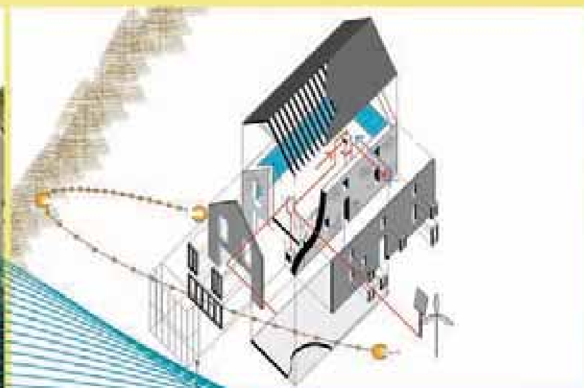
SUSTAINABLE ENERGY IRELAND

Retrofitted Passive Homes

GUIDELINES FOR UPGRADING EXISTING DWELLINGS IN IRELAND TO THE PASSIVHAUS STANDARD



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 SEI Renewable Energy Information Office and MosArt Architecture.
Cover images courtesy of Cooney Architects.

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Foreword

The Sustainable Energy Authority of Ireland, SEI, operates programmes and activities to advance the Government's ambition for Ireland to become a world leader in sustainable energy as part of our transition to a low carbon economy. Thus, we seek to accelerate the development and deployment of cost effective low carbon technologies. Following the implementation of the EU Energy Performance of Buildings Directive, recent substantial improvements in Building Regulations energy standards and requirements for the use of renewable energy systems, we have seen substantial improvement in the energy performance required of new buildings.

For several reasons, attention must focus now on our existing buildings. The recent extension of the Building Energy Rating to all buildings being sold or rented coupled with the introduction of a national residential energy efficiency programme, and the knowledge that cost-effective opportunities to reduce greenhouse gas emissions are most readily found in buildings are all combining to provide an extraordinary impetus to home energy saving.

The PassivHaus standard is recognized in Europe as a progressive and advanced benchmark for building energy performance. In 2008 SEI published 'Guidelines for the Design and Construction of Passive House Dwellings in Ireland' which have been very well received, with some 5,000 copies now in circulation. These companion guidelines 'Retrofitted Passive Homes - Guidelines for Upgrading Existing Dwellings in Ireland to the PassivHaus Standard' extend the available support and information for the upgrading of existing dwellings to achieve the ambitious PassivHaus Standard.

There has been a noticeable increase in the number of successfully retrofitted PassivHaus projects in continental Europe in the past three to five years and it is expected that this trend will carry over to Ireland.

These guidelines provide sound and practical advice on how the retrofitting of older buildings could potentially achieve a standard which will greatly increase comfort, cut energy costs dramatically, and offer a home which is far more "future proofed". There are over 1.5 million homes in Ireland that could each benefit from implementing even some of the measures contained in this document.

Professor J Owen Lewis
CEO, 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 all 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 space heating system; the air supply system essentially suffices to distribute the remaining space heat requirement. A passive house provides a very high level of thermal comfort and 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 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 to retrofitting dwellings in Ireland and in all cases when referring to a passive house is describing a house upgraded to the requirements of the Passivhaus Standard. These guidelines should be read in conjunction with the Guidelines for the Design and Construction of Passive House Dwellings in Ireland published by SEI in July 2008 (www.sei.ie/phguidelines).

1.1.1 Definition of the Passivhaus Standard

The Passivhaus Standard is a specific construction standard for buildings which results in good comfort conditions during winter and summer, without traditional space heating systems and without active cooling.

The primary focus in building to the Passivhaus Standard is directed towards creating a thermally efficient envelope which makes the optimum use of free heat gains in order to minimise space heating requirement. Structural airtightness (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 back-up system (using a renewable energy source, for example) can be used to boost the temperature of the fresh air supplied to the house. Renewable energy sources are used as much as possible to meet the resulting energy demand (PEP, 2006), including that required for the provision of domestic hot water (DHW).

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

- Annual space heating requirement of 15 kWh/(m^{2}a) treated floor area;
- 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; and

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- Additionally, the air-leakage test results must not exceed 0.6 air changes per hour (ac/hr) 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 passive house, the heat losses are reduced dramatically (through better insulation and airtight detailing) so that internal gains and passive solar gain contribute a relatively high proportion of the total need. As a result of this, a smaller space heating system is therefore required compared to that needed in a conventional poorly performing dwelling.

A semi-detached, two storey Irish house built in the mid 1970's before the introduction of thermal insulation standards would be expected to have a space heating requirement of over 200 kWh/(m^{2}a) and to have a total primary energy demand of over 400 kWh/(m^{2}a) for all applications. The equivalent house built to the requirements of TGD Part L 2007 would be liable to use 40-50 kWh/(m^{2}a) delivered (useful) energy for space heating and 90-95 kWh/(m^{2}a) primary energy. The Passivhaus Standard requirement for space heating is 15 kWh/(m^{2}a). When compared to a house built in the mid-1970's, with little or no insulation and poor performing glazing, a house retrofitted to the Passivhaus Standard thus represents a saving of more than 90% on the space heating demand.

One of the key benefits of a passive house is that it becomes affordable to provide thermal comfort conditions around the clock at much reduced energy consumption. This is a very positive aspect of passive houses that is often forgotten. The energy consumption for heating an existing house around the clock would be significantly higher and much less affordable.

Measure/Solution	Retrofit Passivhaus Standard for the Case Study Semi-Detached House in the Irish Climate
1. Super Insulation	
Insulation Walls	U ≤ 0.10 W/(m^{2}K)
Insulation Roof	U ≤ 0.09 W/(m^{2}K)
Insulation Floor	U ≤ 0.10 W/(m^{2}K)
Window Frames, Doors	U ≤ 0.8 W/(m^{2}K)
Window Glazing	U ≤ 0.6 W/(m^{2}K)
Thermal Bridges	Thermal bridges with a linear heat coefficient Ψ ≥ 0.01 W/mK will be very common in most retrofit projects and will require calculating
Structural Airtightness	n50 ≤ 0.6 ac/hr @ 50 Pascal
2. Heat Recovery/ Air Quality	
Ventilation counter flow air to air heat exchanger	Heat recovery efficiency ≥ 85%
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 0.37 ac/hr or 30m^3 /person/hr
Ventilation Supply Ducts Insulated	Where applicable
DHW Pipes Insulated	Where applicable
3. Passive Solar Gain	
Window Glazing	Solar energy transmittance g ≥ 50%
Solar Orientation	Minimal glazing to north where possible
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 the Case Study Project Presented in Section 6
Source: MosArt Architecture

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/(m^{2}a) for the Irish climate. Specifying U-values is dependent upon many variables and the effect on energy performance can only be verified through testing the performance of the dwelling design in the Passive House Planning Package (PHPP) software. In a typical retrofit situation, Passivhaus principles such as orientation, position of glazing, thermal bridging and compactness will generally not have been considered in the original design. For that reason, the required U-values for retrofit projects will often be far lower than for buildings that were, from the very outset, designed in strict accordance with the Passivhaus Standard. The U-values included in Table 1 have been tested for the case study house presented later in Section 6. This case study house is a terraced two storey house of compact form and with optimal (rear) façade orientation of directly south. A detached bungalow house of sprawling form would likely require even lower (better performance) U-values than those specified in the table above in order to meet the Passivhaus Standard. Readers familiar with the SEI (new-build) Passive Homes Guidelines will recognise that the U-values listed in the table above are considerably lower (better performance) than those specified for the prototype house in those guidelines. The reason for this is that there are often numerous thermal bridges that have to be compensated for in retrofitting an older dwelling compared to new-build. The case study dwelling is also partly shaded which reduces passive solar gain, requiring a better insulated envelope.

1.2 Applications of the Passivhaus Standard in the EU and Ireland

1.2.1 Evolution of Retrofitting Dwellings to the Passivhaus Standard in Europe

The Passivhaus Institut (http://www.passiv.de) was founded in Darmstadt, Germany in 1996 by Dr. Wolfgang Feist as an independent research institute. 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 overseas. The Institute developed the "Passivhaus Projektierungs Paket" (PHPP - Passive House Planning Package), an Excel worksheet used to determine the energy supply / demand balance for passive buildings (available in Ireland from SEI Renewable Energy Information Office (www.sei.ie/resourcecentre).

Since completion of the first certified new-build passive houses in Darmstadt in 1991, there has been an emerging trend in recent years of retrofitting buildings to the Passivhaus Standard.

1.2.2 Application of Passivhaus Standard in Ireland

The Kyoto Protocol came into force 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% by 2010. 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 2006, the residential sector accounted for 25% of primary energy consumption and used 2,990 ktoe of final energy representing 23% of Ireland's Total Final Consumption. With regard to CO_2 emissions, the average dwelling was responsible for emitting approximately 8.1 tonnes of CO_2. A total of 4.8 tonnes CO_2 (59%) was from direct fuel use, the remainder being the result of upstream emissions from electricity usage.

Examining CO_2 emissions per dwelling, the average Irish dwelling in 2005 emitted 47% more CO_2 than the average dwelling in the UK. Emissions were 92% higher than the average for the EU-15, 104% more than the EU-27.

Following the Government's 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 to dwellings where planning permission was submitted after 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 retrofitted to the Passivhaus Standard is even lower than the 40% improvement that applies to all new dwellings in Ireland from July 2008. As inefficient existing dwellings represent the majority of the building stock, the retrofitting of existing stock to the Passivhaus Standard represents a great potential for reducing energy consumption.

From January 1st 2009, all existing dwellings which are offered for sale or rent must undergo a building energy assessment and have a Building Energy Rating certificate. This requirement, perhaps above all other initiatives, is likely to result in a rapid and dramatic appreciation by homeowners of the importance of energy efficiency in older dwellings.

The EU Parliment has proposed a binding requirement that all new buildings needing to be heated or cooled be constructed to a 'passive house' or equivilant standard from 2011 onwards (reference European Parliament resolution of 31 January 2008 on an Action Plan for Energy Efficiency: A6-0003/2008). As the energy efficiency of new-build dwellings steadily improves, there may well be increasing pressure to reduce the energy consumption of older homes in order that they can compete for buyers attention on the open market.

Minister Gormley announced in July 2008 his ambition that all new domestic buildings be constructed to a 'carbon neutral' standard by 2012 or 2013. Such a move will likely result in a significant increase in the market penetration of renewable electricity generating technologies which will, inevitably, spill over in terms of application to the second-hand housing sector.

Lastly, there are several grant schemes available through Sustainable Energy Ireland at present which are focused towards building energy efficient dwellings and the deployment of renewable energy technologies including the Greener Homes Scheme and the Low Carbon Homes Scheme. In addition the Warmer Homes Scheme tackles the issue of energy efficiency in low income, older dwellings and is of potential relevance to these Guidelines. In 2003, SEI estimated that approximately 220,000 households in Ireland live in either persistent or intermittent fuel poverty.

1.3 Dwelling Energy Assessment Procedure

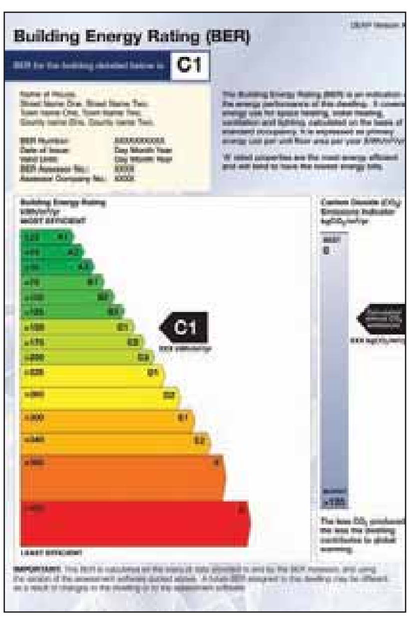
1.3.1 Dwelling Energy Assessment Procedure

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, and also takes into account 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 (BER) for a dwelling.

1.3.2 Building Energy Rating

A BER is an objective scale of comparison for the energy performance of a building ranging from A1 to G (see sample label below). 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.



Building Energy Rating Label.
Source: Sustainable Energy Ireland.

1.3.3 PHPP and DEAP

Whereas DEAP is the mandatory method for both producing a BER 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.

References

[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

Additional Reading

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Section Two

Review of Building Stock in Ireland

Review of Building Stock in Ireland

An overview of the current building stock in Ireland is provided below in order to gain some impression of the potential application of these guidelines.

There were an estimated 1.46 million permanently occupied dwellings in the State at the end of 2006. The most common house type in Ireland in 2006 was the detached house which accounted for 42.8% of the total, followed by semi-detached houses at 27.2% and terraced houses at 17.6%[2].

was €1,767, an increase of 4% on 2005 and 70% on 1990 (3.4% per annum on average) – this increased to approximately €2,000 in 2008.

In 2006 the residential sector accounted for just under a quarter of all energy used in Ireland and after transport it was the second largest energy using sector. The sector was responsible for 25% (11,896 kt CO_2) of energy related CO_2 emissions. In 2006 the 'average' dwelling consumed a total of 25,304 kWh of energy based on climate corrected data.

In terms of real numbers, it is estimated that 930,000 houses in Ireland were built before the first ever building regulations in 1991, with approximately 1 million homes built before the 1996 Building Regulations. 350,000 houses in Ireland have no wall insulation, 200,000 houses have no roof insulation and 350,000 houses have single glazed windows.

Stock of Private Households in Permanent Housing Units - Types of Accommodation

DWELLING TYPE	2006 number	2006 % of Total
Detached House	625,988	42.8
Semi-Detached House	398,360	27.2
Terraced House	257,522	17.6
Flat / Apartment[1]	139,872	9.6
Bed-sit	8,751	0.6
Not Stated	31,803	2.2
Total	1,462,296	100.0

Source: SEI

In 2006, the majority of dwellings (75%) were either owned outright or were in the process of being purchased (mortgaged) representing a slight decrease on the 1991 proportion of 79%.

