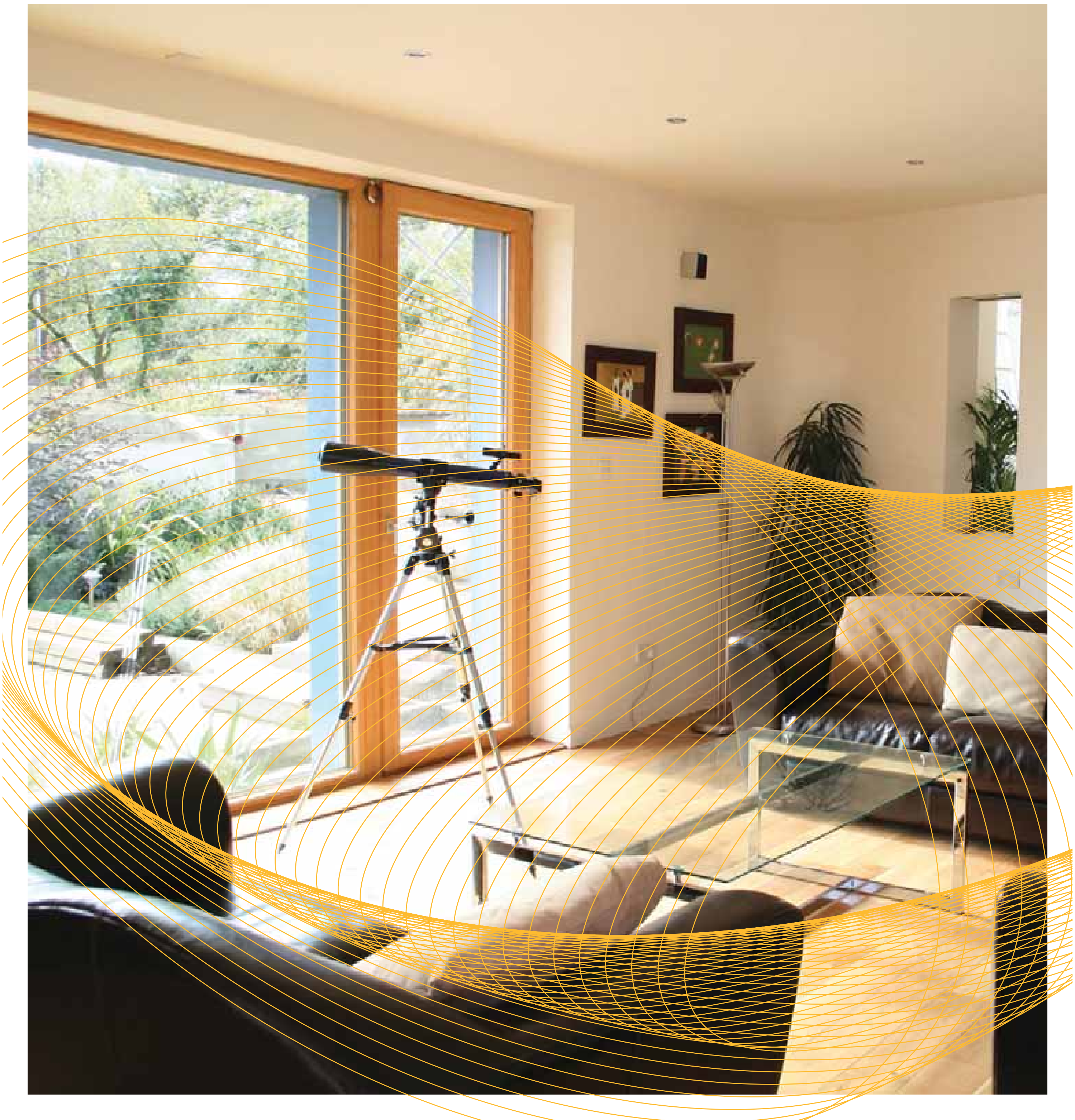
SEI SUSTAINABLE ENERGY IRELAND

Passive homes

GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF PASSIVE HOUSE DWELLINGS IN IRELAND



Sustainable Energy Ireland (SEI)

Sustainable Energy Ireland was established as Ireland's national energy agency under the Sustainable Energy Act 2002. SEI's mission is to promote and assist the development of sustainable energy. This encompasses environmentally and economically sustainable production, supply and use of energy, in support of Government policy, across all sectors of the economy including public bodies, the business sector, local communities and individual consumers. Its remit relates mainly to improving energy efficiency, advancing the development and competitive deployment of renewable sources of energy and combined heat and power, and reducing the environmental impact of energy production and use, particularly in respect of greenhouse gas emissions.

SEI is charged with implementing significant aspects of government policy on sustainable energy and the climate change abatement, including:

- Assisting deployment of superior energy technologies in each sector as required;
- Raising awareness and providing information, advice and publicity on best practice;
- Stimulating research, development and demonstration;
- Stimulating preparation of necessary standards and codes;
- Publishing statistics and projections on sustainable energy and achievement of targets.

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Prepared by MosArt Architecture, UCD Energy Research Group and SEI Renewable Energy Information Office

Table of Contents

Preface

By Dr Wolfgang Feist, Founder of the Passive House Institute, Germany

Energy Efficient Passive Houses – Reducing the Impact of Global Warming

The February 2007 report of the Inter-Governmental Panel on Climate Change (IPCC) has shown that climate change is already a very serious global issue. The negative effects it will have on the ecosystem, the world economy and on living conditions are anticipated to be on a massive scale.

Climate change is caused largely by human behaviour due mainly to the use of fossil fuels as our main source of energy generation. The magnitude of future climate changes is closely linked to worldwide CO_2 emissions into the earth's atmosphere. The worst effects of global warming, such as a thawing of the entire land-borne ice in Greenland and Antarctica, can still be prevented. However, this requires a substantial reduction in worldwide CO_2 emissions far below the current level.

There is hardly any doubt that an energy system ready for the future will have to be sustainable. Sustainable development is economic development that can be continued in the future without causing significant problems for other people, the environment and future generations.

Passive Housing can play a major role in reducing the impact of global warming. The energy requirement of a passive house is so low that a family will never again need to worry about energy price hikes. Passive Houses are virtually independent of fossil sources of energy and can be fully supplied with renewable energy if a compact heat pump unit is used in combination with an ecological electricity supplier. Due to the low energy requirement of passive houses the regionally available renewable energy sources are sufficient to provide a constant supply of energy for everyone.

Ireland's mild climate puts it in a favourable position to introduce Passive Houses to mainstream construction compared to the more severe climates prevalent in central Europe.

Foreword

Sustainable Energy Ireland is Ireland's national energy authority, set up to support Irish government energy policy objectives. Following the introduction of new legislation, most notably the European Community Directive on the Energy Performance of Buildings and the recent announcement of the intent to regulate and require the use of renewable energy systems in new buildings, we are seeing the emergence of extraordinary standards of energy performance for building construction in Ireland, as well as a rapid increase in the uptake of renewable energy technologies for building services.

Ireland is facing a number of serious challenges including rising energy costs and meeting our emissions obligations under the Kyoto protocol. These and other factors have given rise to a fundamental rethink in the way we design, construct and operate buildings. it is becoming clear that building 'green' has evolved and is fast becoming the preferred choice, providing high quality, high efficiency, dynamic and cost effective solutions for consumers and businesses. The passive house is the ultimate in low energy building and is recognised in Europe as the most advanced in terms of energy performance of buildings. Interestingly, the European Commission is set on implementing more stringent requirements for the refurbishment of existing buildings and moving towards the passive house standard.

Today, the passive house offers one of the most desirable technological and economical solutions for comfortable living and working. It can be applied to new and existing buildings in the commercial, industrial, public and residential sectors. With over 6,000 passive houses built in Europe, this well proven and tested innovative standard is now attracting significant interest in Ireland with pioneers like MosArt and Scandinavian Homes leading an emerging movement in the construction industry.

In response to the need to educate professionals and their clients on how to design, specify and construct passive houses and facilitate the further development of this standard here in Ireland SEI commissioned 'Guidelines for the Design and Construction of Passive House Dwellings in Ireland'. These detailed guidelines for self-builders and architects focus on new build houses and cover both conventional block construction and timber frame construction methods. They will ultimately become part of a suite of guidelines to cover, for example, multiple dwellings, non-residential buildings, extensions, renovations etc.

The guidelines cover the rationale and definition of the passive house standard, how to design and specify a passive house along with, construction options, associated services, cost considerations and lifestyle issues. SEI hopes they will be useful in increasing awareness and understanding of the key principles and techniques in designing, constructing and operating the ultimate low energy building – the passive house.

Brendan Halligan
Chairman, Sustainable Energy Ireland

Section One

The 'Passive House'

The 'Passive House'

1.1 Passive House and the Passivhaus Standard

A passive house[1] is an energy-efficient building with year-round comfort and good indoor environmental conditions without the use of significant active space heating or cooling systems. The space heat requirement is reduced by means of passive measures to the point at which there is no longer any need for a conventional heating system; the air supply system essentially suffices to distribute the remaining heat requirement. A passive house provides a very high level of thermal comfort and provision of whole-house even temperature. The concept is based on minimising heat losses and maximising heat gains, thus enabling the use of simple building services. The appearance of a passive house does not need to differ from a conventional house and living in it does not require any lifestyle changes. Passive houses are naturally well lit due to large glazed areas designed to optimise solar gains, as well as healthy buildings in which to live and work due to fresh air supply through the controlled ventilation system.

The Passivhaus Standard is a construction standard developed by the Passivhaus Institut in Germany (*http://www.passiv.de*). The standard can be met using a variety of design strategies, construction methods and technologies and is applicable to any building type.

This publication outlines the requirements in applying that standard in Ireland, and in all cases when referring to a passive house is describing a house built to the requirements of the Passivhaus Standard.

1.1.1 Definition of the Passivhaus Standard

The Passivhaus Standard is a specific construction standard for buildings with good comfort conditions during winter and summer, without traditional space heating systems and without active cooling. Typically this includes optimised insulation levels with minimal thermal bridges, very low air-leakage through the building, utilisation of passive solar and internal gains and good indoor air quality maintained by a mechanical ventilation system with highly efficient heat recovery. Renewable energy sources are used as much as possible to meet the resulting energy demand (Promotion of European Passive Houses (PEP) 2006), including that required for the provision of domestic hot water (DHW).

It should be noted that the primary focus in building to the Passivhaus Standard is directed towards creating a thermally efficient envelope which makes optimum use of free heat gains in order to minimise space heating requirement. While there are also limitations on the amount of primary energy that can be used by a dwelling for such demands as DHW, lighting and household appliances, this will not be the primary focus of these guidelines. That is not intended to imply that such energy uses are insignificant, however. In fact, a passive house may have similar DHW requirements as would apply to any typical house in Ireland and given the low energy required for space heating the energy demand for DHW will thus represent a relatively high proportion of the overall consumption. In order to address this, some guidance is provided on

Passive house in Ghent, Belgium (2004). Source: Passiefhuis Platform vzw.

Passive house in Oberosterreich, Austria (2000). Source: IG Passivhaus Osterreich Innovative Passivhaus projekte.

Interior of passive house in Oberosterreich, Austria (2000). Source: IG Passivhaus Osterreich Innovative Passivhaus projekte.

Passive house in Hannover, Germany (2004). Source: IG Passivhaus Deutschland Innovative Passivhaus projekte.

Air-leakage (or infiltration) is the uncontrolled penetration of outside air into a building. It takes place through openings, primarily through inadequate and imperfect sealing between window frames and walls, between the opening sections of the windows and along the joints of the building.

Thermal bridging refers to a material, or assembly of materials, in a building envelope through which heat is transferred at a substantially higher rate (due to higher thermal conductivity) than through the surrounding materials. Junctions between window or door and wall, wall and floor, and wall and roof should be designed carefully to avoid or minimise thermal bridging. A thermal bridge increases heat loss through the structure, and in some extreme cases may cause surface condensation or interstitial condensation into the construction. Surface mould growth or wood rot may be the consequences of a thermal bridge.

Measure/Solution	Passivhaus Standard for the Prototype House in the Irish Climate
1. Super Insulation	
Insulation Walls	$U \leq 0.175$ W/(m^{2}K)
Insulation Roof	$U \leq 0.15$ W/(m^{2}K)
Insulation Floor	$U \leq 0.15$ W/(m^{2}K)
Window Frames, Doors	$U \leq 0.8$ W/(m^{2}K)
Window Glazing	$U \leq 0.8$ W/(m^{2}K)
Thermal Bridges	Linear heat Coefficient $\Psi \leq 0.01$ W/(m^{2}K)
Structural Air Tightness	$n50 \leq 0.6$/ air changes per hour
2. Heat Recovery/ Air Quality	
Ventilation counter flow air to air heat exchanger	Heat Recovery Efficiency $\geq 75\%$
Minimal Space Heating	Post heating ventilation air/ Low temperature heating
Efficient small capacity heating system	Biomass, compact unit, gas etc.
Air quality through ventilation rate	Min 0.4 ac/hr or 30m^3/pers/hr
Ventilation Supply Ducts Insulated	Applicable
DHW Pipes Insulated	Applicable
3. Passive Solar Gain	
Window Glazing	Solar energy transmittance $g \geq 50\%$
Solar Orientation	Minimal glazing to north
Thermal Mass within Envelope	Recommended
4. Electric Efficiency	
Energy Labelled Household Appliances	A rated appliances
Hot water connection to washing machines/ dishwashers	Recommended
Compact Fluorescent or LED Lighting	Recommended
Regular maintenance ventilation filters	Recommended
Energy Efficient Fans/Motors	Recommended
5. On-site Renewables	
DHW Solar Heating	Area to be dictated by house size and occupancy
Biomass system	Recommended
Photovoltaics	Application in a case by case basis
Wind Turbine	Application in a case by case basis
Other including geothermal	Application in a case by case basis

Table 1. Technical Definition of the Passivhaus Standard for Ireland.

strategies to ensure that renewable energies are employed as much as possible for production of DHW.

Structural air-tightness (reduction of air infiltration) and minimal thermal bridging are essential. A whole-house mechanical heat recovery ventilation system (MHRV) is used to supply controlled amounts of fresh air to the house. The incoming fresh air is pre-heated, via a heat exchanger, by the outgoing warm stale air. If additional heat is required, a small efficient backup system (using a renewable energy source, for example a wood pellet stove) can be used to boost the temperature of the fresh air supplied to the house.

The energy requirement of a house built to the Passivhaus Standard is:

- Annual space heating requirement of 15 kWh/(m^{2}a) treated floor area (TFA), and
- The upper limit for total primary energy demand for space and water heating, ventilation, electricity for fans and pumps, household appliances, and lighting not exceeding 120 kWh/(m^{2}a), regardless of energy source.

Additionally, the air-leakage test results must not exceed 0.6 air changes per hour using 50 Pascal over-pressurisation and under-pressurisation testing.

In order to maintain high comfort levels in any building, heat losses must be replaced by heat gains. Heat losses occur through the building fabric due to transmission through poorly insulated walls, floor, ceiling and glazing as well as from uncontrolled cold air infiltration through leaky construction and poorly fitted windows and doors. In a typical older dwelling, such heat losses have to be balanced by heat gains mostly

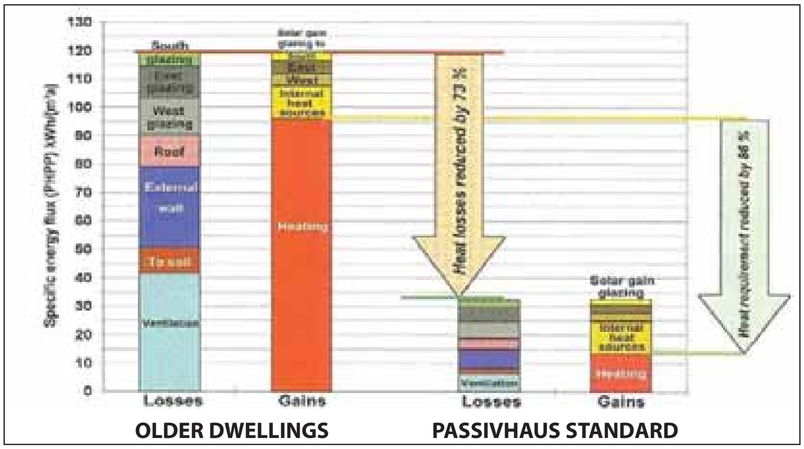
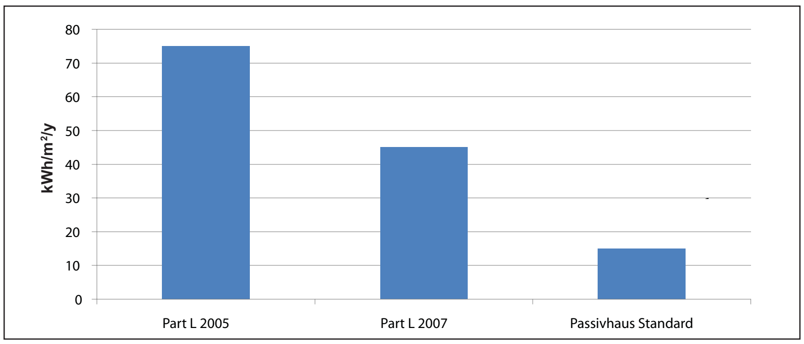


Illustration of comparative heat losses and heat gains in older dwellings and in dwellings built to Passivhaus Standard. Source: Passivhaus Institut. http://www.passiv.de.



Space heating energy comparison, Building Regulations (TGD) Part L 2005 and 2007 and the Passivhaus Standard . Source: Sustainable Energy Ireland

contributed by a space heating system. The internal heat gains from occupants and other sources such as household appliances as well as passive solar gains contribute a relatively small proportion of the total overall need in a conventional older dwelling. In a passive house, the heat losses are reduced so dramatically (through better insulation and airtight detailing) such that the same internal gains and passive solar gain now contribute a relatively high proportion of the total need. As a result of this, a smaller space heating system is required compared to that needed in a conventional older dwelling.

Primary energy, in kWh/year: This includes delivered energy, plus an allowance for the energy "overhead" incurred in extracting, processing and transporting a fuel or other energy carrier to the dwelling. For example, in the case of electricity it takes account of generation efficiency at power stations. SEI, Dwelling Energy Assessment Procedure (DEAP), 2006 version 2, pp. 28.

Delivered energy, in kWh/year: This corresponds to the energy consumption that would normally appear on the energy bills of the dwelling for the assumed standardised occupancy and end-uses considered.

A new built semi-detached, two storey Irish house built to comply with the requirements of Building Regulations Technical Guidance Document (TGD) Part L 2005, Conservation of Fuel and Energy), uses approximately 75 kWh/(m²a) energy requirement for space heating and 156 kWh/(m²a) primary energy. The equivalent house built to the requirements of TGD Part L 2007 would be liable to use 40-50 kWh/(m²a) delivered / useful energy for space heating and 90-95 kWh/(m²a) primary energy. The Passivhaus Standard requirement for space heating is 15kWh/(m²a). When compared, and having regard to constraints imposed by other requirements in the Building Regulations Part L, a passive house thus represents a saving of around 70% on space heating demand relative to a typical house built to the Building Regulations 2005, and around 60% relative to a typical house built to the Building Regulations 2007.

