THE *PASSIVHAUS* STANDARD IN EUROPEAN WARM CLIMATES:
DESIGN GUIDELINES FOR COMFORTABLE LOW ENERGY HOMES

Part 1. A review of comfortable low energy homes

Passive-On project

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Part 1. A review of comfortable low energy homes

Edited and compiled by: Brian Ford, Rosa Schiano-Phan and Duan Zhongcheng, School of the Built Environment, University of Nottingham

The work described in this report was carried out under contract as part of the EC funded project Passive-on (‘Marketable Passive Homes for Winter and Summer Comfort’ EIE/04/091/S07.38644, 2004-‘07). The views expressed in this report are those of the contractors and do not necessarily reflect those of the European Commission.

PARTNERS

Politecnico di Milano, Italy
Dipartimento di Energetica (e-ERG)
Piazza Leonardo da Vinci 32
20133 Milano
Andrew Pindar (Co-ordinator)
Lorenzo Pagliano

University of Nottingham, UK
School of the Built Environment
University Park
Nottingham NG7 2RD
Brian Ford
Rosa Schiano-Phan

AICIA, Spain
Asociación de Investigación y Cooperación Industrial de Andalucía
Escuela Superior de Ingenieros. Camino de los Descubrimientos s/n
E-41092, Sevilla
Servando Alvarez
Jose' Manuel Salmeron Lissen

ICE, France
International Conseil Energie
6 rue de Verdun
93450 Ile-Saint-Denis
Sophie Attali & Dominique Maigrot

Natural Works, Portugal
Projectos de Engenharia
Calcada Marques de Abrantes N48 2D
1200-719 Lisboa
Maria Malato Lerer
Guilherme Carrilho da Graca

INETI, Portugal
National Institute of Engineering Technology and Innovation I.P.
Estrada do Paço do Lumiar
1648-038 Lisboa
Helder Gonçalves
Luisa Brotas

MAIN SUBCONTRACTOR

Passivhaus Institut
Rheinstraße 44/46
D-64283 Darmstadt
Juergen Schnieders

ACKNOWLEDGMENTS

This document is derived from the work of all the partners and the main subcontractor of the Passive-on project. In addition we would like to thank the industrial partners for their invaluable contribution to this project: Nicola Agnoli, Rockwool Italia; Daniela Origgi, BASF; Massimo Gattolin, Provincia di Venezia.

Special thanks go to the peer reviewers who kindly offered their comments on the earlier drafts of this report: Simos Yannas, Architectural Association; Mark Brinkley, Journalist; Gavin Hodgson, BRE; Julian Marsh, Architect; Derek Trowell, Architect.

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July 2007

TABLE OF CONTENTS

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 is central to two recent research dissemination projects funded under the IEE programme by the European Commission (The ‘Passive-On’ and the ‘PEP’ project). 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.

In the warm climates of southern Europe, heating demand is generally lower than northern Europe, but this is not just related to the number of ‘degree days’ for a particular location but also the amount of solar radiation. This has been addressed in the definition of a ‘Climate Severity Index’ (described in Chapter 4) which can be used as the basis for mapping and comparing the benefits of increased insulation levels or glazing specification in different parts of Europe.

The terms ‘Passive’ and ‘*Passivhaus*’ can lead to confusion, and so the project partners (Italy, France, Germany, Spain, Portugal and the UK) have made a distinction between ‘Passive’ approaches to design, and the *‘Passivhaus’* standard (Chapter 1). Also, since thermal comfort is as central to the *Passivhaus* concept as energy efficiency, a succinct review of indoor comfort in the Passivhaus standard is provided in Chapter 2.

Each partner in the project put forward an ‘affordable’ house proposal (described in Chapter 3) which was designed to meet the Passivhaus standard in terms of both predicted energy consumption and thermal comfort criteria. While the proposals are related to the country of origin of the different partners, it should not be concluded that the proposals are therefore appropriate for other locations in that country. Climatic variations within countries can be significant, and hence the value of the Climate Severity Index (CSI) maps to enable meaningful comparisons to be made.

Of course it is not just the climate which differs around Europe, but the nature of the housing market, construction costs and practice differ substantially. Nevertheless, it can be useful to make comparisons between the cost of different design approaches in the different countries (Chapter 5). Generally it can be 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 (Fig. 1.0).

Fig. 1.0 – Partner countries of the ‘Passive-on’ project

1 *PASSIVHAUS* FOR WARM CLIMATES

1.1 WHAT IS PASSIVE DESIGN?

The era of cheap fossil fuels, which has lasted approximately 100 years, is nearly over. In that time, numerous mechanical and electrical devices have been developed to heat, cool, ventilate and light the interiors of our buildings. A new profession, the building services engineer, arose to design and specify appropriate 'active' (mechanical) devices for different building types. One of the by-products of the mechanically conditioned interior was that the building envelope ceased to be the primary moderator of the external climate on the internal environment, and architects abdicated responsibility for environmental control to the engineer. However, following the oil crisis of 1973, many architects and engineers saw the wisdom of reducing dependency on fossil fuels, and developed a renewed interest in the rich, varied and subtle vocabulary of an architecture which successfully moderates the internal environment according to the season by virtue of its design. This has led to a rediscovery of the principles of environmental control through the manipulation of the building form, the disposition of openings and the thermal performance of materials: so called 'passive' design.

Passive design seeks to maximise the thermal and environmental benefits which can arise through careful consideration of the thermal performance of building components and systems, to minimise heat losses in winter and heat gains in summer. A purely 'passive' design would include no mechanical intervention. However, this is often not appropriate, since the incorporation of mechanical and electrical devices (particularly to provide a control function) is normally desirable in order to enable the 'passive' elements to function appropriately.

'Passive Design' is therefore a generic term, and is used to define a strategic approach to design which is open to interpretation by different people in different locations and climates, with the objective of minimising fossil fuel energy consumption for heating, ventilation, lighting and cooling. In northern Europe, heating demand is still the most significant, whereas in southern Europe residential heating needs are minimal, while demand for mechanical cooling has been increasing rapidly. There has therefore been increasing interest in strategies to achieve both 'passive heating' and 'passive cooling'.

Design strategies for passive heating and cooling rely on the exploitation of ambient heat sources (e. g. the sun) and sinks (e. g. the night sky). Much of the early work in this area was done in the US in the 1970s under the Carter administration. This was taken up and developed further in Europe during the 1980s with funding from the European Commission's R&D programmes. It is in this context that the *Passivhaus* concept was developed.

Fig. 1. 1 – A *Passivhaus* in Germany

Fig. 1. 2 – White washed houses and narrow streets in the Santa Cruz district of Seville, Spain. Just two of the many different strategies employed by traditional architecture to keep houses cool in summer.

1.2 *PASSIVHAUS* STANDARD

In 1991 Wolfgang Feist and Bo Adamson applied the passive design approach to a house in Darmstadt, 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.

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-efficient: Considering the lifecycle cost of the building, a *Passivhaus* need not be more expensive than a conventional new dwelling (see Chapter 5).

In total more than 8.000 houses have now been built in Germany and elsewhere in central Europe (for example Austria, Belgium, Switzerland, Sweden) which conform to the current *Passivhaus* standard. 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.

Fig. 1. 3 – Single-family *Passivhaus* in Ganderkesee, Northern Germany. (Architect: team 3, Oldenburg)

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. Here are the five points that define the **current German *Passivhaus* Standard for Central European Countries**:

- 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 h^{-1}.
- 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.

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 six points that define the proposed *Passivhaus* Standard for Warm European Climates are listed below:

- Heating criterion: The useful energy demand for space heating does not exceed 15 kWh per m² net habitable floor area per annum.
- Cooling criterion: The useful, sensible energy demand for space cooling 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: 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 h^{-1} is usually sufficient to achieve the heating criterion.
- Comfort criterion room temperature winter: The operative room temperatures can be kept above 20 °C in winter, using the abovementioned amount of energy.
- 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.

This definition, especially in relation to cooling demand, will be reviewed in time as greater experience will be gained on building *Passivhaus* in warm climates.

2 INDOOR COMFORT

Without attention, discussions on low energy buildings can neglect other important aspects of building design. Indeed, it must be remembered energy use is a means and not an end. One of the most important needs is that buildings provide comfortable environments in which to work, relax and play.

Although homes in southern Europe still need to be warm in winter this is accompanied by a need to ensure comfort in summer, which at times can be the predominant issue. As noted in the previous section the *Passivhaus* standard has been recently revised to make it pertinent and useful to the specific needs of warmer climates. One of the major changes with respect to the previous definition which concentrated on central European climates has therefore been the introduction of explicit requirements on indoor summer comfort conditions.

To achieve the *Passivhaus* standard it now becomes necessary that indoor summer temperatures, more specifically operative temperatures, remain lower than the maximum temperatures defined by the EN 15251 standard.

According to EN 15251 standard, acceptable comfort temperatures actually depend on the type of system used to provide summer comfort. If cooling is provided by an active system then indoor temperatures must respect those defined by the Fanger Model. Instead if summer comfort is provided by passive cooling strategies then the upper temperature limit is set by the Adaptive Model.

The difference between the Fanger and Adaptive Models is explained briefly in the following section and in more detail in the second part of the guidelines. However, leaving aside the actual indoor comfort temperatures defined by the different models, probably the most important aspect is that the indoor summer comfort temperatures are now an explicit requirement of the revised *Passivhaus* standard. As a consequence the *Passivhaus* standard provides an overall quality mark for passive homes not offered by other energy performance standards.

2.1 SUMMER COMFORT MODELS

Comfort Models describe quantitatively (based on large surveys of people) in what range of conditions people will feel thermally comfortable in buildings. Choosing too narrow a range of conditions can lead to unnecessary consumption of energy.

In evaluating the thermal comfort provided by buildings, there is a choice between using:

- the comfort model originally proposed by Fanger or Predicted Mean Vote (PMV) model,
- and the model which takes into account the ability of occupants of buildings to adapt to the prevailing climate (Adaptive comfort model)

The two models are applicable in different conditions; roughly speaking the Fanger Model is applicable in mechanically conditioned buildings (within a specified range of temperatures, humidity, air velocities,...), and the Adaptive Model in non mechanically conditioned or naturally ventilated buildings. There is an ongoing research on the boundaries of applicability of the two models with some studies having tested the Adaptive Model in mechanically conditioned buildings. A correction should be made when evaluating summer conditions to take into account the increase of comfort produced by increasing air velocity by using natural ventilation or fans.

In the Fanger Model the optimum internal condition of a building (that is the one at which occupants will report comfort) is correlated exclusively to parameters referring to conditions internal to the building (for example air temperature and velocity, mean radiant temperature, air humidity) and to the clothing level and metabolic rate of the occupants. The Fanger Model is based on the correlations between people's subjective impression of Comfort and the thermal conditions (e.g. operative temperatures, relative humidity, metabolic rate, and clothing level) in a controlled closed test environment. Although the Fanger Model makes allowance for how people are clothed and the activity they are performing, when used in practice ‘typical values’ of clothing and metabolic rate are often assumed which can lead designers to specifying a static, narrow band of ‘comfortable’ room temperatures to be applied uniformly through space and time. Static temperatures disfavour passive technologies, which are effective at moderating external temperature fluctuations but generally are unable to completely decouple the indoor environment form the outside.

Care should be taken in order to apply the Fanger Model only within its validity limits, as prescribed in ISO 7730 (issued in 1994 and revised in 2005)

The Adaptive Comfort Model proposes a correlation between the comfort temperature for occupants of a building and the outdoor air temperature. The underlying concept is the documented process by which the human body adapts (including making changes to the metabolic rate) to the seasonal and local climate. As a consequence occupants will consider different indoor temperatures as comfortable depending on the season and location. The Adaptive Model is based on the measured correlations between people's subjective impression of comfort and indoor temperature in hundreds of real buildings.