There have been historically high levels of ownership in Ireland compared to other European countries. For example in Austria the proportion of owner occupied dwellings was 51% in 2004 and for the UK it was 69%.

Dwellings in Ireland are gradually increasing in size. For example, the average floor area of new houses granted planning permission grew from 130m^2 in 1990 to 161m^2 in 2007 (an increase of 24%). In 2006 the average annual spend on energy by households

This comprised 19,713 kWh (78%) in the form of direct fossil fuels and the remainder as electricity.

Putting Irish dwellings into an international context. Examining CO_2 emissions per dwelling, the average Irish dwelling in 2005 emitted 47% more CO_2 than the average dwelling in the UK. Emissions were 92% higher than the average for the EU-15, 104% more than the EU-27.

Focusing on the quality of the building stock in Ireland, The Economic and Social Research Institute (ESRI) completed a study in 2002 titled 'Irish National Survey of Housing Quality 2001 – 2002 (NSHQ)' on behalf of the Department of the Environment, Heritage and Local Government (DoEHLG). At the time of the survey, 57% of all dwellings had been built before the introduction of the first Irish Building Regulations which came into force in 1991. Approximately 750,000 homes were built prior to any thermal insulation requirements (introduced 1979) but the survey indicates a degree of energy improvement across the older housing stock. Nevertheless, in 2001 24% of all households surveyed had no insulated walls (equating to 63% of pre-1940 built houses), 18% had no insulated roof (40% of pre-1940 built houses) and 31% had no double glazing (49% of pre-1940 built houses).

The percentage of dwellings with central heating had increased from 52% in 1987 to 91% in 2005.

Energy efficiency and dwelling age

Pre-1940 dwellings were mainly solid-wall construction, while during the 1940s through to the 1970s, cavity-wall construction was implemented. During the 1980s, improved U-values for both walls and attics were introduced in various building regulations, increasing the thermal efficiency of dwellings, and these U-values have since been further enhanced with the introduction of more stringent building regulations.

The graph across highlights the trend from 1972 to 2010 in terms of energy efficiency of dwellings in Ireland. The most significant improvement in this period was post 1979, when the first Building Regulations were introduced. It would appear from this data, therefore, that dwellings built pre-1979 would benefit most from retrofitting to the Passivhaus Standard (amounting to approximately 750,000 dwellings).

Fuel Poverty SOURCE:
HEALY AND CLINCH (2002)

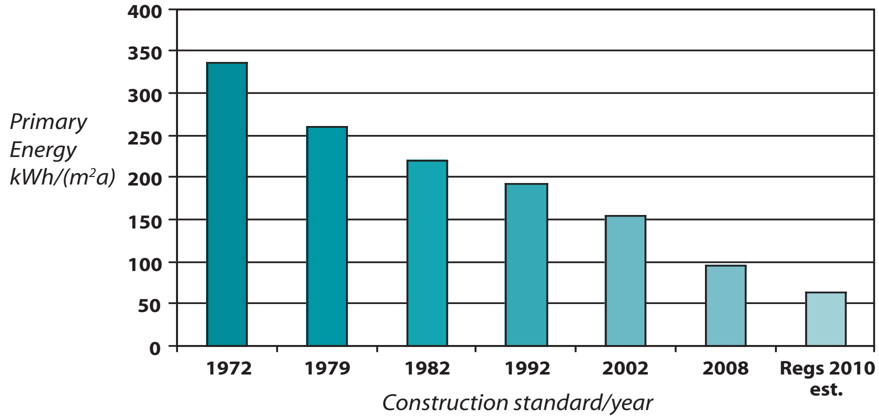
The study by Healy and Clinch highlights that older dwellings are more likely to be occupied by those experiencing fuel poverty than newer dwellings, with the highest absolute numbers found in homes built in the 1940s-70s, where some 111,000 households are affected. As might be expected, those in newer homes experience a lower level of fuel poverty. Retrofitting older dwellings to the Passivhaus Standard would therefore assist in addressing the issue of fuel poverty in Ireland.

Summary

It is likely that dwellings which are older than 30 years and have had little or no prior upgrading are most suited to retrofitting to a significantly higher energy performance standard (such as Passivhaus Standard) given their completion prior to introduction of thermal insulation standards in the late 1970's. Further, due to the age of these dwellings, they may well require significant upgrading of the building fabric which often provides a stimulus to upgrade energy performance.

In short, the older the building the more effective would be retrofitting to the Passivhaus Standard.

Energy rating of Irish housing: Indicative Trends over 4 decades



References

[2] *Energy in the Residential Sector, 2008 Report, by Fergal O'Leary, Martin Howley and Dr. Brian Ó Gallachóir*

Source:MosArt Architecture

Section Three

Principles of Passive Houses

Principles of Passive Houses

The principles of passive houses will be outlined below in brief. More detailed information is provided in Chapter 2 of SEI's Guidelines for the Design and Construction of Passive House Dwellings in Ireland (www.sei.ie/phguidelines).

The building envelope consists of all elements of the construction which separate the indoor climate from the outdoor climate. The aim of retrofitting to the Passivhaus Standard is to upgrade the building envelope in order to minimise heat loss and optimise solar and internal heat gain to reduce the space heating requirement to 15 kWh/(m²a).

The following 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
6. Introduce renewable energy technologies such as solar thermal

Passivhaus Planning Package 2007 – An Essential Design Tool

The Passivhaus Planning Package 2007 (PHPP) is a software package based on a series of extensive and interlinked Excel data sheets which collectively allow building designs (including retrofit strategies) to be verified against the Passivhaus Standard. The latest version of the PHPP software can be purchased from SEI's Renewable Energy Information Office (www.sei.ie/resourcecentre). The verification requires the input of very specific and detailed data about the building 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 retrofitted. 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 for which the passive house is being designed. 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 thermal conductivity (λ-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 are entered into this sheet, along with the U-values of the glass and frames as well as other technical specifications.
- 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 space heat requirement must be less than 15 kWh/(m²a).
- Heat Load (W/m²) – 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 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 retrofitting strategy will likely have to be modified in order to achieve the required standards. In a retrofit situation, this will typically involve improving the U-values of the building envelope.


Certificate

Quality Approved Passive House

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

Extracts from the PHPP software are included later in Section 6 pertaining to the retrofit case study house.

Passive House Certification

At the time of writing these Guidelines, a passive house in Ireland can be certified by the Passivhaus Institut in Darmstadt, Germany (http://www.passiv.de) or certifying body approved by the Passivhaus Institut. For further information on certification of passive houses in Ireland contact SEI's 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/(m^{2}a)
- Pressurisation Test Result n50 max. 0.6 air changes per hour
- Entire Specific Primary Energy Demand max. 120kWh/(m^{2}a) 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' certificate is issued (PHPP 2007, pp.28).

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 a small number of passive house buildings), aims to ensure that the design of a particular passive house can deliver the specific energy requirements in accordance with the PHPP and confirms 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 airtightness of the completed building by a fan pressurisation test performed in accordance with IS EN 13829.

Building Envelope Insulation

There are several different methods and materials available to upgrade the performance of the building envelope in dwellings to the Passivhaus Standard and the most typical scenarios likely to be encountered are illustrated in the next Section. 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. Achieving this in a retrofit situation is more challenging than for a new-build.

Insulation of the building envelope can be divided into four distinct areas: external wall, floor, roof and windows/doors. 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). Typically triple glazed window units are used in passive houses in Central and Northern Europe.

These U-values are far below (i.e. better than) the limits set under the Irish Building Regulations.

According to the current Technical Guidance Document Part L 2007 the required U-values are 0.27 W/(m^{2}K) for walls, 0.16 – 0.22 W/(m^{2}K) for roofs, 0.25 W/(m^{2}K) for ground floor slab, 0.15 W/(m^{2}K) for ground floor slab with under floor heating and 2.0 W/(m^{2}K) for windows, rooflights and external doors.

Optimising passive solar gain

The optimal approach to the design of a passive house is to avoid an excessive area of north facing glazing and place relatively large windows facing 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. Achieving the optimal distribution of glazing when dealing with existing dwellings will often be very challenging and in many instances it will simply not be possible to increase passive solar gain due to the aspect of the dwelling. A detached house in its own grounds might provide some scope for alteration and provision of south-facing windows, but an east-west facing mid-terrace house will not have the same scope. The PHPP software can be used to determine whether or not the Passivhaus Standard can be reached with any given aspect and it will typically be possible to compensate for lack of passive solar gain by increasing the level of insulation of the building envelope.

Extensive areas of glass on the south facing façade in a well insulated and airtight dwelling might well lead to overheating on 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 degrees C.

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. 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. Special care must be taken to ensure that retrofit measures do not increase the likelihood of creating such problems which can affect the health and longevity of the building.

The Passivhaus Standard for linear thermal transmittance should not exceed 0.01 W/(mK). This requires the building designer to identify and locate all potential thermal bridging in the construction, applying careful specification and detailing of those elements providing where possible a continuing layer of insulation as well as taking care to execute those elements on site as per design details. The impact of thermal bridging can be tested and verified in the PHPP software as the design of the retrofitting scheme 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 air-tightness 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. The air tightness of a building can be accurately (IS EN 13829) measured by carrying out a blower-door test and the Passivhaus Standard is reached when there are less than or equal to 0.6 air changes per hour @ 50 Pascal pressure.

The airtight construction required should reduce the penetration of radon in to the building. Radon which can still be detected inside of the building will be partly contributed from outside air as well as off-gassing from building materials. To mitigate against effects of low radon concentrations recommended air changes of 25 to 30 m^3/person provided by a mechanical ventilation system are sufficient[3].

The Radiological Protection Institute of Ireland (RPII) (www.rpii.ie) and the Irish Building Regulations provide advice about the treatment of radon in the built environment.

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 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 two thirds of the total space heat load for the case study passive house retrofit project presented in Section 6.

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, due to the small space heating requirement involved, the following building services are sufficient in a passive house:

- Mechanical ventilation system with heat recovery which provides most of the space heat requirement.
- Back-up system capable of heating the air passing through the dwelling via mechanical ventilation to meet any auxiliary space heating needs, expected to be small. Typical fuel sources for the back-up system include biomass, heat pump, 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.

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 smells 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 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 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 retrofitting a dwelling to include MHRV, occupants will likely have no experience of the maintenance requirements involved with the system.

What happens in the event of a power failure?

If there is a loss of electricity (and the dwelling has no back-up 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. However, 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.

Additional details on MHRV aspects are provided in SEI's publication Guidelines for the Design and Construction of Passive House Dwellings in Ireland.

Back-up Heating System

As previously highlighted in these guidelines, the space heating requirement in a passive house is so low that there is no need for a traditional space heating system. 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 building systems. The optimal way to transfer the small amount of required heat throughout the house is through the mechanical ventilation system.

The PHPP software will accurately predict the following two measurements for each retrofit 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/(m²a).
- **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/m².

For the retrofit case study the annual space heat requirement (without losses of the heating system) is 15 kWh/(m²a) reduced from an initial 214 kWh/(m²a). Including the losses the so called final energy (post retrofitting) is 30 kWh/(m²a) equating to approximately 2,490 kWh over an entire year (the house measures 83m² in treated floor area). Annually, this would equate to 230 litres of oil, 240 m³ of mains gas or 450 kg (0.45 tonne) of bagged wood pellets.

The heat load, on the other hand, has been reduced from 80 W/m² (6.64 kW for 83m²) to 9 W/m² (0.74 kW for 83m²). This amount of energy could be provided by a very small wood chip / pellet boiler/stove 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:

- Water to air heat exchanger;
- Compact unit with electrical heat pump; and
- Wood pellet/wood log boiler/stove with integral back boiler.

An overview of the typical back-up heating systems used in passive houses to provide thermal comfort[3] is provided in Section 4.4.

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 the BER 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 technologies.

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

- The optimal orientation is 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, then expected orientation losses can be overcome by increasing the collector area.
- The optimal tilt of the solar panels 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 main types of solar collectors typically used, namely flat plate panels and evacuated tubes.

References

[3] *Translated from Protokollband Nr. 30, Lueftung bei Bestandssanierung: Loesungsvarianten, Dr. Wolfgang Feist Passivhaus Institut*

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), 2008 version 3, pp. 31.

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.

Section Four

Typical Phases of Retrofitting

Typical Phases of Retrofitting

4.1 Survey

A detailed survey of the building to be retrofitted is an important basis for a good low-energy design.

The existing build-up (in terms of materials, performance and dimensions) of the different elements of the thermal envelope and details of junctions, possible thermal bridges, windows and doors have to be accurately recorded. In many cases, the precise build-up of the envelope will not be known to the owner of the dwelling (for example whether external walls are of cavity block, hollow block or solid block) and in these situations it will be necessary to create an inspection opening to clarify the construction type.

Details of the heating and DHW system as well as data on energy consumption over a three year period are also critically important as a means of verifying the thermal performance of the existing building fabric. In parallel with this, it is also important to consider the comfort levels experienced by the dwelling occupants. Low energy bills could be misinterpreted as a reflection of an efficient dwelling when in fact the occupants might have been living in some considerable discomfort during the heating season due perhaps to lack of resources (fuel poverty) or malfunctioning heating systems.

A blower door test would be helpful to ascertain the current level of airtightness and to identify where cold air may infiltrate the building fabric in the heating season. The Passivhaus Standard requires an airtightness performance of 0.6 air changes per hour measured at 50 Pascal pressure and the majority of older dwellings will perform considerably poorer than this.

Blower door airtightness test.
Source: MosArt Architecture

The National Standard Authority of Ireland (NSAI) recently introduced a registration scheme for service providers involved in the Air Tightness Testing of Domestic dwellings to IS EN 13829:2000. This scheme should ensure high standards in terms of independence and quality of testing and evaluation.

The use of a thermal imaging camera can also be very helpful in locating weak points in the thermal envelope but such a procedure is not necessarily mandatory especially if the survey and assessment is being undertaken by someone with experience in retrofitting.