1.1.2 Technical Definition of the Passivhaus Standard for Ireland

In Table 1 a range of U-values is specified in order to meet the Passivhaus Standard of annual space heating requirement of 15 kWh/(m²a) for the Irish climate. Specifying U-values is dependent upon many variables and can only be verified through testing the performance of the dwelling design in the Passive House Planning Package (PHPP) software. The U-values included in Table 1 have been tested for the prototype passive house presented later in Section 3. This prototype house is a semi-detached two storey house of compact form. A detached bungalow house of sprawling form would require much lower U-values to meet the Passivhaus Standard. Due to the mild Irish climate, it is possible to meet the standard using U-values for walls in the prototype house that are higher than those typically recommended by the Passivhaus Institut for colder central European climates.

A sensitivity analysis was undertaken using different U-values for the prototype house in order to see whether it would be possible to relax the building fabric requirements e.g. in relation to glazing, in Ireland and still achieve the Passivhaus Standard. The results of this analysis are included in Section 2.

1.2 Applications of the Passivhaus Standard in the EU and Ireland

1.2.1 Evolution of the Passivhaus Standard in Europe

The Passivhaus Standard originated in 1988 by Professor Bo Adamson of the University of Lund, Sweden and Dr. Wolfgang Feist of the Institute for Housing and the Environment. The concept was developed through a number of research projects and first tested on a row of terraced houses by Dr. Wolfgang Feist in 1991 in Darmstadt, Germany. The Passivhaus Institut (*http://www.passiv.de*) was founded in Darmstadt, Germany in 1996 by Dr. Wolfgang Feist as an independent research institution. Since then, it has been at the forefront of the Passive House movement in Germany and has been instrumental in disseminating the standard throughout Europe and

Passive house in Guenzburg, Germany (2006)
Source: UCD Energy Research Group

Passive house Eusenstadt, Austria
Source: Construct Ireland Issue 2, Vol 3

Multi-family dwelling ' Hohe Strasse' Hannover, Germany Source: UCD Energy Research Group

Kronsberg Passivhaus Complex Hannover,
Source: UCD Energy Reseach Group

overseas. The Institut provides a number of services including: "Passivhaus Projektierungs Paket" (PHPP - Passive House Planning Package), a worksheet used to determine the energy supply / demand balance for passive buildings (available in Ireland from SEI Renewable Energy Information Office *email:renewables@reio.ie*); consultancy design of passive buildings and building components; and certification of quality approved passive houses (more details in Section 2).

Over 6,000 dwellings built to the Passivhaus Standard have been constructed all over Europe in recent years. This includes 4,000 in Germany and Austria,[2] where the Passivhaus Standard was first applied as well as Norway, Sweden, Denmark and Belgium and numbers are continuing to grow. CEPHEUS[3] (Cost Efficient Passive Houses as European Standards) was a research project (1998-2001) that assessed and validated the Passivhaus Standard on a wider European scale. The project was sponsored by the European Union as part of the THERMIE Programme of the European Commission, Directorate-General of Transport and Energy. Under CEPHEUS, 14 housing developments were built, resulting in a total of 221 homes constructed to the Passivhaus Standard in five European countries. Another project supported by the European Commission Directorate General for Energy and Transport is PEP, which stands for 'Promotion of European Passive Houses' (*http://www.european passivehouses.org*). PEP is a consortium of European partners aiming to spread the knowledge and experience on the passive house concept throughout the professional building community, beyond the select group of specialists.

1.2.2 Application of Passivhaus Standard in Ireland

The Kyoto Protocol was ratified in 2005 and the proposed targets of reducing greenhouse gas (principally CO_2) emissions by 8% compared to 1990 levels by the period 2008-2012 became legally binding for EU Member States (UNFCCC, 1997). Within the EU burden sharing agreement in this regard, Ireland's target limit of 13% above 1990 levels had been reached in 1997, and it is likely that the limit will be overshot by up to 37% (74Mt CO_2) by 2010 (O'Leary et al, 2005). The EC Green Paper on Energy Efficiency (EU, 2005), states that it is possible for the EU-25 Member States to achieve energy savings of 20% by 2010, and sees the greatest proportion of these savings (32%) coming from the built environment.

In Ireland the residential sector accounts for 25% of primary energy consumption and energy related CO_2 emissions (11,896 kt CO_2), the second largest sector after transport at 35%. The average dwelling is responsible for approximately 8.1 tonnes of CO_2 emissions, 4.8 tonnes from direct fuel use and 3.3 tonnes from electricity use. Irish dwellings have a higher average level of fuel, electricity and energy related CO_2 emissions per dwelling compared to the average of the EU-15 (SEI, 2008).

Following the Government White Paper 'Delivering a Sustainable Energy Future for Ireland' (DCMNR, 2007), and the subsequent Programme for Government, the Building Regulations Part L in respect of new dwellings have been strengthened to bring a 40% reduction relative to previous standards in respect of primary energy consumption and associated CO_2 emissions arising from space heating, water heating, ventilation, associated pumps and fans, and lighting energy usage. These provisions apply from July 2008. This policy has committed to a further review in 2010 with the aim of extending that improvement to 60%.

It is clear that the performance of both new build and existing housing stock must be addressed if we are to achieve the objectives set out both at European and national level. The energy requirement of a house built to Passivhaus Standard goes beyond the 40% improvement that applies from July 2008.

The Passivhaus Standard was first introduced in Ireland by the Swedish architect Hans Eek at the 'See the Light' conference organised by Sustainable Energy Ireland (SEI) in June 2002. Tomás O'Leary of MosArt Architects, a delegate at the conference, was so enthused by Mr Eek's presentation that he decided on the spot to sell his townhouse, buy a site in the countryside in Co. Wicklow and build a passive house. The O'Leary family has been living in the "Out of the Blue" house since Spring 2005. This house is the first Irish passive house to be certified by the Passivhaus Institut in Germany, and has been the focus of a research, demonstration and energy monitoring project funded by SEI. MosArt Architects, the Passivhaus Institute of Dr Wolfgang Feist and the UCD Energy Research Group are partners in the project. The project has been instrumental in establishing the basis for the deployment of the Passivhaus Standard in Ireland in different ways:

- it has provided a learning experience for professionals involved in the design, specification, construction and servicing stages
- it will provide a scientific basis for performance assessment through monitoring and evaluation
- it is an excellent demonstration tool and has been the focus of many visits, presentations and journal articles.

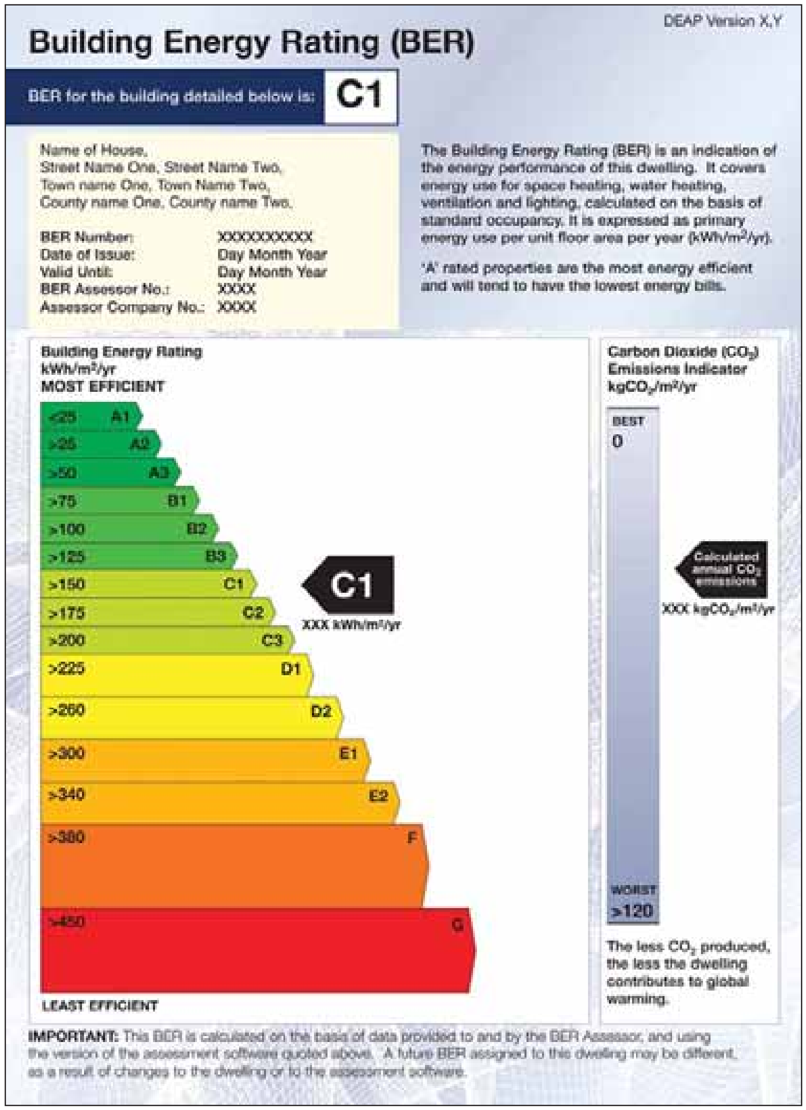
1.3 Dwelling Energy Assessment Procedure

1.3.1 Dwelling Energy Assessment Procedure

The Dwelling Energy Assessment Procedure (DEAP) is the Irish official procedure for calculating and assessing the energy performance of dwellings. The procedure takes account of the energy required for space heating, ventilation, water heating, associated pumps and fans, and lighting, less savings from energy generation technologies. The DEAP calculations are based on standardised occupancy and the procedure determines annual values for delivered energy consumption, primary energy consumption, CO_2 emissions and costs. These values are expressed both in terms of annual totals and per square metre of total floor area of the dwelling.

As the national methodology, DEAP serves two primary functions. The first is to demonstrate compliance with certain provisions in the Building Regulations and the second is to produce a Building Energy Rating for a dwelling.

The EU Energy Performance of Buildings Directive (EPBD) was transposed into Irish law on 4th January 2006. This states that when a building is constructed, rented or sold a Building Energy Rating (BER) certificate and label must be made available to prospective buyers or tenants. The BER is expressed in terms of KWh of primary energy/m^2/year. A passive house has the potential to achieve an A2 or even an A1 rating as shall be demonstrated in Section 3(MosArt).



Building Energy Rating Label. Source: Sustainable Energy Ireland.

1.3.2 Compliance with the Building Regulations

The DEAP methodology is used to demonstrate compliance with certain aspects of Part L of the Irish Building Regulations (The Conservation of Fuel and Energy - Dwellings: 2007). In particular, it is used to calculate the primary energy consumption associated with the space heating and ventilation, water heating, associated pumps and fans, and lighting requirements of a dwelling and to determine the amount of CO_2 emissions associated with this energy use.

If both the energy consumption and the CO_2 emissions are below the limits set by the regulations (determined relative to what would arise for a "reference dwelling" of the same dimensions) then the dwelling is deemed to be compliant.

1.3.3 Building Energy Rating

A Building Energy Rating (BER) is an objective scale of comparison for the energy performance of a building ranging from A1 to G (see graphic on previous page). Essentially a BER is an asset rating, based on a standardised occupancy and usage pattern, and is calculated for a dwelling using DEAP. The rating is the annual primary energy consumption of the dwelling expressed in terms of kWh per m^2 of floor area. The CO_2 emissions associated with this energy consumption are also reported on the BER certificate and expressed in terms of kg of CO_2 per m^2 of floor area.

Ireland's 1st Passivhaus, Wicklow
Source: Tomás O'Leary, MosArt Architecture

1.3.4 PHPP and DEAP

Whereas DEAP is the mandatory method for both producing a Building Energy Rating and for demonstrating compliance with certain aspects of the Irish Building Regulations, the Passivhaus Standard and the associated PHPP is a voluntary design standard for achieving low levels of total energy consumption within a dwelling.

While it is to be expected that a dwelling conforming to the Passivhaus Standard will comply with Irish Building Regulations Part L, a separate calculation using DEAP will be required to demonstrate both this and to determine its BER.

The Passivhaus Standard can be met using a variety of design strategies, construction methods and technologies. In general, the low energy consumption required to meet the standard will result in a dwelling achieving a favorable BER, provided that attention is paid to the advice outlined in later sections of these guidelines.

[1] *A passive house is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to fulfill sufficient indoor air quality conditions (DIN 1946) - without a need for recirculated air. Source: http://www.passivhaustagung.de/Passive_House_E/passivehouse_definition.html*

[2] *See http://www.passiv-on.org/*

[3] *See http://www.passiv.de/07_eng/ news/ CEPHEUS_final_short.pdf*

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Section Two

How to Design and Specify a Passive House in Ireland

How to Design and Specify a Passive House in Ireland

This section introduces the passive house building design process as well as explaining the balance between energy losses and gains. It also provides an overview of the various building systems and technologies typically employed in a passive house and presents the PHPP software used for energy balance calculations. The design and specification of the example prototype passive house in the Irish climate developed as part of these guidelines will be covered in greater detail in Section 3.

2.1 Building Design Process for a Passive House

Client's Brief

The design of a passive house will typically commence with developing a brief with the client, whether this is a family wishing to build a single rural dwelling, a Local Authority progressing a housing scheme or a commercial developer proposing a mixed residential project. The brief would typically outline the client's practical requirements in terms of space functions and density and also their preferred image or concept for the building(s). Clients interested in building a passive house will often have carried out some research on the subject and so may already be relatively well informed regarding the benefits of living in a passive house.

Site Visit

A site visit is important to identify the presence of structures, landform or evergreen trees which might cast shadows on the house during the short winter days when the sun is low in the sky (thus reducing the potential for achieving a glazed south facing façade). It may happen that the best views from the site are to the north suggesting the placement of large glazing areas on the northern façade in order to exploit that view. All orientation options must be considered by the designer at this stage – the house must not only function well in terms of energy efficiency but also in terms of optimising the potential of the site and its surroundings.

Sketch Design

The next phase of the design process is to develop a sketch design for the house. The basic principles of passive house design will greatly inform the development of the initial design. An ideal approach would be to have the longest façade of the house facing south, a bias of glazing towards the southern elevation with reduced glazing area on the northern elevation and a compact form in order to minimise surface to volume ratio. Shading devices may be required in order to protect against the risk of overheating in summer and the aesthetic integration of this is essential. In terms of internal layout, it is preferable to organise, where possible, family rooms and bedrooms on the southern elevation with utility room and circulation spaces on the northern elevation where availability of sunlight is not so critical.

Initial Evaluation of Energy Performance

Once the sketch design has been approved by the client, it is important to test the energy balance of the house design using the Passive House Planning Package (PHPP). The essential elements of the design are entered into the spreadsheet, including U-values of walls, floors, roof and glazing as well as orientation, volume, and size of the house. This will provide an early indication of whether the Passivhaus Standard is being achieved.

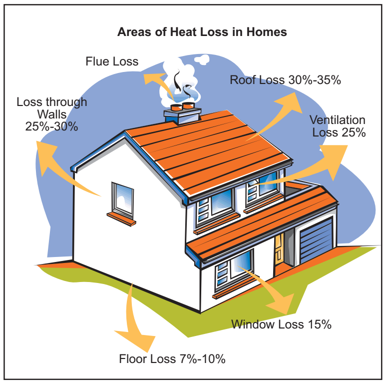
If the space heat requirement is significantly above the threshold of 15 kWh/(m^2a) then the building will have to be modified whether in terms of improved U-values, reorganisation of glazing or adjustment of form. The designer should intuitively know how improvements can best be achieved while broadly remaining true to the agreed sketch design. If the space heat requirement is significantly less than the threshold level, then it might be possible to increase the U-values and therefore save on insulation costs.

Care should also be taken to note other performance indicators calculated by the software, such as frequency of overheating, for example.

Detailed Design and Specification

The design of the house is next developed to the level of detail required to apply for planning permission. Typically this would not require all construction details but it is wise to consider the various technologies at this stage in order to avoid difficulties later on.

The type of construction will need to be considered, whether timber frame, masonry, externally insulated masonry, insulated concrete formwork, steel frame or straw bale as well as the space required for services such as solar panels, large domestic hot water tank, mechanical ventilation equipment with supply and exhaust ducting. The specification of such services might be outside the expertise of the house designer and it may be required to commission the services of a Mechanical and Electrical Engineer.



Comparison typical building fabric heat loss patterns in a detached dwelling, excluding ventilation and infiltration (Source: UCD Energy Research Group)

It is also critically important to plan ahead in terms of airtightness and cold bridging detailing as these often represent the most challenging aspects of passive house design.

The detailed design should be re-tested in the PHPP software to ensure that the Passivhaus Standard is achieved. At this stage all the required data fields have to be completed as accurately as possible (details of the PHPP tool datasheets are outlined in section 2.2.1). The result of this detailed test might suggest that minor alterations are required to the initial house design in order to meet the passivhaus standard. The client should be kept informed at all times of the decisions being made by the design team and have the opportunity to suggest alterations should the need arise.

Tender Documents and Drawings

Once planning permission has been granted, a more detailed set of technical drawings will be required in order to enable the construction of the house. As highlighted above, the emphasis will be on detailing of junctions between different elements of the building, practical requirements for minimising heat loss through cold bridging, planning for airtightness and the location and routing of services. The sizing of the ventilation equipment, backup space heating, solar domestic hot water system, as well as details of controls for space and water heating and ventilation, will have to be specified at this stage. The detailed drawings and specification can then be issued for tender to competent contractors.

Site Operations

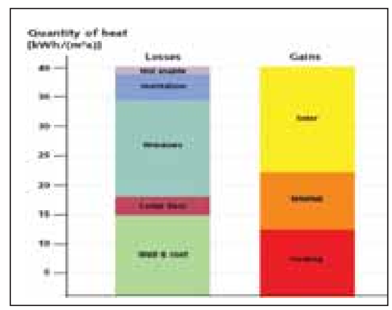
The detailed design of the passive house must now be realised on-site and quality control is paramount to achieving the standard envisaged in the PHPP software. The most challenging aspect will typically be achieving the required level of airtightness, as this is greatly affected by the quality of craftsmanship on site. The challenge becomes all the more difficult if the building contractor has no prior experience of building to the Passivhaus Standard. More challenging again is the common practice of the house built by 'direct labour' and without an experienced supervisor with overall responsibility to achieve the high standards set.

It will usually be necessary to engage specialist sub-contractors to supply and install such elements as the ventilation equipment, solar system, back up heating systems and controls.