Compared to the Fanger Model, the Adaptive Model considers a wider range of temperatures as “comfortable” and therefore allows for easier integration of passive cooling technologies. For example applying the Adaptive algorithm defined in the EN 15251 standard to typical annual weather data predicts maximum summer neutral temperatures (in correspondence with a sequence of hot days) for Frankfurt, Milan, Lisbon and Seville as respectively 26.1°C, 27.2°C , 26.7°C, and 28.7°C. As a comparison a building cooled by an active air conditioning system will work to a fixed set point chosen between 23°C and 26°C.

The Adaptive Comfort Model has been refined over the years, and tested in various field studies (Humphreys, 1975; 1978; 1979; Nicol, 1993; de Dear, 1998; Nicol & McCartney, 2001). In most current building regulations, the definition of thermal comfort follows the ISO 7730 standard which is based on the steady-state Fanger Model.

However in recent years, some international standards (e.g. the US norm ASHRAE 55 2004 and the European norm EN 15251) have proposed Adaptive Comfort Models based on in-field comfort surveys. These have replaced the previous Fanger-based temperature standards with ‘Adaptive’ ones for indoor temperature in naturally ventilated buildings.

2.2 INDOOR COMFORT AND THE *PASSIVHAUS* STANDARD

The Cooling Demand is the energy required to maintain a given set of indoor temperature and humidity conditions during the summer period. The nature of the building envelope, the internal gains and the required indoor conditions define the size of the Cooling Demand, with lower indoor summer temperatures leading to higher cooling loads (i.e. more energy is needed to keep the building at the required temperature).

As seen the Adaptive Model generally defines both higher and more variable Comfort temperatures than those predicted by the Fanger Model. Often the neutral Adaptive Comfort Temperature can be achieved by using passive cooling strategies, such as window shading and night time ventilation. When this occurs the Cooling Demand is effectively reduced to zero and no mechanical cooling is required.

In some locations guaranteeing the comfort temperatures defined by the Adaptive Model requires some energy. For example, Palermo in Sicily has low diurnal temperature swings with external night time air temperatures only a few degrees below those in the daytime. In this situation night time ventilation strategies do not provide a really effective way of cooling the building. As a consequence the *Passivhaus* in Palermo has a cooling demand of around 2 kWh/m^2/year which requires the home to have some form of active mechanical cooling system to reduce the peak temperatures (though the main means of cooling is still passive). However, although the *Passivhaus* in Palermo has a cooling demand, it is nevertheless so low, that total annual and heating and cooling loads remain below the 15 kWh/m^2/year limit set by the *Passivhaus* standard.

Since the Fanger Model generally leads to lower indoor neutral comfort temperatures than those predicted by the Adaptive Model the cooling loads and cooling demand of the buildings are higher. There is thus an obvious advantage to promoting passive cooling strategies.

However, in some locations applying effective passive cooling techniques can be problematic. Particularly in cities it can be difficult to realize effective night time ventilation strategies (by which cold night air is used to cool the building’s thermal mass) both since occupants might close windows at night to cut back outside noise and since diurnal temperature swings are reduced due to local heat island effects. In these cases other cooling techniques can be explored (see Part 3) or, alternatively, active cooling systems installed in order to provide acceptable indoor conditions for occupants in summer.

As a consequence, in the proposed revised standard for Warm European Climates, homes must now meet the following requirements:

If cooling is provided by mainly **passive** means

Indoor Comfort Requirements: As defined by the Adaptive Model of the Annex A.2 ("Acceptable indoor temperatures for design of buildings without mechanical cooling systems") of the EN 15251

Heating and Cooling demand: < 15 kWh/m^2/year

Total primary energy: < 120 kWh/m^2/year

If cooling is provided by **active systems**

Indoor Comfort Requirements: As defined by the Fanger Model of the EN 15251 (i.e. for mechanically cooled buildings)

Heating demand: < 15 kWh/m^2/year

Cooling demand: < 15 kWh/m^2/year (this value may be updated and possibly reduced based on field studies)

Total primary energy: < 120 kWh/m^2/year

The proposed standard, however, makes the recommendation that mechanical systems should only be used if there are technical limits to the use of mainly passive solutions.

3 *PASSIVHAUS* PROPOSALS

3.1 INTRODUCTION

This chapter presents examples of how the *Passivhaus* standard can be applied in the five partner countries (France, Spain, Portugal, Italy and the UK) under climatic and socio-economic conditions which differ from the German original context of application. The exercise was undertaken by the partners with the aim of applying the *Passivhaus* standard, as detailed in Chapter 1 and 2, intended as a performance standard rather than a list of prescriptive requirements.

The national proposals were formulated by reference to the standard typology of a semidetached three-bedroom house. This was adapted and optimised from the design point of view in order to achieve the required level of comfort and low energy demand. Performance analysis of the proposed options was undertaken with the aid of dynamic thermal simulation; however, it was not possible to use the same simulation tool across the group. The analysis aimed at exploring the ranges of heating and cooling demand in the various locations and the feasibility of the proposed standard.

The exercise revealed that heating loads are relatively low in many southern European countries and generally stay below the 15kWh/m^2 mark. Comparatively, however, they are marginal to other household energy requirements such as water heating, lighting and appliances. It emerged that in many cases there are cooling loads to take into account but that often these can be met by passive strategies alone.

This has lead to a wide range of design solutions reflected in the national proposals described hereafter. These show that it is possible to design low energy comfortable homes adopting a raft of appropriate solutions which can avoid the use of active cooling in many locations. Reference to a list of generic passive strategies is presented in more detail in Part 2, whereas the assumptions and detail results of the performance analysis undertaken on each national proposal is included in Part 3 of this work.

3.2 *PASSIVHAUS* UK

3.2.1 The house

The starting point for the UK *Passivhaus* proposal by the School of the Built Environment (SBE) at Nottingham University was a standard three bedroom semi-detached house complying with Building Regulations 2006. 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, in the UK there is widespread scepticism among 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. Therefore, in the SBE proposal, 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 degree of control over the opening of windows. Air tightness is still important but the minimum fresh air supply is introduced via the buffer space through automated ventilators and trickle vents.

The typical UK *Passivhaus* 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 UK *Passivhaus* 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. 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. The extra costs of the proposed UK *Passivhaus*, compared to a standard house, is of 49 £/m^2 with a payback period of 19 years.

Fig. 3. 1 – Example of zero fossil energy housing in the UK, Bedzed

(Architects: Zed Factory)

Fig. 3. 2 – 3D of UK *Passivhaus* proposed by SBE

3.2.2 The strategy

The environmental design strategy proposed varies from the German *Passivhaus* strategy in combining 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 to cool down the building and the thermal mass of the interior. 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 typical UK *Passivhaus* avoids the use of active cooling by shading and natural ventilation coupled with exposed thermal mass.

In order to minimise fabric and infiltration losses, high levels of insulation are assumed with typical U-Values ranging from 0.2W/m^{2}K to 0.15W/m^{2}K for walls and roof respectively. 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 was 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 are assumed, while infiltration rates of 3ach at 50Pa are assumed.

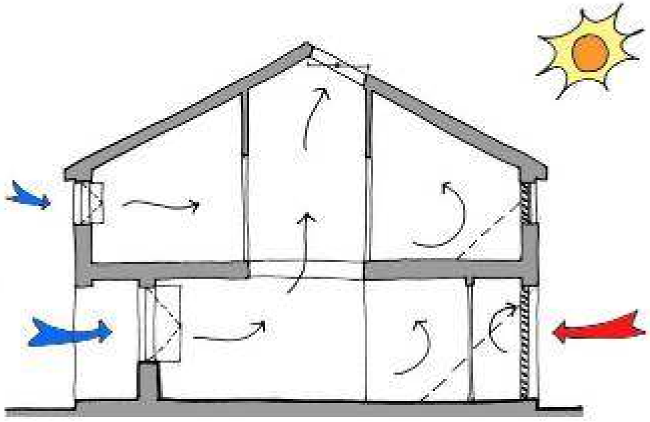

Fig. 3. 3 – Summer ventilation strategy

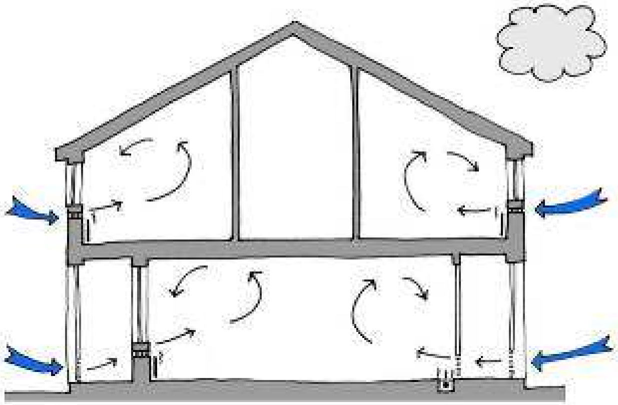

Fig. 3. 4 – Winter daytime ventilation strategy

3.2.3 Performance: energy and comfort

The annual heating energy demand of the UK *Passivhaus* proposed by the SBE 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. Active cooling is not required due to the provision of passive mitigations strategies as described above. 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.

The comfort criteria adopted during the summer analysis were based on the calculation of comfort indexes (see Part 2). 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. When assessing comfort using this index a low index indicates better performance, with the optimum performance being zero. For the proposed UK *Passivhaus* the AI2 was zero. With regard to summer temperature conditions, 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 (for wider discussion on comfort issues see Chapter 2). 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 typically range between 10 and 24°C exceeding ambient temperatures by 5 - 15°C.

The foregoing demonstrates that the strategy adopted for the design of the 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 meeting 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.

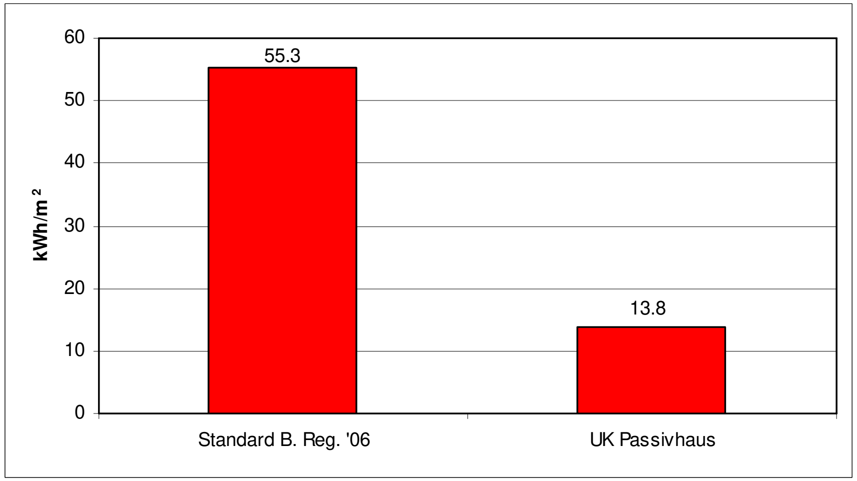

Fig. 3. 5 – Predicted annual heating demand for Standard House and *Passivhaus*

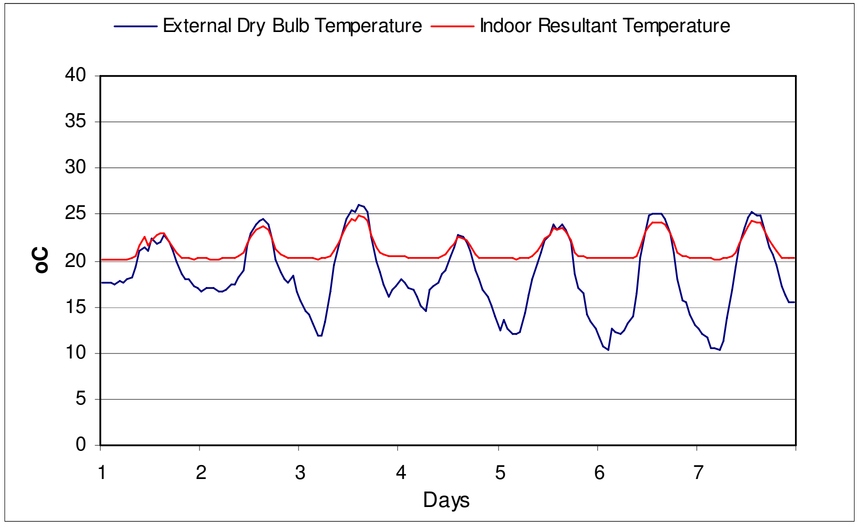

Fig. 3. 6 – Typical Dry Resultant Temperatures in summer without additional cooling

3.3 *PASSIVHAUS* SPAIN

3.3.1 The house

The starting point is a typical semidetached or terraced Spanish dwelling located near a main city. It has between three and four bedrooms and a total treated floor area of 100 m^2. It fulfils the current Spanish regulations called “Building Technical Code” mandatory from 2007 and specifically the part that limits the energy demand.