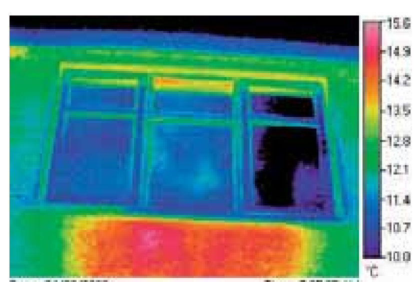
Given the importance of maximising passive solar gain, the overall aspect of the building facades as well as area and orientation of glazing is important to note. It will also be necessary to ascertain the extent of the shading surrounding the building by surveying the position, shape and height of adjacent obstacles such as buildings and trees.

Lastly, the completion of a detailed survey will provide the opportunity to locate potentially harmful or toxic substances such as asbestos. These substances should be replaced with more suitable material during the building process.

Initial PHPP Calculation

It is recommended to do a PHPP calculation of the existing building and to compare the 'theoretical' with the actual energy consumption. If there is a considerable difference between both estimates (for example greater than 10%), it would first be important to verify the comfort levels of the occupants.

The initial testing of the dwelling in the PHPP software will quickly determine its current performance compared to the Passivhaus Standard and will provide a good indication of the extent of upgrading works that would be required. For example, the current space heating requirement of the case study retrofit



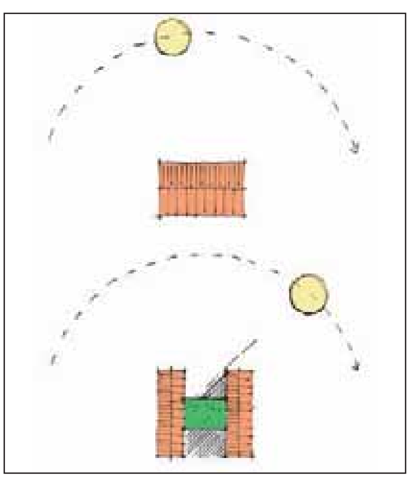
Thermographic Image
Source: GreenBuild Building Information Services

house presented in Section 6 was estimated in the PHPP as 214 kWh/(m²a) which is approximately 14 times less efficient that the 15 kWh/(m²a) required by the Passivhaus Standard.

4.2 Changes in layout/design

In some cases, it might be possible to alter the dwelling layout and / or arrangement of glazing in order to increase overall energy efficiency. Given that the existing building is already modelled in the PHPP, any changes that are being considered to the building form and orientation of glazing can be tested during the design process regarding the effect on energy performance as well as the risk of overheating (which might arise if a dwelling has an excess of south-facing glazing without a screen to keep the high summer sun out).

When considering a major retrofit project, the owners might also consider using the opportunity to extend their home or to modify the internal layout or arrangement of rooms. In such instances, it should be remembered that larger homes, no matter how energy efficient, will undoubtedly consume more energy than smaller houses of a similar specification. There has been a tendency for dwellings in Ireland to become larger over the years and homeowners should consider very carefully the extent of space that their families really need. Minimising the area of extended floor space will reduce build cost and perhaps leave additional funds for enhancing the overall retrofit specification.



Maximise passive solar gain
Source: MosArt Architecture

If it is proposed to change the overall form of the dwelling, care should be taken to bear in mind the important principles of achieving compactness (reducing the surface to volume ratio), maximizing the proportion of exposed glazing to the south, east and west (to be tested and verified in the PHPP), and avoiding unnecessary recesses and projections that might cause shading. An iterative process should be established between the architectural re-design of the dwelling and cross-checking the overall energy performance in the PHPP. For instance, existing windows to the south, east and west of the building could possibly be enlarged in order to increase solar gain and thereby reduce the space heating requirement.

4.3 Upgrade Thermal Envelope

As highlighted earlier, a key performance threshold given by the Passivhaus Institut is the maximum specific space heat requirement of 15 kWh/(m²a). For all retrofit projects (and especially for older dwellings), it will inevitably be required to significantly upgrade the insulation performance of the thermal envelope and install highly efficient windows and doors and mechanical heat recovery ventilation system in order to reach the above threshold.

The heat recovery system will be discussed in Section 4.4. If no heat recovery is included in the retrofit scheme, the energy savings that it would have brought to a project would have to be compensated for by an even more efficient building fabric.

Guidance on upgrading the performance of the thermal envelope is provided below, considering the following aspects:

- Insulation (internal and external);
- Windows and doors;
- Airtightness; and
- Thermal bridges.

4.3.1 Insulation

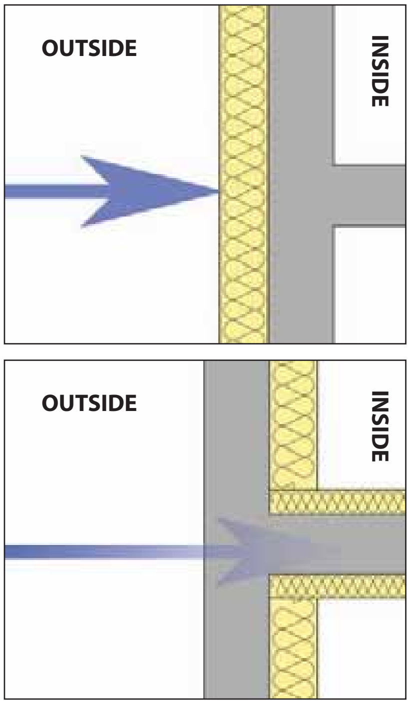
One of the key challenges in upgrading overall insulation levels in dwellings is to choose from the wide variety of materials available on the marketplace. Above all, the insulation has to be appropriate to its application. Some insulation products are suited to use for fill in cavity walls, for example, whereas others are not. Some are load-bearing for use under concrete floors whereas others are 'soft' and better suited to fitting in the attic space. Some products have very low thermal conductivity values ((λ) lambda values) - which means they have high insulating properties and can provide a higher level of insulation for a given thickness compared to lesser performing products. Insulation types will also vary on price, fire safety issues and amount of processing and / or chemicals involved in their manufacture.

Different thicknesses and thermal conductivities of insulation products can easily be tested in the U-value sheet in the PHPP. Dependent on the overall retrofit strategy, the additional insulation might be placed on the outside of the structural building shell (sometimes referred to as 'outsulation'), the inside (so-called 'dry-lining') and/or within the construction envelope (eg. filling the cavity space created by two leaves of

APPLICATION OF DIFFERENT INSULATION TYPES

	Roof	Ceiling	Floor	Wall	Façade	Perimeter
Mineral wool	x	x	x	x	x	
Polyurethane	x	x	x	x		x
Polyisocyuranate	x	x	x	x		x
Phenolic	x	x	x	x	x	
EPS	x			x	x	
XPS	x[1]				x	x
Wood fibre	x	x	x	x	x	
Wood wool	x	x		x		
Calcium silicate				x[2]		
Cork	x				x	
Cocos fibre			x	x		
Foam glass	x[3]	x	x	x		x
Cellulose	x	x	x	x		

Notes: [1] Cold roof construction, [2] Internal insulation, [3] Flat Roof, Sedum Roofs.



In the top diagram, the risk of creating a thermal bridge is greatly reduced using external insulation. Source: MosArt Architecture

external and internal blockwork or, in the case of timber frame between the wall studs).

Ideally, the insulation layer should be continuous all around the building fabric without any breaks. While this is relatively easy to achieve with a new-build project, avoiding breaks in the insulation layer is considerably more challenging when retrofitting.

The location of insulation relative to the structural envelope can have a significant influence on thermal bridges. External insulation, for example, is typically the most effective in reducing thermal bridges, whereas internal insulation would be the least effective.

In every case, it is critically important that the retrofit designer makes sure that the proposed insulation strategy will not cause more interstitial condensation in the structure that can be evaporated to the exterior over the course of one year. The amount of condensate that can potentially build up within the envelope of a building is influenced by climate (temperature and humidity) and internal air conditions (high or low occupancy, internal average temperature and humidity). All calculations in these Guidelines are based on (a) climate conditions for Dublin and (b) low occupancy (according to BS EN ISO 13788, Annex A).). The danger of interstitial condensation is that it is, by definition, hidden within the structure and therefore may be reducing the thermal performance of the envelope unknown to the homeowners, potentially causing structural defects in the medium to long term as well as health risks from resulting mould growth. There is free software available which can be used to test the risk of causing interstitial condensation with different insulation strategies and application of such tools is strongly recommended herein.

4.3.1.1 Internal Insulation

There are advantages as well as disadvantages of internally insulating the building envelope which need to be considered at an early stage of the retrofitting strategy.

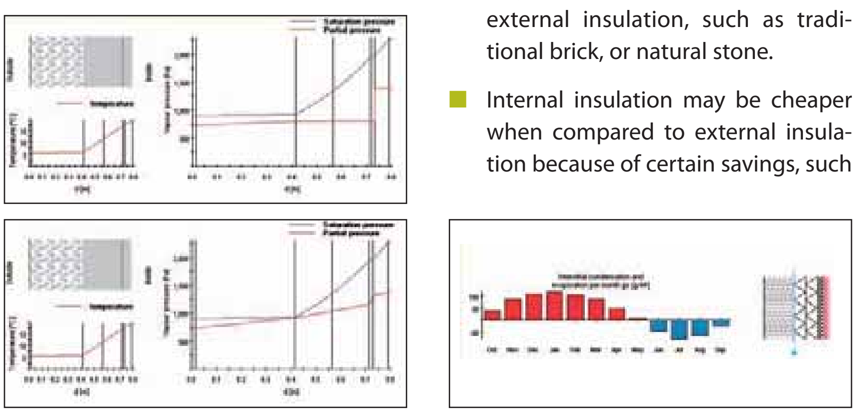
In terms of advantages, the following attributes are highlighted:

- The external facade of the building will remain untouched by the upgrading works which would be beneficial when dealing with certain external finishes which homeowners might be reluctant to cover with external insulation, such as traditional brick, or natural stone.
- Internal insulation may be cheaper when compared to external insulation because of certain savings, such as not having to use scaffolding and not being dependent on reasonable weather to carry out the works.
- In terms of thermal comfort, a room which is internally insulated will typically heat up much quicker due to the avoidance of having to heat up massive external walls.

Considering disadvantages, the following are highlighted:

- Internal insulation will reduce the usable net floor area of rooms with external walls. In the case of the semi-detached retrofit house presented later, this reduction would be approximately 20% (300 mm insulation) of the total net usable floor area for insulation with a thermal conductivity value of 0.035 W/mK (such as mineral wool or cellulose) and 14 % for an insulation with a thermal conductivity value of 0.025 W/mK (such as polyisocyuranate). Related to this, any surface mounted services located on the internal face of external walls, such as electrical switches and sockets, will have to be re-mounted on the new surface.
- Inevitably thermal bridges will be created for example at external/internal-wall-junction or external-wall/ceiling-junction. As a result of this, additional insulation may be necessary along internal elements such as walls and ceilings to reduce the effect of the thermal bridges with all details having to be studded very carefully to avoid any condensation in joints.
- Usually there has to be a vapour barrier on the warm side of the insulation. When fixing paintings or cupboards with nails or screws this vapour barrier could be penetrated which would compromise its performance and result in a higher risk of mould growth and damages in the wall construction through condensing water. A service cavity may be necessary to avoid penetration of the vapour barrier. This again reduces the treated floor area.

Internally insulating on the top of an existing concrete floor slab would create a number of practical knock-on-effects. For example, the clear height of internal



Testing of various insulation strategies for risk of creating interstitial condensation. Source: MosArt Architecture and external doors and windows would be compromised by the higher finished floor level, the balustrade height of windows or railings might be too low and the height of the lowest riser of an internal staircase might not be consistent with the height of the other risers which would be unacceptable from a health and safety point of view.

4.3.1.2 External Insulation

External insulation is typically used with masonry construction types but might also be considered as an option for upgrading timber frame dwellings. The key principle behind this insulation method is to completely wrap around the entire structural building envelope thereby significantly reducing thermal bridges which can otherwise arise where external walls and foundations connect to internal walls and the floor slab. If external insulation is being proposed for a cavity wall construction, then it would be imperative to also fill the cavity with insulation in order to avoid thermal looping occurring from the 'cold' unheated cavity through the internal block leaf to the inside of the dwelling. This would also reduce the visible thickness of insulation required externally.

There are two options of external wall insulation, as follows:

- The so-called 'composite system' or 'single-skin system' is where insulation is either stuck or mechanically fixed directly to the external face of masonry wall, reinforced with for example a plastic or glass fibre mesh and then rendered. To avoid complications regarding damages or warranty it is important to use components of one building system only. This composite system is used widely on Continental Europe as a technique to upgrade existing buildings to the Passivhaus Standard. With this single skin construction type, care should be taken that the system has Agrement Certification for insurance purposes.
- The second system is where instead of the above single-skin system a ventilated cavity is created between the external cladding and the insulation, the latter of which is otherwise fixed to the exterior of the existing walls in a similar manner to the other option.

