432: The Passivhaus standard in the UK: Is it desirable? Is it achievable?

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Abstract

Public, commercial and global research interest in the delivery of zero carbon housing has never been higher. The recent shift in design culture and legislative climate is reflected in a number of existing and developing low energy and zero carbon standards in the UK as well as Europe. Also, the number of homes built and certified under these standards is rapidly increasing, with many thousands built in Central and North of Europe. This paper reports on the outcome of an EC funded research on ‘Marketable Passive Homes for Winter and Summer Comfort’ and on the applicability of the German Passivhaus Standard to the context and climate of the UK. A case study is presented, which explores the applicability of the Passivhaus standard as a performance rather than a prescriptive standard. The paper suggests that some of the measures prescribed by the Passivhaus standard, such as mechanical ventilation with heat recovery, may not be necessary or desirable for the UK context and that the heating energy performance standard of 15kWh/m^2.year can be achieved with a series of ‘passive design’ measures (e.g. thermal buffering, insulation, controlled natural ventilation, etc.). The paper will also report on the recently completed BASF house at the University of Nottingham’s School of the Built Environment, which has been designed to meet the Passivhaus performance standard and that showcases an example of an affordable low carbon house.

Keywords: Passivhaus standard, zero carbon, low energy

1. Introduction

The success of the Passivhaus Institute in developing and implementing an approach to house design in central European climates, which is not only very energy efficient but also meets year-round comfort criteria, naturally led to the question of whether this is applicable in other countries and other climates. This question was central to two recently completed research dissemination projects funded under the IEE programme by the European Commission (the ‘PEP’ and the ‘Passive-On’ project). Whilst the PEP project looked at the applicability of the Passivhaus Standard in north of Europe, the ‘Passive-On’ project (see http://www.passive-on.org/en/) primarily addresses the question of its applicability in southern Europe (Portugal, Spain and Italy), but also relates to the UK and France as ‘warming’ climates.

As a result of the Passive-on project, each partner in the project put forward an ‘affordable’ house proposal which was designed to meet the Passivhaus standard in terms of both predicted energy consumption and thermal comfort criteria. The various proposals took into account the nature of the housing market, construction costs and practice, which differ substantially around Europe. However, it was concluded that, where the lifecycle cost of a project is assessed, then Passivhaus standards of energy efficiency and thermal comfort can be achieved cost-effectively in the European countries reviewed. This paper focuses on the proposal made by the School of the Built Environment (SBE).

2. The Passive-on project

2.1 The Passivhaus standard

In 1991 Wolfgang Feist and Bo Adamson applied the passive design approach to a house in Darmstadt [1], with the objective of providing a show case low energy home at reasonable cost for the German climate. The design proved successful both in terms of energy consumption and comfort such that the same passive systems were applied again in a second construction in 1995 in Groß-Umstadt [2]. By 1995, based on the experience from the first developments, Feist had codified the Passive Design of the Darmstadt and Groß-Umstadt homes, into the Passivhaus standard. The standard fundamentally consists of three elements: an energy limit (heating and cooling); a quality requirement (thermal comfort); a defined set of preferred Passive Systems which allow the energy limit and quality requirement to be met cost effectively. It already featured all characteristics of what is today known as the current German Passivhaus standard: very good insulation, including reduced thermal bridges and well-insulated windows, good air tightness and a ventilation system with highly efficient heat recovery.

For Central European climates, it turned out that these improvements in energy efficiency finally result in the possibility to simplify the heating system. It becomes possible to keep the building comfortable by heating the air that needs to be supplied to the building to guarantee good indoor air quality. The whole heat distribution system can then be reduced to a small post-heater (heat recovery system). This fact renders high energy efficiency cost-effective: considering the lifecycle cost of the building, a Passivhaus need not be more expensive than a conventional new dwelling. In total more than 8.000 houses conforming to the current Passivhaus standard have now been built in Germany and elsewhere in central Europe. To most professionals in Germany and to many in the general public a Passive House now equates with the Passivhaus standard but its applicability elsewhere in Europe has yet to be tested.

