun shading is provided in most houses (Strom, 2005).

METHOD

The relationship between occupant behaviour and technical services in dwellings represents an interdisciplinary research field that links the social en technical sciences. Work in this field started with involvement in problem analysis and technical trouble shooting and expanded towards studies of user complaints about environmental health. The home visits (500 dwellings) provide data on technical performance, perception and behaviour.

The paper presents an exploration into the indoor environment of passive houses, based on dscribed cases (Daniels, 2007; Greml, 2004; Mlecnik, 2005-2008; Castagna, 2008; Römer, 2005; Strom, 2005) and participating in international discussions on passive houses (Demohouse, Green Solar Cities, Passive House expert meetings). Field data are collected in two passive houses, in minimum energy houses and standard houses, that include installations or design features that are common in passive houses. Therefore the focus is on discussion rather than the presentation of results.

DISCUSSION

Inspections, interviews and measurements have been performed on the indoor climate systems in two passive houses: in Heusden-Zolder and Bocholt. In general, the occupants are positive about the house. Surprising new occupant experiences refer to certain design freedom and a constant indoor climate. The dwelling acts as a well stirred bowl, with small temperature differences, and this allows for architectureal 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 acousticly 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, while the circulation is experienced as poor, caused by the (wrong) type and location of air inlet dampers. The installations are complex and unfamiliarity creates potential control and maintenance problems or unpredicted costs.

Occupant behavior has a considerable influence on performance of energy efficient houses and on the successful control of modern appliances for heating, ventilation, domestic hot water and domestic services such as laundry washing and drying and cooking. Behavior is influenced by needs and perceptions, which includes the level of understanding of how a system works. Learning how to use a product is influenced by the user as well as the 'learnability' of the product. The ventilation performance depends among others on the flow-rate settings chosen by the occupants. Where indoor air problems occur, poor behavior can be the cause, and/or poor performance of technical systems, even when users try to compensate problems with adapted behavior (Hasselaar, 2006). Occupant behaviour expresses the identity of different types of households, different steps in the housing career, culture, physical and metnal condition and comfort needs. Comfort has great influence on behaviour: comfort optimising is an important motivation for control of ventilation and heating, for cleaning habits, etc. Comfort optimising can conflict with healthy housing, for instance when fear of draughts limit the use of air inlet openings. Because it is hard to influence behaviour, the user-friendliness of technologies is a key indicator of performance (Hasselaar 2006).

Houses that are densely occupied (more than one person per room average) have more important pollution concentrations that houses with large volume and few people or pets. It means that the ventilation quality of small and over-occupied houses needs proper attention.

Ventilation

All passive houses have heat recovery ventilation (HRV). The preheated air is ducted into each room. According to the Dutch Building Decree the volumes must be based on the surface area of rooms, not on people present, which causes potential insufficient ventilation in bedrooms < 15 m² with two adult people. The location of the inlet damper influences the airflow and air change efficiency. The inlet is often near the separating door, not in the facade area. Several occupants of the newly constructed neighborhood of Vathorst in Amersfoort in the Netherlands reported health complaints that they relate to the HRV system (Ginkel ,2007). The results show that the ventilation capacity failed to meet the requirements in the majority of the dwellings. The quality of the indoor environment was inadequate for the parameters noise, draught, CO_2, formaldehyde and high indoor temperatures in summer. These factors contributed to the health risks, not so much the heat recovery ventilation per se, however, the health complaints occurred more often in dwellings with HRV than with CMV (Ginkel, 2007). One of the reasons is that occupants could not ventilate “around”thi system because natural inlet opening could not compensate for the low mechanical air inlet. Complaints in these inspected projects are mainly: fresh air is not fresh; the ventilation capacity is low, the system makes noise when at standard fan speed, ceilings or walls become dirty from deposition of particles and the the system contributes to overheating, when not supplied with a 100% bypass. Due to reports in other cities these problems are considered non-specific for Vathorst, but point at problems in possibly 20-30 % of modern houses with HRV.

Dirty filters reduce the air volume with 15-25% and create imbalance between inlet and exhaust (Römer, 2003). Maintenance visits can restore the capacity, which requires that the capacity is measured and dampers are adjusted. Cleaning is required at short intervals, while filters, units and ducts tend to be cleaned only at intervals of 6 months to one year, the unit once in 8 years and the ducts after 15 years or longer (Hasselaar, 2004; 2006). Cleaning the fan alone does not restore the capacity.

Occupants in general do not know how much air change is required and how well a ventilation system works. They tend to overreact: the window is opened widely after sensation of bad smell, but closed again after a short while. Permanent ventilation is problematic when this function is associated with noise, draught or cost of electricity and heating. Fear of draught while in bed and disturbance by noise are reasons for sleeping with closed inlet openings and mechanical inlet at lowest set point (Soldaat, 2006).