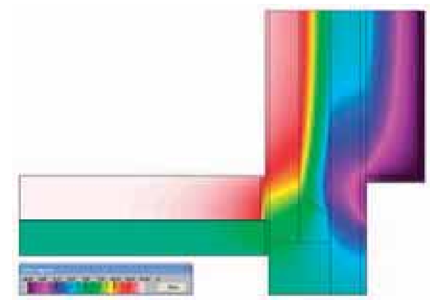
Insulating the Roof Space

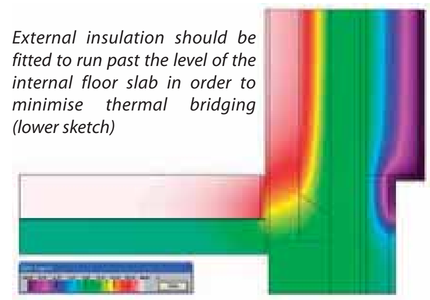
When considering insulating the roof space, the first decision to make is to determine the position of the thermal envelope of the dwelling. In most homes, the thermal envelope will be on the horizontal and just above the plastered ceiling comprising of insulation rolled out between the roof joists. In other situations, such as where there is a vaulted ceiling for example, the thermal envelope will be within the sloping roof comprising of insulation fitted between the roof trusses. In the case of where the former scenario exists, it might be worth considering changing the position of the insulation to the sloping part of the roof which would result in extending the heated volume of the dwelling. This has the advantage of creating a heated attic space into which it might be possible to position some of the service equipment typically found in passive houses, including a large solar hot water tank as well as the mechanical heat recovery ventilation equipment. By positioning this equipment within the (extended) thermal envelope, transmission heat losses will be minimised. Furthermore, not having to lay thick insulation within and above the roof joists might facilitate placing a floored surface in the attic which would provide additional storage space for the homeowners. A leaky attic hatch would also be avoided when the sloped section is insulated.

Shifting the thermal envelope to the sloping roof should be verified in the PHPP software and the load-bearing capacity of the roof trusses should be checked prior to placing additional loads thereon.

In dwellings where sloping ceilings are found, the implications of placing additional insulation underneath the roof trusses should be evaluated with respect to clear head height. There may be insufficient space internally to place additional insulation, in which case it might be required to place the insulation externally (above) the roof trusses. This is only likely to be economically feasible if the roof coverings (tiles or slates) are in very poor condition and need upgrading or replacing.

To externally insulate a ground floor slab would require completely removing the existing concrete slab and more than





External insulation should be fitted to run past the level of the internal floor slab in order to minimise thermal bridging (lower sketch)

Source: MosArt Architecture

likely the hardcore there under before placing a damp-proof membrane, a layer of insulation and a new floor screed. Just as externally insulating a roof, this would be costly, hugely disruptive for homeowners and might not be justifiable in terms of cost and return on investment.

If it is decided not to excavate the ground floor slab to provide an insulation layer, some compensation will be provided by externally insulating the external walls down as far as the foundation. Externally insulating external walls as far as the foundation will marginally reduce the heat loss from internal floors as well as marginally reduce thermal bridges emanating from the rising walls.

4.3.1.3 Wall Cavity Insulation

Cavity wall insulation in Ireland is now commonplace and involves filling the cavity between the inner and outer leaf of concrete blocks with appropriate insulation material. It is quite likely that insulating the cavity alone, however, will not be enough to achieve the required U-values for the Passivhaus Standard. In such cases, cavity insulation will have to be combined with internal and / or external insulation to achieve the targeted U-value identified in the PHPP software.

The proper installation of cavity insulation can be proven by using a thermal imaging camera which will immediately highlight parts of the construction that have not been fully insulated due to their detection as being colder than the fully insulated areas.

4.3.1.4 Windows and Doors

The greatest heat losses in a dwelling typically occur through windows and doors. The better the thermal performance of these elements, therefore, the less insulation will be necessary in walls, floors and roofs.

There is a growing range of windows and doors available in Ireland which are suitable for passive house design. Many of these will have insulation integral to the frame so that thermal bridging from the exterior to interior surface is minimised. Specifiers and homeowners should be aware that mullions and stanchions (glazing bars) will reduce the area of glass and, accordingly, the

Traditional sash window with mullions and stanchions which reduce solar gains and create a thermal bridge from outside to inside
Source: MosArt Architecture

Externally insulated window frame reducing heat loss
Source: Optiwin GmbH

amount of solar gain.

It also should be considered that as the U-value of the glass components, e.g. double glazing / triple glazing improve, the glass will let through less solar and light gains in addition to reductions due to increased frame, mullion and stanchion proportions. However, improved U-values will provide a net decrease in energy consumption.

The joints between windows and doors to walls and floors have to be sensibly detailed. Ideally, an external insulation layer would be used to overlap the window or door frame by at least 65 mm in order to reduce potential thermal bridges to a minimum. Furthermore the above joints have to be vapour proof on the inside and weather proof externally.

To prevent overheating in summer it might be worth considering shading devices such as overhangs, balconies or bris soliel which block direct sunlight when the sun is high in the sky in the summer time. In winter, when the sun is lower in the sky, passive solar gain will be provided by the sun's rays passing underneath the shading device.

4.3.1.5 Airtightness

The Passivhaus Standard requires a maximum hourly air change rate of 0.6 at an under and over-pressure of 50 Pascal. That means the entire air volume of the dwelling changes through gaps, cracks and other openings in the building fabric at a maximum of 0.6 times in one hour at an air pressure of 50 Pascal.

Compared to the current Part L, this level of airtightness is quite a high performance standard but is nevertheless achievable when both design detailing and site operations have been well executed.

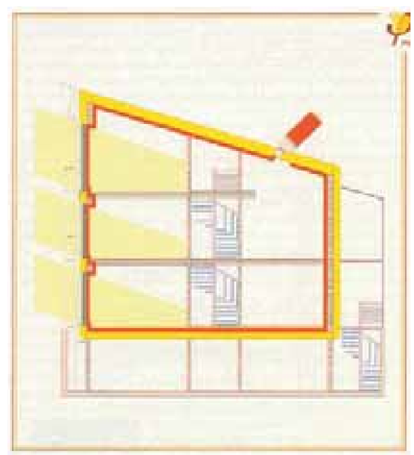
The airtight membrane or layer should always be located on the warm side of the insulation and should be continuous around the building fabric without any break. In masonry buildings, the plastered internal face of walls is regarded as the 'airtight' layer, whereas a separate membrane would be required if the wall construction is comprised of timber or steel frame.

Different construction configurations will require different strategies with

DEFINITION OF VAPOUR BARRIER AND VAPOUR CHECK/ VAPOUR CONTROL LAYER:

μ value is the vapour resistance factor of a material (see also IS EN 12524)
d is the thickness of a layer
sd is the equivalent air layer thickness i.e. a vapour barrier with an sd of 1500 m is equivalent to 1500 m thickness of still air in terms of vapour resistance and is calculated as follows :
sd [m] = μ x d [m]
vapour check: 0.5 m < sd < 1,500 m
vapour barrier: sd > 1,500 m
BRE IP 2/05 Modelling and Controlling Interstitial Condensation in Buildings.

regards to protection from the dangers of interstitial condensation. For example, in certain instances a vapour check membrane with a relatively low resistance factor might be sufficient (i.e., allowing some moisture to pass through the wall), whereas in other situations, a complete vapour barrier might be required which totally prevents any moisture entering the construction. There are currently vapour membranes available on the market which are so-called 'intelligent' insofar as their vapour resistance can change depending on the relative difference in vapour pressure between internal and external environments. They can thus 'close' or 'open' as



Source: Passivhaus Institut

Use of rubber gasket to seal a penetration of the airtight membrane. Source: MosArt Architecture appropriate. Whichever membrane is used, it must be remembered that it will function as the airtight layer and must be treated with great care during the construction process.

The timing of carrying out an airtightness test (commonly referred to as a 'blower door test') is very important in the overall retrofit procedure. It is important to carry out the test prior to the completion of final finishes so that if the test fails then any gaps or cracks in the airtight layer can be precisely located and accessed for repairs. The use of smoke puffers / pencils / sticks can be very useful to precisely identify leaks while the building is pressurised or depressurised. The test should ideally be carried out once the airtight layer has been completed but while it is still exposed, including most especially the taped joints between the windows and doors to the building envelope as well as joints between different elements of the dwelling (ceiling, walls and floors). All persons working on the site must make sure not to subsequently compromise the airtight layer which can easily happen, for example, where services such as cables or pipes have to penetrate the barrier.

4.3.1.6 Thermal Bridges

The concept of thermal bridges has been introduced earlier in Section 3.

There are two types of thermal bridges of interest to these Guidelines, namely (a) repeating thermal bridges and (b) linear thermal bridges.

Repeating thermal bridges would include studs or rafters in the insulation layer or indeed wall ties in masonry construction. This kind of thermal bridge can be calculated in the PHPP by entering the percentage of the insulation layer occupied by the material (such as timber studs) as well as the thermal conductivity of that material. Repeating thermal bridges are thus accounted for within the normally quoted U-values for walls, roofs and ground floors. An extract from the PHPP software is included below to illustrate how repeating thermal bridges can be calculated.

Linear thermal bridges, on the other hand, can be found at junctions of internal and external walls, at the eaves where there is little or no space for insulation and even around opes for windows and doors. These bridges were not accounted for at all until they were recognised in recent versions of the building regulations. The calculation of thermal bridges is a specialist field that will probably require assistance from a professional.

The linear thermal transmittance (ψ) values have to be verified in accordance with EN ISO 10211. The ψ values for several products certified by the Passivhaus Institut can be found on their website (www.passiv.de) or on their product certificates.

4.4 Upgrade Ventilation and Heating System

The upgrading of the ventilation and heating system is the second step in retrofitting dwellings to the Passivhaus Standard.

Ventilation System

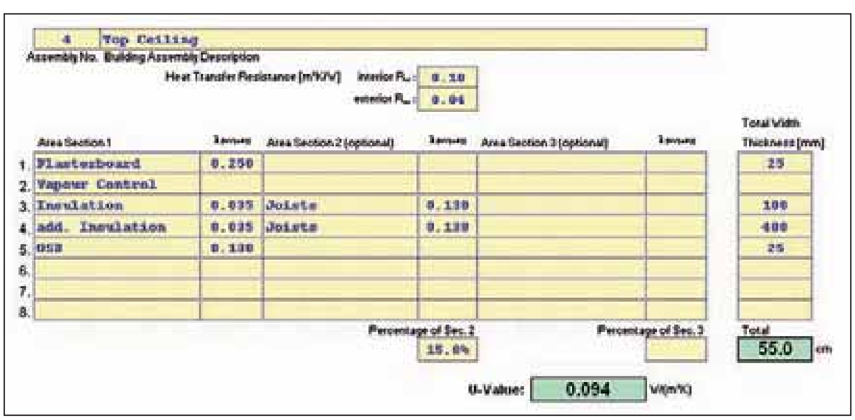
The dwelling to be retrofitted might be ventilated in a number of ways, including through controlled means by extract fans, vents in the wall with adjustable grills and openable windows or by simply by uncontrolled means through drafts and leaky construction. As highlighted in the previous section, however, it is vital for the Passivhaus Standard that a very high level of airtightness is achieved in order to minimise heat loss. Airtight construction, in turn, is accompanied in the Passivhaus Standard with mechanical heat recovery ventilation systems. This next section of the guidelines will provide an outline of considerations necessary in planning such a system in the context of retrofitting a dwelling.

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 at normal pressure, 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 change 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 retrofit case study presented later in Section 6 as an example, an occupancy of 2.4 persons would require 71 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 case study house these total 100 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



4 Top Ceiling
Assembly No. Building Assembly Description
Heat Transfer Resistance [m²K/W] interior R_{si}: 0.10
exterior R_{se}: 0.04

	Area Section 1	[illegible]	Area Section 2 (optional)	[illegible]	Area Section 3 (optional)	[illegible]	Total Width Thickness [mm]
1.	Plasterboard	0.250					25
2.	Vapour Control						
3.	Insulation	0.035	Joists	0.130			100
4.	add. Insulation	0.035	Joists	0.130			400
5.	OSB	0.130					25
6.							
7.							
8.							

Percentage of Sec. 2: 15.0% Percentage of Sec. 3: Total: 55.0 cm
U-Value: 0.094 W/(m²K)

Source: MosArt Architecture

accurately set by using a digital anemometer and adjusting the valves on the vents in each room as required.

Mechanical Heat Recovery Ventilation (MHRV) System

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 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 IS EN 13141-7:2004[4]. 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.

(See www.sap-appendixq.org.uk).

Current accreditation testing procedures for mechanical ventilation systems often produce unrealistically positive test results. If reliable measured values are not available, or a certificate is not presented, then the values are calculated by subtracting 12% from accreditation test results.

In DEAP a default efficiency of 0.66 is assumed for mechanical heat recovery systems and the default Specific Fan Power (SFP) is assumed to be 2W/[l/s]. This default value is considerably less than is achievable in practice (as verified by institutes such as the Passivhaus Institut).

The Passivhaus Standard can be achieved without a heat recovery system as well. However, when eliminating the MHRV system the savings foregone in recovering the thermal energy have to be compensated by other measures such as additional insulation of the thermal envelope. This could turn out to be a false economy, therefore. As a practical example, if a MHRV system was omitted in the case study building (Section 6), the space heating requirement would double the maximum allowed by the Passivhaus Standard.

Insulation and Positioning of Duct Work and Vents

It is very important to adequately insulate the 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 as short as possible by ideally positioning the MHRV unit in the centre of the house.

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 (10mm is sufficient) 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.

There are a number of MHRV products available on the market that have been specifically developed for retrofitting to the Passivhaus Standard.

Heating System

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; and
- Wood pellet/wood log boiler.

These three options are explored in outline only below with additional details provided in SEI's Guidelines on Passive Homes. It may well be possible to continue to use the existing heating system in the dwelling (for example, oil boiler with radiators) albeit in many cases it might not be an efficient model and might be at or near the end of its useful life. In addition, the design output of the heating system is likely to be too large for the retrofitted dwelling which could have a heat load demand of less than 20% of that of the original need. Another strategy would be to retain the pipes and radiators already existing in the dwelling but to replace the older larger boiler with a smaller and more efficient one that can serve not only space heat requirements but also domestic hot water production. One advantage of keeping the radiators results in the homeowner being able to control individual room temperatures by adjusting the valves manually to suit their needs or using Thermostatic Radiator Valves (TRV) to set the room temperatures. Even if the original radiators are being retained as the primary heating system, there will still be a need for a MHRV system which will now not only supply fresh pre-heated air to the dwelling but will also distribute the heat generated by the radiators throughout the house. A further issue to consider in debating whether or not to retain the original radiators is the fact that they will probably have to be moved if internal insulation is proposed for the dwelling.