Post Construction Testing

This is the final stage to determine whether the constructed dwelling actually meets the airtightness requirements of the Passivhaus Standard. The air-leakage must not exceed 0.6 air changes per hour using 50 Pa (0.6ac/h @ 50 Pa) overpressurisation and underpressurisation testing. An independent inspection and testing body should conduct the testing activities. It is important to undertake this test as soon as the airtight layer is complete so that any leaks can be rectified. Where the dwelling does not meet the requirements further testing may be required.

2.2 General Principles: Heat Energy Losses and Heat Energy Gains



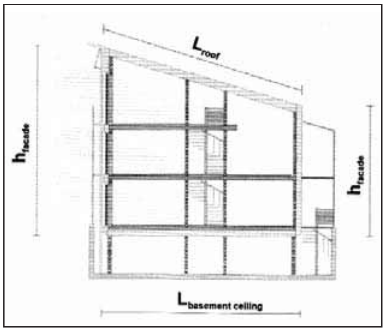
Comparison of energy rating between different German construction standards and the passive house. (Source: Passivhaus Institut, Germany http://www.passiv.de

2.2.1 Passive House Building Envelope

The building envelope consists of all elements of the construction which separate the indoor climate from the outdoor climate. The aim of the passive house is to construct a building envelope that will minimise heat loss and optimise solar and internal heat gain to reduce the space heating requirement to 15 kWh/(m²a).

Comparison between PHPP and DEAP

The dimensions used in PHPP are always external dimensions (Figure 2.2.1.1). DEAP calculates with internal dimensions.



Calculation of building element areas using external dimensions. Source PHPP 2007 Handbook, pg 37

The following building envelope parameters are fundamental in this process:

1. Well insulated building envelope
2. High energy performing windows and doors
3. Minimised heat loss through thermal bridging
4. Significantly reduced structural air infiltration
5. Optimal use of passive solar and internal heat gains

Building Envelope Insulation

Many building methods can be used in the construction of a passive house, including masonry, lightweight frames (timber and steel), prefabricated elements, insulated concrete formwork, straw bale and combinations of the above. The prototype passive house presented in this publication (details in Section 3) illustrates both masonry and timber frame construction as representative of the most typically used building methods for dwellings in Ireland.

Continuous insulation of the entire thermal envelope of a building is the most effective measure to reduce heat losses in order to meet the Passivhaus Standard.

A thermographic image can be used to illustrate the difference between good and poor levels of insulation in a house. Heat loss through the building envelope is highlighted by the green, yellow and red colouring. The green areas represent the best insulation whereas the red represents the warmest outer surface (hence the worst insulated). The amount of thermal radiation emitted increases with temperature, therefore warm objects stand out well against cooler backgrounds. In the passive house some heat is lost through windows but heat lost through external walls is very low. In the conventional building, on the other hand, there can be significant heat loss from the entire building envelope, especially through windows.

Insulation of the building envelope can be divided into four distinct areas: external wall, floor, roof and windows. Existing passive houses in Central and Northern European countries have been achieved with U-values for walls, floors and roofs ranging from 0.09 to 0.15 W/(m^{2}K) and average U-value for windows (including glazing and window frames) in the region of 0.60 to 0.80 W/(m^{2}K). These U-values are far below (i.e. better than) the limits currently set under the Irish Building Regulations, with the most marked difference pertaining to windows, wall and floor.

A sensitivity analysis using the Passive House Planning Package (PHPP), v. 2007, was undertaken using a range of U-values for the timber frame and masonry constructions of the prototype house using climatic data for Dublin. In all options tested, the same data input was used for airtightness 0.6ac/h@50Pa, ventilation and minimised thermal bridging. Various parameters were tested in order to determine, for example, the required level of U-values for the building envelope in the Irish climate, and to ascertain whether it would be possible to use double glazing and still achieve the Passivhaus Standard in Ireland. The results as outlined below are: Option 1 being the most energy efficient house and Option 8 being the least energy efficient. An

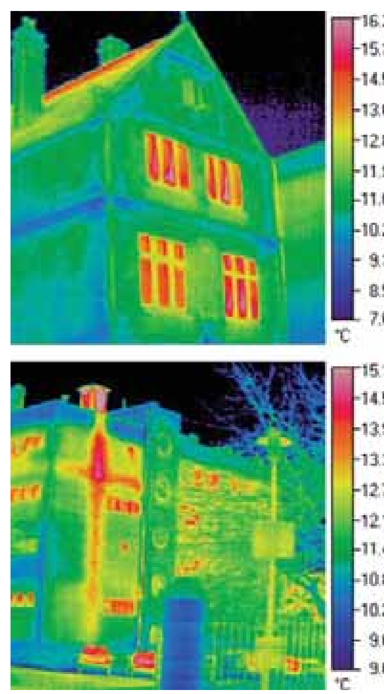
Thermal transmittance (U-value) relates to a building component or structure, and is a measure of the rate at which heat passes through that component or structure when unit temperature difference is maintained between the ambient air temperatures on each side. It is expressed in units of Watts per square metre per degree of air temperature difference (W/m^{2}K).

Source: Building Regulations Technical Guidance Document, Conservation of Fuel and Energy (TGD Part L) 2007.

Irish Building Regulations, Elemental Heat Loss Method (Building Regulations Technical Guidance Document L, Conservation of Fuel and Energy TGD Part L 2007).

Maximum average elemental U-value W/(m^{2}K)

- Pitched roof, insulation horizontal at ceiling level 0.16
- Pitched roof, insulation on slope 0.20
- Flat roof 0.22
- Walls 0.27
- Ground Floors 0.25
- Floors with underfloor heating 0.15
- Other exposed floors 0.25
- Windows and roof lights 2.00



Thermographic image illustrating difference in heat loss through building envelope in a conventional and passive house building.
Source:http://upload.wikimedia.org/wikipedia/en/f/f2/Passivhaus_thermogram_gedaemmt_ungedaemmt.png

Option	U-values of ext. wall	U-values of roof	U-values of floor	Average U-value of windows and doors	Space heating requirement
1	0.10 W/(m²K)	0.10 W/(m²K)	0.10 W/(m²K)	0.80 W/(m²K)	7 kWh/(m²a)
2	0.15 W/(m²K)	0.15 W/(m²K)	0.15 W/(m²K)	0.80 W/(m²K)	12 kWh/(m²a)
3	0.175 W/(m²K)	0.15 W/(m²K)	0.15 W/(m²K)	0.80 W/(m²K)	13 kWh/(m²a)
4	0.10 W/(m²K)	0.10 W/(m²K)	0.10 W/(m²K)	1.50 W/(m²K)	20 kWh/(m²a)
5	0.27 W/(m²K)	0.16 W/(m²K)	0.25 W/(m²K)	0.80 W/(m²K)	20 kWh/(m²a)
6	0.10 W/(m²K)	0.10 W/(m²K)	0.10 W/(m²K)	2.00 W/(m²K)	31 kWh/(m²a)
7	0.15 W/(m²K)	0.15 W/(m²K)	0.15 W/(m²K)	2.00 W/(m²K)	37 kWh/(m²a)
8	0.27 W/(m²K)	0.16 W/(m²K)	0.25 W/(m²K)	2.00 W/(m²K)	48 kWh/(m²a)

Sensitivity analysis of the prototype passive house in Ireland outline test results for eight options. Source: MosArt Architecture

outline description of each of the eight options analysed is provided. Only the first three achieve the Passivhaus Standard set for annual space heating of 15 kWh/(m²a) treated floor area:

- Option 1 – U-value 0.10 W/(m²K) for all building elements combined with triple glazed windows with average U-value (including glazing and window frames) of 0.80 W/(m²K) results in space heating requirement significantly below the standard limit required of 15 kWh/(m²a).
- Option 2 – U-value 0.15 W/(m²K) for all building envelope elements combined with triple glazing. The results show space heating requirement below the Passivhaus Standard limit.
- Option 3 – this is the option that has been used in the design of the prototype passive house in Ireland as part of these Guidelines, with U-value of 0.175 W/(m²K) for external walls and U-value 0.15 W/(m²K) for all other building envelope elements, coupled with triple glazed windows.
- Option 4 - U-value for all building envelope elements of 0.10 W/(m²K) combined with an efficient double glazed unit with low U-value of 1.5 W/(m²K) which does not achieve the Passivhaus Standard.

Note: Advantages and disadvantages of using triple glazed windows are discussed in detail in section 'Windows & Doors')

- Option 5 – U-values for walls, roof and floor employed at the limits of the individual elemental heat loss requirements in the Irish Building Regulations, (Building Regulations TGD Part L, Conservation of Fuel and Energy 2005 and 2007) combined with triple glazed windows, failing to achieve the required standard.
- Option 6 – also a failure is the combination of U-value 0.10 W/(m²K) for building fabric in combination with standard double glazed units.
- Option 7 – U-values 0.15 W/(m²K) for walls, roof and floor as the prototype house but with standard double glazing U-value 2.0 W/(m²K) which comes way above the limits set for the Passivhaus Standard.
- Option 8 – U-values for walls, roof and floor employed at the limits of the individual elemental heat loss requirements in the Irish Building Regulations, (Building Regulations TDG Part L, Conservation of Fuel and Energy 2005 and 2007) and standard double glazed units, failing to achieve the Passivhaus Standard.

Note: Results presented here are indicative only and should be used as starting point for specification of a passive house dwelling in Ireland. Meeting the Passivhaus Standard must be tested and verified with the PHPP software for the specific dwelling design.

Thermal Conductivity

Thermal conductivity (λ-value) relates to a material or substance, and is a measure of the rate at which heat passes through a uniform slab of unit thickness of that material or substance, when unit temperature difference is maintained between its faces. It is expressed in units of Watts per metre per degree (W/mK), (Building Regulations Technical Guidance Document Part L, Conservation of Fuel and Energy 2007). Insulation materials for walls, roofs and floors vary in terms of thermal conductivity. Typical conductivities for different insulation materials are included below as well as the approximate thicknesses required in order to achieve a wall (or roof) U-value of 0.15 W/(m²K) and 0.10 W/(m²K)

Typical insulation materials used in Ireland include mineral/rockwool, polystyrene, polyurethane, polyisocyanurate, sheep wool and hemp. Different insulation materials may suit different types of construction application and it is important to consider the material best suited for the situation and pay attention to detail in its proper installation. For example, quilted or loose fill insulation is generally suitable for use on the floor of an open attic space where it will fill completely between ceiling joists, but care needs to be taken in ensuring ventilation in the attic whilst avoiding risk of wind displacement of insulation near eaves. In contrast, rigid insulation may be at lower risk of displacement by wind, but would need to be cut perfectly to fit snugly between the joists, to avoid a risk of thermal looping or leakage. As a further example, a high density rigid insulation tends to be better suited under a floor slab compared with insulation that easily compress or are affected by moisture.

The U-value of the construction is determined by the conductivity of materials and components used from the internal surface to the external surface of the thermal envelope. Examples of typical construction methods and materials used for the prototype passive house in Ireland are illustrated later in Section 3.

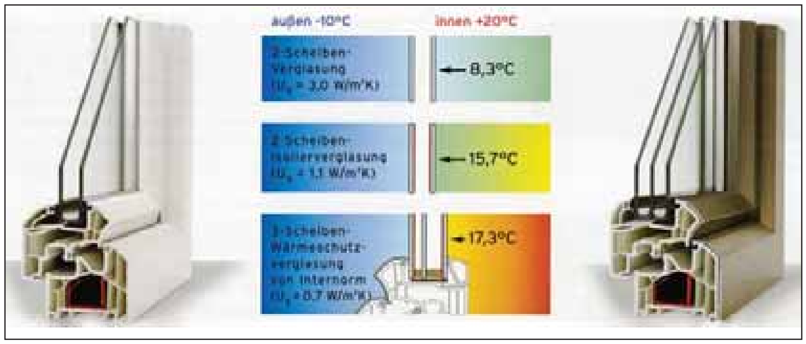
Windows & Doors

The recommended approach to the design of a passive house is to have avoid an excessive area of north facing glazing and place relatively large windows facing south or due south. This is in order to minimise heat losses through the north facing elevation, which receives no direct sunlight during most of the heating season, while maximising 'free' solar heat gains on the south. An advantage of large windows is an increase in interior daylight levels which in turn reduces the need for use of electricity for artificial lighting and also ensures a more pleasant natural light-filled living environment.

There is, however, a balance to be achieved between heat losses through the glazing and solar heat gains through the south/east/west facing windows. When designing a passive house, the PHPP software should be used to calculate the heat losses and heat gains taking into account building orientation, areas of glazing and specific types of glazing so the optimum balance of glazing for each passive house design can be reached. Also, as highlighted further below, there is a need for the design to ensure that the risk of solar overheating is minimised.

It has been illustrated above that the use of windows and doors with average U-values of 0.8 W/(m²K) can be combined with U-values for opaque elements of 0.15 W/(m²K) to comfortably achieve the Passivhaus Standard in Ireland. There are

Light filled room in a passive house. Source: MosArt Architecture.



Comparison of the interior surface temperature depending of the type of glazing. Source: Internorm, fenster – Licht und Leben catalogue 2007/2008, pp.91.

a number of advantages in using windows with average U-values of 0.8 W/(m²K) as well as highly insulated doors, principally the assurance of a comfortable indoor climate due to the lower cold radiation heat transfer at the surface of the glass. One will not sense a drop in temperature standing immediately adjacent to this standard of window, unlike the experience of standing next to a conventional double glazed unit with U-value, for example of 2.0 W/(m²K). An added benefit of using highly energy efficient windows and doors includes significant draught reduction due to the fact that they have typically two seals or gaskets (compared with conventional double glazed units which often have only one) as well as excellent sound insulation. Finally, natural convection which is driven by temperature difference between the inside face of the glass and the room interior is much reduced, thereby avoiding this source of cold air flows and thermal discomfort.

The sensitivity analysis for a passive house dwelling in Ireland showed that in the case of Option 4 above the Passivhaus Standard yearly space heating requirement could not be achieved with efficient double glazed windows with a U-value of 1.5 W/(m²K).

Typically triple glazed window units are used in passive houses in Central and Northern Europe. The Passivhaus Institut has certified a range of glazing and door units suitable for use in passive house buildings. Although it is not a prerequisite to use certified passive house products (http://www.passiv.de) in a passive house, choosing approved products means the validity of technical data has been tested and verified by an independent certifier. The principal characteristics and advantages of using triple glazed windows in a passive house are listed below, for both glazing and the frames:

Insulation Material Type	Thermal conductivity W/mK	Thickness for U-value of 0.15 W/(m²K)	Thickness for U-value of 0.10 W/(m²K)
Polyisocyuranate or polyurethane	0.023	145mm	220mm
Polystyrene, sheep wool	0.035	220mm	340mm
Cellulose, Hemp and Rockwool	0.04	250mm	400mm
Wood	0.15	825mm	1,250mm

Conductivity of insulation materials and approximate thickness to achieve specific U-value for external walls (k values will vary according to density). Source: MosArt Architecture

Cross section though a triple glazed insulated window and frame. Source: MosArt Architecture.

Glazing:

- Three panes of glass separated by special low-conductivity spacers eliminates the risk of condensation at the bottom of the glass in cold weather (which could lead to rotting of timber frames over time);
- High solar energy transmittance (g ≥ 50), referring to the amount of solar radiation which can penetrate the glass and thereby contribute towards heating of the dwelling;
- A low emissivity (low-e) coating on the inside of the outer two panes which reduces thermal re-radiation back out through the glass. It should be noted that a 'soft coat' has slightly better U-value but a 'hard coat' glazing has higher solar transmittances.
- Insulating gases between the glass panes, typically argon or krypton, which help to reduce heat escaping through the glass.

The quantity which describes the heat loss associated with a thermal bridge is its linear thermal transmittance (ψ). This is a property of a thermal bridge and is the rate of heat flow per degree per unit length of bridge that is not accounted for in the U-values of the plane building elements containing the thermal bridge.

Source: SEI, Dwelling Energy Assessment Procedure (DEAP) 2005 edition, version 2, pp.55

- With triple glazing the solar energy transmittance (gs), i.e. the amount of solar energy entering through that glazing is somewhat reduced compared to double glazing due to the effect of the additional layer of glass. A requirement of the Passivhaus Standard is to use glazing with minimum solar transmittance of 50% or higher.

Frame:

- The frame must be well insulated and also have a thermal barrier (be "thermally broken"). Even wood conducts heat and a thermally broken timber window frame will result in much lower heat losses than a solid one.
- There will typically be two weather gaskets on triple glazed windows used in a passive house dwelling, the primary function of the outer one being for weathering with the inner one serving to improve airtightness. The majority of these types of window open outwards which is commonplace in Continental Europe; however, there are models of inward opening windows being developed which will be available soon in the Irish market. One advantage of outward opening windows is that they don't intrude in the room space which might be important in more compact dwellings.
- Triple glazed window frames are typically much wider and stronger construction than their conventional double glazing counterparts.

The use of larger areas of glazing on the south elevation is helpful in maximising the amount of sunlight available in the short days of winter. It must be remembered, however, that highly energy efficient windows allow less daylight (visible light transmittance) into a building than normal double glazed windows without e-coating. Light transmittance is an optical property that indicates the amount of visible light being transmitted through the glazing. It varies between 0 and 1 (0 to 100% light transmitted), representing the proportion of light transmitted. A double glazed window with low-e coating will typically transmit 72% of visible light. A triple glazed energy efficient window will typically transmit 65% of visible light (these are indicative values only - actual values depend on the manufacturer's specification).

In a conventionally constructed older house in Ireland radiators are typically positioned under windows in order to heat the cold air entering through the single or double glazing. In a passive house, locating a heat source beneath windows is simply not required as the heat load is transferred throughout the house via the mechanical ventilation system. This has the added benefit of enabling unobstructed use for placing furniture against all external walls.

Thermal Bridging

Thermal bridging (i.e. un-insulated joints between walls, floors/ walls, ceilings/ adjacent walls, windows/walls etc) are weak points of thermal resistance in the building envelope and cause unwanted losses of energy which should be eliminated or significantly reduced to a degree that the associated heat losses become negligible.

A thermal bridge increases heat loss through the structure, and in some extreme cases this may cause surface condensation or interstitial condensation in the structure. Surface mould growth or wood rot may be the consequences of a thermal bridge. Typical effects of thermal bridges are:

- Significantly increased heat losses;
- Decreased interior surface temperature (cold spots) which may also result in high humidity in parts of the construction; and
- Mould growth cause by warm internal air condensing on cold surfaces.

All of the above situations can be avoided in houses built to the Passivhaus Standard. The Passivhaus Standard for linear thermal transmittance (Ψ) should not exceed 0.01 W/(mK). This requires the building designer to identify and locate all potential thermal

Comparison between PHPP and DEAP

Thermal bridges are calculated in PHPP on the external face of the thermal envelope whereas in DEAP the thermal bridges are calculated on the internal surface of the envelope.

bridging in the construction, applying careful specification and detailing of those elements providing where possible a continuous layer of insulation, as well as taking care to execute those elements on site as per design details.