Defining a standard for low energy homes has offered a number of advantages both for the building industry as a whole and the German market in particular. In fact it has been a major reason for the explosion of the construction of low energy homes in Germany. The five points that define the current German Passivhaus Standard for Central European Countries [2] are:

- Heating criterion: The useful energy demand for space heating does not exceed 15 kWh per m² net habitable floor area per annum.
- Primary energy criterion: The Primary Energy demand for all energy services, including heating, domestic hot water, auxiliary and household electricity, does not exceed 120 kWh per m² net habitable floor area per annum.
- Air tightness: The building envelope must have a pressurization test result according to EN 13829 of no more than 0.6 ach^{-1} at 50 Pa.
- Comfort criterion room temperature winter: The operative room temperatures can be kept above 20°C in winter, using the abovementioned amount of energy.
- All energy demand values are calculated according to the Passive House Planning Package (PHPP) and refer to the net habitable floor area, i.e. the sum of the net floor areas of all habitable rooms.

2.2 The Passivhaus Standard for Warm Climates

However, although in central Europe (e.g. Germany, Austria, Northern Italy, etc.) passive design is increasingly associated with the Passivhaus standard, this is not necessarily the case in southern Europe (e.g. Spain, Italy, Portugal and Greece). Here to most architects a passive house generally means any house constructed in line with the principles of passive solar design. Furthermore many professionals in the field disagree with associating the generic word “passive” with a specific building standard, which proposes an active ventilation system.

The ‘Passive-on’ consortium has therefore formulated a revised proposal for the application of the Passivhaus standard in Warm European Climates, which takes into account the climatic as well as the philosophical issues mentioned above. The additional and amended points that define the proposed Passivhaus Standard for Warm European Climates are listed below:

- Cooling criterion: The useful, sensible energy demand for space cooling does not exceed 15 kWh per m² net habitable floor area per annum.
- Air tightness: If good indoor air quality and high thermal comfort are achieved by means of a mechanical ventilation system, the building envelope should have a pressurization test (50 Pa) result according to EN 13829 of no more than 0.6 ach^{-1}. For locations with winter design ambient temperatures above 0 °C, a pressurization test result of 1.0 ach^{-1} is usually sufficient to achieve the heating criterion.
- Comfort criterion room temperature summer: In warm and hot seasons, operative room temperatures remain within the comfort range defined in EN 15251. Furthermore, if an active cooling system is the major cooling device, the operative room temperature can be kept below 26°C.

3. A Passivhaus for the UK

3.1 The SBE Proposal

The starting point for the proposal by the School of the Built Environment (SBE) at the University of Nottingham was an affordable three bedroom semi-detached house. The energy and comfort standards of the German Passivhaus were adapted to the British context taking into account the local climate, construction standards, technical and economic framework as well as the difference in lifestyle and expectations of UK house buyers regarding use of space and interaction with the building. For example, one of the main features of the German Passivhaus is the mechanical ventilation system with heat recovery. For this to work (i.e. deliver a net energy saving) the house needs to be very air tight. However, there is evidence from studies in the UK that MVHR may not deliver low energy performance [3]. Also, there is widespread scepticism among UK house builders about the necessity for extremely airtight houses and the need for mechanical ventilation. This is in part due to the milder winter climate and the perceived difficulty of achieving very low infiltration rates. In the SBE proposal, passive pre-heating of winter supply air is provided via buffer or earth tubes. Whole house ventilation is achieved naturally by means of low level (manually controlled) and high level (automatically controlled) openings. This has the benefit of avoiding the capital and maintenance costs of a mechanical system and allows occupants to have a greater degree of control. Air tightness is still important but the minimum fresh air supply is introduced via the buffer space through automated ventilators and trickle vents.

The SBE proposal follows the general layout of a traditional semidetached three bedroom house. The ground floor plan includes two 'buffer spaces' on the north and south sides. Although they subtract some habitable space from the total floor area, these can be used as temporary storage, greenhouse or clothes drying areas. The north side buffer space also acts as an entrance lobby, while on the south side it is like a conservatory included within the volume of the building. The other features of the SBE proposal are the roof vent on top of the stairwell, which provides an outlet for the stack ventilation, and the automated openings with trickle ventilators throughout the house. Insulation of about 300mm is provided in the roof and about 200mm in the walls, achieving typical U-Values ranging from 0.2W/m^{2}K to 0.15W/m^{2}K for walls and roof respectively. The glazed buffer space on the south side is provided with Venetian blinds for solar control in summer and insulated shutters against heat losses in winter.