Water to Air Heat Exchanger

This method involves using a heating device placed immediately on the fresh air supply outlet of the MHRV. 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'. The hot water 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 or evacuated tubes.

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 electrical 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).

Water to air heat exchanger unit. Source: MosArt Architecture

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

Wood pellet/Wood pellet stove/Wood log boiler

A boiler is typically located in a separate plant room whereas a stove is located in an internal room for example a living room. Wood pellet stoves/log boilers can serve as an auxiliary or back-up source of heat as well as for domestic hot water production. 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 and wood pellet stoves 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 just 7 kW output would be sufficient for all space heating and DHW needs.

Compact unit including ventilation heat recovery and air to water heat pump. Source: Drexel und Weiss

- 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. It is important to check if your chosen product can accommodate direct connection to the external air.
- Most wood boilers/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 boiler/stove. This flue must comply with Part J of the building regulations.
- 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 as described above. If there is a need to back-up the MHRV the stored hot water will be used to re-heat the fresh air.
- 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 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. Storage underground is also possible in special containers. Wood pellets need to be kept dryer than chips or logs.

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 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.

The above levels of control should be incorporated into any dwellings retrofitted to the Passivhaus Standard.

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.

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.

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 (20 degree C) for the whole house and this would be typical for most houses retrofitted to the Passivhaus Standard.

DHW is produced typically by the back-up heating system, supported by solar collectors. Hot water can also be produced electrically but this will increase the primary energy consumption and therefore adversely affect the BER.

4.4 Site supervision

An overview of the various works required to achieve the Passivhaus

Standard has already been provided, including emphasising the different insulation methods that could be used, the importance of minimising thermal bridges, the risks associated with unwittingly creating interstitial condensation and the need to achieve a high level of airtightness. It is vitally important that both the contractor(s) carrying out the work as well as the energy advisor inspecting the works must be suitably experienced in all of the above issues in order that a successful result is achieved for the homeowner.

There is a rather high margin for error in retrofitting to the Passivhaus Standard and care should be taken at every step of the way.

During the construction while opening wall, floor or ceiling constructions harmful substances (Asbestos, pollutant emitting materials, respirable glass fibre …) may appear. The opportunity should be taken to remove these and replace with harmless materials.

For further information on asbestos removal - www.epa.ie.

References

[4] *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.*

Section Five

Upgrading of Typical Construction Types

Upgrading of Typical Construction Types

This section illustrates many of the most common construction types in Ireland and various means of upgrading their performance to the Passivhaus Standard. It must be appreciated that there are many different construction types as well as numerous techniques and materials available to reduce thermal losses and to deal with all the permutations and combinations would not be possible within these Guidelines. It is hoped that the variety of examples covered below, however, provide as useful guidance for most scenarios that will be encountered by persons interested in retrofitting.

It must be stressed that readers should not copy techniques from these guidelines without checking the suitability of the building being upgraded! For all parts of the thermal envelope, the risks of interstitial condensation have to be calculated and verified. Furthermore, there may be other issues such as structural stability and fire safety considerations to be considered.

Retrofitters should only use IAB approved products with installation by specialist contractors only to ensure insurance by Home Bond.

5.1 Walls

The following Section explains how to upgrade different wall constructions which are common in Ireland.

For all construction types care has to be taken when externally insulating at the base of walls. The insulation here should be a type of material which is suitable for a humid environment. Furthermore the detail has to be developed in that way so no moisture can infiltrate the construction.

Readers should also note that a change in external finishes may require planning permission.

5.1.1 Random Rubble and Hollow Block Wall

Walls constructed of random rubble or hollow block are often found in very old dwellings and, accordingly, are often not insulated.

If the stone used in the dwelling is exposed and of high aesthetic quality, homeowners might well be reluctant to clad over this with external insulation which would completely alter the character of the building. In situations where this is not the case, however, external insulation might be considered.

When insulating externally there are two possible options, either using a loose insulation type with a ventilation cavity or using a single skin insulation type. Using loose external insulation typically requires a substructure comprising wooden battens which are fixed to the wall and bear the load of the new façade. Depending on the thickness of the insulation required, it might be necessary to counter batten externally to the first layer of battens to provide enough depth. An oriented strand board (OSB) or a wood fibre board is then fixed to the external side of the battens followed by a breather membrane. Thereafter, a ventilation cavity is formed with vertical battens which can be clad with appropriate materials.

The other option is to insulate externally with insulation boards which create a single skin structure (ie. no ventilation cavity). In this case, the insulation of required thickness can be mechanically fixed to the structural wall and thereafter plastered with an approved render system.

In many situations, random rubble walls or hollow block walls will already be insulated internally (commonly referred to as 'dry-lining'). If the wall is already dry lined, the plasterboard and plastic sheeting should be removed in order to check the condition of the timber or metal studs as well as the existing insulation. If these are not in good condition, they should be replaced or upgraded and closed with OSB and an airtight layer/ vapour control layer. As has been stressed earlier, great care has to be taken when insulating internally in order to avoid causing interstitial condensation. A membrane with a high vapour resistance (vapour 'barrier') may help to prevent the build up of condensation, but this should be proven by calculation.

It is recommended to create an insulated service cavity for cables and pipes running along the external walls in order to protect the vapour control layer from being penetrated by nails or screws.

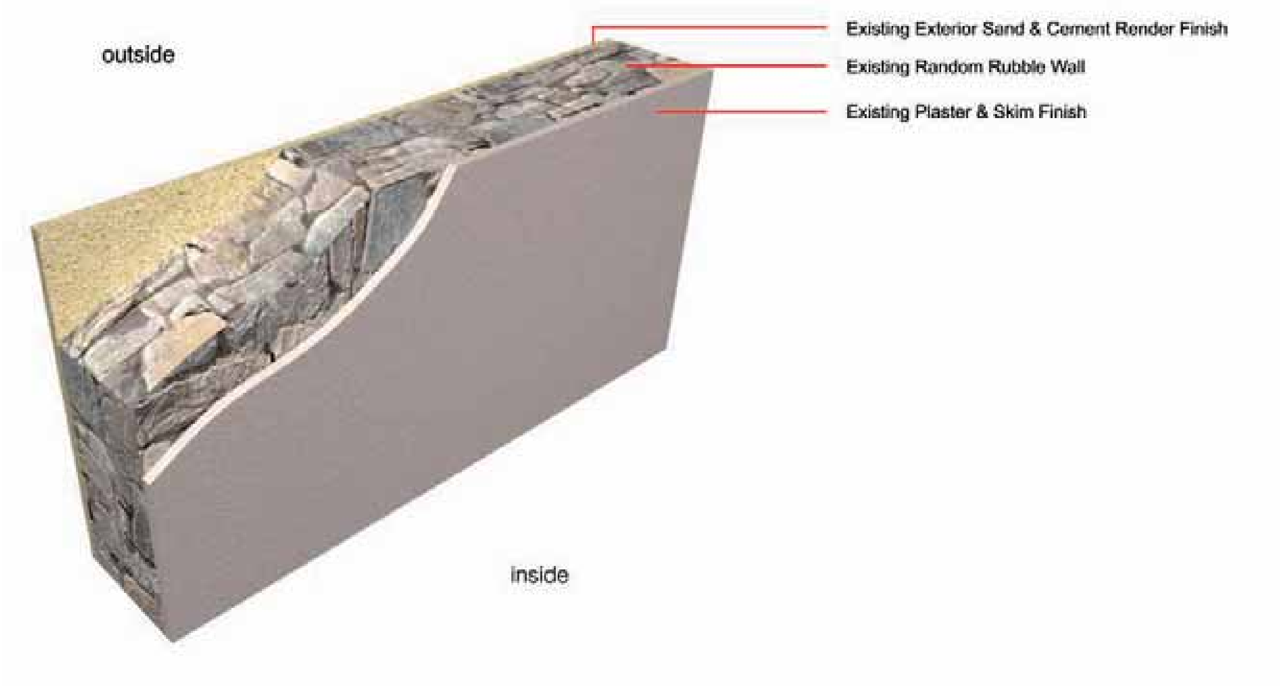
It is possible to mix both external and internal insulation techniques but there is likely to be more costs involved due to additional labour and materials.

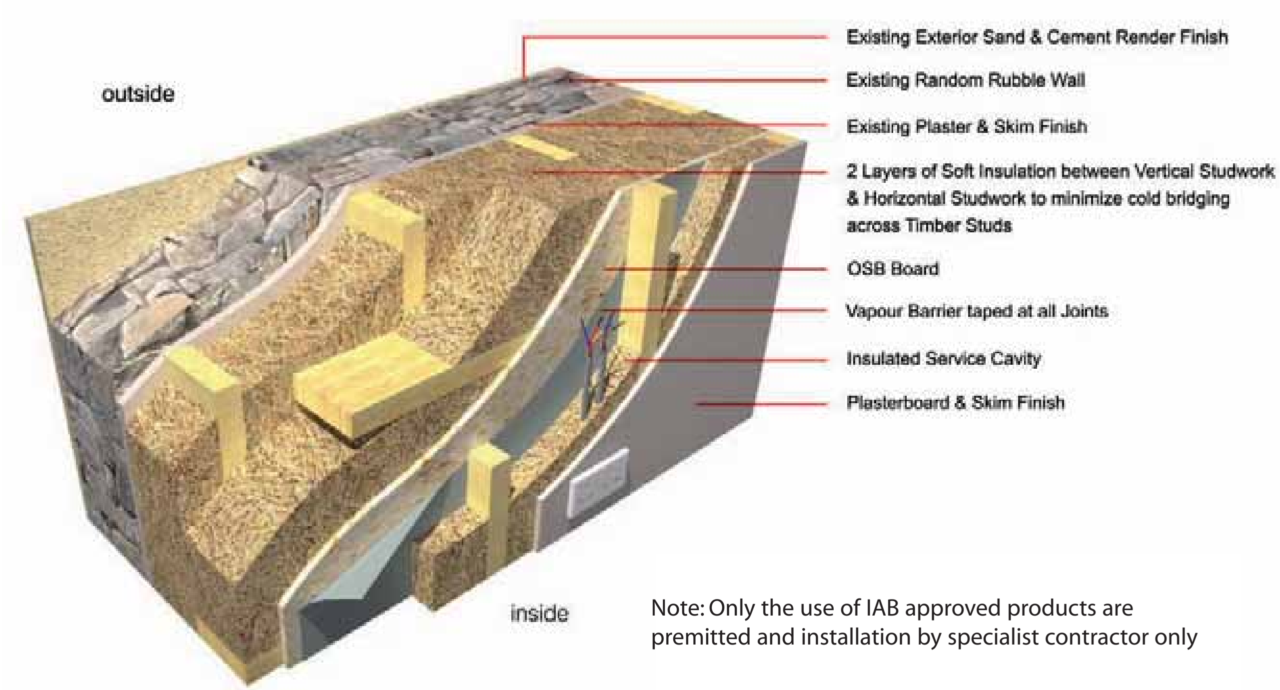
A number of 3D images are provided to illustrate different possible approaches to significantly upgrading the energy performance of random rubble and hollow block walls. These sketches are not exhaustive. Rather, they serve as examples of the kind of approach that might be used.