Designing and building a passive house in Ireland requires the development of construction details that go far beyond guidance provided (to avoid excessive heat losses and local condensation) in Building Regulations Technical Guidance Document Part L, Conservation of Fuel and Energy. Building practitioners could refer to the accredited construction details specifically developed for passive house building published in Germany "Thermal Bridge-Free Construction" (PHPP 2007, pp.96). Thermal bridging can be tested and verified in the PHPP software as the design of the passive house building is being developed.

Structural Airtightness and Draught-Proofing

Building an airtight or leak-free structure is imperative to achieving the Passivhaus Standard. If there are gaps in the building structure then uncontrolled amounts of cold external air can infiltrate the building. Achieving a high level of airtightness eliminates cold draughts and associated comfort losses. It also prevents condensation of indoor moist, warm air penetrating the structure, and possible structural damages due to decay, corrosion and frost.

Air tightness is achieved in masonry construction by careful application of appropriate membranes and tapes or wet plastering within the building envelope. A great deal of attention must be paid to detailing and workmanship in order to ensure that the airtight layer is continuous all round the building, especially around junctions between walls and floors, roof, windows, doors, etc. Penetrations of the airtight layer by mechanical and electrical services must be properly sealed.

The air tightness of a building can be accurately measured by carrying out a blower-door test. The test involves placing a powerful fan suspended in a sealed canvas sheet within a door opening and operating the fan at very high speeds thereby creating either negative or positive pressure within the house. By sucking air out of the house, for example, a negative pressure is created with the result that external air will be sucked in through any gaps or cracks in the building envelope. The pressure used for such tests is 50 Pascal which can be accurately set by the blower door equipment.

When undertaking the test it is usually quite easy to identify any major leaks due to the presence of a strong draught which can be felt by the hand or, for smaller leaks, can be detected by a thermographic camera. The cause of these draughts can then be sealed with appropriate materials as the test is on going. It may also happen that the leaks in the envelope are very minor and therefore difficult to locate. In these situations it is typical to reverse the direction of the fan and blow air into the house putting it under positive pressure. Odorless smoke can then be released into the building and leaks can be observed from the outside where the smoke appears through the envelope. It is important to notify the fire service if you are carrying out such a test in case it is mistakenly reported as a house fire by passers by.

The Passivhaus Standard is reached when there are less than or equal to 0.6 air changes per hour @50 Pa pressure.

The most critical issue regarding testing for airtightness is timing during the building process. It is important that remedial measures can be carried out in order to remedy any leaks or cracks. The test should be carried out before second fix carpentry, for example, where there are no skirting boards or window boards fitted and where the junctions covered by such materials are still accessible and can be sealed. The test should also be carried out after all mechanical and

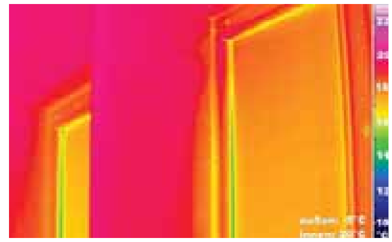
Comparison between PHPP and DEAP

In the ventilation sheet of PHPP the air changes @ 50 Pa have to be entered. The DEAP calculation uses air changes @ normal pressure for its inputs.

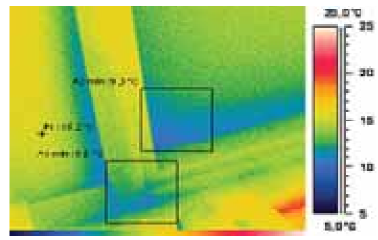
The results of the blower door test @ 50 Pa have to be divided by 20 to enter the correct value in DEAP

Example: 0.6 ac/hr / 20 = 0.03 ac/hr

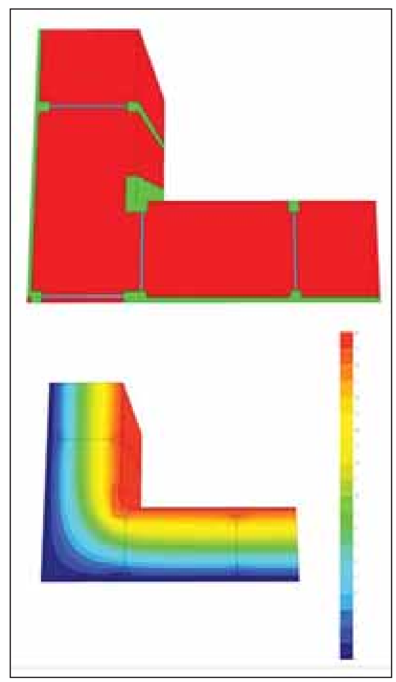
Input PHPP: 0.6, Input DEAP: 0.03



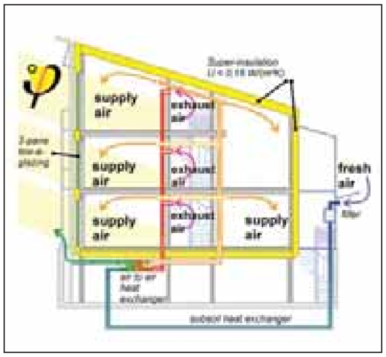
Infrared image of the interior of a passive house window. All surfaces (wall structure, window frame, and the glazing) are pleasantly warm (over 17 °C). Even at the glass edge, the temperature does not fall below 15 °C (light-green area)
(Source: Passivhaus Institut, http://www.passiv.de from the passive house Kranichstein)



For comparison, a typical older double glazed window is shown. The centre of glass surface temperature is below 14 °C. In addition, there are large thermal bridges, particularly where the window meets the external wall. The consequences are significant radiant temperature asymmetry, drafts, and pooling of cold air in the room.
(IR-photography: Passivhaus Institut offices, http://www.passiv.de)



Timber Frame I-Beam construction reducing thermal bridging. Source: Passivhaus Institut, Germany.



Correctly insulated house avoiding thermal bridge. Source: Passivhaus Institut, Germany

Continuous Airtight Membrane. Source: Passivhaus Institut, Germany

Timber frame house pre-cladding fitted airtight membrane. Source: Passivhaus Institut, Germany.

electrical services that need to penetrate the building envelope have been installed. Otherwise, installing such services after the test could severely compromise the airtightness of the building.

In a typical Irish house built in accordance with TGD Part F 2002 the method in which habitable rooms are ventilated has usually been via a hole in the wall or ventilator in the windows of 6,500mm^2 fitted with a controllable grille. Such means of ventilation can result in large amounts of cool external air infiltrating the building depending on wind speed and pressure. The same is true for open chimneys or flues in conventional houses.

In a passive house, on the other hand, the supply of fresh air is provided by a whole house mechanical ventilation system with heat recovery which negates the necessity for openings in the wall or windows. Thereby draughts are eliminated and structural air tightness is not compromised.

In developing the building design it is very important to anticipate differential movement and decay of adhesives and chemical bonds by detailing junctions which will assist in maintaining an airtight layer for the life of the building. Many excellent details, for example, can be found at the website of the Scottish Ecological Design Association (www.seda2.org/dfa/index.htm). It can also be important to use membranes and plasters that are both airtight but also vapour diffuse which allow the structure to "breathe" to its cold side. This means allowing moisture within the structure to escape to the outside thereby reducing the risk of interstitial moisture and the threat of rot and decay over time.

There are two measurements used to define airtightness, namely cubic metres of air per square metre of exposed fabric per hour (m^3/m^2/hr) or air changes per hour (ACH). While the measured result for the former is generally 20% greater than that of the latter, the difference is practice greatly depends on the building form.

Example to convert:

The prototype house in section 3 has a volume of 503.40 m^3 and a total envelope area of 324.21 m^2.

The blower door test result is assumed, with 0.6 ac/h @ 50 Pa

503.40 m^3 x 0.6 ac/hr / 324.21 m^2 = 0.47 m^3/m^2/hr

Passive Heat Gains

Passive heat gains in a passive house are a result of the combination of solar gains and internal gains.

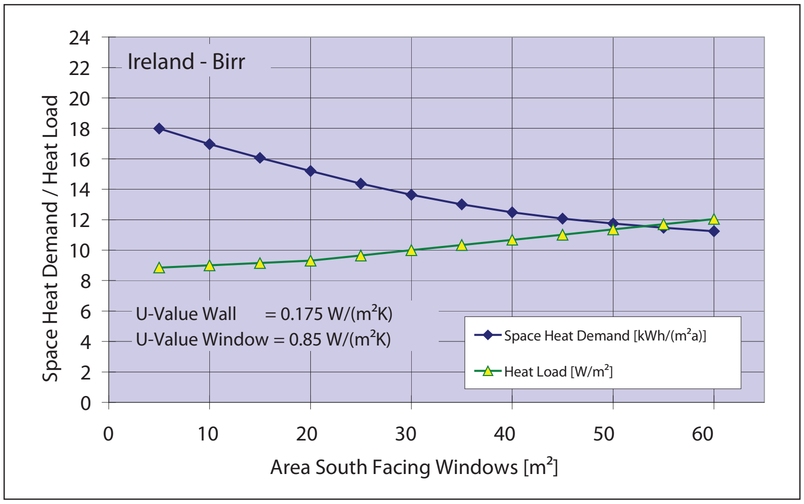
Solar Heat Gains

Passive solar gain is optimised by providing an east-west alignment to the building, if possible with the site, resulting in the longest façade facing south, and by placing the majority of the glazing towards the south. Very high quality windows (average U-value ≤ 0.8 W/(m^{2}K)) facing south will have a positive thermal balance – they will have more heat gain than heat loss throughout the year. Results of a recent parametric study by J. Schnieders of the Passivhaus Institut "Climate Data for Determination of Passive House Heat Loads in Northwest Europe" illustrates the relationship between the area of south facing glazing and the space heat demand for a passive house dwelling located in Ireland (measured climate data for Birr used). The parametric study uses the first passive house built by Dr. Wolfgang Feist of the Passivhaus Institut as a case study building, shown below. It can be seen that the space heating demand initially decreases quite steeply with increasing south facing glazing. There are diminishing returns from increasing the area of south facing glass, however, and there eventually comes a point where there is little or no benefit in providing more south facing glass as the net heat loss is greater than the heat gains over the year.

There is no optimal ratio of glazing to floor area that can be used as a rule of thumb in deciding what proportion of a given façade should be glazed. The area of glass has to be determined as part of the design verification procedure using the PHPP software.

Internal Heat Gains

A passive house is very efficient at utilising 'free' internal heat gains from domestic household appliances, kitchen and utility equipment, electronic equipment, artificial lighting, and occupants. Heat losses from stoves or boilers also contribute towards the overall space heating requirement as long as they are positioned within the building envelope. Occupants of the building also contribute to meeting the heat load; a



Source: Climate Data for the Determination of Passive House Heat Loads in Northwest Europe, J. Schnieders, Passivhaus Institut, pp.17.

typical adult human continuously emits 100W of heat when stationary. A family of five persons, therefore, can emit up to 0.5 kW of heat. This may seem like a small amount but it equates to approximately one third of the total space heat load for the prototype passive house presented in Section 3.

Risk of Overheating

Placing extensive areas of glass on the south facing façade in a well insulated and airtight dwelling might lead to overheating in warm sunny days. The PHPP software will alert the designer to any risk of overheating by calculating the frequency of overheating and expressing this as a percentage of the year in which the internal temperature in the house rises above 25˚C. If the frequency of temperatures over this comfort limit of 25˚C exceeds 10% of the year (measurement referring to hours rather than days), additional measures for reducing overheating should be included in the dwelling. To prevent uncomfortable indoor temperatures in a passive house dwelling it is recommended to specify shading devices (blinds, overhangs or awnings, etc.) which will let the low sun enter the home in winter but prevent the high sun entering in summer.

In the first Irish passive house in Wicklow shading was not in place on south facing glazing during the first summer and the house did overheat. A balcony was installed ahead of the second summer, which significantly reduced the frequency of overheating. In mid-summer when the daylight hours are long the sun only enters the building in the middle period of the day while during winter when the daylight hours are short the low sun completely illuminates the entire interior of the building.

In the temperate climate in Ireland where external temperature rarely exceeds 25˚C, the risk of overheating can be easily avoided by careful consideration of shading devices and provision of openings for natural ventilation in combination with thermal mass inside the dwelling (exposed concrete floor; masonry wall, etc.). In some cases the mechanical ventilation system could be used to distribute fresh air throughout the building by switching to a 'summer bypass' setting. This however should be avoided where possible as the ventilation system will consume electricity resulting in increased primary energy. It is preferable that the dwelling designer should employ 'passive' cooling strategies to minimise overheating.

2.2.2 Passive House Building Systems

As indicated earlier a passive house does not need a conventional space heating system of radiators or underfloor heating to maintain a comfortable indoor climate. Instead, typically, the following building services are required in a passive house:

- Mechanical ventilation system with heat recovery which provides most of the space heat requirement
- Backup system capable of heating the air passing through the dwelling via mechanical ventilation to meet

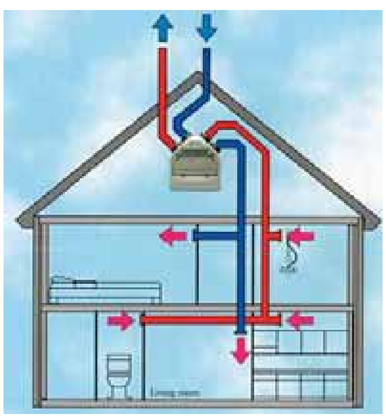
No more than 0.6 air changes/hour at 50 Pascal pressure should be observed in accordance with the Passivhaus Standard. This should be checked for compliance with a blower-door test which will immediately highlight leaky areas. Airtightness can be achieved through the use of membranes, roofing felts and plasters combined with sealants and vapour diffusion resistant materials.
Source: UCD Energy Research Group

Location of overhang and balcony.
Source: MosArt Architecture.

Lighting contributes towards internal heat gains.
Source: MosArt Architecture.

Photo depicting how the low winter sun enters the room below the overhang/awning/balcony. Source: MosArt Architecture.

Photo depicting how the house is shaded from the high summer sun by the overhang/awning/balcony. Source: MosArt Architecture.



Schematic of the supply air ducts, the extract air ducts and the heat exchanger within mechanically ventilated house. Source: Passivhaus Institut.

The sommer-bypass can be used for cooling in the summer if needed. Source: MosArt Architecture.

any auxiliary space heating needs, expected to be small. Typical fuel sources for the back up system include biomass, gas, and in some instances electricity (for example 'green electricity' from renewable sources). The back up system is also used to provide hot water, either throughout the year or during winter if a solar water heating system is used during summer.

Each of these items is dealt with separately in greater detail below.

Given the lengths to which the designer and builder must go to in terms of ensuring a highly insulated building envelope, excellent airtightness and minimal thermal bridging, it is important that the building services in a passive house are as energy efficient as possible. This is especially critical in the case of the mechanical ventilation heat recovery system. Therefore, the required efficiency of the mechanical ventilation system with heat recovery for a passive house dwelling is at least 75%. It is also very important to consider comfort, health and safety issues in the design of the building services for a passive house, ensuring for example that the backup heating system is adequately sized to deal with extreme weather conditions, that filters in the ventilation equipment are replaced regularly and that there is an independent fresh air supply for any combustion devices such as a boiler. These and other issues are dealt with in greater detail below.

Mechanical Heat Recovery Ventilation (MHRV)

An airtight house requires a well-designed mechanical ventilation system to provide good indoor air quality. A passive house is ventilated using a mechanical system which incorporates air to air heat recovery (mechanical heat recovery ventilation, or MHRV). Exhaust air is extracted from rooms that typically produce heat, moisture and unwanted odours such as kitchens and bathrooms. Before this air is expelled to the outside it passes through a heat exchanger where the heat is transferred to the separate stream of incoming fresh air, thereby eliminating the need to completely heat the fresh air as it enters the building. It is important to appreciate that the stale exhaust air and clean fresh air do not mix in the heat exchanger and therefore there is no risk whatsoever of what might be referred to as 'sick building syndrome'. Rather, the stale air and clean air is channelled through closely spaced but separate narrow sleeves in the core of the heat exchanger.

Ventilation systems use electric power and therefore have a slightly negative impact on the primary energy consumption. This will have affect the Building Energy Rating. In our example in Section 3, the energy used by the MHRV is about 10% of the annual primary energy demand.

The benefits of having a whole-house mechanical heat recovery ventilation system (MHRV) are many, including:

- Constant supply of the correct amount of fresh air to all habitable rooms thereby reducing indoor CO_2 levels and removing the cause of stuffiness and tiredness;
- Simultaneous extraction of moisture-laden air from bathrooms, utility rooms and kitchens as well as ventilating noxious gases and unwanted smells if present; and
- A lowering in humidity levels reducing mould and fungus that may appear over time and decreasing dust mite levels.

There are databases (SAP Appendix Q or www.passiv.de) in which various MHRV products are listed in terms of efficiency and performance.

MHRV System Efficiency

The efficiency of the heat exchanger in the MHRV determines the amount of heat that can be recovered from the exhaust air and, therefore, has a very significant influence on the additional space heating that may be required in a passive house. The aim is to use the warm exhaust air to raise the temperature of the cool fresh air to provide for thermal comfort all around the house. On a night where outside temperatures are below freezing, the fresh air might be raised to, for example, 18˚C having passed through the MHRV. The efficiency of sensible heat recovery should exceed 75% for the nominal range of flow rates specified for the unit when measured in terms of the supply-air side temperature ratio as described in EN 13141-7:2004[1]. Specifiers and designers should be wary of products claiming extraordinary efficiency rates of 95% or higher. The safest route is to install equipment that has been independently tested and verified by such bodies as the Passivhaus Institut.

The graph below is based on actual testing of the first Irish passive house in Wicklow. It illustrates, for example, how mechanical ventilation ensures good indoor air quality by removing the high concentrations of a tracer gas that was deliberately released into the house as part of the test procedure. In less than 1.5 hours the air quality in the house had returned to normal.

Recommended Ventilation Rate

According to the Passivhaus Institut, the appropriate air change rate for dwellings is between 0.3 and 0.4 times the volume of the building per hour, with a general recommendation of leaning toward the lower rate. This maintains high indoor air quality while ensuring a comfortable level of humidity and maximizing energy savings.

Compliance with the Irish Building Regulations Part F might require more air changes per hour than the Passivhaus Institut recommends. It is possible to enter a higher air changing rate into the PHPP which consequently leads to a slight increase of the energy consumption.

The PHPP software suggests that 30m^3 per person per hour should be provided to dwellings to ensure good air quality. These two measurements can be used to choose an appropriately sized machine for different dwelling designs. Taking the prototype house presented later in Section 3 as an example, an occupancy of five persons would require 150 m^3 of fresh air delivered to the house per hour. In terms of extract, the PHPP software uses the following rates for different room types as default values, kitchen = 60m^3/h, bathroom = 40m^3/h , shower = 20m^3/h and WC = 20m^3/h. In the prototype house these total 140 m^3/h which is close to the supply volume which will ensure that the whole house system will be balanced. The supply and extract volumes can be accurately set by using a digital anemometer and adjusting the valves on the vents in each room as required. A photograph of this process is shown below.