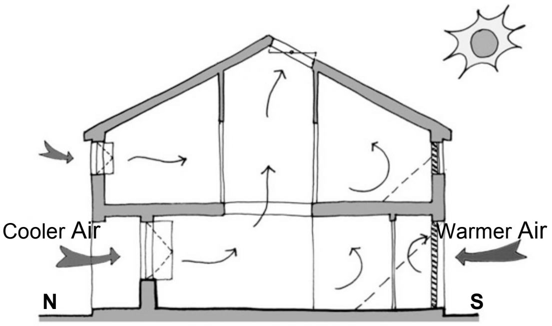

Fig 1. Summer ventilation strategy

The environmental design strategy proposed (Fig. 1, 2) combines natural ventilation with a high thermal capacitance interior. In winter, supply air is preheated through the south buffer space which can reach temperatures in excess of 20°C. Where space allows, ground pipes can be installed in the garden to deliver pre-heated (or pre-cooled) air to the buffer space. The residual heating load is so low that this could be met by a carbon neutral source such as a woodchip boiler which could provide hot water as well. In summer, during hot days, the buffer space is open to the outside in order to avoid overheating, and acts as an extension to the living space. At night in summer, automatic control of high level ventilators will promote convective cooling. Security is maintained by using high level automated vents and low level trickle ventilators. The high thermal capacitance interior can be achieved by exposed pre-cast concrete floor panels, or, where lightweight construction is preferred, by the use of phase change materials (PCM) encapsulated within plasterboard. The high capacitance interior is important in helping to avoid overheating and the need for cooling, which with global warming will become an increasing priority. Therefore, the SBE proposal avoids the use of active cooling by shading and natural ventilation coupled with exposed thermal mass. Low-e Double Glazing (not triple glazing as used in the German Passivhaus) is proposed for the inner glazing whilst the outer layer of the buffer space is single glazed. The outer layer could be double glazed also which could improve the performance substantially but modelling predicted that with the glazing described the space achieved the required heating standard. Typical U-values for windows of 1.8W/m^{2}K and low infiltration rates of 3ach^{-1} at 50Pa are assumed [4].

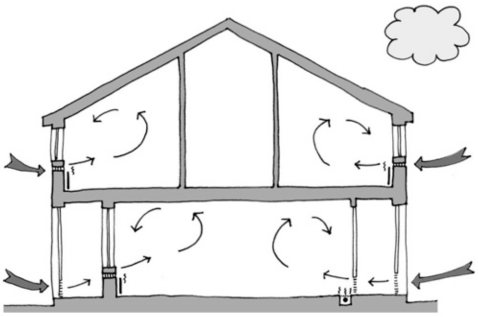

Fig 2. Winter daytime ventilation strategy

3.2 Performance predictions

The annual heating energy demand (Fig. 3) of the proposed house has been estimated to be a total of 13.8kWh/m^2. This complies with the Passivhaus standard of 15kWh/m^2, and compares with a typical annual heating energy requirement for the same house built to current building regulations standard of 55kWh/m^2. It should be remembered that this house incorporates an exposed gable wall, and that therefore a terraced house with the same layout could achieve this performance with a slightly reduced specification. Active cooling is not required due to the provision of passive mitigations strategies as described above. However, the simulation was performed using the Birmingham.ewy weather file (from TAS database) and the effect of a warmer climatic scenario was not investigated.