5.1.2 Cavity Walls

When dealing with cavity walls, it is usually best to full-fill the cavity with

Existing Standard Random Rubble Exterior Wall



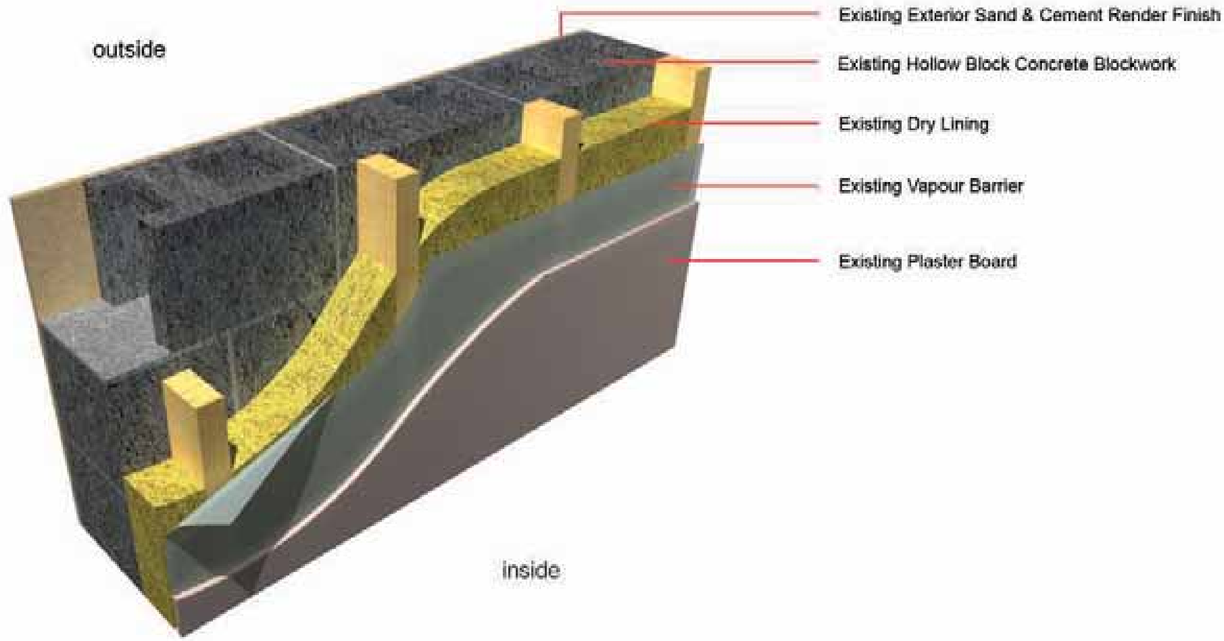


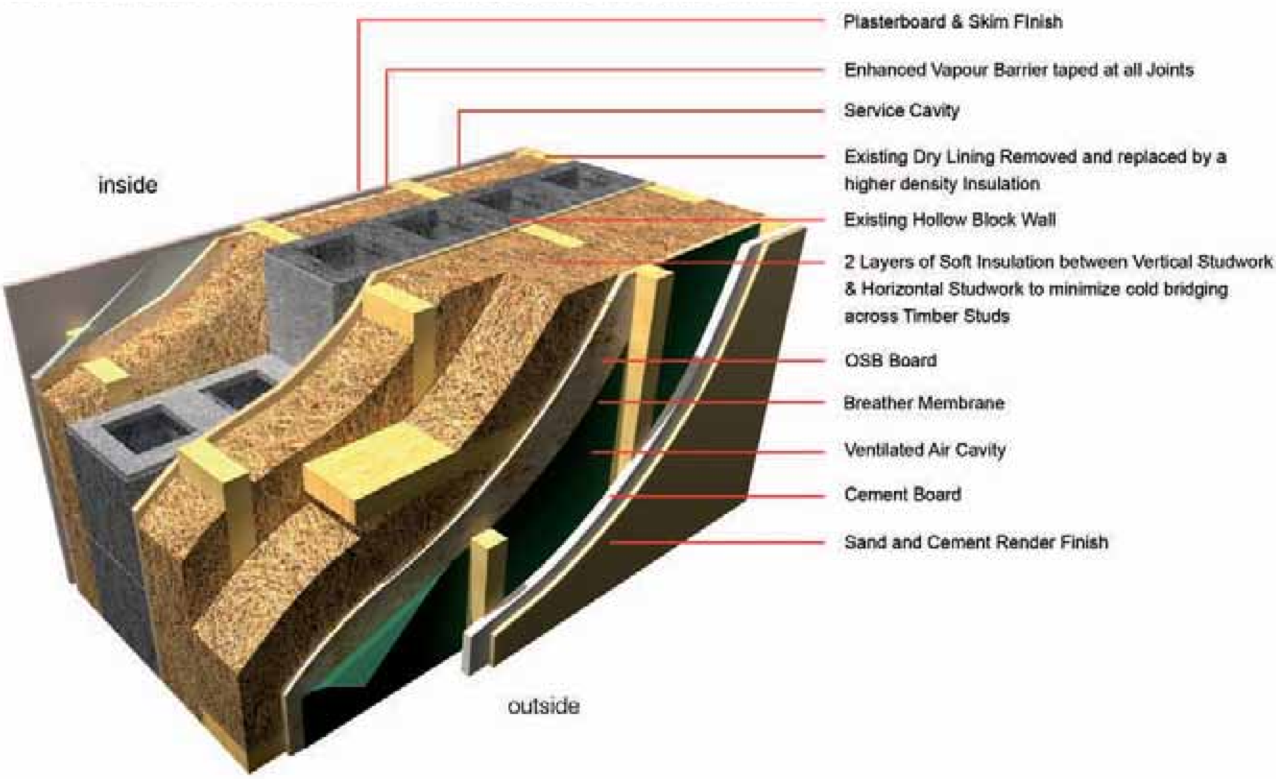
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Random Rubble Exterior Wall Upgraded to Passivhaus Standard - Internal "Loose" Insulation

Source: MosArt Architecture

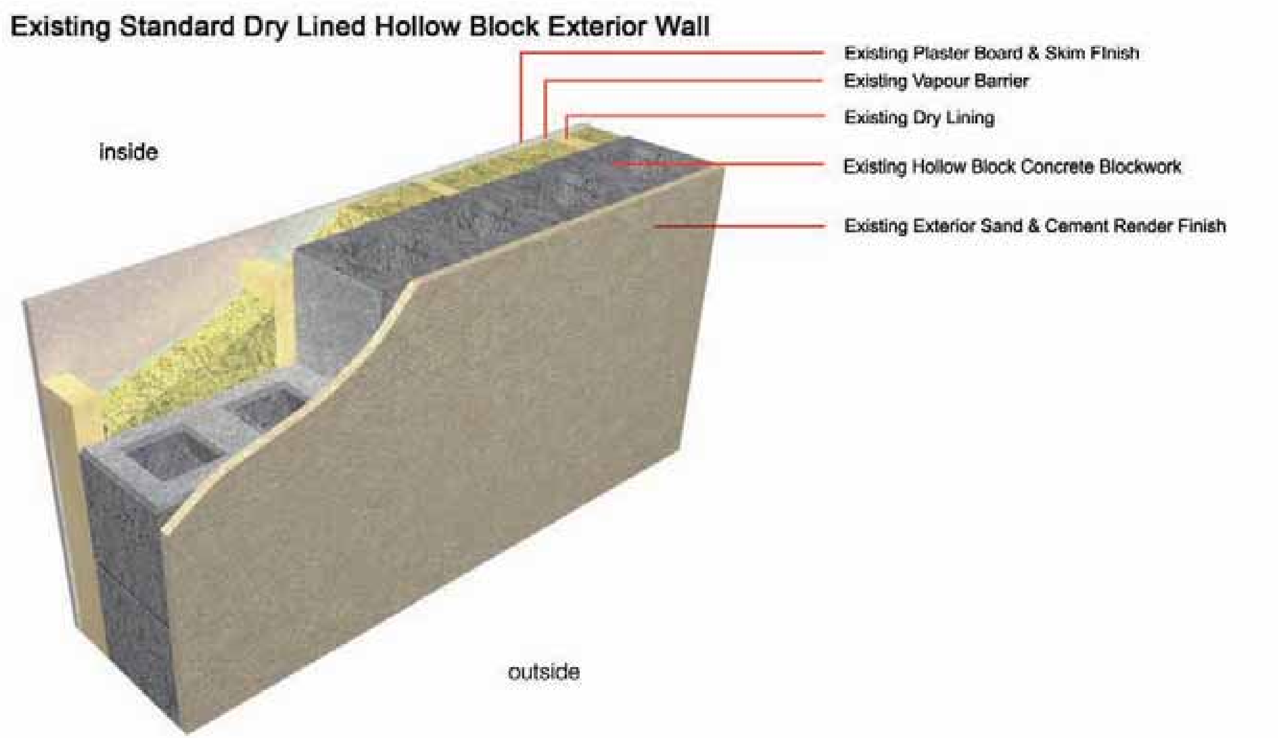
Standard Dry Lined Hollow Block Exterior Wall

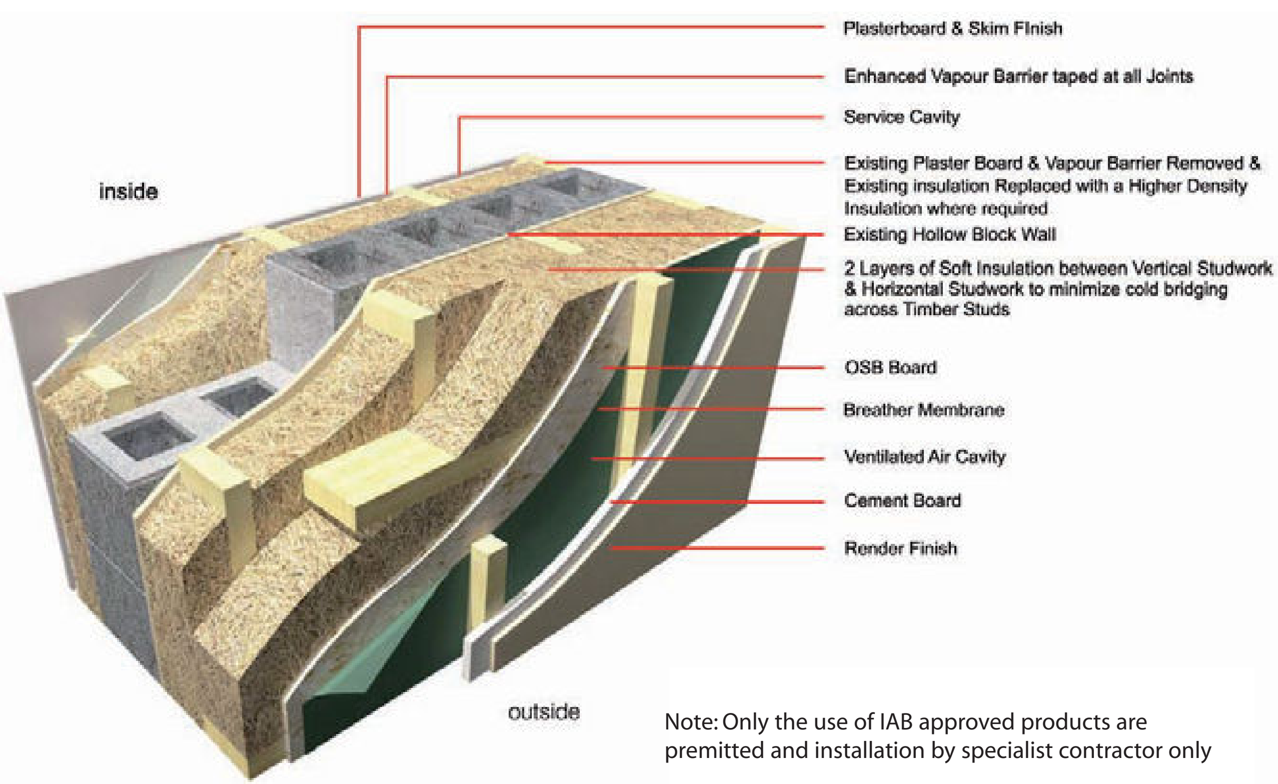




Dry Lined Hollow Block Exterior Wall Upgraded to Passivhaus Standard

Source: MosArt Architecture



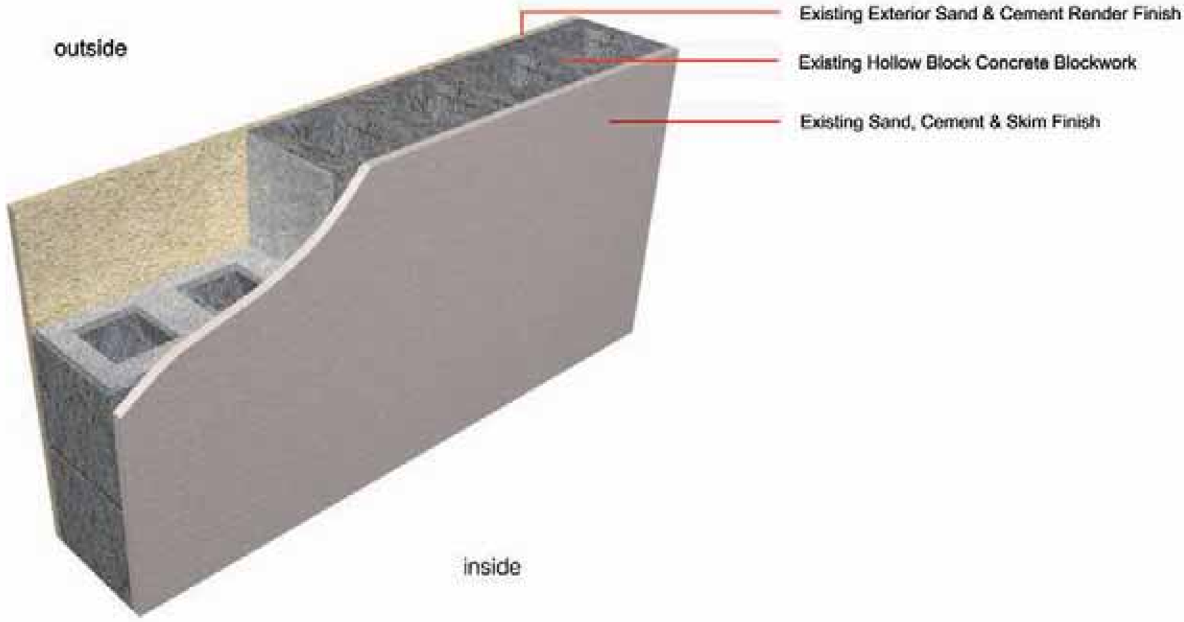


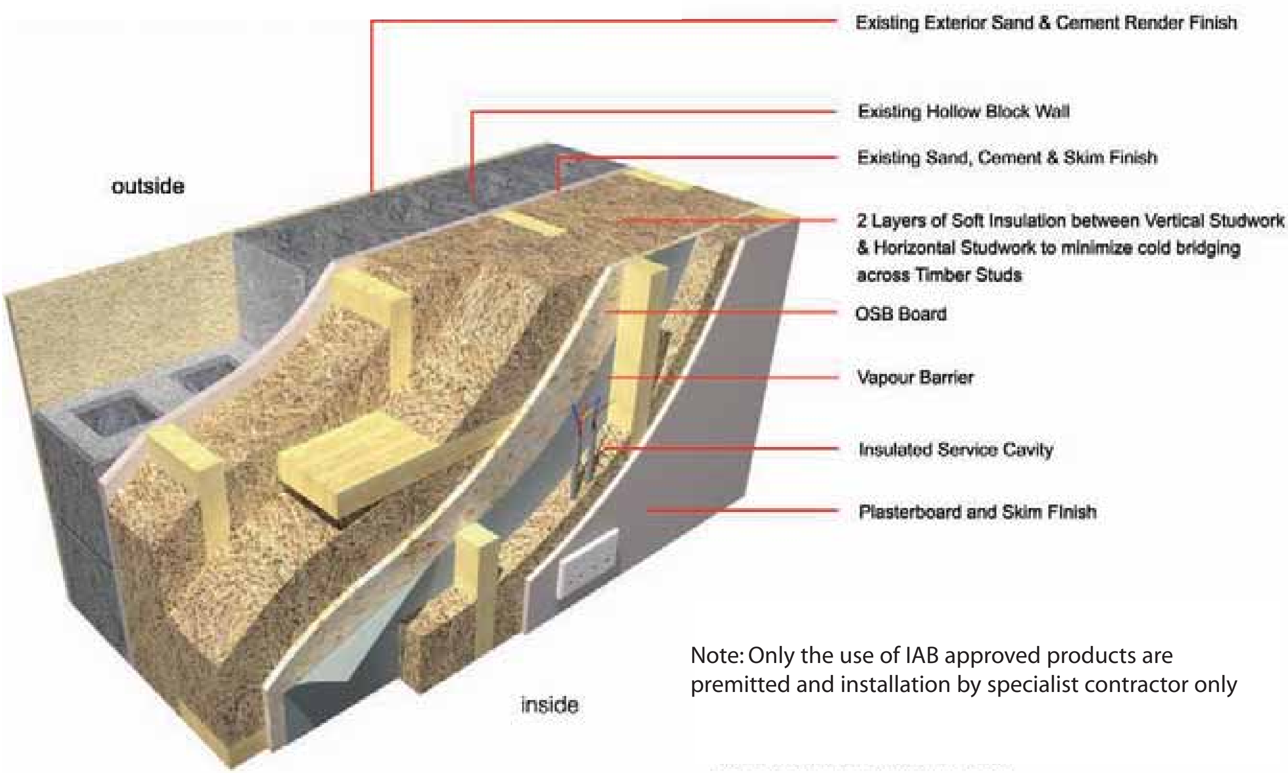
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Dry Lined Hollow Block Exterior Wall Upgraded to Passivhaus Standard - External "Loose" Insulation