Adjustment of Fan Speed and Exchange Rate

Most MHRV machines have different settings for different circumstances. These are often referred to as a 'party' setting, where there are a lot of people in the house and where additional fresh air is required, and 'holiday' setting, where the house is being left vacant and the flow of air is reduced. Under normal occupancy, the former of these settings will use more energy and also decrease the level of humidity whereas the latter will use less energy and perhaps lead to an increase in humidity.

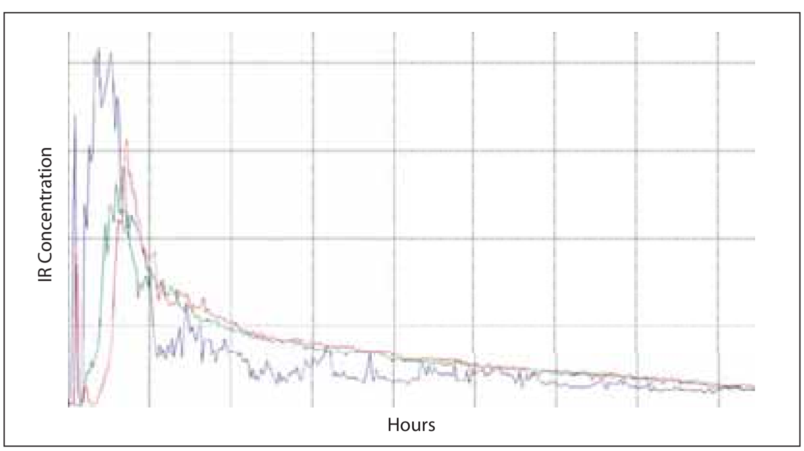
It is not advisable to constantly run the equipment on the lower setting just to save energy when the house is occupied. MHRV machines uses surprisingly little energy given the important role that they play in the passive house. The PHPP software uses a standard value of 0.45Wh for every m^3 transported air in the calculation of electricity (due to MHRV). When designing a passive house in Ireland the specific fan power should be carefully considered as the electricity consumed for fans has direct impact in terms of primary energy performance and hence the Building Energy Rating (BER). Therefore, specific fan power for fans should be less than 1 W/l/s .

Winter and Summer Mode

There are generally two ventilation modes in a passive house: Summer Mode and Winter Mode. In winter, the MHRV uses the heat in the exhaust air to warm the incoming fresh air. In summer, a bypass in the equipment can be set to open automatically (controlled by thermostats) such that the incoming fresh air is not heated. Alternatively in summer natural cross ventilation may be used and the MHRV system can be switched off.

Insulation and Positioning of Duct Work and Vents

It is very important to adequately insulate the supply air ducting so that there is minimal loss of temperature in delivering warm air around the house. The thickness of insulation generally used in passive houses is between 6 cm and 10 cm for ductwork. It is also preferable to locate the ducting within the thermal envelope and to keep pipe runs



Graph depicting how mechanical ventilation ensures a good indoor air quality by removing the high concentrations of tracer gas that were inserted into the house under test conditions. Source: UCD Energy Research Group.

Using a digital anemometer.
Source: MosArt Architecture

Ceiling air supply vent.
Source: MosArt Architecture.

Dust laden used air filter.
Source: MosArt Architecture.

Water to air heat exchanger unit.
Source: MosArt Architecture.

as short as possible by ideally positioning the MHRV unit in the centre of the house. This requires careful planning at a very early stage of building design.

Vents are normally placed in the ceiling but can also be placed in the wall if necessary. The air inlets are typically designed to spread the air horizontally across the ceiling, minimising downward draughts. There should be a gap either under or over the door of each room to enable the easy movement of air from one room to the next. If doors are fitted tight without such a gap, rooms with exhaust vents would be under negative pressure and rooms with supply air would be under positive pressure.

Noise

Fan and valve noises can be almost completely eliminated by sound control measures (e.g., vibration isolation mounts, low air speed and acoustic lining in ducts). The grilles on vents generally guide incoming air along the ceiling from where it uniformly diffuses throughout the room at velocities that are barely perceptible. If the ventilation equipment is operating on a high setting ('Party Setting') the noise of the equipment and the air flow may be more noticeable. MHRV machines are generally housed in a well insulated casing and noise should not be a critical issue.

Maintaining Good Air Quality

It is important that attention is paid to regular replacement of air-filters for both incoming and exhaust air. Filters are used not only to provide clean air for the occupants but also to ensure that the heat exchanger is not clogged with dust and other matter. If the filters are not regularly replaced (for example every six to twelve months) and they themselves become clogged with dirt the MHRV will have to work harder to provide the same volume of air to the house, thereby increasing the speeds of the fans and, ultimately, using more energy. In countries where this system is relatively new, occupants may not be aware of this maintenance need and indoor air quality may suffer as a consequence. Equipment differs with respect to the types of filters used; some have to be replaced while others can be washed and reused.

In single family houses, the extractor hood in the kitchen is sometimes connected to the MHRV equipment to extract kitchen smells and to use the waste heat from cooking to warm the incoming fresh air. In such instances, it is very important that the hood is fitted with a high quality filter that can easily be cleaned or replaced in order to prevent the built up of grease in the ducting system which could be a health and fire hazard.

What happens in the event of a power failure?

If there is a loss of electricity (and the dwelling has no backup generator) the ventilation system will stop working and the supply of fresh air will be cut off. If power is lost for a short while (for example a few hours), then there is likely to be no noticeable difference in indoor air quality. If the loss of power is prolonged, the simple solution is to open the windows and to create natural cross flow ventilation through the building.

Backup Heating System

As previously highlighted in these guidelines, space heating requirement in a passive house is so low that there is no need for a traditional space heating system. The optimal way to transfer the small amount of required heat throughout the house is through the mechanical ventilation system. This section of the guidelines will provide an overview of the typical backup heating systems used in passive houses to provide thermal comfort[1].

It is recommended to use high efficiency heat generation systems for this auxiliary purpose. The HARP database (viewable on www.sei.ie) provides output and efficiency data on a wide range of boilers and other heating appliances, and is updated on a monthly basis.

Insulated distribution pipes and hot water cylinders are mandatory to reduce the heat losses, achieve a quicker response and increase the efficiency of the heating and hot water system. The details (length of pipes, size of hot water storage, thickness and thermal conductivity of the insulation) can be entered into PHPP.

Furthermore the fuel has to be taken into account. Electric energy has a primary energy factor of 2.7 whereby for gas or oil the factor is 1.1. Where practicable therefore, the use of electrical heating appliances should be avoided to prevent incurring such a penalty in primary energy use, which will have an adverse effect on the Building Energy Rating (BER) using the official DEAP methodology. This penalty is greatly reduced if using a correctly sized and high efficiency heat pump for such an auxiliary purpose.

PHPP specifies for wood pellets, chips and logs a primary energy factor of 0.2. Because DEAP calculates with a primary energy factor of 1.1 for wood based fuel the results for the primary energy demand for space heating and DHW differ significantly between PHPP and DEAP.

Space heating demand in a passive house is typically met through passive solar gains (40 – 60 %), internal heat gains (20 - 30%) and the remainder (10 - 40%) needs to be provided from auxiliary heating systems .

The PHPP software will accurately predict the following two measurements for each passive house design:

- Annual Space Heat Requirement – this measures the amount of energy that is needed to maintain a comfortable indoor temperature, specified in kilowatt hours per square metre of treated floor area per year, or kWh/(m^{2}a).

- Heat Load – this measures the capacity of the space heating system required to maintain comfortable indoor temperatures at any one time, specified in Watts per square metre of treated floor area, or W/m^2.

For the prototype house the annual space heat requirement (without losses of the heating system) is 13 kWh/(m^{2}a). Including the losses the so called final energy is 26 kWh/(m^{2}a) equating to approximately 2,860 kWh over an entire year (the house measures 110m^2 in treated floor area).This would equate to 270 litres/year of oil, 280 m^3/year of mains gas or 570 kg/year of wood pellets (in bags)

The heat load, on the other hand, is approximately 1,800 W, or just 1.8 kW. This amount of energy could be provided by a very small stove / heater / boiler compared to what might be typically required in a family home.

The most common method of 'heating' in a passive house is by post-heating the fresh air after it has already been warmed by the exhaust air in the MHRV. There are a number of ways in which the temperature of the air can be boosted, including those listed below:

- Water to air heat exchanger;
- Compact unit with electrical heat pump
- Wood pellet/wood log boiler; and
- Compact unit with natural gas

The first three of these are explored in outline below. The compact unit with natural gas, while used in Central Europe, is virtually unheard of in Ireland and would have to be approved for use by the appropriate authorities.

Water to Air Heat Exchanger

This method involves using a heating device placed immediately on the fresh air supply outlet of the MHRV. There is a small radiator inside this device and it is heated by hot water connected to the domestic hot water tank. If the house needs additional heat (which is determined by a thermostat) then hot water is circulated through the device, hence the title of 'water to air heat exchanger'. Once the house has reached the programmed temperature, the hot water stops circulating and the air is no longer heated. The water in the domestic hot water (DHW) tank is heated, in turn, by using a number of energy sources including a stove or boiler (for a larger house) in combination with solar hot water panels. The principal advantage of this system over the compact unit system described below is that when fueled by a combination of firewood and sunshine it is carbon neutral.

Compact Unit with Electrical Heat Pump

This system is so-named as it incorporates all of the technology required for a passive house in a relatively small unit, namely the MHRV, the DHW and the heating power for the home, in this case powered by an electrically powered heat pump. It is therefore very suited to smaller homes where space might be limited for large tanks, stoves and storage for wood. It is important to use a heat pump with the highest possible efficiency (coefficient of performance or CoP) based on test results for these circumstances of use. Compact units are becoming more widespread in use in passive houses built in Central and Northern Europe.

A 3D model of a typical compact unit is illustrated right.

Wood pellet/wood log boiler

Wood pellets or wood logs can be used as a heat source for a simple stove, back boiler or for a boiler in the plant room to serve as an auxiliary or backup source of heat. The following issues should be remembered when considering installing a wood stove or boiler:

Pellet boilers are available in types loaded automatically or manually, whereas wood log boilers for domestic use are only manually charged.

- The equipment must be sized appropriately to the heat load of the house. This will be defined by the 'Verification page' in the PHPP software. Taking the prototype house presented in these guidelines, a stove of 3kW output would be sufficient for all space heating and DHW needs.
- An independent combustion air supply must be provided to any stove or boiler in a passive house bearing in mind the level of airtightness that has to be achieved. The provisions of an air supply and flue for stoves or boilers will generally not significantly impact on airtightness or the balancing of ventilation flows due to the 'closed' nature of their construction. Air required for combustion is drawn in through a relatively small diameter duct and expelled through the flue.
- Most wood stoves are highly efficient (up to 80 – 90%) and when burning pellets there is very little ash remaining following combustion. A flue will be required to take exhaust gas emissions safely away from the house, as with any typical stove.
- A stove or boiler that directs most of the heat output to the DHW tank is essential if the hot water is to be used to heat the ventilation air. If there is a need to back up the MHRV the stored hot water will be used to re-heat the fresh air. This system can be used in combination with thermal solar panels or other heat sources. A model that simply radiates all the heat into the space in which it is located cannot generally be used for whole house heating. Besides, it should be appreciated that there is a

Compact unit including ventilation heat recovery and air to water heat pump. (Source: Passivhaus Institut, Germany http://www.passiv.de) high risk of overheating when using a room heater or back boiler in the living area because passive houses have very low heat losses through the building envelope.

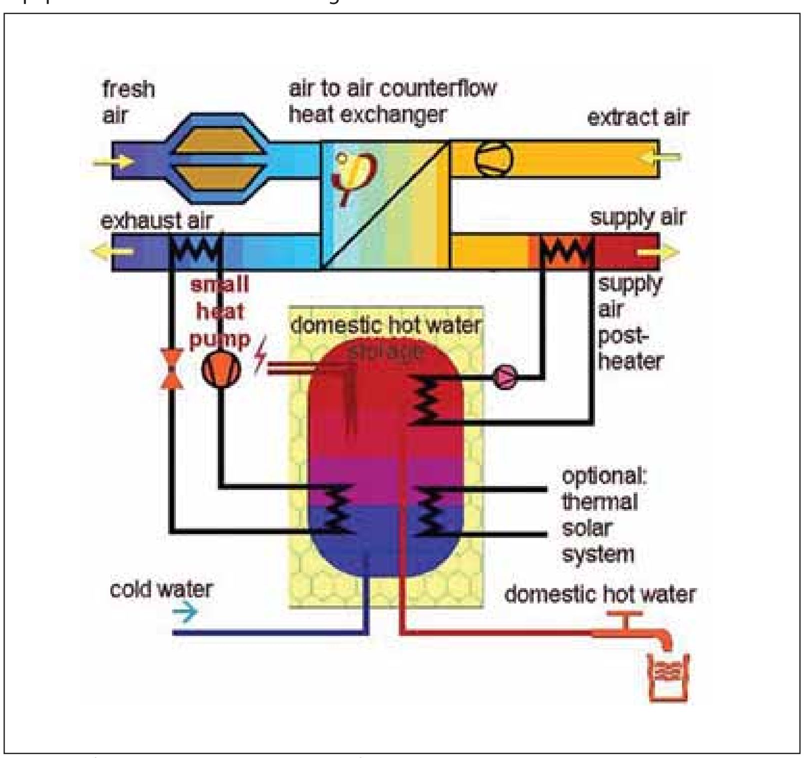
- As previously indicated, it will often be logical for such units to be used for not only auxiliary space heating but also for auxiliary water heating.
- Although the demand for such wood fuel will be low, a dry space for storage has to be provided. Wood (whether logs, chipped or in pellets) is bulky and a considerable volume is required for storage especially if it is purchased in bulk to keep costs to a minimum.It is recommended that the demand of at least 1.5 years is stocked up. The consumption of pellets in the example in Section 3 is about 0.5 tonnes per year.

Integrated controls for heating in a Passive House

Heating systems in Ireland have traditionally been simple, with among the most common boiler based systems being a timer and a cylinder thermostat, and with sometimes even room thermostats being absent. However, the Building Regulations Part L require minimum levels of control, installing equipment to achieve the following:

- Automatic control of space heating on the basis of room temperature;
- Automatic control of heat input to stored hot water on the basis of stored water temperature;
- Separate and independent automatic time control of space heating and hot water;
- Shut down of boiler or other heat source when there is no demand for either space or water heating from that source.

Additional control features can be incorporated to a heating system so the overall system performance improves. One example is the 'weather compensation' feature, which is the ability to adjust the output of the system based on the measured external temperature. The main advantage of using weather compensation is that the heating system closely monitors external temperature trends and adjusts the output accordingly. If, for example, the external temperature starts to drop rapidly, the system can 'anticipate' that the dwelling may come under pressure to maintain its current internal temperature and can verify whether there is sufficient power to generate the backup heat that might be required.



Schematic of mechanical system that can be used for back-up heating in a passive house. Source: Passivhaus Institut, Germany (http://www.passiv.de).

The preferred internal temperature can be set using an internal thermostat. If the internal temperature goes below the thermostat setting, the system will automatically start to heat the fresh air passing through the ventilation equipment. The principal function of the heating control system is to ensure that there is always sufficient heat in the buffer tank to deliver the heat load required to maintain the comfort levels set by the occupants. In the case of the Out of the Blue demonstration house, if there is insufficient heat in the buffer tank, and the solar input can not cover the heat demand at that particular time, the pellet stove can be ignited automatically to provide the backup required. The pellet stove will then cut out when there is sufficient energy available. A similar control system is found in the compact units, except that a heat pump is used instead of a pellet stove.

The amount of heat delivered to the fresh air by the heat exchanger is regulated by the internal and external temperatures. The control system is usually set up to deliver a relatively high heat load if the temperature outside is very cold, or alternatively a low heat load if it is not too cold.

It would also be possible to use an 'instantaneous' system eliminating the need for a large buffer tank. Such systems do not typically suit the use of a pellet boiler, however, as the boiler would have to switch on and off for short periods of time to maintain an even temperature in the house.

The PHPP software assumes that the heating system is controlled by programmable timer and thermostats. However, the use of DEAP needs more detailed input data from the designer, specifier or BER assessor on the auxiliary heat generation, distribution and control system here.

Individual Room Temperature Control

Different rooms may have different temperatures due to solar gains, occupation and internal heat loads. Room based temperature controls for temperature differentiation between different rooms may be necessary if individual comfort requirements are set for different rooms. In a centralised ventilation heating system, however, the supply air temperature is relatively constant for the whole house and this would be typical for most houses built to the Passivhaus Standard.

Domestic Hot Water Production

As in any type of dwelling, the passive house requires a system that provides domestic hot water (DHW). As with space heating, it is important that the system is energy efficient, well controlled and has an adequate capacity to meet demand. Generally the DHW system in a passive house is combined with a heat source such as a wood stove, solar thermal collector, compact unit or heat pump for space heating. Most passive house examples encountered have utilised solar thermal collectors as they reduce the use of primary energy and CO_2 emissions. It is important to note, however, that the Passivhaus Standard is indeed achievable without solar based water heating. The introduction of Building Energy Rating system as an indication of the energy performance of dwellings in Ireland, together with the mandatory requirement in the Building Regulations Part L 2007 in relation to renewable energy provision is likely to increase the installation of solar technology.

The required volume of DHW is dependent on occupancy. PHPP assumes 35 m^2 treated floor area per person. It is also possible to enter in the verification sheet the actual number of occupants. The default settings for DHW in PHPP are 25 l per person per day with a flow temperature of 60° C.

Approximately 530 kWh/yr of useful heat per person plus provision for storage losses and distribution losses must be supplied.

Domestic Water Heating – Solar Input

It is reasonable to expect that an optimized solar based system (flat plate or evacuated tubes of 5-7m^2 area) will produce up to 60% of total annual hot water demand in the Irish climate. They tend to have a relatively shorter pay back period in comparison to other renewable energy technologies such as wind turbines or photovoltaic panels. In Ireland the amount of solar irradiation received each year is approximately 900-1150 kWh/ma. After conversion into heat, this is the equivalent of over 30 litres of oil. Many people would be surprised to learn that Dublin receives a similar amount of annual irradiation as Paris.

The table over the page shows that the solar input and gain are dependent on the efficiency, orientation and angle of the solar collectors.

Assuming an area of 7.5 m^2 south orientated flat plate solar collectors with a tilt of 45° the solar contribution in our example is 60% of DHW demand. The remaining energy for DHW has to be provided by the backup heating system.