The goal was to apply the principles of the “German *Passivhaus*” starting from this house and taking into account the characteristics of Spanish climate. The analysis focussed on the regional climate of Andalusia: Seville and Granada. Both localities have Mediterranean climate influences but with some peculiarities that make them more extreme and complex than other locations such as Cadiz or Almeria. Seville has a very severe summer whereas Granada a very severe winter.
Also, it is intended to obtain dwellings that, in the frame of the new energy labelling regulation, achieve the maximum energy label (A the best-E the worst) using passive heating and cooling techniques, at low cost, and satisfying comfort conditions as expressed in the EN 15251.

The plan distribution of dwelling does not match the typical Spanish. In fact, terraced or semi-detached houses have exterior walls with the minimum surface. And party-walls have the higher surface. This option maximizes the compactness (see “Compactness” in Part 2) which is very adequate for very severe winter climates and where solar radiation is not high. However, in Seville and Granada it is worthwhile to sacrifice compactness in order to have more area oriented to the South, increase the heat transfer area in this orientation and, as a result, decrease the heating energy demand. In this situation we will have in our prototype higher surface walls to outdoor. The main orientation of the façades are south – higher glazing area (around 50%) - and north –lower glazing area (around 10%). This design can create problems in the urban layout because it is not common but it is the best under the energy point of view.

The extra cost of Spanish *Passivhaus* is around 25 €/m^2 – this represents an increase of a 5% respect to standard building construction costs- and the average Discounted Payback (DPB) is around 5 years. This figure is lower than in other countries due to the fact that our proposal is more based on the design than in the use of innovative systems or high levels of air tightness.

Fig. 3. 7 – Low energy housing in SP, Seville

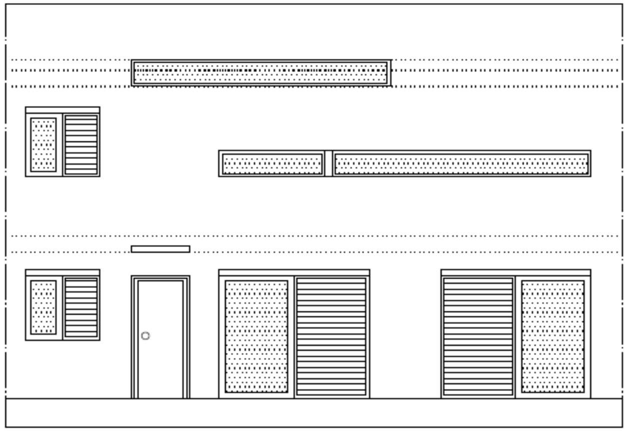

Fig. 3. 8 – North facade of SP *Passivhaus* proposed

3.3.2 The strategy

The environmental strategy for the Spanish *Passivhaus* example comprises of the elements detailed below.

Pre-heating of inlet air
A mechanical ventilation system (with very high levels of air tightness required for the building) was not considered as this is not compatible with the Spanish buildings characteristics.

Glazing
The high level of glazing to the South maximizes solar heat gains in winter. The main advantage of South orientation, as opposed to the East and West one, is that it has lower levels of solar radiations in summer – when it is undesirable; also it is easier to control solar ingress. Solar control is achieved with the use of movable shadings (see: "Glazing and Solar Energy" in Part 2). On the North side it is recommended to use the minimum glazing surface to meet daylighting requirements. In locations with severe winters it is suggested to improve the U-value of North glazing.

Thermal mass and inertia
Two solutions are proposed: traditional low inertia with a brick of 6cm to indoor space, and another of high inertia with a low density-ceramic block. The high inertia one is not feasible in Granada due to structural considerations. In any case a high inertia solution has to be used together with:

- Ventilation that put the inlet air in contact with high inertia (high thermal mass) internal walls, the other walls do not have to have high inertia.
- A correct distribution of the mass, in order to get solar radiation impinging on more massive walls.

Night ventilation
North space in the stairs acts like a chimney that allows the air extraction during the summer night-time.

Lighting
In the top of the stairs it has been envisaged a long window oriented to the south, this solution allows the natural lighting of this north zone.

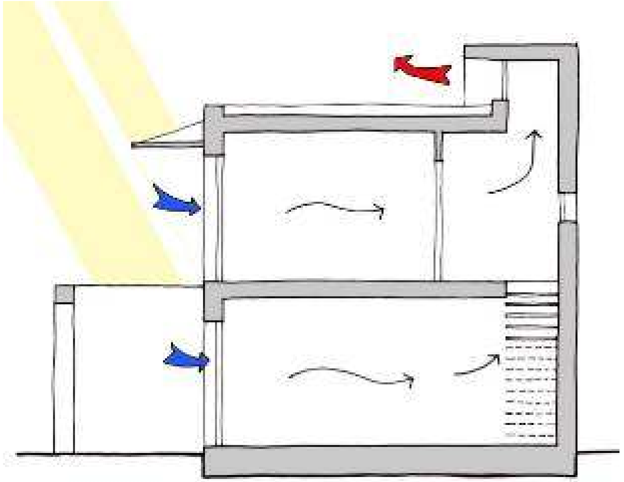
Fig. 3. 9 – Strategy of lighting-ventilation in summer

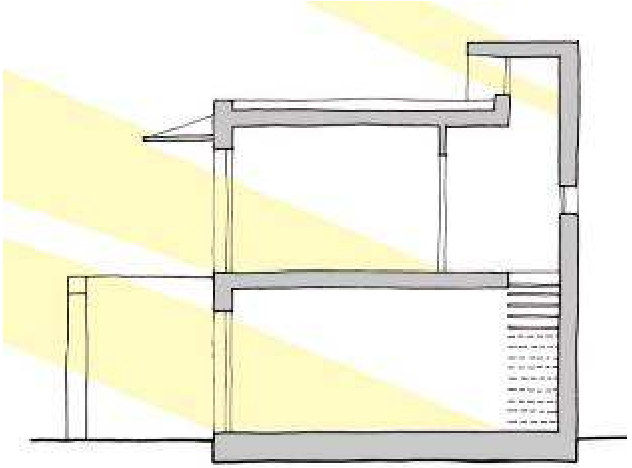
Fig. 3. 10 – Strategy of lighting-use of radiation in winter

3.3.3 Performance: energy and comfort

Total energy demand of the Seville dwelling is 24.5 kWh/m^2 (2.8 kWh/m^2 heating demand and 21.7 kWh/m^2 cooling demand); this does not fulfil the *Passivhaus* requirements for summer. However, these values correspond to very good levels in the national energy labelling (A in heating - B in cooling). The average total energy demand for a new standard dwelling is 57.3 kWh/m^2, the proposed Spanish *Passivhaus* design produces a 57% of reduction in this value.

Total energy demand of the Granada dwelling is 16.6 kWh/m^2 (8.7 kWh/m^2 heating demand and 7.9 kWh/m^2 cooling demand); this does fulfil the *Passivhaus* requirements. The average total energy demand for a new standard dwelling is 69.0 kWh/m^2, with the proposed design achieving 76% of reduction in this value. This *Passivhaus* proposal would have an energy labelling of A in heating and B in cooling.

These values are so low that there is virtually no need for active cooling or heating systems (except for the higher cooling demand in Seville). In fact, simulations show that the overall strategy adopted for the design of Spanish *Passivehaus* fulfils the envisaged requirements in terms of heating/cooling and thermal comfort.

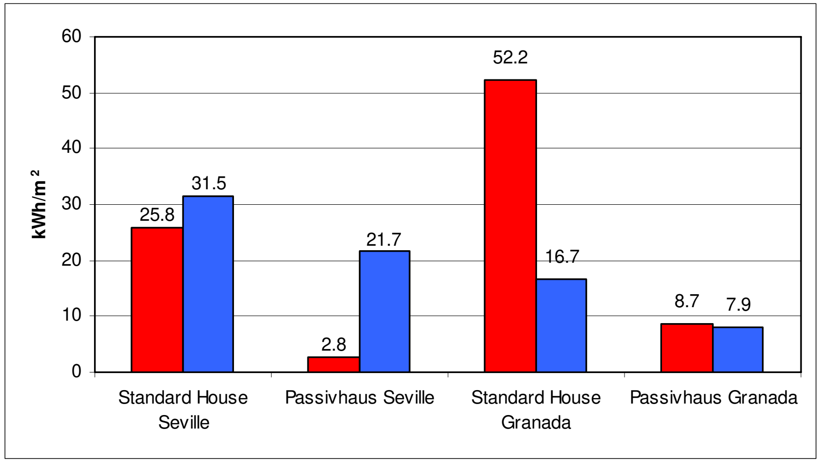

Fig. 3. 11 – Predicted annual heating demand for Standard House and *Passivhaus* in Seville and Granada

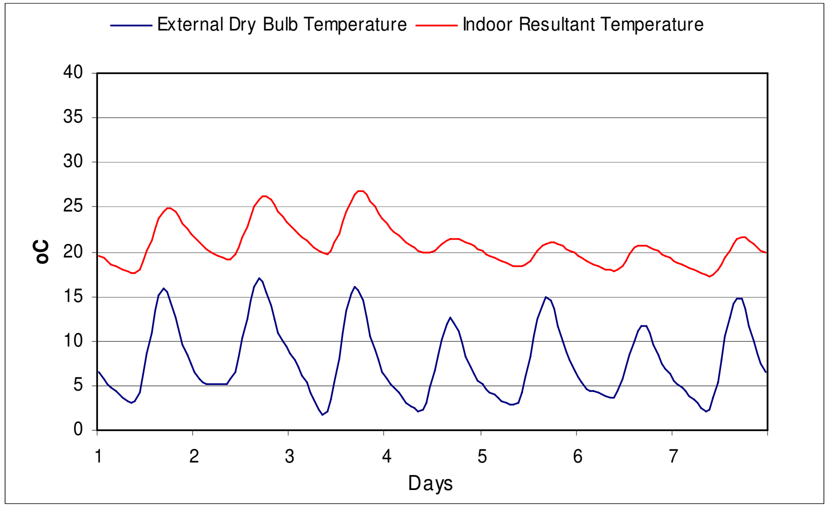

Fig. 3. 12 – Predicted temperatures during one winter week in the *Passivhaus* in Granada, SP

3.4 *PASSIVHAUS* PORTUGAL

3.4.1 The house

The starting point for the Portuguese *Passivhaus* proposal was a single floor, two bedrooms house, complying with the national Building Regulation 2006 (RCCTE, DL 80/2006). The strategies dealing with energy and comfort standards of the Passivhaus were adapted to the Portuguese context, particularly in regards to a long cooling season. The current proposal takes into account the local climate (case study for Lisbon), the construction standards, and the technical and economic framework.

Fig. 3. 13 – Picture of existing Low Energy House in Portugal (Janas House)

A simple prototype is proposed to allow architects the freedom to design the house. It has a rectangular plan with two bedrooms and a flat roof, with a total useful area of 110 m^2. The simple layout suggested can be easily enlarged to offer more rooms and/or floor area.