Bedrooms in dwellings without heat recovery ventilation are flushed daily for about 30 minutes, which is not sufficient to remove moisture and pollutants that are absorbed by bedding and surface areas. Poor circulation is in the first place the effect of low exhaust capacity. Cross-ventilation and flushing is well understood by occupants, implying that problems may occur mainly in houses without openings that allow cross flow. These properties are excluded in most passive houses: the circulation relies upon mechanical driving forces. The ventilation requirements point at services that are especially crucial in Passive houses: continuous ventilation with (almost) standard volumes at low acoustic level, natural summer and nighttime ventilation, peak mechanical exhaust (reciculation hood in the kichen) and with attention to the need of heat recovery ventilation during the winter period, while “winter” refers to a shorter period in well insulated dwellings than in traditional dwellings.

Health issues

Complaints about the indoor environment indicate that certain health complaints are more prevalent with heat recovery ventilation systems. The occupancy level of dwellings is an indicator of health risk exposure as well (Hasselaar, 2006). Especially the social rented dwellings have both a high occupancy and smaller number of rooms with smaller dimensions compared to owner occupied dwellings. Higher occupancy is related with more pets, because many parents like to bring their children in contact with pets. Smaller and well occupied passive houses are more at risk, with the following indicators of potential health hazards:

-the use of gas cookers (or other fuels that emit into indoor environment);
-the use of fossil fuels in heaters or a fire place;
-chemical emissions from decoration materials;
-emissions from cleaning materials, pesticides, fragrances, candles, incense, etc.;
-biological emissions, based on the age of the mattress, the type and humidity and cleanliness of surface (flooring) materials, soft decorations and other dust pockets;
-excessive moisture production: more than 3 showers per day and laundry drying indoors;

-pet keeping (animals with hairs or feathers);
-smoking in the house with other people present.
-legionella risk in domestic water buffers with heat from solar panels or heat pumps.

The difference in perceived health problems between HRV and conventional mechanical exhaust systems and natural inlets was studied in Vathorst in the Netherlands. See Figure 1, based on Ginkel (2007). Poor overall ventilation explains these problems.

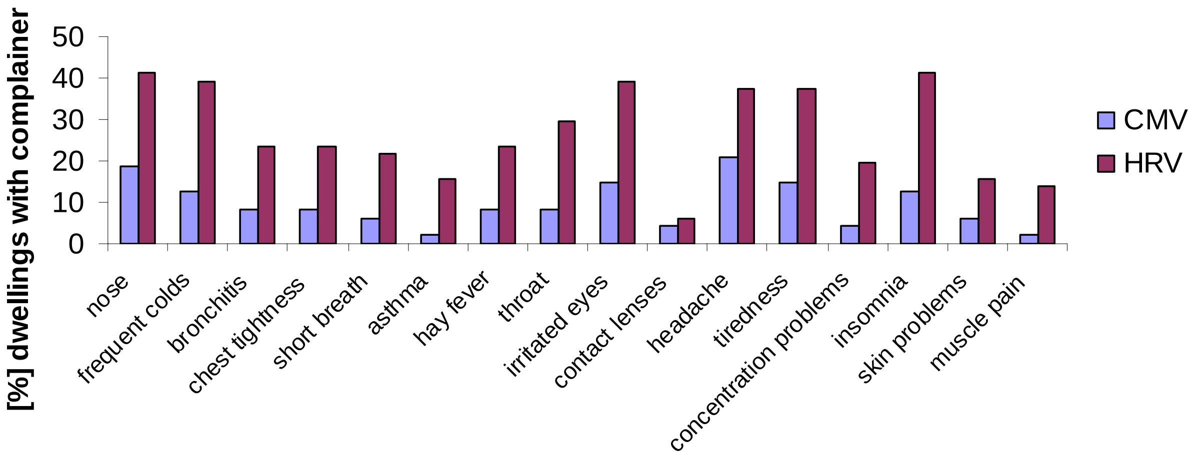

Figure 1. Percentage of non-case dwellings with a health problem. CMV = conventional mechanical (exhaust) ventilation with natural inlet functions, HRV = heat recovery balanced flow mechanical ventilation