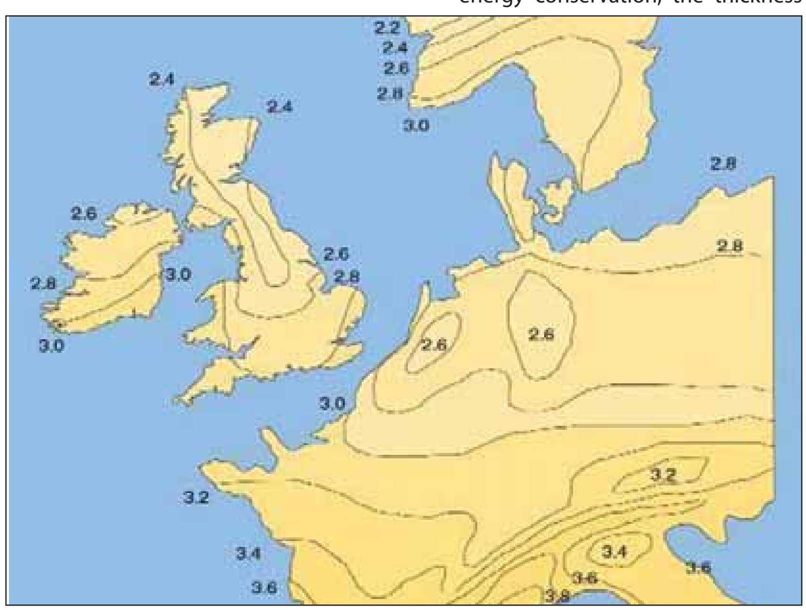
In terms of specifying a solar collector system, the following outline guidance should be considered:

- The optimal orientation is directly due south and deviation from this will reduce the contribution of the collectors to DHW production. In places where there is no south facing roof, correspondingly larger panel areas can be fitted to east or west facing roofs.
- The optimal tilt of the solar panels to meet approximately 50% of the annual heating demand for DHW is approximately 45 degrees (in a pitch that is greater than 45 degrees the potential annual output is compromised somewhat).
- There are two types of solar collectors typically used, namely flat plate panels and evacuated tubes.

A comparison of the performance of these types, based on 5m^2 collector area, along with consideration of orientation and angle of incidence, is provided in the table over the page. The calculation was developed as part of these guidelines for the prototype passive house using the calculation methodology for solar water heating in the Dwelling Energy Assessment Procedure (DEAP 2005, version 2).

Three different inclinations of solar panels (30˚, 45˚, 60˚) and three different orientations were calculated, with the following specification: standard number of 3.6 occupants according to DEAP assumption, water storage tank 300 litres, with 150 litres dedicated to solar, and 50mm factory insulation, with thermostat control.

- As a general rule of thumb, the area of solar panels is roughly 1 to 2 m^2 of collector area per person. The system should be capable of providing up to 50 litres of DHW per person per day in season.
- In terms of sizing a solar tank, a minimum of 80 and preferably 100 litres storage per m^2 of collector should be provided. In a typical Irish home this could mean installing a tank of between 300 and 500 litres capacity. It is important to use a proper solar water tank which is very well insulated. Insulation of hot water pipes is also important for energy conservation, the thickness



Yearly total of global horizontal irradiation (kWh/m2) UK and Ireland. Source: European Commission Directorate General, Joint Research Centre http://re.jrc.cec.eu.int/pvgis/countries/europe/g13y_uk_ie.png

5 square meters of FLAT PLATE collectors (η_0=0.75 and a1=6)
No obstructions:

Tilt of collector	Solar Input kWh/year		
	South	SE/SW	E/W
30°	1264.9	1246.3	1191.2
45°	1264.2	1240.4	1167.9
60°	1248.5	1221.3	1137.0
Tilt of collector	Solar input to demand ratio		
	South	SE/SW	E/W
30°	49%	48%	46%
45°	49%	48%	45%
60°	48%	47%	44%

5 square meters of EVACUATED TUBE collectors (η_0=0.6 and a_1=3)
No obstructions:

Tilt of collector	Solar Input kWh/year		
	South	SE/SW	E/W
30°	1324.3	1300.7	1231.5
45°	1323.4	1293.2	1202.5
60°	1303.4	1269.1	1164.4
Tilt of collector	Solar input to demand ratio		
	South	SE/SW	E/W
30°	51%	50%	48%
45°	51%	50%	47%
60°	50%	49%	45%

Domestic solar water heating - solar input (flat plate collectors and evacuated tube) for the prototype passive house (described in Section 3), calculated with the Dwelling Energy Assessment Procedure DEAP 2005 version 2.
Source: UCD Energy Research Group.

of insulation should be at least equivalent to the pipe diameter and preferably 1.3 times the pipe diameter.

The 40% or more of DHW needs that are not provided by solar energy can be met by several means including biomass boilers or stoves, immersion heaters or natural gas. An outline of the first of these is provided below. It must be remembered that space heating in a passive house is often provided by using hot water to heat the air passing through the ventilation system. In such cases, hot water production is essential in the heating season when solar panels on the roof will not be sufficient to meet the demand for heating the hot water. Accordingly, many passive houses will have a biomass stove burning either natural logs or wood chip or pellets. An advantage of the last two of these is that they are more easily automated so that they fire up and switch off in the same way as a conventional gas or oil burner.

Electricity Consumption in a Passive House

The Passivhaus Standard primary energy requirement has a limit of 120 kWh/(m^2 year), regardless of energy source for all space and water heating, ventilation, electricity for fans and pumps, household appliances, and lighting energy requirements of the house. This limit means that in a passive house the efficiency of household appliances and all electrical systems is crucial to meet this challenging requirement. This is emphasised with the fact that the primary energy factor for electricity taken in the PHPP software (as well as in the DEAP, Dwelling Energy Assessment Procedure) is 2.7. Therefore 1kWh electricity used in a passive house accounts for 2.7kWh of primary energy.

When designing a passive house, the PHPP software is used to calculate the electricity balance. The first step is to calculate the electricity requirement in the house including all household appliances and lighting. In order to achieve the above mentioned Passivhaus Standard it is necessary to specify refrigerators, freezers, cookers, artificial lighting, washing machines, dryers, etc. with the highest energy efficiency available on the market (i.e. category 'A' energy rated household appliances). The second step is calculating the auxiliary electricity requirement, in which electricity consumption is specified for mechanical ventilation system fans and controls, DHW circulation pumps, and any other present in the dwelling. Calculation results are presented in primary energy kWh/(m^{2}a) and included in the PHPP 'Verification page'.

Comparison between PHPP and DEAP

Primary energy factor (most important values)

	PHPP	DEAP
Oil	1.1	1.1
Gas	1.1	1.1
Electricity	2.7	2.7
Wood Pellets/Log/Chip	0.2	1.1

2.3 Energy Balance Calculations and Passive House Specification

2.3.1 PHPP Software and Applications

An introduction to the PHPP was provided at the beginning of this Section within a discussion of the building design process for passive houses. PHPP is a software package based on a series of extensive and interlinked Excel data sheets which collectively allow building designs to be verified against the Passivhaus Standard. The latest version of the PHPP software can be purchased for a nominal fee from SEI Renewable Energy Information Office. The verification requires the input of very specific and detailed data about the design, materials and components into the PHPP spreadsheets and is then related to the climate data for the region in which the house would be built. The validity of the result from this process is of course highly dependent upon the validity of the data entered.

Some of the principal datasheets included in the software are listed below, along with their main functions:

- Climate data – it is possible to choose the climate which the passive house is being designed for. This has a potentially significant impact on the U-values required to achieve the threshold annual heat requirement.
- Verification – this sheet collates the results of the overall evaluation of the building including the space heating requirement, specific primary energy requirement, heat load and frequency of overheating. The user can see at a glance on this sheet whether or not the building can be certified as a Passive House.
- U-value – this sheet enables the assessor to specify the construction of all the opaque (ie. does not include windows) elements of the building envelope for the purposes of calculating the U-values of those elements. The sheet requires the input of the lambda value of the building materials proposed as well as their thicknesses and the proportion of insulation occupied by structural elements.
- Windows – the orientation and size of all windows is entered into this sheet, along with the U-values of the glass and frames as well as other technical specifications which have discussed earlier in this Section.
- Annual Heat Requirement – this value is calculated by determining the heat losses through transmission and ventilation and subtracting the total solar and internal heat gains. The annual heat requirement must be less than 15 kWh/(m²a).
- Heat Load – the building's heat load is based on energy balance calculations estimated by subtracting the minimum solar gains and internal heat sources from the maximum transmission and ventilation heat losses.

The PHPP software is comprehensive and detailed and therefore requires some training prior to embarking on practical application to a real project. However, the software is also quite user friendly and the Verification page enables the user to check whether or not such thresholds such as Space Heating Requirement are met. In the event that the key Passivhaus Standard criteria are not met, for example, the assessor will firstly have to check to see if there are any fundamental errors in terms of data entry. If this is not the cause of the problem, then the building will likely have to be modified in order to achieve the required standards. This will typically involve improving the U values of the building envelope, or altering the proportion and orientation of glazing.

Extracts from the PHPP software are included later in Section 3 pertaining to the prototype passive houses.

2.3.2 Passive House Certification

At the time of writing these Guidelines, a passive house in Ireland can be certified by the Passivhaus Institut in Darmstad, Germany (http://www.passiv.de) or certifying body approved by the Passivhaus Institut. For further information on certification of passive houses in Ireland contact the SEI Renewable Energy Information Office or the Passivhaus Institut directly. The evaluation criteria for the certification (Source: PHPP 2007, pp.23) are:

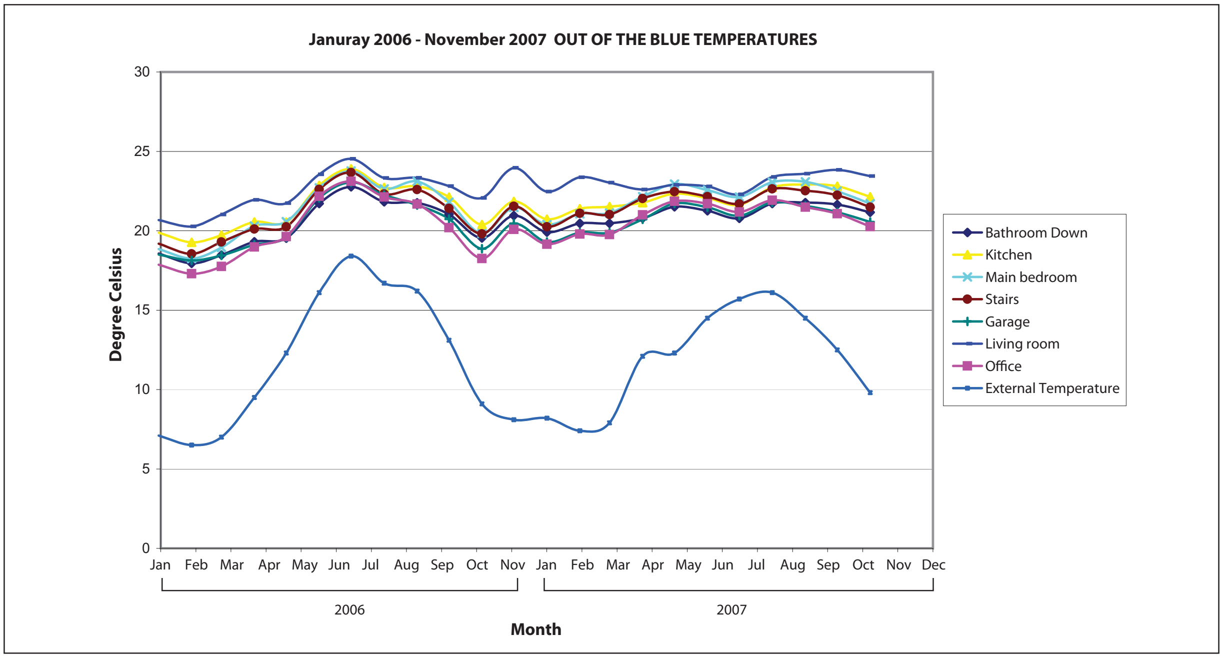
- Specific Space Heat Demand max. 15 kWh/(m²a)
- Pressurisation Test Result n50 max. 0.6ac/h
- Entire Specific Primary Energy Demand max. 120kWh/(m²a) including domestic electricity.

The above criteria have to be verified with the PHPP 2007, and the required list of documentation for the passive house quality approval certificate, construction drawings and technical specification with product data sheets, must be submitted to the certifying party (including PHPP calculations). Also, verification of the airtight building envelope according to IS EN 13829, a record of adjustment of the ventilation system, declaration of the construction supervisor and photographs of the complete building must also be submitted. Upon examination of received documentation the applicant receives the results of the examination from the certifying party. If the necessary verifications have been found to be correct and the above criteria have been met the 'Quality Approved Passive House Dr. Wolfgang Feist' certificate is issued (PHPP 2007, pp.28).

Passivhaus Institut Certificate example, Quality Approved Passive House.
Source: Passivhaus Institut, Germany.

A wider European passive house certification scheme was developed within the Intelligent Energy Europe project (2005-2007) "Promotion of European Passive Houses, PEP" *(http://www.europeanpassivehouses.org)*. This certification scheme is applicable to 'an emerging market scenario' (i.e. countries with small number of passive house building), aims to ensure that the design of a particular passive house can deliver the specific energy requirements in accordance with the PHPP and confirm the airtightness of the completed building. This certification scheme involves the verification of the 'as built' design (i.e. that reflects the actual construction, incorporating any modifications made during construction) in accordance with the PHPP and confirmation of the air tightness of the completed building by a fan pressurization test performed in accordance with IS EN 13829.

Since the above assessment criteria apply to the 'as built' design details and the completed building, there is a significant risk that any non compliances due to fundamental errors will be difficult to correct when the building is complete. It



Average daily temperatures, January 2006 – November 2007, monitoring results for the first passive house in Wicklow. Source: UCD Energy Research Group.

is therefore recommended that the design is checked against the PHPP before construction is started to confirm that the criteria for the specific heating and primary energy requirements are met, that the construction on site is checked to ensure that the dwelling design has been realised and that air permeability measurements are made during the construction process so that air leakage problems can be identified and remedied while access to the membranes etc is still available.

Since the actual performance of the building will be very dependent on the correct operation and maintenance by the occupant, it is recommended that adequate written information and instructions are provided to the occupants, at the time when the certificate is issued. Also, an approach to certification of products and technologies used in passive house designs has been developed. (Source: PEP Promotion of European Passive Houses, passive house building certification, *http://www.europeanpassivehouses.org*).

For further information on passive house certification in Ireland contact Sustainable Energy Ireland Renewable Energy Information Office, SEI REIO *email: renewables@reio.ie*

Lifestyle Issues

It is a common misconception that windows cannot be opened in a passive house. They can indeed be opened but they don't have to be opened. In a passive house the ventilation system ensures that a constant controlled amount of fresh air is circulated around the house so a stuffy or uncomfortable atmosphere is avoided. If the occupants would prefer to have the windows open at night or provide natural cross ventilation during a hot summer's day then it is entirely possible to open whatever windows or doors one chooses. The MHRV should be switched off if there are a lot of windows or doors being left open as it would be an unnecessary waste of electrical energy.

Living in a passive house encourages a greater interest in and awareness of weather patterns and the impact they have (or don't have) on indoor climate. The passing of cloud cover brings with it instant brightness and rising temperatures on the display panel for the solar collectors. A very hard frost will sometimes leave a veil of ice crystals on the outside pane of the glazing which rapidly melts in the morning sunshine. Extremely cold clear weather usually means that the backup heating is not required during the day due to the high levels of solar irradiation available. Dull muggy days, on the other hand, while not especially cold, may well require the use of the pellet stove due to the lack of sunlight. Windows may have to be flung open to cool the house on New Years Eve night depending on how many friends and neighbours you manage to attract to join the celebrations!

As an illustration of the indoor temperature comfort, monitoring results of the room temperatures in the passive house in Wicklow and site measured temperature is shown below. The graph represents measured average indoor and outdoor temperatures from January 2006 to November 2007.

The above diagram illustrates temperature variation in different parts of the house and cooler average temperatures in the first heating season (early 2006) compared to the second and third heating seasons (late 2006 / early 2007 and late 2007 respectively). The reasons for these variations are interesting and warrant some elaboration, below:

- The three coolest rooms ('office', 'garage' and 'bathroom down') are each on the north side of the building, receive no direct sunlight during the winter months and are very infrequently used compared to the remainder of the house. The first two of these spaces have three external walls and so are more prone to heat losses compared with the rest of the house.
- The three warmest rooms ('kitchen', 'main bedroom' and 'stairs') all open out to the south of the house and so

receive the maximum amount of solar gain in winter. Furthermore, they are occupied for significant parts of the day and / or night.

- In the first few months of 2006, the only backup heat source in the house was a pellet boiler in the sitting room. This alone was insufficient to heat the entire house as its direct output into the room is just 2kW. As a result, those rooms on the northern side of the house were below thermal comfort levels for the first few months of 2006. This went largely unnoticed by the family due to the fact that the rooms in question are not used. Since then the temperatures have continued to improve.
- In the autumn of 2006, a water-to-air heat exchanger was fitted to the MHRV equipment which enabled heating the fresh air as it passes throughout the house. This was actively used for the first time in December 2006 which resulted in raising the temperatures in all rooms (even those three on the north side) to well within the normal comfort level. In late 2007 the temperatures have improved yet again.
- There is still in evidence a temperature gradient (increasing in temperature) from north to south and from first floor to ground floor.

The specification of materials and very high quality build creates a strong sense of living in a well-built house that will last the test of time. The heavy doors and windows close with a reassuringly solid 'clunk' and keep out draughts and reduce external noise. The walls are thick and substantial and are packed full of insulation to keep out the cold and the heat in. There is no condensation on the internal glazing early on a cold morning.

The health aspects of living in a mechanically ventilated house are also readily apparent, with no lingering odours, little or no condensation in washrooms after showering and an overall sense of high indoor air quality throughout. Changing the filters on the ventilation system is always an eye opener – seeing what dust and dirt is taken out of the incoming air and what is extracted from the indoor air.

Living in a house that has a low carbon footprint can bring about other changes in lifestyle that are positive for the environment, including growing your own food and reducing the impact of travel whether by car or by plane. Raising children in a passive house will also bring about positive change for the next generation who will expect to improve even further on what their parents achieved.

Perhaps the overall lifestyle benefit of living in a passive house is that it provides very high levels of overall comfort without compromising the environment and at a fraction of the cost of living in a traditional so-called 'normal' house .

References

Passive House Planning Package 2007, "Protokolband 16:Waermedrueckenfreis Konstruiren (Thermal Bridge-Free Construction)", pp.96. PHPP 2007 Technical Information PHI-2007/1(E), Passive House Institut, Dr. Wolfgang Feist.

Passive House Planning Package 2007, "Certification of Passive Houses", pp.28. PHPP 2007 Technical Information PHI-2007/1(E), Passive House Institut, Dr. Wolfgang Feist.

European Commission (EC), 2006. " Promotion of European Passive Houses (PEP)". [Internet] PEP. Available at: http://www.europeanpassivehouses.org/html

Schnieders J. 2006, "Climate Data for Determination of Passive House Heat Loads in Northwest Europe". Darmstadt, Germany, Passivhaus Institut.