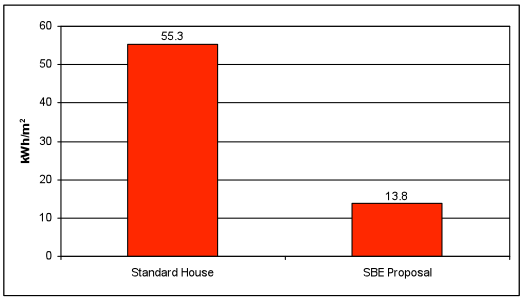

Fig 3. Predicted annual heating demand for Standard House and SBE Proposal

The comfort criteria adopted during the summer analysis were based on the calculation of comfort indexes. The indexes sum the "distance" between the predicted operative room temperature and the neutral temperatures at each hour over the entire year. The Adaptive Comfort Index (AI2), applied to free running buildings (i.e. without supplementary heating and cooling), refers to a neutral comfort temperature defined on the basis of the monthly Adaptive Models reported in ASHRAE 55 [5]. When assessing comfort using this index a low index indicates better performance, with the optimum performance being zero. For the proposed house the AI2 was zero. With regard to summer temperature conditions (Fig. 4), the resultant (or operative) temperature, which is the average between air and radiant temperature, is kept below 25°C for 96% of the occupied time. In winter, the indoor air temperature is kept at 20°C by conventional heating to determine the residual heating demand. However, with no supplementary heating system, the percentage of time when the indoor resultant temperature is above 18°C is 68%. In the living area the Resultant temperatures range between 10 and 24°C exceeding ambient temperatures by 5-15°C.

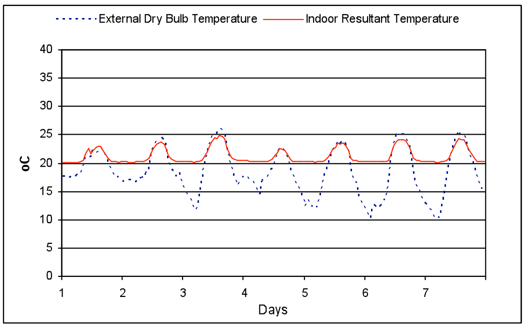

Fig 4. Typical Dry Resultant Temperatures in summer without additional cooling

4. The Creative Energy Homes Project

4.1 Background

The industry linked Creative Energy Homes project at the University of Nottingham, School of The Built Environment, is a research showcase of innovative homes of the future. The project aims to stimulate sustainable design ideas using Modern Methods of Construction (MMC) and promote new ways of providing affordable, environmentally sustainable housing that are innovative in their design. Five homes are to be constructed on the University Park campus designed to various degrees of innovation and flexibility to allow the testing of different aspects of MMC including layout and form, materials, environmental performance, sustainable/ renewable energy technologies and others.

4.2 The BASF House

The BASF house, designed by Derek Trowell Architects, was the second house to start and its construction was completed in January 2008 (Fig. 5). The design team also included the School of the Built Environment and the client and sponsor, BASF. The main targets of the design brief were to minimise (as close as possible to zero) the carbon emissions through energy efficiency and to maximise the affordability through cost effective solutions. These characteristics resulted in a house with compact floor area and greater reliance on passive solar design.

Fig 5. View of BASF House from the South (Source: BASF [6])

The ground floor includes a 'buffer space' on the north side (Fig. 6), which acts as an entrance lobby, houses the control system and is also used as storage for bikes and biomass fuel. This floor has an open plan except for two rooms, the WC and the utility room where the equipment (such as the biomass boiler, solar thermal hot water cylinder and rainwater harvesting control system) are housed. The house is naturally ventilated and the staircase is located in the middle of the plan allowing warm air to flow to the first floor by stack effect and to be extracted by windows placed close to the roof ridge line. The first floor has two main south bedrooms, one smaller north bedroom and a family bathroom. There are no windows on the East and West façade so the house can be built as a terrace or semi-detached house in future developments. The 'buffer space' on the south side is a double-height sunspace contained within the house's volume was designed to contribute to the home space heating requirements in winter. The space has a number of different opening apertures to ensure that both of the glazed screens to the sunspace can be opened or closed to facilitate heating or cooling. It also has external shading and internal manually controlled blinds.

The materials chosen for the building were polystyrene formwork (ICF) filled with concrete to the ground floor and walls and above ground floor level, a prefabricated timber insulated sandwich panel (SIPS). These materials were chosen due to practicality, price, high performance and the ability to be prefabricated off-site speeding up the construction. Although ICFs can be classified as a heavy weight material, they do not offer great thermal mass as the concrete is sandwiched between polystyrene panels. To overcome this, Phase Change Materials (PCM) embodied in wallboards produced by BASF (known as Smart