Temperature control

Well insulated (passive) houses tend to be warm, because the effect of indoor heating load (people, computers, lighting, etc.) is high, relative to the minimal heating demand. The indoor heat load plus the diffues sunlight create potential overheating periods. Overheating can cause peak pollution concentrations, caused by "baking out" of emissions. "Dry air" is often a misperception of polluted air in combination with emission peaks caused by high temperatures. Dutch manufactured HRV systems with 100% bypasses over the heat recovery unit became available in 2004 but are not often applied because of their higher cost. An alternative is turning off the inlet fan, which requires that natural inlet openings are available. Cool night air can remove the overload of heat, provided it is possible to reach ACH = 2.5 or more per individual room during the very early morning hours. In passive houses in the moderate climate regions of western Europe the indoor temperatures will be above 16°C for most of the year and likely 18-21°C as soon as the sun hits the windows, even without heating. Some cases show constant temperatures of 21-23°C without heating. In the test houses of the Ecobuild-Research project, that are well insulated (Rc=5 m2K/W and U-value of glazing lower than 1 W/m2K) with large openings facing south, no heating is required even with outdoor temperatures below zero, on sunny days (Römer 2003). A phenomenon that has caused complaints is the high radiant temperature from sunlit double glazing ($U<1.4$ W/m²K). The temperature of the inner window blade reaches temperatures of 33 – 40°C and the effect is a large heating load with high radiant temperatures. Triple glazing is expected to avoid this problem. The temperature also increases behind perpendicular sun screens inside the house or parallel to the façade outdoors. Sun shades that allows free airflow under the screens allow colling of the glass panes by outdoor air. Complaints of overheating causes stress and this phenomenon emphasises the need for effective natural ventilation services, regardless of the type of ventilation system that is being applied.

Ventilation has become a control feature of the temperature in well-insulated houses, especially in bedrooms all year round and in the living room during the summer season. However, when in passive houses the indoor environment has cooled down, because of flushing with outdoor air, and no heating system is available, or the capacity is low, it may take awhile before the temperature is corrected. Occupants tend to open doors to circulation areas in that case. Other occupants prefer a place where one can warm up in a short time, in the bathroom or in the living room, after coming home from the cold. It means a preference in passive houses form some small climate systems with "personal" control features and enough capacity for fast adjustment to lower or higher temperatures.

Participation in the planning process

Participative design is viewed either as not needed, or otherwise too costly, too complex and too time consuming. Certain good examples indicate, however, that participation procedure can speed up the design and building processes, creates better insight into the market potential of developments and results in empowered occupants who understand how to use the house, who trust the housing manager and learn more about their neighbors in the process (Versteeg 2007). Home visits represent a powerful communication strategy with more impact on mutual respect and on understanding needs than questionnaires and large meetings. This form of participation replaces in recent projects the concept of "community representation" in which a few socially active persons influence decisions that have impact on a community. Also, horizontal communication tends to replace social action strategies. The goal is a better power balance through harmonious cooperation.

Participation procedures can be successful especially when stakeholders are experts as users and where social learning is instrumental for good communication between the housing manager and tenants. Design qualities that occupants value to a great extent in housing projects are an elevator in multi-story housing, a large balcony, a quality kitchen and bathroom, and reward for personal taste and preferences for certain materials and colors. Insulating glazing is appreciated for thermal comfort and acoustic quality, but the acoustic effect increases the need of acoustical measures between houses. Thermal insulation reduces temperature differences and associated draught. Also, low noise levels from appliances are required, either by design or by sound silencing measures. Occupants tend to favor robust and low-maintenance solutions. Individual control of climatic conditions in individual rooms is an important feature.

CONCLUSION

Passive house technology is rewarded with enthusiasm in several Western European countries. The technology driven promotion and the strict application of the concept creates increased risk of design dictatorship. The promotion of the idea that the user must "be educated" and that SMART solutions are needed to prevent wrong behavior by the occupants, shows the need for participative design methods and for more flexibility in control functions for the users. The discussion on health risk and potential user dissatisfaction can support the improvement of passive house technologies.

Occupant preferences that need special attention in passive designs are:

-personal adjustment of temperature to create a warm spot;

-large capacity ventilation services with fine controls;

-means to control the temperature of individual rooms;

-flushing services to reduce overheating, or ceiling fan, ground to air heat exchanger;

-peak ventilation in the kitchen (discussion: exhaust through HRV unit or directly to outside);

-measures to prevent dirt deposition in the fan unit and heat exchanger from the cooker hood;

-clean air (polluted air is mistaken for "dry" air);
-low maintenance attention and easy to perform maintenance activities.

Criteria for improvements are summarized in Table 1.

Table 1. Functional and technical design and user criteria.

Topic	**Functional criteria**	**Technical criteria**
Insulation package	Deep position for windows	Integrated in construction
Space for installations	Easy to inspect/maintain	Ducts, water, gas pipes in sight
Flexible heat source	Personalized heating	Heat radiant electric lighting electric blanket, electric radiator
Natural ventilation	Safe summer and night use, design of hybrid system	Permanent basic ventilation, flexible ventilation services
HRV ventilation	Only when heating required, adjustable volume per room	Within two hours dry shower, sufficient ACH during sleep
Containment of pollutants	Closed kitchen	Bathroom with inlet and exhaust
Summer cooling	Shading, south oriented	Ceiling fan, automatic shading device
Domestic functions: laundry washing, drying, cooking	Prevent pollution indoors: remove/isolate moisture production	Covered outdoor area, special room, electromagnetic oven, induction cooker
Low noise level indoors	Insulated technical room	Acoustic level maximum 28-30 dB(A)
Maintenance protocol	Cyclic and by experts	Filter cleaning /2 weeks , volume adjustment /3 y, ducts clean /5 y
Participative design	Direct involvement of users in design process	Social contract, transparent decision making, feedback

The major recommendations are: design of hybrid ventilation system, reduction of the noise level of HRV ventilation, frequent cleaning of the components of the air inlet system, good sun shading and innovation for flexible heating sources.