Source: MosArt Architecture

Existing Standard Hollow Block Exterior Wall



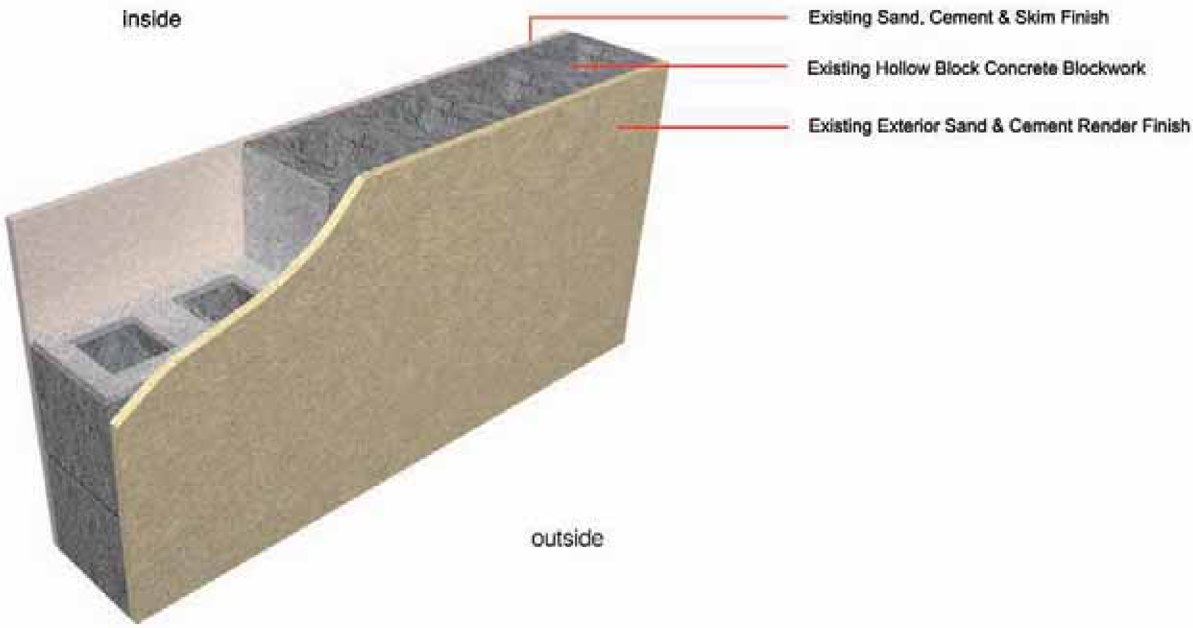


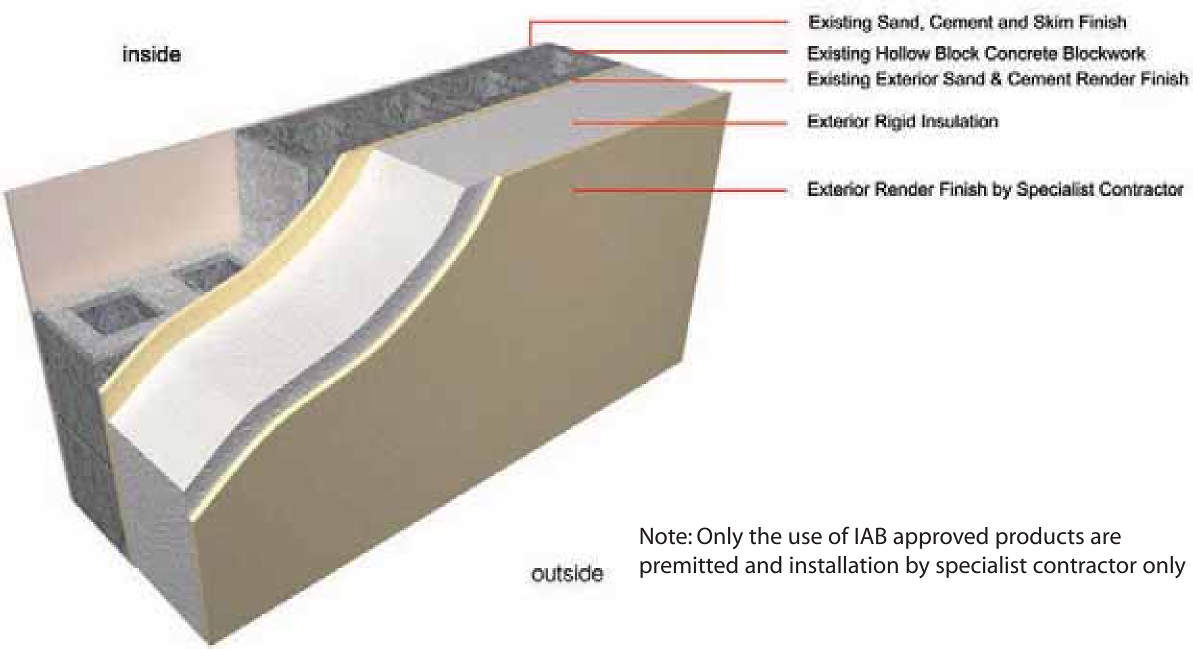
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Hollow Block Exterior Wall Upgraded to Passivhaus Standard - Internal "Loose" Insulation

Source: MosArt Architecture

Existing Standard Hollow Block Exterior Wall





Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Hollow Block Exterior Wall Upgraded to Passivhaus Standard - External "Rigid" Insulation

Source: MosArt Architecture

insulation in order to reduce the thickness of the additional insulation that will inevitably be required. This is normally done by injecting suitable insulation (such as beads) into the cavity.

Make sure when filling the cavity that the insulation material does not transmit water coming from driving rain to the inner leaf (there is a variety of certified products available on the market so please ensure the installer is IAB certified (Check www.nsai.ie).

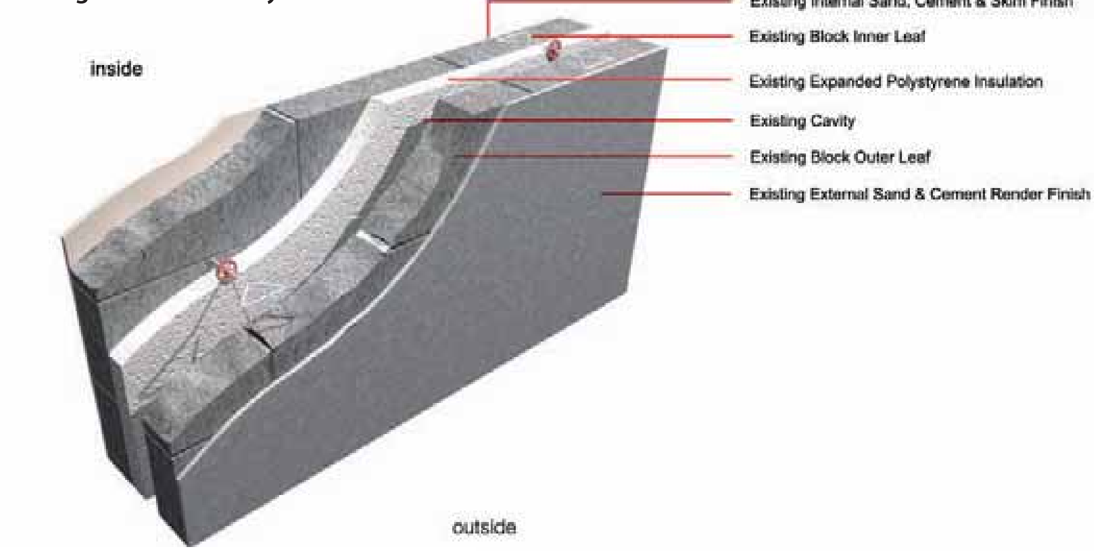
As for the random rubble and hollow block wall, there are two means of externally insulating, namely with a (new) ventilated cavity construction or as a single skin construction. It is likely that the insulation layer does not have to be as thick as for the random rubble or hollow block wall because of the better thermal performance of the cavity wall.

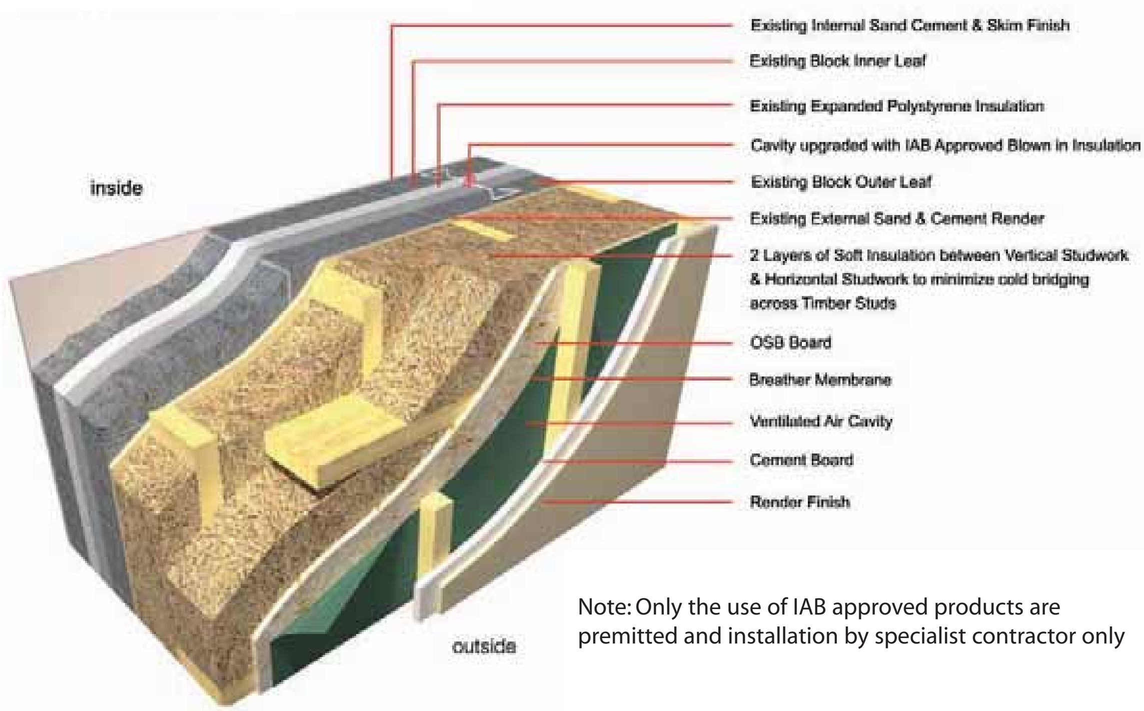
If it is decided that the wall should be insulated internally, care should be taken that potential interstitial condensation is considered in the detailing and design. As before, it is recommended to remove existing insulation and airtight layers where they exist and upgrade these in best practice manner including service cavity as described in Section 4.3.1 and 5.1.1.