The level of insulation in walls and roofs exceeds the national standards and the air infiltration is controlled (about 0.8 ach at 50 Pa). Nevertheless, insulation and air-tightness are not the major issues for the current proposal. The three main aspects explored in the proposed house are: relation with the sun, ventilation for cooling and high thermal mass to control temperature swings. Solar availability is quite high in Portugal, even during the heating season. Therefore~~,~~ a key factor in this house is the relation with the solar radiation, captured both directly (windows) and indirectly (thermal solar system). Large windows are mainly oriented south increasing the useful solar gains during winter. Smaller areas are oriented east and west and minimal areas to north. Solar protection is chosen according to the orientation: overhangs to the south windows, thus reducing the solar incidence during summer, and exterior Venetian blinds in all windows.

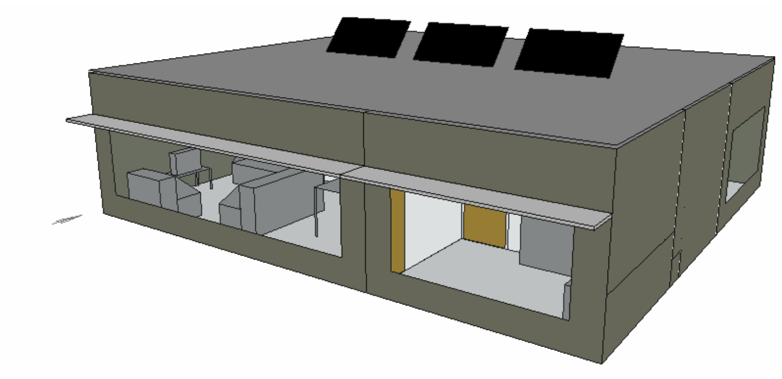

Fig. 3. 14 – 3D of *Passivhaus* proposed for Portugal

A very important feature of the proposal is the use of a thermal solar system. The new Thermal Regulation for Buildings makes compulsory the use of a thermal solar system for domestic hot water (unless a convenient solar exposure is not available). The current proposal extends the solar installation to also cover a significant portion of the heating demand~~,~~ by increasing the solar panels area and using a low temperature hydraulic heat distribution (for instance~~,~~ radiant floor). As proposed for the *Passivhaus* standard, the active heating and cooling capacity is limited to 10 W/m^2. The extra costs of the proposed Passivhaus for Portugal is 57 €/m^2 with a payback period of 12 years.

3.4.2 The strategy

The house combines the ability to collect solar heat (large south windows) and the capacity to regulate inside temperature with its high thermal inertia.
In order to reduce heat losses and gains, 150mm and 100mm of insulation are proposed for the roof and exterior walls, with U-values of 0.23 W/m^2.K and 0.32 W/m^2.K, respectively. Insulating the floor slab (80 mm) is beneficial in colder climates. However, where cooling is more relevant than heating, only a 1m stripe of the perimeter below the floor slab should be insulated to allow the core of the house to release heat to the soil during summer. Windows facing south correspond to around 60% of the total glazed area; about 20% of glazed area faces East and another 20% west. The house has approximately 1.2 m^2 of south glazing for every 10 m^2 of net area (total of 2.1 m^2 of glazing for every 10 m^2 of net area). Low-emission double glazing can be very effective in colder climates of Portugal, but in most situations standard double glazing is more cost-effective (U-values of 2.9 W/m^{2}K for standard double glazing and 1.9 W/m^{2}K for low-emission glazing are considered).

The thermal solar system provides most of the heating demand of the house. The solar panels are installed facing south, tilted 50º from horizontal plane, to increase the efficiency during winter.

In order to avoid overheating during the cooling season, particularly in the south and west facing rooms, it is important to use solar control devices (blinds and overhangs), and combine high thermal inertia with ventilation, mainly at night (outside air temperature drops considerably during night). High thermal inertia can be achieved by exposing the heavy concrete slab, using brick internal partitions and applying external insulation to the roof and walls. However, there is still some scepticism among Portuguese house builders to the mechanical performance of exterior insulation. Therefore, it is proposed to use the traditional double brick wall with an insulation layer in the cavity.

An effective cross ventilation strategy can release the heat stored in walls and slabs. In the bedrooms ventilation should take place in the evenings, to avoid drafts during the sleeping period; in all other spaces, all night cooling can be used. An effective solar control as well as a night ventilation strategy, which dissipates solar and internal gains, can reduce the power of the active cooling system or make unnecessary its installation.

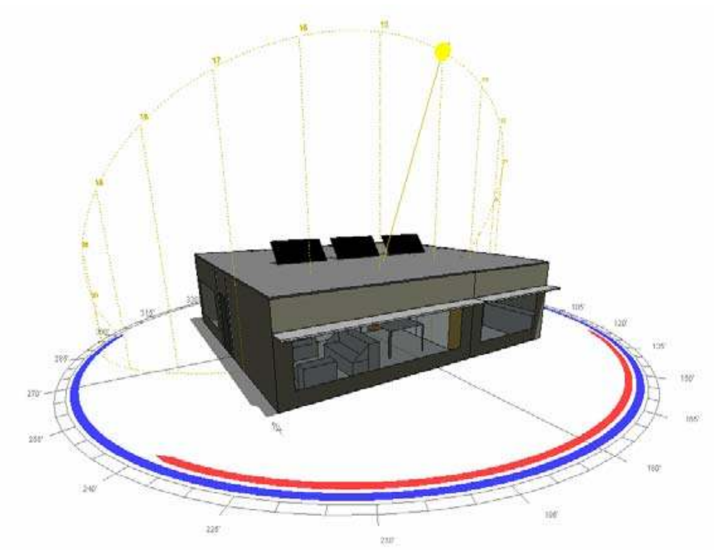

Fig. 3. 15 – Summer solar incidence, view from SW

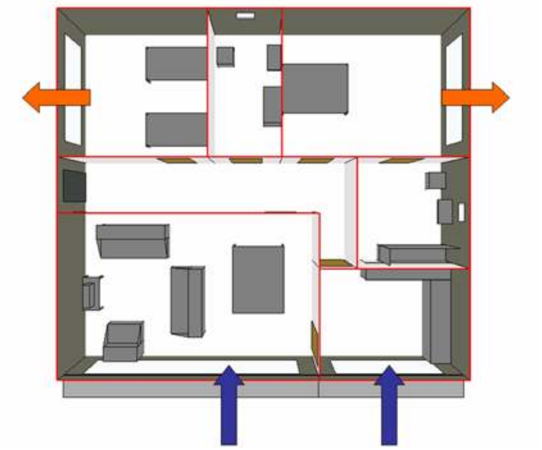

Fig. 3. 16 – Summer ventilation strategy

3.4.3 Performance: energy and comfort

The annual heating energy demand of the *Passivhaus* proposed for Portugal has been estimated as 16.9 kWh/m^2, of which 11 kWh/m^2 are supplied by the solar system (in this analysis priority of the solar system is given to heating and the solar fraction for domestic hot water is 48%). The annual cooling energy demand is 3.7 kWh/m^2. The sum of net heating and cooling demand is 9.6 kWh/m^2.year. According to the thermal regulation, the limits of heating and cooling for this house built in Lisbon, are 73.5 and 32 kWh/m^2.year, respectively.

The analysis of the thermal comfort is based on the resultant (or operative) temperature, which is the average between air and radiant temperature. The comfort criteria adopted during the summer analysis were based on the calculation of comfort indexes (see Part 2). The indexes sum over the period the "distance" between the predicted room operative temperature and the neutral temperatures at each hour. Therefore, a low index indicates a better performance.

The current house, with an active cooling, has a Fanger Comfort Index of 811 (the house is penalized by the influence of the radiant temperature of the high glazed area). If no active cooling is present, the Adaptive Comfort Index (AI2) applies (ASHRAE 55). For the proposed *Passivhaus* for Portugal, the AI2 was 16. For this house, the resultant temperature is kept below 25°C for 71% of the occupied time, and below 28 ºC during 98% of the occupied time. If no active cooling is to be installed, the size of the windows and the thermal insulation of the walls should be reduced (though this could increase the heating demand).

In winter, the low power heating system of 10 W/m^2 is in use, resulting in only 8% of time with a resultant temperature below 19.5ºC (lower resultant temperature achieved is 18ºC).

The previous analysis shows how the strategies adopted for the design of a *Passivhaus* for the heating and cooling climate of Lisbon can be successful, both regarding the energy demand limits and the comfort levels requirements. Although specific design can be very diverse from the simple layout presented, the applied strategies have proven effective in its relation with the climate.

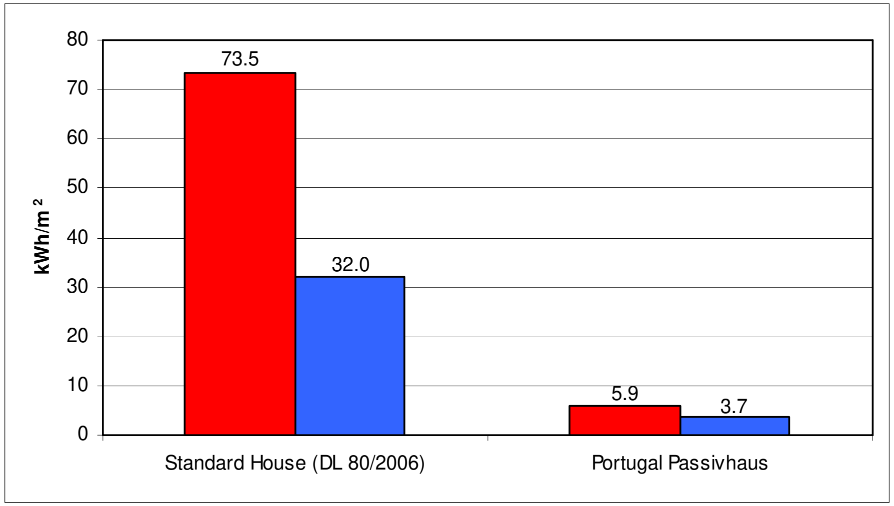

Fig. 3. 17 – Predicted annual heating (red) and cooling (blue) demand for Standard House and *Passivhaus*

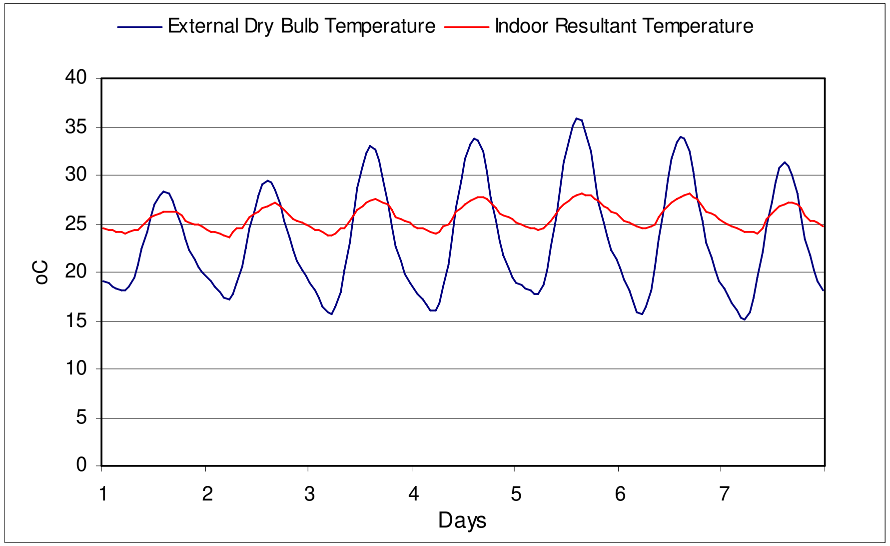

Fig. 3. 18 – Resultant Temperatures during very hot week, without active cooling

3.5 *PASSIVHAUS* ITALY

3.5.1 The house

The Italian *Passivhaus* is developed on the premise that the design solutions commonly implemented in the central European *Passivhaus*, namely high envelope insulation, lack of thermal bridges, active ventilation with heat recovery are both pertinent to many areas of Italy with relatively severe if short winters (e.g. Milan and the North in general) and also to mountainous regions further south. The other assumption is that these solutions can, when integrated with additional measures, provide an effective strategy for passive summer cooling. However, the Italian *Passivhaus* adopts additional strategies such as solar shading provided by roof eaves or Persian shutters reducing solar gain through windows. Also, a natural night time ventilation strategy supplemented with active cooling using a low power reversible heat pump on particularly warm days.