The indoor air quality depends, because of prevailing critically low ventilation capacities, on the emission by household activites such as washing and laundry drying, emissions from storage in a workshop and noise and even emissions from the installations for heating and ventilaiton To prevent pollution, a place outside the protecting envelope could be designed for these functions. The same goes for uncontrollable or indispensable heat sources, especially when there is no option to increase the ventilation volume.

The design of the air duct system is crucial for noise production and for energy efficient function of fans: the heat exchanger and fan unit require a central position in the dweling, with air ducts designed for low pressure losses. Inlet openings opposite from exhaust openings work better than circulation depending on the induction effect of inlet dampers. In general, the air volumes tend to fall back because of clogging of filters and dirt on fan blades, asked for over-capacity in the design stage. The two inspected cases reveal poor attention to inspection and cleaning of ducts. Pollution from deposited dirt in the system can become a health risk after some years.

Air volumes require control per room. Application of different zones supports different heating levels through ventilation air. The bathroom may require a heat source to provide instant higher radiant temperatures: a heated mirror or other electrical resistance heaters.

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REFERENCES

Castagna M., Schmitt Y., Troi A. 2008. Analysis and optimization of a monitored passive house in Italy with dynamic simulation. *12. Intern. Passivhaustagung*, Nürnberg, April 2008.

Daniëls A. 2007. *Life and living in low energy houses – Study of technical solutions in low energy houses, satisfaction, lifestyle and changes for the residents*, National Consumer Research Center, Working Papers 102 • 2007, Helsinki, Finland.

De Gids W.F., Op't Veld P.J.M. 2004. "*Onderzoek naar ventilatie in relatie tot gezondheidsaspecten en energiegebruik voor een representatieve steekproef van het Nederlandse woningbestand*", 2003-GGI-R064, Delft, (The Netherlands), TNO Bouw.

Ginkel J.T. van. 2007. *Inventarisatie woninggerelateerde gezondheidsklachten in Vathorst*", report for Municipality of Amersfoort, Delft (The Netherlands), OTB.

Greml A., Blümel E., Kapferer R., Leitzinger W. 2004. *Technischer Status von Wohnraumlüftungen* (Technical status of ventilation systems for buildings), Bundesministerium für Verkehr, Innovation und Technologie (in German), 296 pages.

Hasselaar E., Jamriska M. 2004. Quantification of aerosol losses in mechanical exhaust and balanced air flow ventilation systems, in *Proceedings of CIB 2004 conference Building for the future, pp. 1-9*, Toronto, Canada, Institute for Research and Construction.

Hasselaar E. 2006. *Health performance of housing, indicators and tools.* Amsterdam: IOS Press under the imprint of Delft University Press, *PhD thesis*, 298 pages.

Lustgraaf R.H. van de, Veen J.L. 2005. *Volwaardige bewonersparticipatie met de Sociocratische methode*, accessed March 10, 2008, at: http://www.angenent.biz/soclog/2006/01/bewonersparticipatie-met-de.html.

Mlecnik E. 2005. 'Passive House Projects in Belgium', 9de internationale Passivhaustagung 29-30 April, 2005, Ludwigshafen, Duitsland.

Ornetzeder M., Rohracher H., ed. 2001. *Nutzererfahrungen als Basis für nachhaltige Wohnkonzepte*, Wien, 198 pages (in German).

Römer J.C., Jong M.J.M., Bakker E.J., Van Helden W.G.J. 2003. *Resultaten metingen in woning D, Ecobuild Research project*, ECN, Petten.

Strom I., Joosten L., Boonstra C. 2005. PEP, *Passive House solutions*, Promotion of European Passive Houses, Intelligent Energy Europe.

Schmitt Y., Dal Savio S., Sparber W., PaMo. 2007. Monitoring of a multi familly Passive House in South Tyrol, Italy. *11th Intern.l Passive House Conference*, Bregenz - Austria, April 2007.

Soldaat K. 2006. Interaction between occupants and sustainable building techniques. In B Cernic Mali & et al. (Eds.), *ENHR conference 2006: Housing in an expanding Europe. Theory, policy, implementation and participation* (pp. 1-14). Ljubljana, Slovenia: Urban planning institute of the republic of Slovenia.