[1] *IS EN 13141-7:2004, Ventilation for buildings/ performance testing of components/products for residential ventilation. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings.*

[2] *Thermal comfort is defined in British Standard IS EN ISO 7730 as: 'that condition of mind which expresses satisfaction with the thermal environment.' It is affected by the key environmental factors as air temperature, radiant temperature, air velocity and humidity.*

SECTION THREE

Passive House Prototype for Application in Ireland

Passive House Prototype for Application in Ireland

This Section of the guidelines demonstrates the practical application of Passivhaus Standard to a prototype passive house designed with a view to its suitability for the mass housing market in Ireland. The house type demonstrated is a semi-detached two storey house[1] measuring approximately 110m^2. The house is depicted in plan and elevation below. The house is typical in most aspects of its design, comprising three bedrooms upstairs (including one ensuite and family bathroom) and a living room, dining room, kitchen / utility and wheelchair accessible WC downstairs. There are also some non-conventional elements including a double-height sun room, solar panels, pellet boiler and shading pergola. These are all described in greater detail below.

The final part of this section examines the capital construction costs associated with the passive house.

3.1 Design and Specification

The two most common construction methods in Ireland were used in the design and specification of the prototype passive house, namely timber frame and concrete block[2]. It is demonstrated below that the Passivhaus Standard can be easily achieved in Ireland using both of these construction methods and that there are no major advantages of one method over another in terms of thermal performance. Both passive house construction types can be built using mostly conventional materials as can be seen from the detailed wall sections provided in section 3.1.3.

3.1.1 Combining Aesthetic and Energy Performance in House Design

The design of a passive house is strongly influenced by the need to minimise heat loss through the building fabric, to maximise solar gains and to cater for the various building services. Form and function played equal roles in the design of the passive house. The overriding principle used in the design of the house was that it should be broadly similar in character to a conventional house, thus maximising ease of acceptance to the current housing market in Ireland.

As has been described in some detail in the preceding sections, much of the 'free' energy required to heat a passive house comes directly from the winter sun through south facing windows. It is therefore typical (though not essential) to have a bias in terms of placement of glazing on the southern elevation. Combined with such glazing is the need to prevent overheating in summer and this is easily ensured through the use of shading, in this case with a balcony and pergola. The walls of a passive house are typically thicker than those of conventional construction due to the need for additional insulation and this must be borne in mind in the early stages of design development. Another key issue to consider when developing the design of a passive house is the need to minimise thermal bridging including that created between the foundation and internal walls, for example. Bearing in mind the above principles of glazing orientation, wall thickness and minimised thermal bridging, the designers commenced the development of the prototype passive house.

The prototype house presented below would achieve a BER rating of A2. Should an A1 BER rating be desired, one method of achieving this would be to improve the U value of the opaque elements of the entire building envelope from 0.15 W/(m^{2}K) to 0.10 W/(m^{2}K), increase the area of solar panels from 7.5m^2 to 10.0m^2, increasing the efficiency of the heating system from 80% to 85% and adding approximately 7m^2 photo voltaic panels. There would be other methods of improving the BER rating other than those specified above. Furthermore, it has to be highlighted that not all buildings designed to the Passivhaus Standard would achieve an A2 or A1 rating. The example below has been especially designed to achieve both a good BER rating as well as meeting the Passivhaus Standard, using both DEAP and PHPP.

3.1.2 Decision Support using Passive House Planning Package (PHPP) Software

The Passive House Planning Package (PHPP V2007) has been introduced already in these guidelines. It is an Excel-based software that can be used to 'test' the energy performance of a building as it is being designed. It includes Irish climatic data which is useful in ensuring that buildings are not over-specified in terms of thermal performance. Key aspects of the emerging prototype passive house are entered into the software with a view to ensuring that the design achieves the minimum requirements of (a) space heating delivered energy demand of 15 kWh/(m^{2}a) treated floor area (TFA[3]), and (b) upper limit for total primary energy demand for space and water heating, ventilation, electricity for fans and pumps, household appliances, and artificial lighting not exceeding 120 kWh/(m²a), regardless of energy source.

The thickness of insulation required in the walls, floor and roof is evaluated and guided by the PHPP software, as is the specification and positioning of the windows, the sizing of the back-up space heating system, the consideration of thermal bridges and many other aspects of the design including ventilation provisions. The design is thus an iterative process. Different insulation types can be tested in the software, with higher performance materials (in terms of lower Lambda values) requiring thinner walls than other less efficient materials.

Two extracts from the PHPP software are included below for both the timber frame and masonry construction prototypes in order to give an insight into how the software can be used to assist the designer. The first extracts comprise the so-called 'Verification' page which summarises the performance of both construction types in terms of such critical matters as space heat demand, confirmation of blower door test results, specific primary energy demand, heating load and frequency of overheating. In both cases, the maximum space heat requirement of 15 kWh/(m²a) has been achieved.

The second extracts provide an insight into how the U-values of major building elements are calculated for both timber frame and masonry construction types. The table provide details on how the required U-values have been achieved for walls, floors and ceiling. The partial thermal bridge caused by the timber studs in the timber frame option is accurately calculated in the software by specifying the proportion of the insulated wall occupied by timber (in this case 10%).

Passive House Verification

Photo or Drawing

Building:	Semi Detached Passive House - Timber Frame + Pelletstove	
Location and Climate:	Ireland, Dublin	IRL - Dublin
Street:		
Postcode/City:		
Country:		
Building Type:	Residential	
Home Owner(s) / Client(s):		
Street:		
Postcode/City:		
Architect:	MosArt Architects	
Street:	Block 6, Broomhall Business Park	
Postcode/City:	Wicklow, Co. Wicklow, Ireland	
Mechanical System:		
Street:		
Postcode/City:		

Year of Construction:	2008				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	503.4	m³	Internal Heat Gains:	2.1	W/m²
Number of Occupants:	3.1				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 109.6 m²

	Applied:	Annual Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	13	kWh/(m²a)		15 kWh/(m²a)	Yes
Pressurization Test Result:	0.6	h^{-1}		0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	62	kWh/(m²a)		120 kWh/(m²a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	29	kWh/(m²a)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kWh/(m²a)			
Heating Load:	14	W/m²			
Frequency of Overheating:	5	%	over	25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)		15 kWh/(m²a)	
Cooling Load:	9	W/m²			

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

signed:

Passive House Verification for the prototype passive house, concrete block construction.
Source: MosArt Architecture.

IFC, Insulated Concrete Forms.
Source: UCD Energy Research Group.

Externally insulated concrete block wall.
Source: MosArt Architecture.

Passive House Verification

Photo or Drawing

Building:	Semi Detached Passive House - Concrete Block + Pelletstove	
Location and Climate:	Ireland, Dublin	IRL - Dublin
Street:		
Postcode/City:		
Country:		
Building Type:	Residential	
Home Owner(s) / Client(s):		
Street:		
Postcode/City:		
Architect:	MosArt Architects	
Street:	Block 6, Broomhall Business Park	
Postcode/City:	Wicklow, Co. Wicklow, Ireland	
Mechanical System:		
Street:		
Postcode/City:		

Year of Construction:	2008				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	503.4	m^3	Internal Heat Gains:	2.1	W/m^2
Number of Occupants:	3.1				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 109.6 m^2

	Applied:	Annual Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	**13**	$kWh/(m^2a)$		15 $kWh/(m^2a)$	Yes
Pressurization Test Result:	**0.6**	h^{-1}		0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	**61**	$kWh/(m^2a)$		120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	29	$kWh/(m^2a)$			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		$kWh/(m^2a)$			
Heating Load:	15	W/m^2			
Frequency of Overheating:	6	%	over	25 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$		15 $kWh/(m^2a)$	
Cooling Load:	10	W/m^2			

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

signed:

Passive House Verification for the prototype passive house, timber frame construction.
Source: MosArt Architecture.

Passive House Planning

U-VALUES OF BUILDING ELEMENTS

Building: Semi Detached Passive House - Concrete Block + Pelletstove

Assembly No. 1 — Building Assembly Description: External Wall - Concrete Block Construction

Heat Transfer Resistance [m²K/W]: interior R_{si} 0.13; exterior R_{se} 0.04

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	PLASTER	1.400					20
2.	CONCRETE BLOCK	0.300					100
3.	KOOLTHERM INS.	0.023					120
4.	CAVITY						
5.							
6.							
7.							
8.							

Percentage of Sec. 2: — Percentage of Sec. 3: — Total: 24.0 cm

U-Value: 0.175 W/(m²K)

Assembly No. 4 — Building Assembly Description: Floor - Cellulose Insulation

Heat Transfer Resistance [m²K/W]: interior R_{si} 0.17; exterior R_{se} 0.00

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	WOOD FLOORING	0.130					20
2.	OSB	0.130					30
3.	INSULATION (CELLULOSE)	0.040	BATTENS	0.130			292
4.	UNDERLAY	0.170					3
5.	CONCRETE	2.100					150
6.							
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: — Total: 49.5 cm

U-Value: 0.150 W/(m²K)

Assembly No. 6 — Building Assembly Description: Ceiling - Rockwool Insulation

Heat Transfer Resistance [m²K/W]: interior R_{si} 0.10; exterior R_{se} 0.04

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	GYPSUM	0.250					13
2.	OSB	0.130					15
3.	INSULATION	0.035	TIMBER	0.130			208
4.	Woodfibre Board	0.040					60
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: — Total: 29.6 cm

U-Value: 0.150 W/(m²K)

Assembly No. 9 — Building Assembly Description: Party Wall - Concrete Block Construction

Heat Transfer Resistance [m²K/W]: interior R_{si} 0.13; exterior R_{se} 0.13

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	PLASTER	1.400					20
2.	CONCRETE BLOCK	0.300					100
3.	INSULATION (MINERAL)	0.035					30
4.							
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: — Total: 15.0 cm

U-Value: 0.683 W/(m²K)

U-value of building elements for the prototype passive house, concrete block construction. Source: MosArt Architecture.

Passive House Planning

U-VALUES OF BUILDING ELEMENTS

Building: Semi Detached Passive House - Timber Frame + Pelletstove

Assembly No.	Building Assembly Description
4	Floor - Cellulose Insulation

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.17 exterior R_{se}: 0.00

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	WOOD FLOORING	0.130					20
2.	OSB	0.130					30
3.	INSULATION (CELLULOSE)	0.040	BATTENS	0.130			292
4.	UNDERLAT	0.170					3
5.	CONCRETE	2.100					150
6.							
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: Total: 49.5 cm

U-Value: 0.150 W/(m²K)

Assembly No.	Building Assembly Description
6	Ceiling - Rockwool Insulation

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.10 exterior R_{se}: 0.04

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	GYPSUM	0.250					13
2.	OSB	0.130					15
3.	INSULATION	0.035	TIMBER	0.130			208
4.	Woodfibre Board	0.040					60
5.							
6.							
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: Total: 29.6 cm

U-Value: 0.150 W/(m²K)

Assembly No.	Building Assembly Description
10	Party Wall - Timber Frame Construction

Heat Transfer Resistance [m²K/W] interior R_{si}: 0.13 exterior R_{se}: 0.13

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	GYPSUM	0.250					13
2.	INSULATION (ROCKWOOL)	0.035	BATTENS	0.130			60
3.	OSB	0.130					15
4.	INSULATION (ROCKWOOL)	0.035	STUD	0.130			116
5.	MDF Board	0.100					30
6.	INSULATION (MINERAL)	0.035					30
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: Total: 26.4 cm

U-Value: 0.175 W/(m²K)

Assembly No.	Building Assembly Description
11	External Wall - Alt. Timber Frame Construction with Rockwool-Insulation

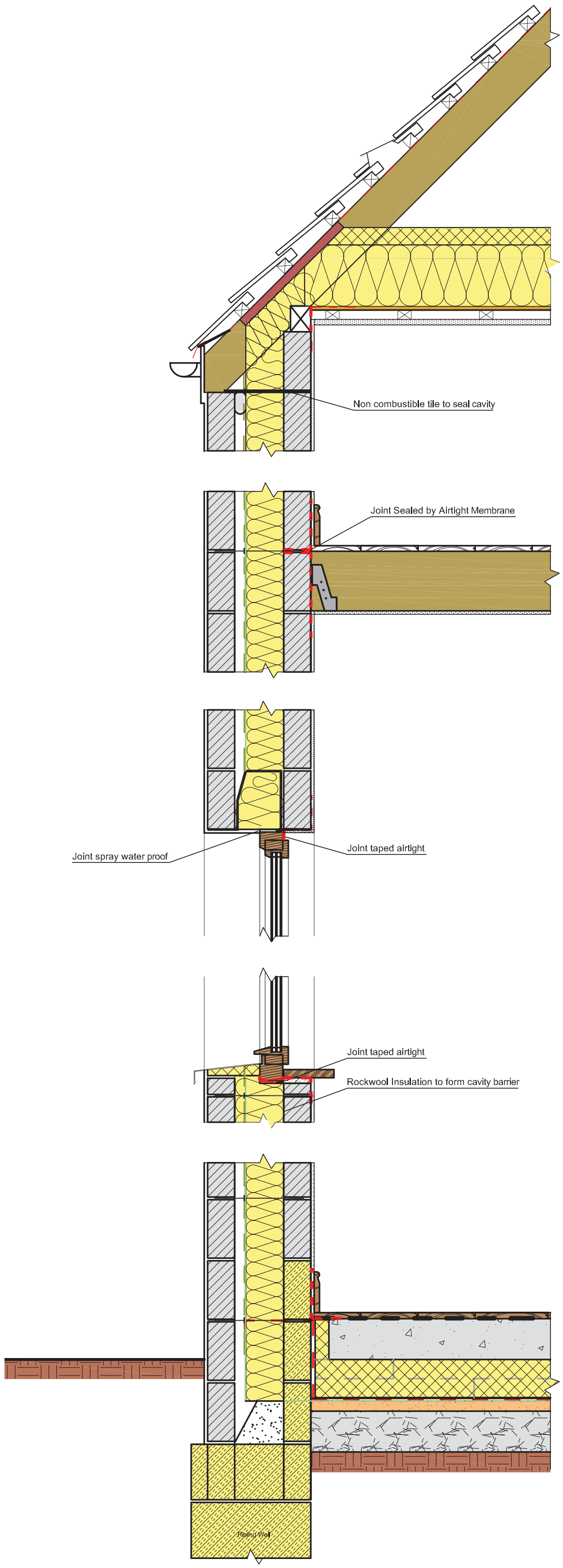
Heat Transfer Resistance [m²K/W] interior R_{si}: 0.13 exterior R_{se}: 0.04

	Area of Section 1	λ [W/(mK)]	Area of Section 2 (optional)	λ [W/(mK)]	Area of Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	GYPSUM	0.250					13
2.	INSULATION (ROCKWOOL)	0.035	BATTENS	0.130			60
3.	OSB	0.130					15
4.	INSULATION (ROCKWOOL)	0.035	STUD	0.130			141
5.	MDF Board	0.100					30
6.	CAVITY						
7.							
8.							

Percentage of Sec. 2: 10.0% Percentage of Sec. 3: Total: 27.9 cm

U-Value: 0.175 W/(m²K)

U-value of building elements for the prototype passive house, timber frame construction. Source: MosArt Architecture.



1 - Roof Structure
Roof tile or slate
Battens Breather membrane
Rafter Continuous vent to eaves
Filler timber insert used to 'jack-up' sloping roof section thereby creating more space for insulation over external wall'

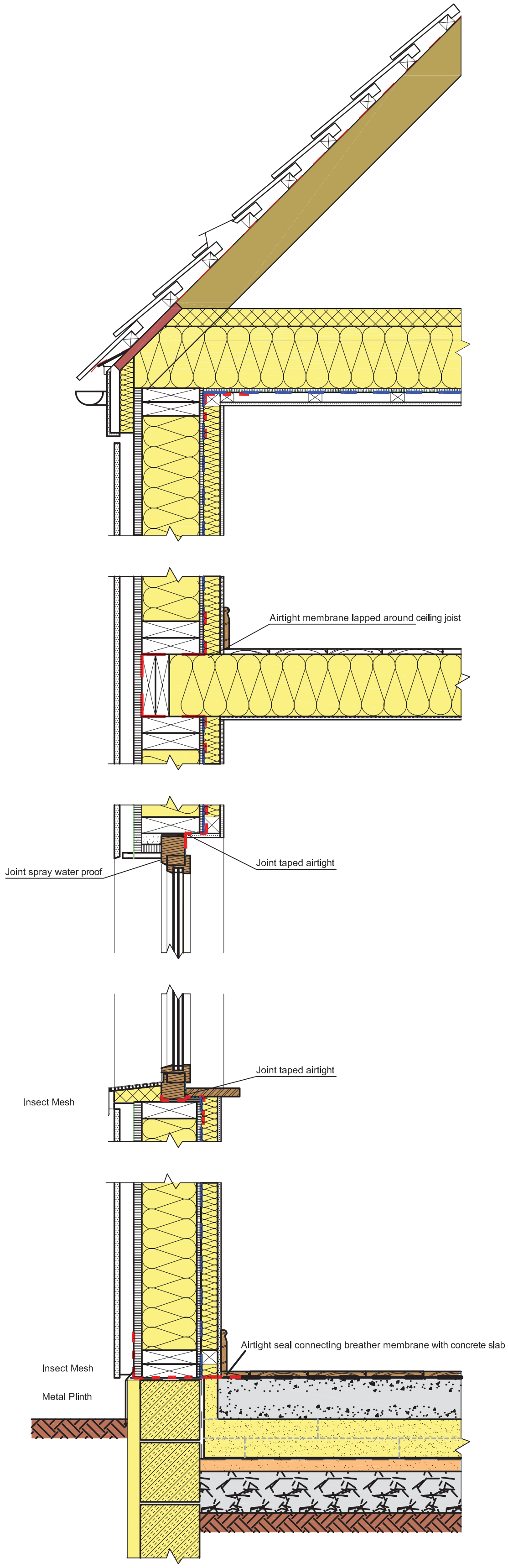
2 - Soffit/Ceiling - Timber Frame Construction - U-Value 0.15 W/m^2K
Wood Fibre Insulation Batt
Timber joist/Rockwool insulation
OSB boards
Vapour Barrier
Service Cavity
Plaster board, skim finish
Airtight tape connecting vapour barrier and block wall

3 - External Wall - U-Value 0.15 W/m^2K
External leaf brickwork
Cavity
Rockwool Insulation
Inner Leaf blockwork
Airtight membrane lapped around joist hanger
Skim finish over airtight tape and blockwork
Precast concrete reinforced lintel over windows

4 - Floor Slab - U-Value 0.155 W/m^2K
Flooring / underlay
Airtight seal connecting block wall with concrete slab
Low thermal conductivity blocks = λ 0.12W/mK overlapping cavity and underfloor insulation
Concrete slab
Rockwool insulation
Waterproof Membrane
Sand Blinding
Consolidated hardcore
Rising wall of low thermal conductivity blocks = λ 0.12 W/mK
Concrete strip foundations

Concrete Block Construction

Cross section, prototype passive house. Concrete block construction. Source: MosArt Architecture.