The advantage of basing the Italian *Passivhaus* on the passive concepts applied in the central European version of the *Passivhaus* is that the concepts can be readily integrated in homes with commonly accepted aesthetics and layout. A *Passivhaus* recently completed (2006) in Cherasco, near Cuneo in North Italy, graphically confirms this (see photo on the right). For example, there is no particular need for large south facing windows or conservatories to provide winter heat gains.

Likewise the *Passivhaus* discussed in the present guidelines follows the "rustic villa" style, which represents a significant part of provincial new construction in Italy in recent years, at least north of Rome. The house is a south facing end of terrace with 120 m^2 net floor area and an S/V value of 0.8 m^{-1}. The terrace is staggered such that 50% of the area of the west wall of the house is protected by the east wall of the adjoining house. Thermal dynamic simulation has shown that with suitable adjustments to the various deign strategies (e.g. changes in insulation levels) the design provides year round comfortable homes in Milan, Rome and Palermo. The technical characteristics of the *Passivhaus* recently built in Cherasco confirm to a large degree the specifications detailed in these guidelines.

For Milan the extra costs of the *Passivhaus* are calculated as 84.00 Euro/m^2 that is roughly 7% more than a home built to current minimum building standards. Considering energy savings of 924 Euro/year this results in a payback of roughly 12 years.

Fig. 3. 19 – The *Passivhaus* constructed in Cherasco, Cuneo, North Italy

3.5.2 The strategy

Although the Italian *Passivhaus* adopts many of the passive concepts of the German *Passivhaus*, specific details do change. Generally the milder climate of Italy allows the *Passivhaus* standard energy limits and comfort conditions to be achieved using less stringent criteria in relation to:

- Insulation levels: A typical German *Passivhaus* will require 25cm of insulation on external walls and 40 cm on the roof. However in Rome 10 cm wall insulation and 15 cm roof insulation proves sufficient.
- Envelope air tightness: The central European *Passivhaus* requires that building envelopes provide at maximum 0.6 h^{-1} air change rate at 50 Pa pressure difference; this is actually part of the current *Passivhaus* standard ($n_{50} < 0.6$ h^{-1}). However in Milan and Rome n_{50} value of a 1 h^{-1} should prove acceptable and in Palermo even higher.

In particular for Winter Comfort the Italian *Passivhaus*:

- Minimises winter heat loss through the highly insulated building shell and the elimination of thermal bridges
- Provides active ventilation with heat recovery from exhausted air
- Provides active heating using a low powered (ground sourced) heat pump (maximum thermal load in winter and in summer = 1.5 kW)
- Allows for solar gains by using 30% glazing of the south facade and reduces losses by limiting glazing on the north facade.

While for Summer Comfort:

- Minimises solar gains through the highly insulated building shell and shaded windows.
- Exports daytime solar and internal gains from the building shell using a natural and active ventilation at night

In regards to the last issue, using a well insulated heavy structure provides an effective basis for utilising the cool night time air in summer to cool the building thermal mass. Night time air is be passed through the building either by wind or natural buoyancy differences, or by using the fans of the active ventilation system. The strategy works in Milan though is most effective in Rome.

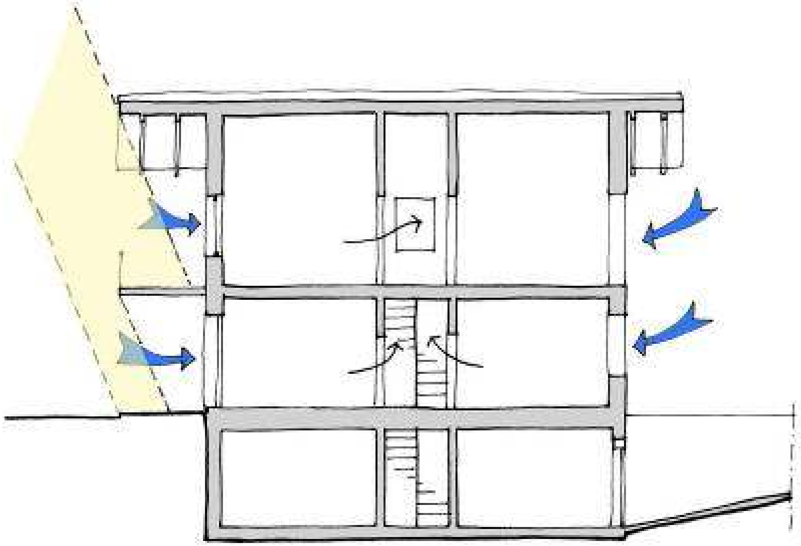

Fig. 3. 20 – Summer strategies

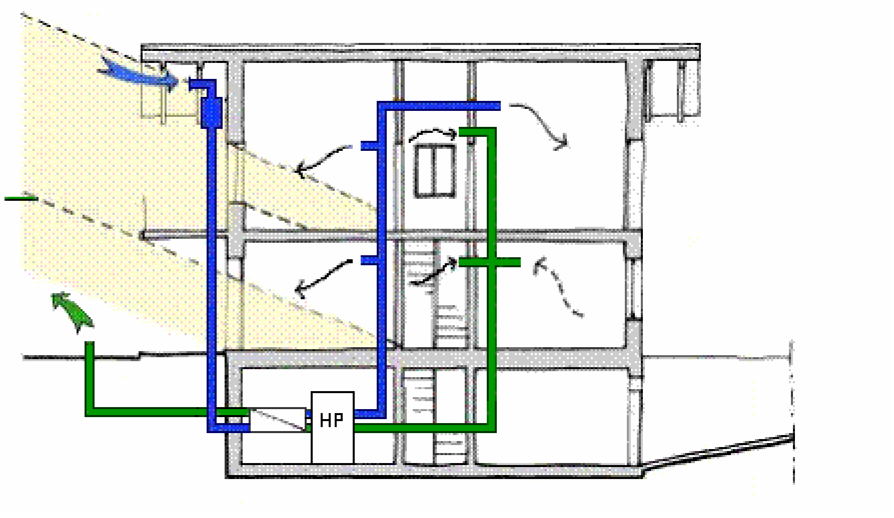

Fig. 3. 21 – Winter strategies

3.5.3 Performance: energy and comfort

In Milan and Rome summer comfort conditions can be provided by entirely passive means. More precisely:

- In Milan the Adaptive Comfort upper temperature limits (according to EN 15251) is never exceeded, though the neutral temperature is exceeded occasionally in August.

- In Rome the Adaptive Comfort upper temperature limits is never exceeded, though the neutral temperature is exceeded for most of the summer in August.

In any case passive cooling provides maximum indoor temperatures in both Milan and Rome of around 30°C.

Although the night time ventilation strategy does work, indoor temperatures can be reduced using the small powered reversible heat pump. Modest energy consumptions bring summer indoor temperatures consistently below the neutral temperature defined by the Adaptive comfort model. (Maximum temperature around 27.5°C)

In Palermo, the natural ventilation strategy is less effective and some form of active cooling is required to provide acceptable summer comfort conditions. Employing purely passive means yields summer temperatures of 32.5°C, which are higher than the upper acceptable comfort temperatures of the Adaptive Model for much of August. In fact, the diurnal temperature swings of only 3°C in July, August and September make the night time ventilation strategy ineffective. Even with significant active cooling (9 kWh/m^2/year) in Palermo the neutral comfort temperature is exceeded for a number of days in August, though indoor temperatures always remain significantly lower than the maximum acceptable temperature. An analysis was also conducted to examine the behaviour of the homes in particularly warm summers by increase summer temperatures by 3°C. Homes in Milan and Rome continued to provide comfortable conditions. However, in Palermo, indoor temperatures were consistently above the neutral temperature even with active cooling.

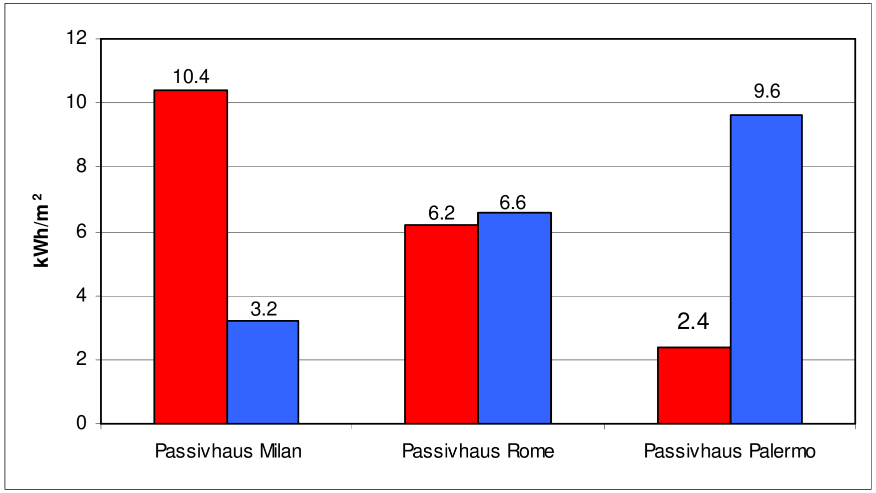

Fig. 3. 22 – Heating and cooling energy demand of the Italian *Passivhaus*

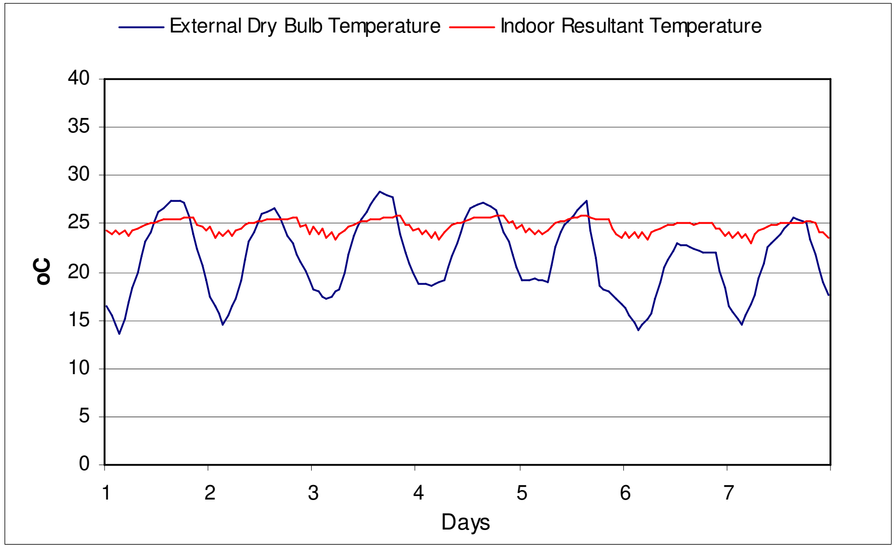

Fig. 3. 23 – The living room temperature in summer in Milan using passive cooling

3.5.4 The house

The climate of northern France is quite similar to the German climate, although somewhat milder because of the influence of the Atlantic Ocean. Therefore, a *Passivhaus* in northern France could look similar to a *Passivhaus* in Germany: very good insulation of the whole building envelope (typically 25 to 40 cm of insulation) without significant thermal bridge effects, air leakages reduced to a minimum, a supply and extract air system with highly efficient heat recovery and insulated window frames with triple, gas-filled, low-e glazing. This allows for simplification of the mechanical system: the heat distribution system can be replaced by one central supply air heater for the whole dwelling unit.