Board™) were incorporated. The different systems used in the construction achieve typical U-Values of 0.15W/m^{2}K for floor, walls and roof. All the windows are double glazed with a U-value of 1.6W/m^{2}K except for the external window of the buffer space in the south side which has and U-Value of 5.7W/m^{2}K. The BASF House is thermally efficient, using its passive house design to provide heat, but a biomass boiler was also installed to ensure the comfort of the occupants. This will also act as the primary hot water heating system on winter days. The boiler is 87% efficient and runs on the waste meal of rape seed. It delivers hot air to a trench heater in the living room perimeter which is expected to warm up the whole house. Solar power will provide an estimated 81% of the hot water using a compact solar thermal DWH system. One more feature of the house is the Earth-Air Heat Exchanger (EAHE). EAHEs work by forcing air to get in contact with the earth before delivering it to the building using for example underground pipes. Warm outdoor air entering the pipes gives up its heat to the cooler earth before entering the building. In winter, EAHEs can still be beneficial by pre-heating the outside air before it is delivered to the space. The EAHE in the BASF house is 36.8m long, has an inner diameter of 186mm and should provide cool air in summer and pre-heated air in winter further heated by the perimeter trench heater.

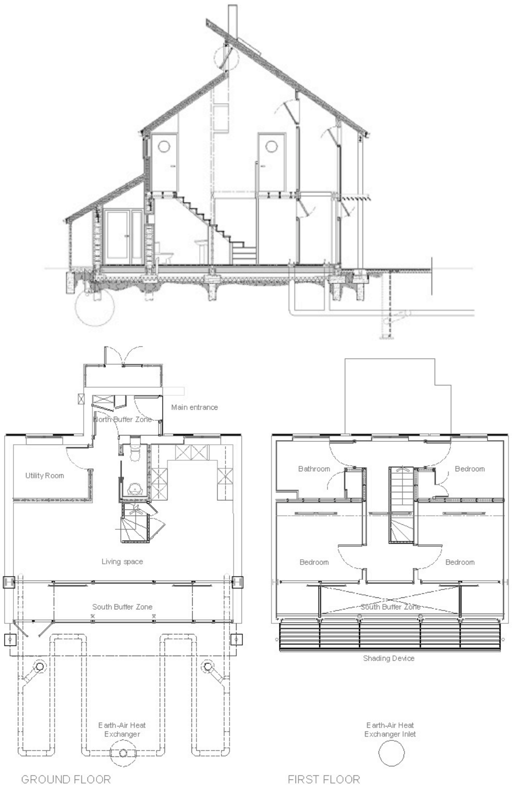

Fig 6. The BASF house's layout (source: Derek Trowell Architects)

4.3 Performance Predictions

The thermal performance of the house was dynamically simulated using TAS by EDSL. Two cases were developed and compared: a Base case using the geometry and original material specification proposed by the architects and Case 1 changing the material specifications to the proposed Passivhaus UK Standard. The assumed infiltration rate was 3.5ach^{-1} at 50Pa which is in line with UK low energy examples [4]. The simulations considered that in summer the windows were manually opened as a function of the zone's temperature. In winter, ventilation is provided by background infiltration and additional ventilation. In the living room and connected zones no trickle ventilation was assumed to account for the benefits of the EAHE which, combined with background infiltration can provide enough fresh air for this areas running at an airflow rate of 174m^3/h. Fig. 7 below compares Base Case and Case 1 annual heating demand to a house built to current building regulation standards and to the Passivhaus standards.