1 - Roof Structure

Roof tile or slate
Battens Breather membrane
Rafter
Continuous vent to eaves

2 - Soffit/Ceiling - Timber Frame Construction - U-Value 0.15 W/m^{2}K

Wood Fibre Insulation batt
Timber joist/rockwool insulation
OSB boards with joints taped
Vapour barrier
Service cavity
Plaster board, skim finish

3 - External Wall - U-Value 0.15 W/m^{2}K

External cladding on vertical battens
Cavity (minimum 40mm)
MDF boards
Timber stud/Rockwool insulation
OSB boards
Breather membrane
Timber battens / rockwool insulation
Service Cavity
Plaster board, skim finish
Rising wall of low thermal conductivity blocks λ = 0.12 W/mK
Double layer of rigid insulation external to rising walls

4 - Floor Slab - U-Value 0.15 W/m^{2}K

Flooring / underlay
Concrete slab
2 no. staggered layers of rigid insulation with λ = 0.0233 W/mK
Rigid insulation with λ = 0.0233 W/mK upstand
Waterproof Membrane
Sand Blinding
Consolidated hardcore
Concrete strip foundation

Timber Frame Construction

Cross section, prototype passive house. Timber frame construction. Source: MosArt Architecture.

3.1.3 Prototype Passive House External Wall Sections

The wall sections for both construction types have been illustrated previously. It should be noted that no dimensions are included on the sections below as they are intended to be schematic only. They should not be used as a basis for detailed construction drawings.

The following key issues can be noted from the detailed wall sections:

- Thicker than normal wall sections are designed in order to accommodate the required depth of insulation. There is also substantial insulation used in both the roof and under the floor.
- The insulation at the junction of roof and wall, as well as wall and floor, overlap in order to minimise thermal bridging at these critical locations. The window frame is also partly bedded in insulation in order to reduce heat loss.
- Membranes and specialist tapes are used to create an airtight envelope. This is especially critical at junctions between different elements, such as around windows, and also where the first floor penetrates the external wall.
- A service cavity is proposed, internal to the airtight layer in the timber frame wall, in order to accommodate mechanical and electrical fittings. A similar cavity is proposed in the underside of the ceiling at first floor level for both house types.
- Special blockwork with low thermal conductivity is used in the rising walls to reduce thermal bridging between foundations and walls.

3.1.4 Prototype Passive House Design including Mechanical and Electrical Services

The final design of the prototype passive house is presented below in plan, elevation, section and, finally, a 3D model. A number of mechanical and electrical features are highlighted which have been included specifically in the development of the passive house prototype:

- In terms of mechanical ventilation, an average air flow rate of approximately 115 m^3/h would be required, representing an approximate air change rate of 0.4 per hour. A fresh air outlet is provided to the living room, dining room, double height sun room (at ground floor level) and bedrooms whereas an extract vent is provided in WC's and bathrooms as well as the kitchen, the utility room and the upper part of the sun room. The heat recovery ventilation unit is located in the utility room and will recover the majority of the heat from the extracted air to warm the incoming fresh air. An airing cupboard is located on the first floor along with the washing machine. This space is connected to the ventilation system and can function as drying cabinet for drying clothes in the winter. Sound attenuators should be used in order to minimise noise travelling along ducts and air filters should be changed as required in order not to compromise indoor airflows and / or air quality.
- A pellet stove is proposed for the backup space and water heating system[4]. For the prototype house the annual space heat requirement (without losses of the heating system) is 13 (kWh/m^2a). Including the losses the final energy is 26 (kWh/m^2a) equating to approximately 2,860 kWh over an entire year (the house measures 110m^2 in treated floor area). This would equate to 269 litres/year of oil, 277 m^3/year of mains gas or 572 kg/year of wood pellets (in bags).
- The design or peak heat load, on the other hand, is approximately 1,800 W, or just 1.8 kW. This amount of energy could be provided by a very small stove / heater incorporating a back boiler, or by a small separate boiler compared to what might be typically required in a family home; there are several such 'small' heating appliances on the market which range in output from 2.4 to 8kW, with an efficiency of up to 80%.
- The pellet stove in the prototype house has been positioned in the sitting room, but space has also been left in the utility room as this might be preferable to users. Care must be taken to use a stove that delivers most of the heat output to a hot water tank which can be used not only for domestic hot water but also as a 'buffer' to work in tandem with a water to air heat exchanger (see below). A stove that only emits radiant heat directly into the room in which it is located would likely overheat that same room due to the high levels of insulation required in a passive house.
- The pellet stove can be filled manually as the need arises, or could be automatically fed using an underground pellet storage 'bunker' located underground to the public road side of the house for ease of delivery. While a house of this size could probably manage without an automatic feed from a bunker (given an average use of approximately 40 kg of pellets per week[5]), the advantage of such a system is in the space saved from having to store pellets in the house or garden shed. In positioning the pellet stove in the sitting room, there is a perceived aesthetic benefit to be gained from visibility of the flames coupled with the delivery of some heat directly into the sitting room.
- It is also critically important that the pellet stove has its own independent fresh air supply, given the airtight nature of the construction, and that there is an appropriate flue for venting of exhaust gases. Such systems are commonplace in passive houses and confer both an efficiency and a safety benefit that will not adversely affect the balanced ventilation system.
- The large domestic hot water tank (1,000 litre), which serves as a 'buffer' heat store as indicated above, is located adjacent to the mechanical ventilation unit, in the utility room. The backup heating system in this case is provided by heating the fresh air circulating around the house from the hot water in the 'buffer' tank using a water to air heat exchanger. In this regard, all supply air ducts should be insulated in order to minimise heat losses, even if they are located within the thermal envelope.

- Solar panels (measuring 7.5m²) are positioned on the south facing roof which is pitched at the optimal angle of 45 degrees. These have been sized in accordance with the needs of such a house and could include either flat plate collectors or evacuated tubes.

Other aspects of the design which are not related to the mechanical or electrical services are listed below:

- All windows in the prototype house are triple glazed with low emissivity coating, thermally broken frames and gaskets especially designed to minimise air infiltration. A passive house triple glazed window is typically three to four times more energy efficient than a standard double glazed unit and, if approximately south facing, will take in more energy in a year than it lets out. The use of such glazing ensures high thermal comfort in cold weather through minimal temperature difference between the internal glass pane surface and room temperature.
- A balcony is provided at first floor level, the primary function of which is to shade the extensive area of glass on the south elevation. This balcony can be accessed via the gallery which overlooks the double-height sun room. A wooden pergola is provided overhead the balcony to shade the upper storey windows. A possible alternative to this pergola could be a deep roof overhang but the steepness of the pitch in the prototype house would mean that this latter solution would restrict high level views from the upper storey.
- The internal party walls can be constructed as per a conventional house as long as it is within the boundaries of the building envelope.
- The hatch to the attic should be very well insulated and completely airtight to minimise cold air infiltration.
- Ceiling insulation is placed horizontally on the attic floor in the prototype passive house. It would also be possible to place this insulation between the rafters, albeit with design and construction implications.
- The timber frame option depicted in these guidelines is ventilated with an external cavity.
- Energy efficient light fittings should be used which use less primary energy (they will also reduce internal heat gains). It is also recommended to use energy efficient household appliances for cooking, wet appliances, cold appliances etc. to enable the primary energy performance target of 120 kWh/(m²a) to be met.

Various building methods can be used in the construction of a passive house, including insulated concrete formwork and externally insulated concrete block wall, shown below. This is in addition to the more common masonry and timber frame construction methods, as illustrated in the prototype house examples shown above.

3.2 Cost Considerations

An analysis of additional costs associated with construction of the prototype house to the Passivhaus Standard was carried out by Gardiner and Theobald, Quantity Surveyors. The additional cost of the key items including enhanced insulation, glazing, airtightness and thermal bridging was estimated, along with the cost of such technologies as MHRV, solar panels for DHW, a pellet stove as well as energy efficient light bulbs and household appliances. Included in their analysis was an allowance for the foregone costs associated with 'conventional' house features such as a fireplace and boiler with radiators. Gardiner and Theobald completed their analysis for both the timber frame and the concrete block construction types.

The additional 'extra over' cost associated with building the prototype house to the Passivhaus Standard was estimated at approximately €25,000 for both construction types, including VAT and design fees (referring to 2007 building costs). Approximately 60% of this cost can be attributed towards improvement of the building shell (enhanced insulation, higher grade windows, improved airtightness and reduced thermal bridging) with the remaining 40% covering building systems including MHRV, solar thermal system, wood pellet boiler and low energy lighting.

Gardiner and Theobald next sought to express the additional passive house costs as a proportion of conventional construction costs. The cost of a conventional house varies considerably according to the quality of finishes required. An average cost of €196,000 was proposed as representing a mid-grade finish, including VAT and design fees. The additional €25,000 thus represents approximately 12.5% of conventional build costs.

[1] *Approximately 17% of the overall housing stock in Ireland are semi-detached dwellings.*

[2] *According to the Irish Timber Frame Manufacturers' Association (ITFMA) the number of timber frame house completions has grown from a market share of 15% in 1999 to a market share of 30% in 2006.*

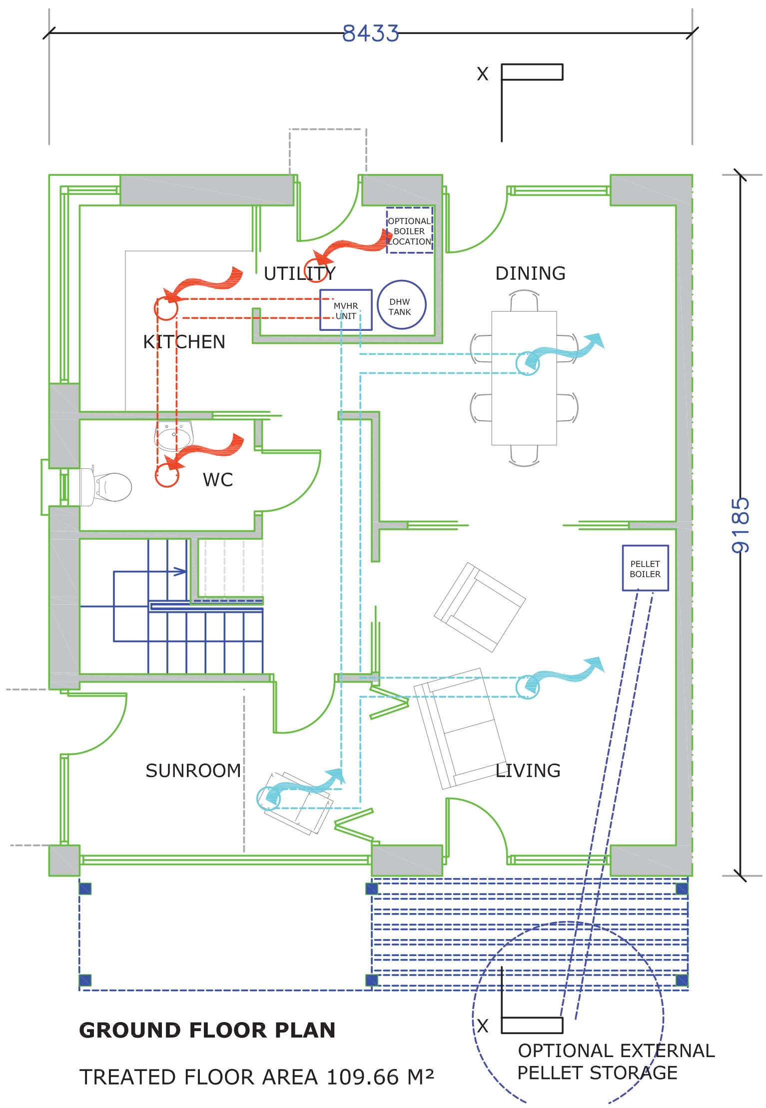
[3] *The TFA is the living area within the thermal envelope. Any rooms or areas beyond the boundaries of the thermal envelope are not considered.*

[4] *Other sources of heat such as gas or heat pumps can also be used.*

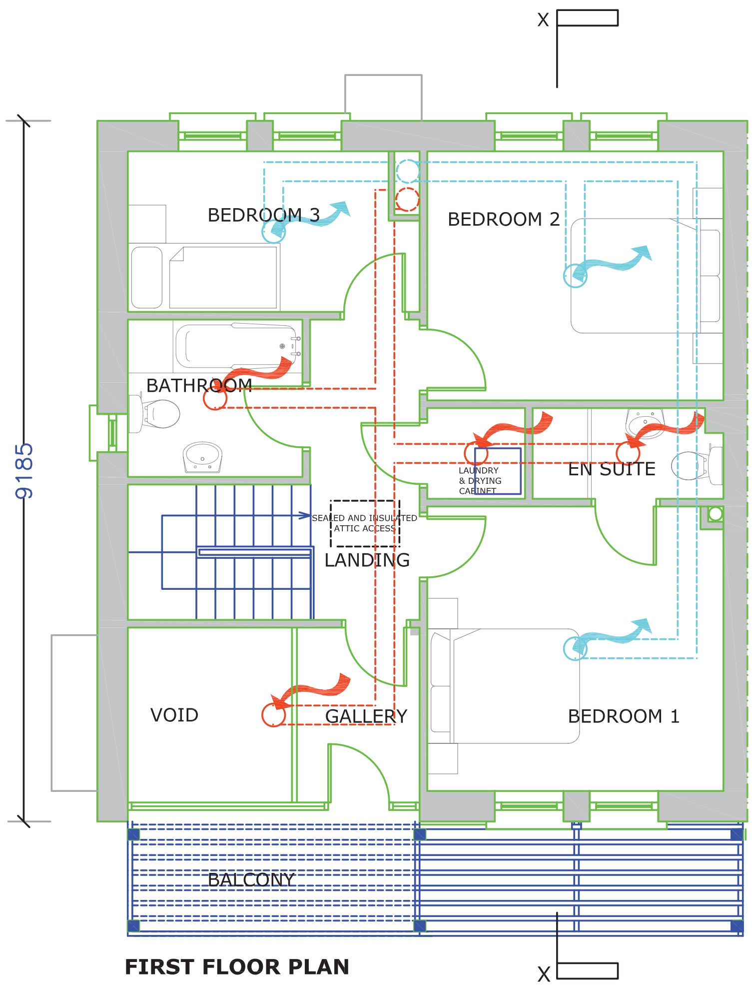
[5] *Estimated heating requirement for hot water (net of 60% SWH) + space heating = 6,300 kWh = c.1,260 kg pellets/year = 40 kg/week over a 30 weeks heating season.*

References

Passive House Planning Package, PHPP 2004, Technical Information PHI-2004/1(E). Darmstadt, Germany. Passive House Institut, Dr. Wolfgang Feist.



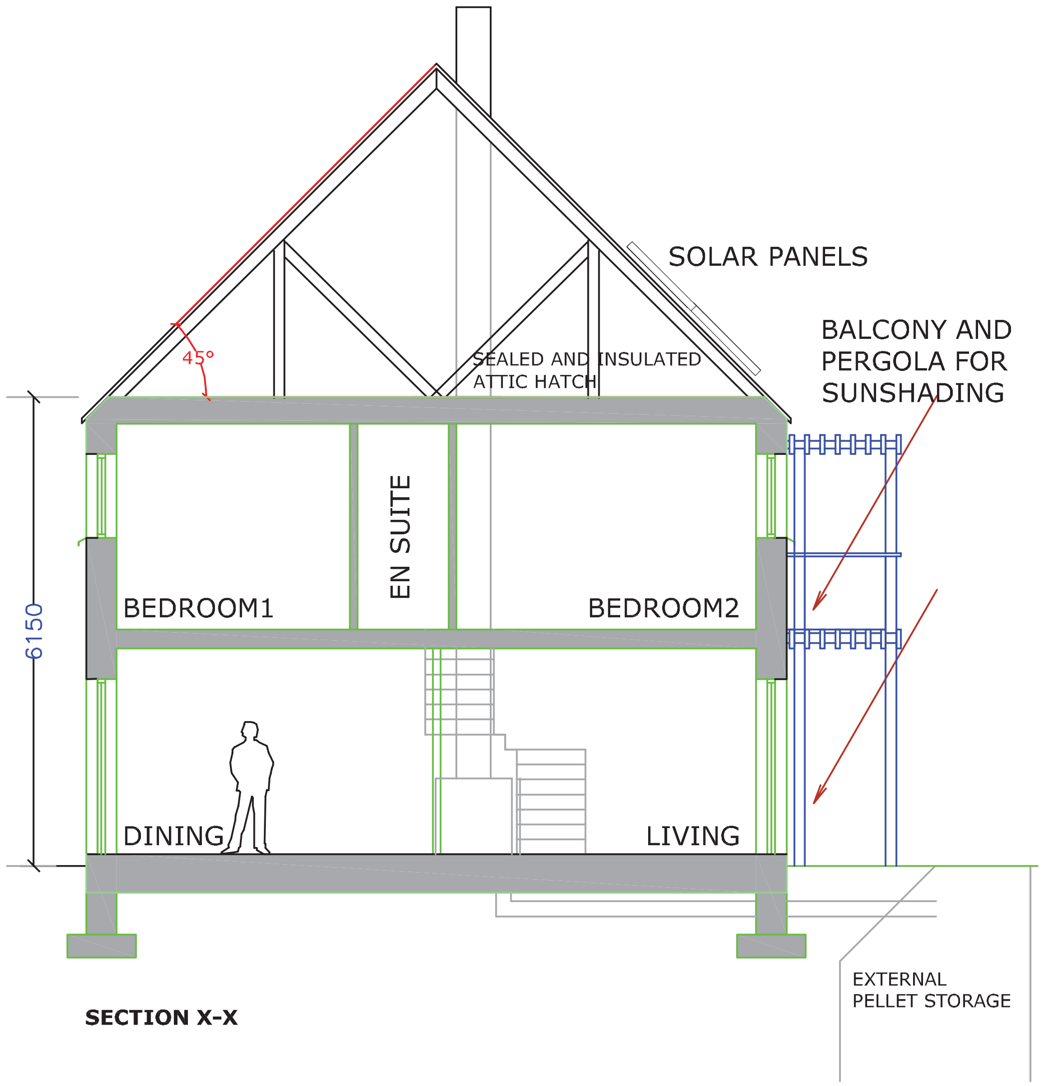
Prototype passive house, floor plans (not to scale). Source: MosArt Architecture



FIRST FLOOR PLAN

FLOORPLANS/SECTION

Prototype passive house, floor plans (not to scale). Source: MosArt Architecture



Prototype passive house, cross section (not to scale). Source: MosArt Architecture

Prototype passive house, front, back and side elevations (not to scale). Source: MosArt Architecture

Prototype passive house, 3D model (not to scale). Source: MosArt Architecture

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