For two Mediterranean climates in southern France, namely Nice and Carpentras, *Passivhaus* proposals were developed by adapting this concept to the warmer climates of the south. The floor layout corresponds to a typical, two-story terraced house like they are being built in large quantities all over Europe, with an unheated basement, an open space on the ground floor and three bedrooms on the first floor. The houses are assumed to be south-oriented with the next row of houses situated at a distance of 23 m.

For Carpentras, the insulation level can be reduced to 15 cm in walls and roof and 8 cm in the basement floor. For the mild climate of Nice, it is already sufficient to use the legally required insulation level. Thermal bridge reduction is applied throughout, except for the load bearing walls between the basement and the first floor. Particularly, this corresponds to the use of exterior insulation, such that the interior walls and ceilings have no relevant thermal bridge effect when exterior dimensions are considered. Double low-e glazing with conventional frames turned out to be appropriate for both climates. Heat recovery ventilation together with leakage reduction is applied. In the mild Mediterranean climates, the same extremely low heating demands can be achieved even with a standard exhaust air system, but, e.g. in Carpentras, would require insulation thicknesses of more than 300 mm and insulated window frames.

Fig. 3. 24 – Hannover-Kronsberg *Passivhaus* rows (in front). The buildings' geometry is similar to the French *Passivhaus* proposal

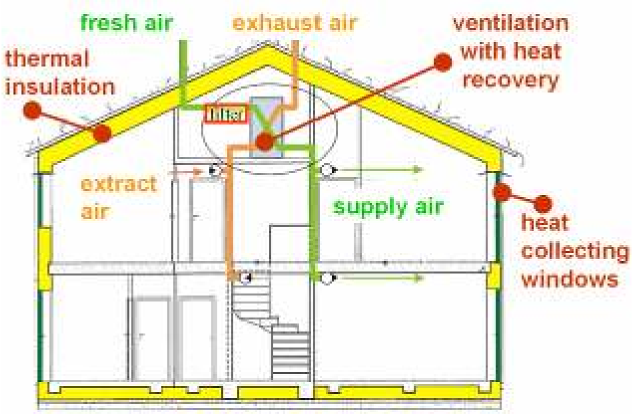

Fig. 3. 25 – Section of the *Passivhaus* for France. The visual appearance of the buildings can easily be adapted to suit local preferences

3.5.5 The strategy

The maximum daily average heat load is small enough to be covered by simple mechanical pre-heating of the supply air. Radiators and a separate heat distribution system are not necessary any more. The principle of heat generation is not of great importance, but direct electric resistance heating should not be used.

Due to the small peak heat load, building services may be significantly simplified. This reduces overall investment costs and thus justifies the higher investment for the efficient envelope. A significant cost reduction can often be achieved when compact heat pump units are used. These units use the exhaust air *after* the heat exchanger as a heat source for the integrated heat pump. The heat pump also heats a DHW storage. All required building services, i.e. heating, DHW and ventilation, are integrated in one unit, with its own integrated and tested control, that can simply be plugged in without the need for refrigerant handling on site. No energy carriers except electricity need to be connected and/or transported to the building.

During summertime, the insulation of walls and roof helps to limit the solar loads that penetrate into the building. Exterior shading devices are required for minimisation of solar radiation through the windows. As the average ambient temperature is below 25 °C during most of the time, the heat recovery of the ventilation system is by-passed during the cooling season.

The rest of the cooling strategies differ depending on the location. In Carpentras, due to the low night time temperatures and the acceptable levels of humidity ratio, night flushing with open windows is sufficient for thermal comfort. For Nice, with its higher humidity levels and less pronounced daily temperature swing, the supply air is cooled actively if required, thereby also achieving some dehumidification. It is technically possible to build compact heat pump units which also provide this supply air cooling, although they are currently not available on the market. The mechanical air change rate is still determined by the requirements of indoor air quality. Only moderate natural ventilation is assumed, which also accounts for users opening windows at pleasant ambient conditions.

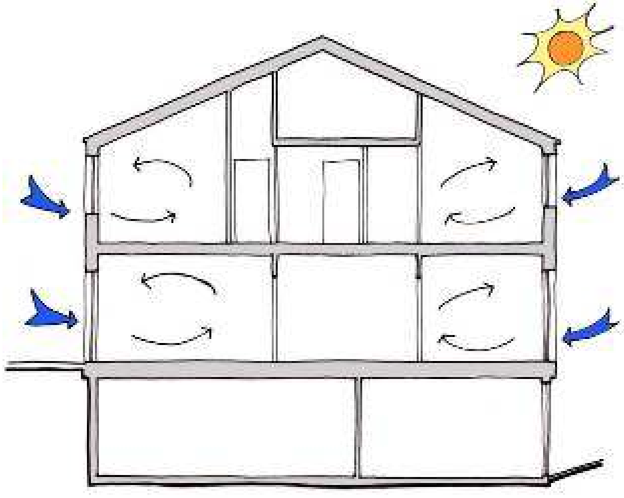

Fig. 3. 26 – Summer strategy

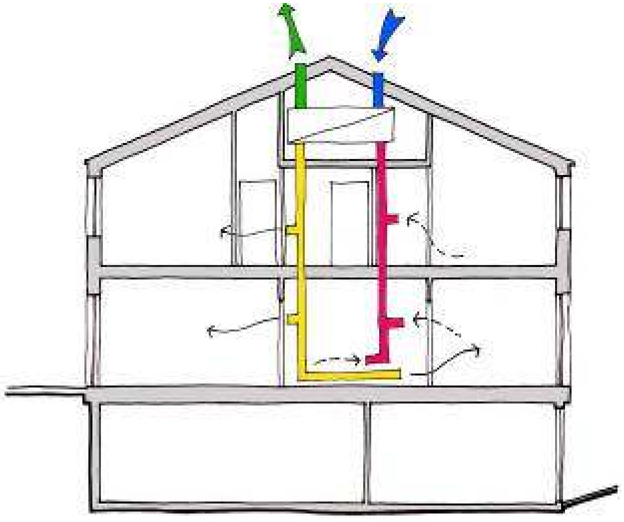

Fig. 3. 27 – Winter strategy

3.5.6 Performance: energy and comfort

In both Carpentras and Nice, the annual heating demand of the building is slightly below 15 kWh/m²yr. Occasionally, on sunny winter days, the indoor temperature will rise 1 or 2 K above the set point of 20 °C.

As described above, the examples in Nice and Carpentras follow different approaches for summer cooling. In Carpentras, due to the passive cooling concept, no cooling energy is required. Solar control and strong window ventilation during favourable periods (mainly at night) keep the temperatures below 25 °C during more than 99 % of the year in all rooms. In Nice, a similar result is achieved with supply air cooling and only moderate additional window ventilation. In both cases, the resulting temperatures stay well below the adaptive comfort temperature during summertime.

An issue that deserves further consideration is humidity. Above a humidity ratio of 12 g/kg, people start to feel uncomfortable regardless of the temperature. In addition, the relative humidity is to stay in the range of 30 to 70 %.

In the case of Carpentras, it was found that these requirements can be met with the passive cooling strategy during most of the time. The upper limit for the relative humidity is exceeded during less than 4 % of the year in all rooms; the fraction during which the absolute humidity limit is exceeded is even lower.

In Nice, on the contrary, the humidity ratios of the ambient air are significantly higher than farther inland. If only temperatures were concerned, passive cooling would easily be possible in this climate, similar to Carpentras. Without dehumidification, however, both upper humidity limits would be exceeded during 13 to 15 percent of the year in all zones. Supply air cooling and the corresponding dehumidification, on the other hand, result in comfortable conditions.

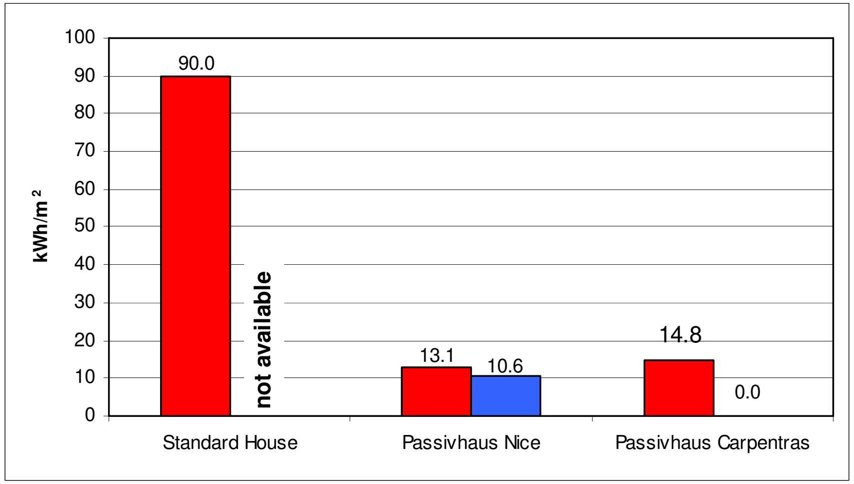

Fig. 3. 28 – Annual heating demand for Standard House and *Passivhaus*

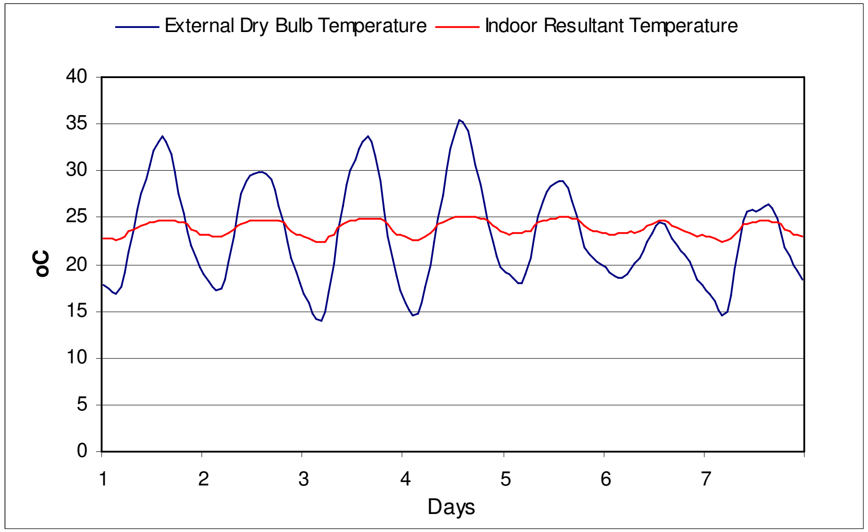

Fig. 3. 29 – Typical Dry Resultant Temperatures in summer without active cooling (Carpentras, maximum of all rooms used for living purposes)

4 CLIMATIC APPLICABILITY

4.1 INTRODUCTION

The aim of this chapter is to investigate the climatic applicability of the strategies and scenarios introduced in the national *Passivhaus* proposals. Although each national proposal contains one or two climatic locations per country, this does not mean that the examples illustrated can be generalised for each country respectively. Different climates, even within the same country, can imply that one specific design solution or passive strategy may work in one context but not in another.

4.2 CLIMATIC APPLICABILITY

The energy demand of a building depends on the climate and the thermal characteristics of the building envelope. The climate parameters that influence the building's energy demand are the outdoor temperature and the solar radiation. Potentially the heating and cooling demand can be assessed on the basis of 'degree-days' but this only takes temperatures into account and does not account for the influence of solar radiation. Thus, in order to compare two different climates we should compare both the outdoor temperature and the solar radiation. This means that it is possible to extrapolate the use of a passive technique/design strategy from one location to another when both have similar outdoor temperature and similar levels of solar radiation. But this poses two new questions: is it possible to compare outdoor temperatures? And: is it possible to compare radiation levels in different locations?