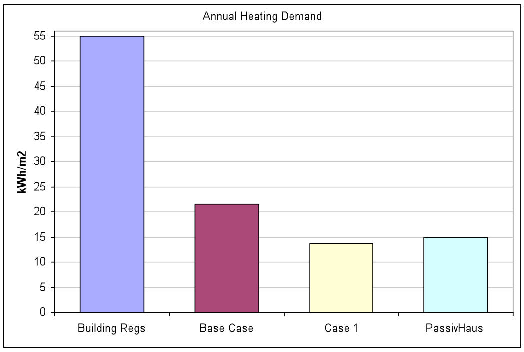

Fig 7. Comparison of annual heating demands

As it can be seen the original specifications proposed by the architects would already mean an improvement of around 60% over building regulations. However, there was still room for improvements as Case 1 is around 35% better than Base Case. In summer, the house performed really well and the only zone that presented significant overheating was the sunspace, with temperature above 25°C for almost 24% of the year. The Smart Board and the EAHE (both not included in the simulation) are expected to completely mitigate the overheating problem. The sunspace performed very well as a buffer space providing the house with most of its heat. In winter, the simulations showed that temperatures can go below the comfort zone just when there is no good availability of solar radiation. In that case additional heating using the biomass boiler was used to meet the comfort requirements. Based on the results, some improvements on the building's envelope were suggested to the design team and a re-evaluation was performed. The final annual heating energy demand of the BASF house has been estimated to be just under the Passivhaus standard of 15kWh/m^2. Active cooling is not required due to the provision of passive mitigations strategies as described.

4.4 Construction

Using ICF and SIPS instead of traditional bricks and blocks has significantly reduced the amount of waste generated on site. The material choice also allowed the whole house to be built in 25 weeks at a very high quality standard. Great attention was given to mitigation of thermal bridging and to air permeability. Due to the house's simple geometry and to the high consideration to details, susceptible areas were well sealed. An onsite pressurisation test was undertaken to determine actual performance values and the result is 5ach^{-1} at 50Pa (3.38 $m^3/h/m^2$) which is higher than the assumed for the simulations but along with UK best practice. The design's passive approach plus minimum use of renewable energy technologies mean that, in a typical 20 homes development, the BASF house could be built for £70,000. This provides designers and house builders with a realistic airtight, thermal efficient building at an affordable build cost.

4.5 Operation and future monitoring

Since its opening in January of 2008, the house has been inhabited intermittently and frequently used for meetings and demonstrations. Overall the internal conditions have been described by users as comfortable on both, warm and cold days. So far there was no need for the biomass heating system to be used for space heating. Occupants have expressed contentment for being able to interact with the house and the outside environment directly by controlling openings and blinds.

From June 2008 the house will be inhabited for at least a year by two people. Their behavior and the house performance will be closely monitored. This real life experiment will provide the University of Nottingham, BASF and industry with vital data on the advantages and disadvantages of living in a low energy home. The sensors and monitoring equipment were provided by WebBrick Systems and were chosen for their affordability, flexibility, expandability and accuracy. The system oversees and controls the ventilation, heating, lighting, security, and blinds. Smart meters have been installed to measure the use of electricity and water, with the data being presented on a touch screen panel mounted in the kitchen. This same touch screen also provides a user interface with a menu of options for controlling the home. A detailed work on post-occupancy house performance and user satisfaction is going to be carried out over the next few years by the University of Nottingham and will be published at a later date.

5. Conclusion

The Passivhaus standards have been successfully implemented since 1991 in Germany and more than 8.000 houses have been built in Central Europe. Naturally this achievement has led to the question of whether this is applicable in other countries. The Passive-on project investigated its suitability in Southern Europe and in the 'warming' climates of UK and France, and proposed a modified version of the Passivhaus standard which ceases to be a prescriptive standard and becomes mainly related to the building's performance.

In the UK, the School of the Built Environment of the University of Nottingham proposed a possible application of the Passivhaus standard adapted to the British context, taking into account the climate, construction standards, technical and economical differences as well as life style. From performance predictions, the proposed house achieves a heating load of 13.8kWh/m² complying with the Passivhaus standard which is around 60% better than current building regulation standards. Active cooling and mechanical ventilation are not required due to passive mitigation strategies as well as the use of controlled natural ventilation. The study demonstrates that the strategy adopted for the design of the SBE house is successful in meeting the Passivhaus standard in terms of heating/cooling demand and in terms of thermal comfort. It also illustrates that the measures required to meet these performance criteria do not need to be prescriptive. This will give both designers and builders greater flexibility when juggling the different priorities to achieve affordable passive housing.

As a successful example of how to achieve the proposed standards cost-effectively, the newly built BASF house is predicted to meet the 15kWh/m² Passivhaus standard for heating and does not require a whole house mechanical ventilation heat recovery system. However, a one year monitoring campaign and post occupancy evaluation will be undertaken from July 2008 giving a better insight on the actual performance of the building. Nevertheless, current occupants already express satisfaction regarding use of the space and interaction with the building.

6. Acknowledgements

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