Summer and winter degree-days can be used to compare outdoor temperatures in different locations and determine the heating and cooling demand. The higher the cooling or heating degree-days, the higher the cooling or heating demand will be. However, by comparing the solar radiation as well as the summer and winter degree-days in two different locations and, being all factors equal, then one solution or technique valid for one climate is also valid for the other one.

With the next four maps, figures 4.1 to 4.4, we can compare the climatic parameters in different locations and, if these four parameters are equal, we can use all the techniques used in the *Passivhaus* of one location with the corresponding other location.

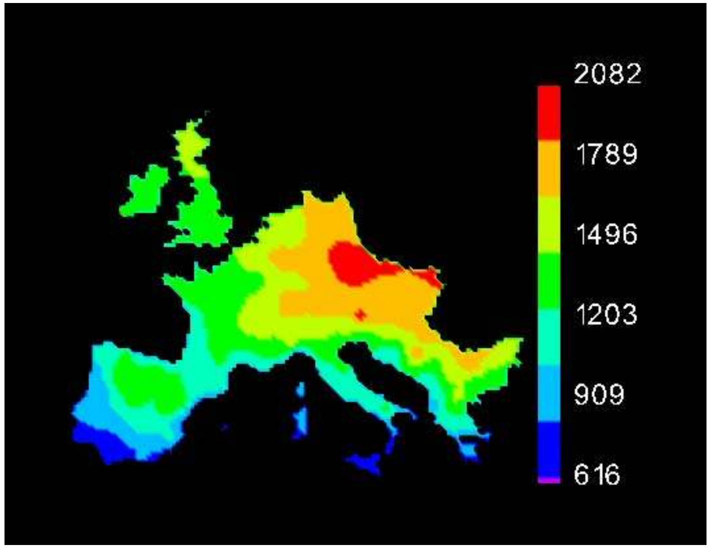

Fig. 4. 1 – Winter Degree-Days

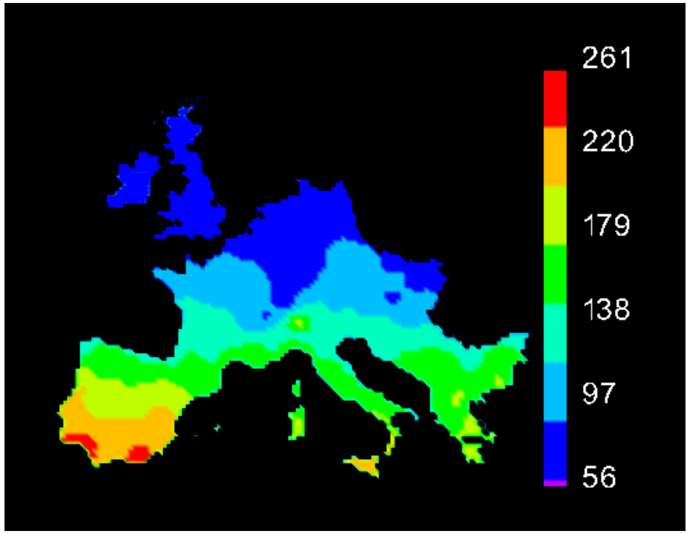

Fig. 4. 3 – Radiation over horizontal surface in winter (kW/m^2)

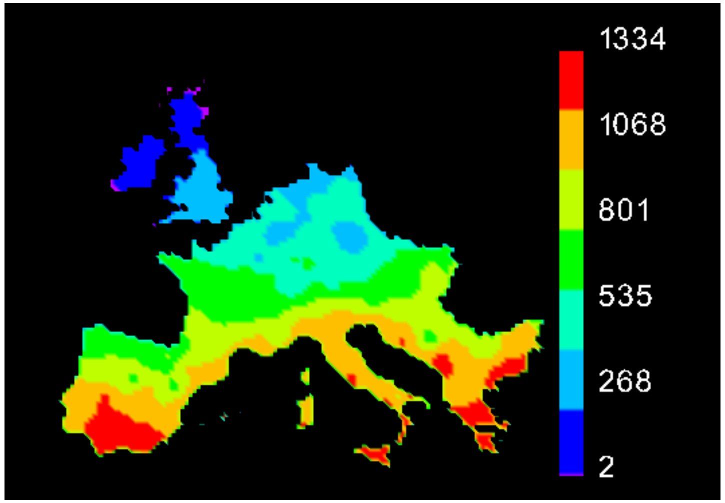

Fig. 4. 2 – Summer Degree-Days

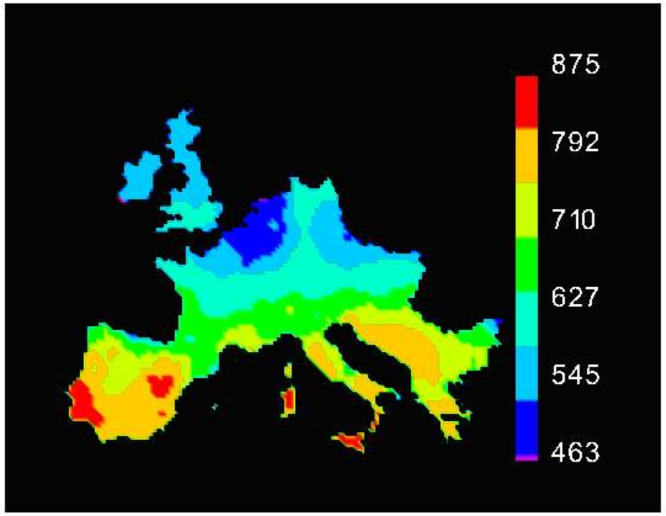

Fig. 4. 4 – Radiation over horizontal surface in summer (kW/m^2)

4.3 CLIMATIC SEVERITY INDEX

The impact of climate on space heating and cooling loads is sometimes expressed in terms of the number of 'degree days' for that location. However, as seen in 4.2, this does not account for the influence of either solar radiation or the thermal characteristics of a particular building.

The 'Climate Severity Index' (CSI) was developed to allow the characterization of climate in relation to a building of known envelope characteristics (Markus et al 1984). The CSI (a single number on a dimensionless scale) is specific for each building and location, and accounts for both temperature and solar radiation. The CSI is calculated separately to represent summer and winter conditions.

Two different winter climatic conditions can be considered identical if the heating demand is the same in a certain building, under both climatic conditions. In this case, we can say that both winter climatic conditions have the same Winter Climatic Severity (WCS). The same definition is valid for cooling demand and the term used would be Summer Climatic Severity (SCS). It is possible that two different climatic conditions have equal winter climatic severity (WCS), but different summer climatic severity (SCS). This can be seen if we compare for example Brighton, UK and Milan, Italy on Table 1.

To illustrate this variation around Europe, the heating and cooling demand have been determined for 8 buildings in 18 locations. Taking the average value of heating demand and cooling demand from all the buildings in each location, one heating demand and one cooling demand have been assigned to each location, and all values have been divided by the values for Madrid. The resulting values are shown in Table 4.1 and illustrated in the winter and summer CSI (fig. 4.4 and 4.5).

These maps, however, are useful for comparing climates and for identifying different climatic zones into a specific country but they are not appropriate for checking applicability of a specific technique in different locations. For this the maps and methodology explained in 4.2 must be used.

Table 4.1 – Climatic Severity Indexes in European locations

Location	**Winter Climatic Severity (WCS)**	**Summer Climatic Severity (SCS)**
Germany (Dresden)	3.31	0.00
Germany (Braunschweig)	2.56	0.05
Germany (Freiburg)	2.14	0.10
United Kingdom (Brighton)	1.83	0.01
United Kingdom (Glasgow)	2.59	0.00
United Kingdom (London)	2.22	0.01
United Kingdom (Newcastle)	2.59	0.00
United Kingdom (Nottingham)	2.36	0.00
France (Agen)	1.44	0.19
France (Carcassonne)	1.24	0.37
Italy (Milan)	1.81	0.46
Italy (Rome)	0.83	1.19
Italy (Trapani)	0.32	1.87
Portugal (Lisbon)	0.37	1.05
Spain (Seville)	0.32	2.56
Spain (Madrid)	1.00	1.00
Spain (Granada)	0.81	1.11
Spain (Burgos)	1.96	0.05

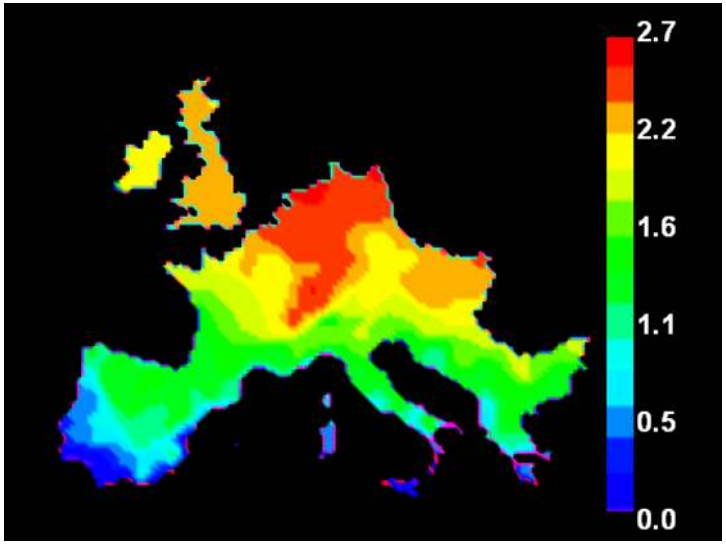

Fig. 4.5 - Winter Climatic Severity Index (WCS)

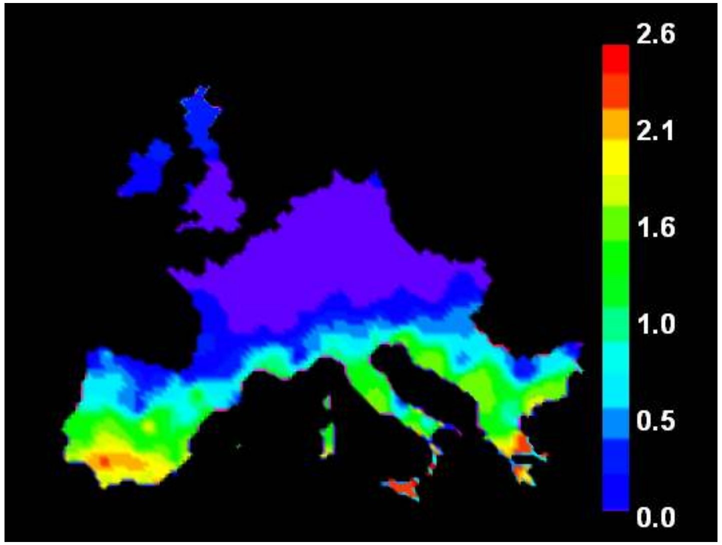

Fig. 4.6 - Summer Climatic Severity Index (SCS)

4.4 ENERGY SAVING MAPS

The next maps, from 4.6 to 4.9, show the average expected savings when improving some components. For the roof and walls, the savings have been expressed in all the cases in kWh per square meter of components when the improvement of their U-value is 0.10 W/m^{2}K; in the case of windows, the savings have been expressed in all the cases in kWh per square meter of glazing when double glazing are changing by double low-e windows.

An example is described below in order to clarify the underlying concepts. For instance, considering a roof with a U-value of 0.45 W/m^{2}K, a reduction of 0.1 W/m^{2}K (e.g. by improving insulation) will give us a new U-value of 0.35 W/m^{2}K. This could be easily achieved with 200mm of insulation with a thermal conductivity of 0.031 W/mK. In summary, by adding 200mm of insulation to the initial solution will lead to a mean energy saving of 6 kWh per square meter of roof in Paris or London; notice that this figure can be as high as 7 in Germany, or as lower as 3 in Lisbon (figure 4.7).

As the energy savings are proportional to the reduction in the U-value, if this is different from 0.1 W/m^{2}K, the mean energy saving can be calculated dividing the reduction of U-value by 0.1 and multiplying the resultant number by the figure in the map. For example, if the reduction in the U-value of the previous example was 0.15, the expected mean energy saving would be of 9 kWh per square meter of roof in Paris or London, this is the number in the figure 4.7 multiplied by 1.5 (i.e. 0.15/0.10).

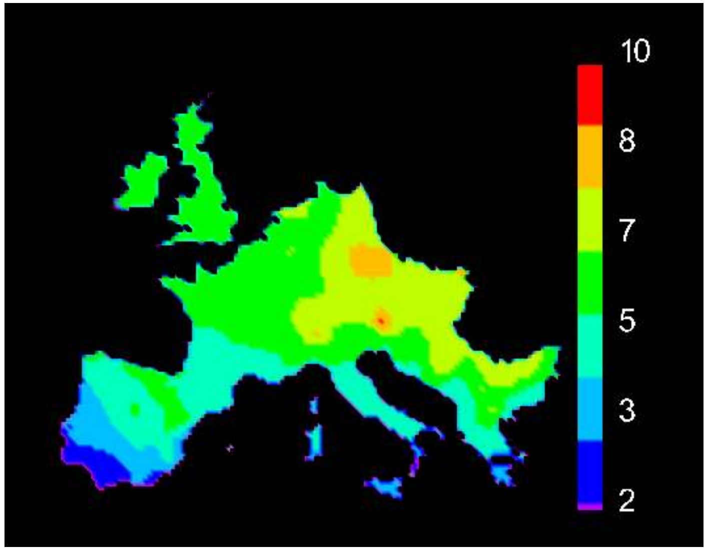

Fig. 4. 7 – Average Saving in kWh/m^2 of component: improving roof

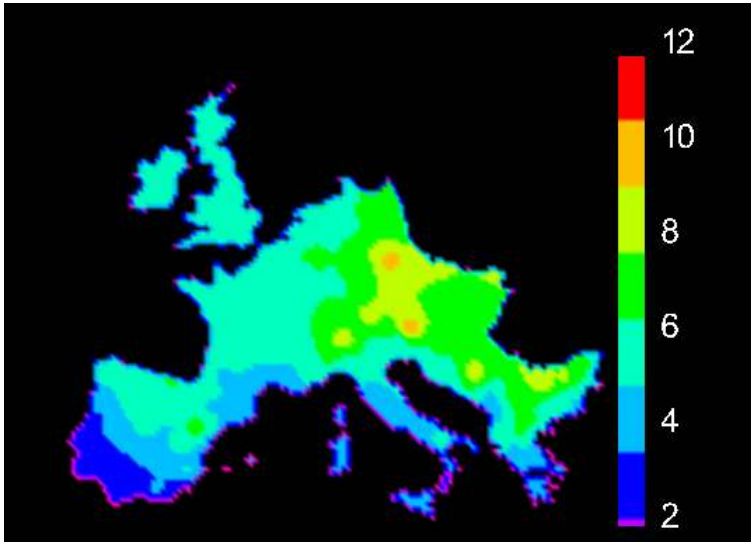

Fig. 4. 9– Average Saving in kWh/m^2 of component: improving N oriented façades

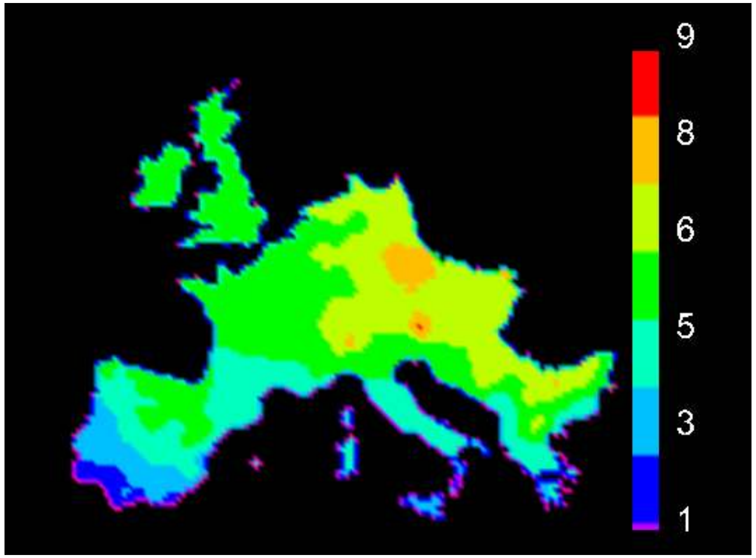

Fig. 4. 8 – Average Saving in kWh/m^2 of component: improving S oriented façades

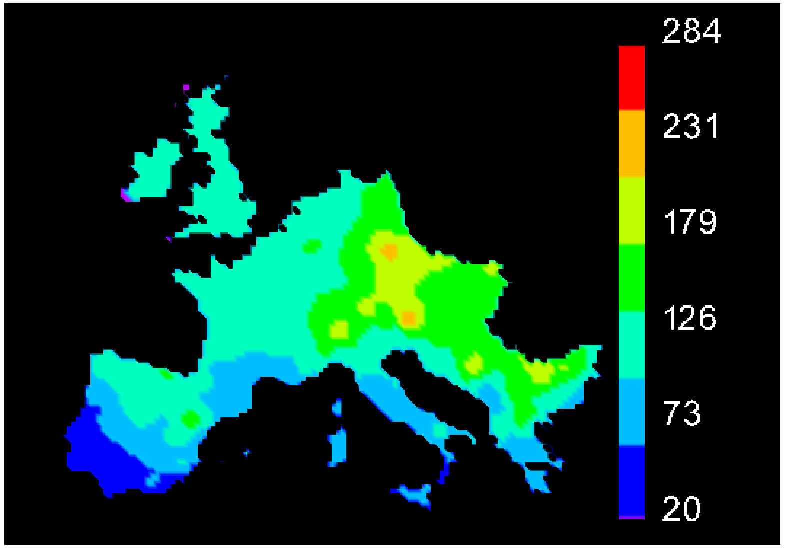

Fig. 4. 10 – Average Saving in kWh/m^2 of component: Improving N oriented glazing from double to low emissive

5 COST OF *PASSIVHAUS*

5.1 INTRODUCTION

The cost of the proposed *Passivhauss* was investigated in the context of the life cycle of the buildings. The economic analysis of each national alternative was undertaken as a result of the collaborative effort of all project participants, as their expertise, local knowledge and contacts with the construction industry were a vital part of the process.

The work aimed at estimating the energy and maintenance savings of the proposed optimised *Passivhaus* according to different building's life-cycle scenarios. The capital cost of construction for the standard and *Passivhaus* proposals in the target countries, as well as the detailed extra costs of the *Passivhaus* options, were estimated in order to appreciate the relative cost difference between the two and to undertake the life cycle cost analysis.

The capital costs estimate was based on publicly available information sources, mainly governmental and industrial statistical reports, on costs associated with the development of standard residential dwellings. The capital costs related to the optimised passive alternatives were estimated on the basis of the different strategies proposed by each partner and their associated components and materials costs.

The detailed extra capital costs required for the optimised passive solutions were established by identifying the different strategies adopted and by assigning the associated products, materials and labour costs to them. These extra costs were estimated by reference to a standard local dwelling. The present work shows figures for Germany, France, Spain (Granada and Seville), IT and the UK.

Life Cycle Cost Analysis (LCCA) is an economic appraisal technique that determines the total expenses associated with owning and operating a facility over a predetermined period of time. Hence, in the present case, the principles of LCCA are used to analyse the economic benefits of the 'optimised *Passivhaus*' proposed by each partner over a standard reference house, and concentrates its efforts on determining both the initial and the future expenditures associated with the operation of the dwellings. The expected economic benefits are analysed from an owner-occupier perspective, or alternatively, from a builder/developer view that would transfer the benefits to future owners.

It is worth noting that the strengths of an LCCA are not only the assessment of the total expenses associated with the optimised passive alternatives over a period of time, but the ability to compare the total costs associated with it to the ones derived from the reference standard alternative. This allows determining which option provides the best 'value for money'. Furthermore, since LCCA is based on a dynamic appraisal model, it considers expected increases in specific costs -i.e. heating fuel and electricity- while considering the opportunity cost of capital and the time value for money.

The main LCCA variables assumed were: the initial and future costs of ownership (1-2%); the period of time over which these costs are incurred or, alternatively, a predetermined period of analysis (10 and 20 years); and the discount rate that is applied to future costs to equate them into a present value (3.5%).

5.2 CAPITAL COSTS & EXTRA COSTS

The following table shows average building costs for standard residential dwellings and the expected building costs of the related passive alternatives. The estimated extra capital costs required to 'upgrade' the reference standard houses into 'passive' quality dwelling are also included.

	Standard House €/m²	***Passivhaus* €/m²**	**Extra Costs €/m²**	**Extra Costs (%)**
France	1100	1203	103	9
Germany	1.400	1.494	94	6.71
Italy	1.200	1.260	60	5
Spain (Granada)	720	744,1	24,1	3,35
Spain (Seville)	720	740,5	20,5	2,85
United Kingdom (€)	1.317	1390	73	5,54
United Kingdom (£)	881	930	49	5,54

As the table shows, the extra capital costs range between 2.85% (Seville) to 10% (France) of the respective standard houses buildings costs. This range reflects different realities in terms of building costs, construction traditions and building standards.

5.3 LIFE CYCLE COST ANALYSIS

The lifecycle costs associated with additional passive measures to reduce heating and cooling energy use in standard houses towards the *Passivhaus* standard was calculated for Italy, Spain, France, Germany and the UK, (a target of 15kWh/m^2 per year for heating and cooling – equivalent to a 'Class A' rated house or flats in the UK).

The following table summarises the individual outputs and allows for direct comparisons among partners. As mentioned before, comparisons should be done cautiously, as local realities and market constraints, which are reflected in the inputs for the calculations, have a significant effect on the results here provided.

It has been found that additional capital costs varied from 3 - 10% between the different centres (Spain requiring the best additional investment). Total energy savings measured against a standard house of the same floor area, were predicted to be between 25 – 65%. In all cases, the LCC over 20 years was lower for the *Passivhaus* than the standard house. In Spain, a reduced LCC was achieved within 10 years.

The discounted payback period varied from 4 – 19 years for the different countries. Moving south through Europe the discounted payback period reduces, from 19 years in the UK and Germany, to 8 years in Italy and 4 – 5 in southern Spain.

This indicates that, for owner occupiers and social housing providers, the additional investment can be regarded as very worthwhile.

Summary table

		France	**Germany**	**Italy**	**Spain Granada**	**Spain Seville**	**UK**
Extra Capital Costs (€/m^2)		103	94	60	24,1	20,5	73
Extra Capital Costs (%)		9%	6,71%	5%	3,35%	2,85%	5,54%
Total Energy Savings (kWh/m^2/year)		55	75,0	86,0	65,5	37,6	39,7
Total Energy Savings (%)		45%	50,0%	65,4%	57,3%	40,7%	26,4%
Extra Costs per saved kWh/m^2/year		1,87	1,25	0,70	0,37	0,55	1,84
LCC 10 years €	Standard	143.731	184.716	193.817	101.828	98.385	108.337
	Passive	152.621	190.104	190.437	95.676	96.100	111.988
LCC 20 years €	Standard	160.343	204.942	221.148	117.928	108.689	117.875
	Passive	160.552	200.579	198.458	103.647	102.290	117.256
Cost-Benefit Ratio, 10 years		-0,72	-0,48	0,39	2,13	0,93	-0,65
Cost-Benefit Ratio, 20 years		0,02	0,39	2,63	4,94	2,60	0,11
Discounted Payback Period (years)		19.5	19	8	4	5	19

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