5.1.3 Timber Frame

Typically in Ireland, the structural part of timber frame constructions is built with OSB on the outside, insulation in

Existing Standard Cavity Exterior Wall



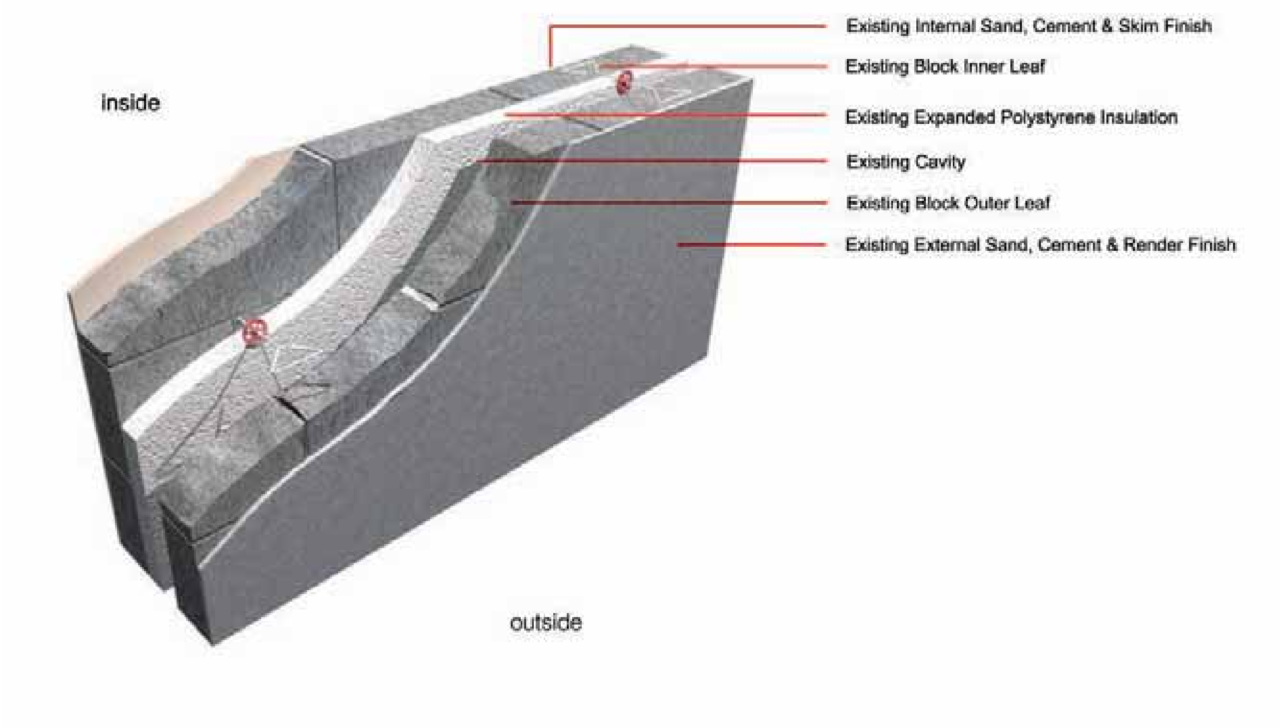


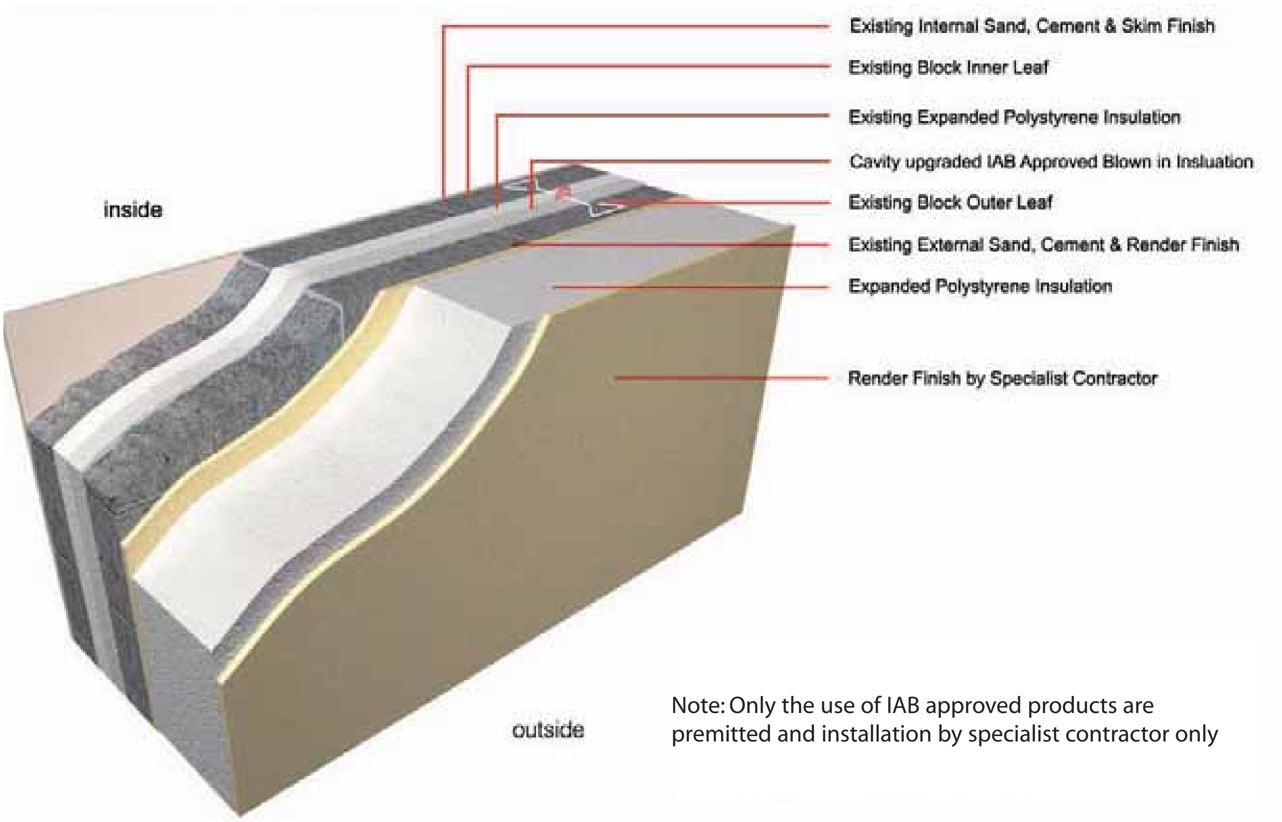
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Cavity Exterior Wall Upgraded to Passivhaus Standard - External "Loose" Insulation

Source: MosArt Architecture

Existing Standard Cavity Exterior Wall





Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Cavity Exterior Wall Upgraded to Passivhaus Standard - External "Rigid" Insulation

Source: MosArt Architecture

between the studs and a layer of polyethylene on the inside. It is more than likely that the polyethylene sheeting will not have been installed as an airtight layer. Therefore the sheeting has to be taken off and the condition of the insulation checked and possibly replaced by a better performing type. Opening the wall will also provide a good opportunity to check the condition of the studs as there might be damage caused over the years by penetrating water. In the worst-case scenario parts of the structure may have to be changed.

The existing cavity (between the timber structure and the external concrete block leaf) should be filled with insulation to reduce the inevitable additional insulation that will be required either on the internal or external face of the construction.

Only certified insulation systems which do not transmit water from the outer to the inner leaf should be used.

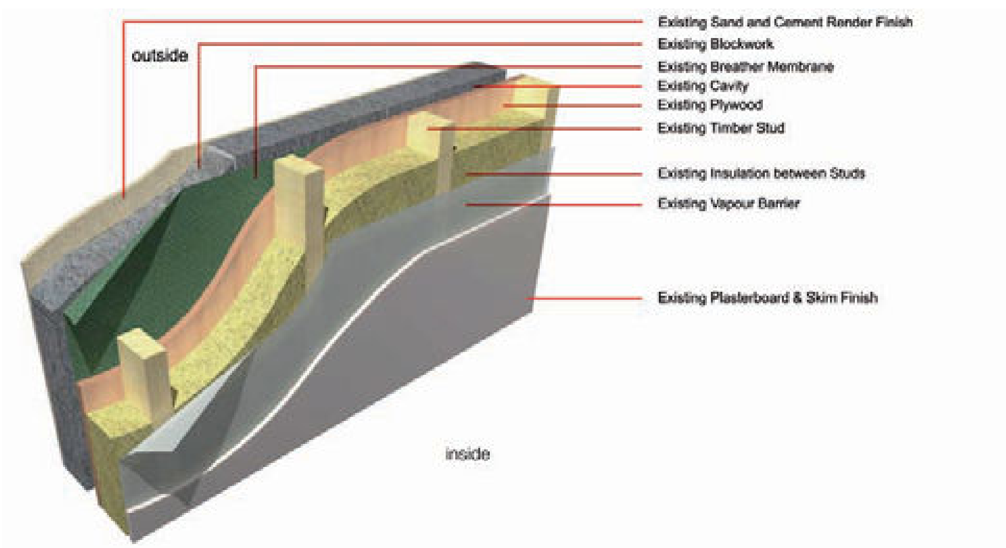
There are again the same possibilities to upgrade the timber frame construction to the Passivhaus Standard externally and internally as mentioned above for the masonry wall constructions. Some of these options are illustrated below.

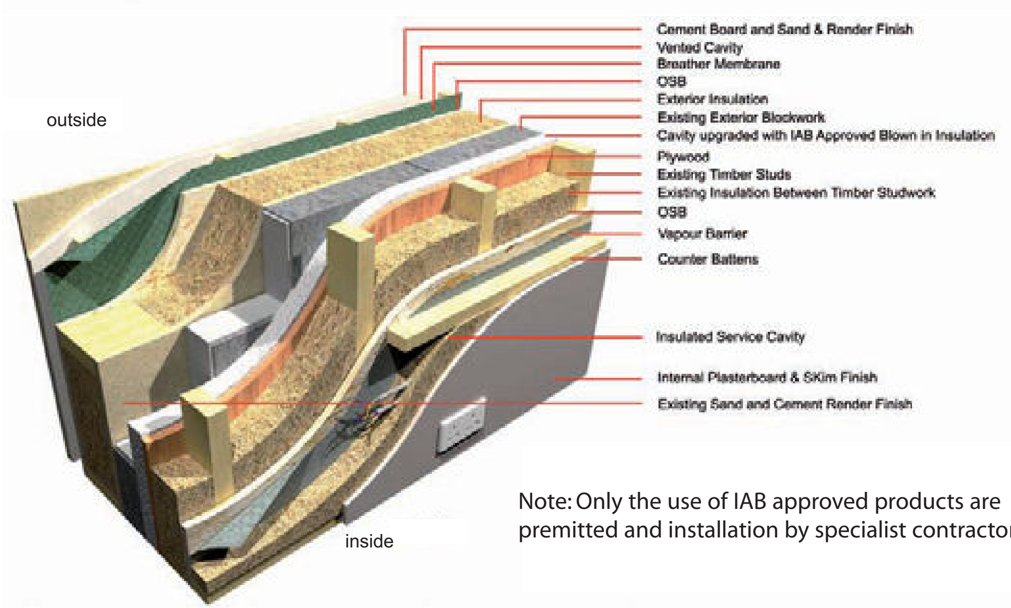
Another option to upgrade a timber frame construction is to remove the outer leaf of concrete block or brick and insert a new insulated timber frame wall in its place. The principal advantage of this approach is that large parts of the walls can be pre-fabricated and therefore produced with a much higher accuracy than on-site assembled constructions. Another advantage is that the footprint of the building would not extend as much as it would if the concrete leaf was retained and additional insulation were placed exterior to that. Such considerations might be important with buildings that are very closely spaced. This option is not illustrated below but the build up will be similar as for external upgrade with loose insulation material. A disadvantage that must be considered is the cost and waste associated with removing the outer masonry leaf.

5.2 Floor Slab

Floor construction types in Ireland typically comprise of either a suspended timber floor, power floated concrete

Existing Standard Timber Frame Exterior Wall



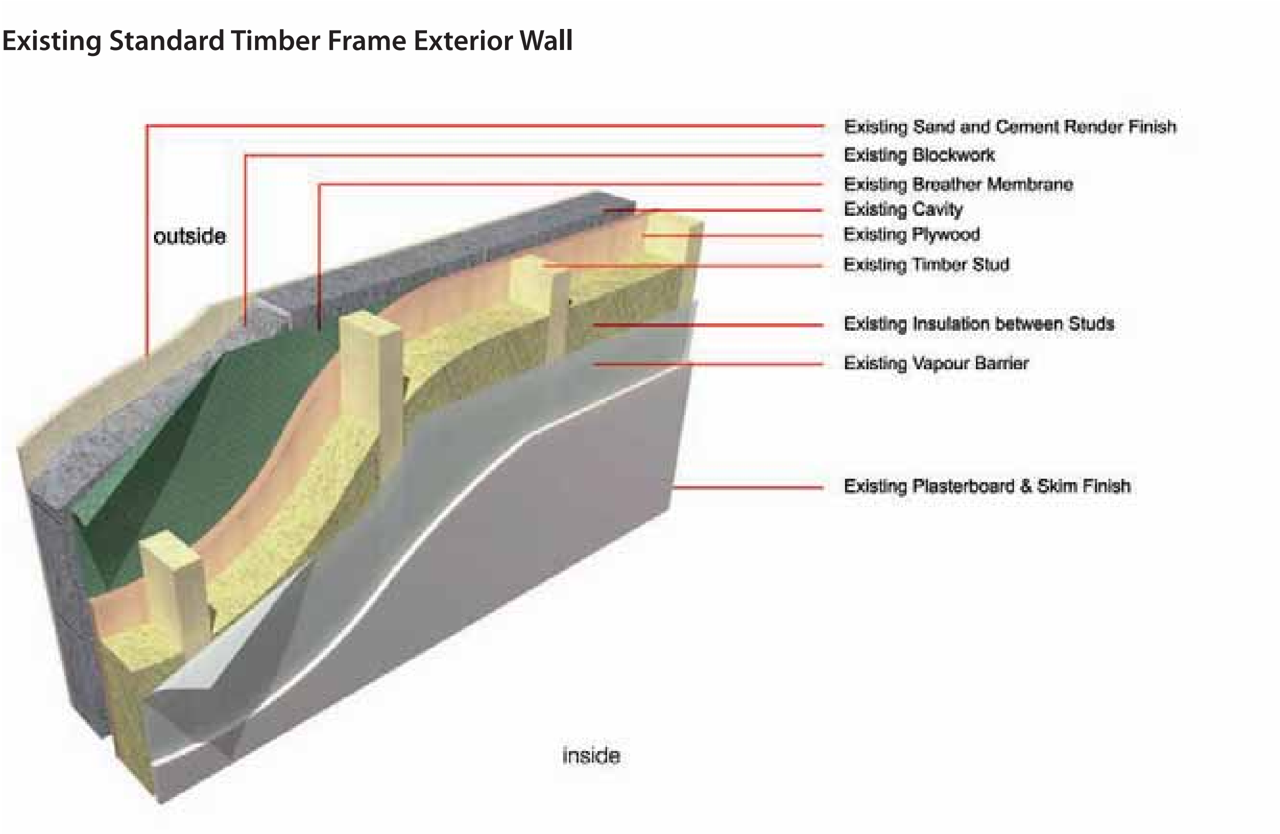


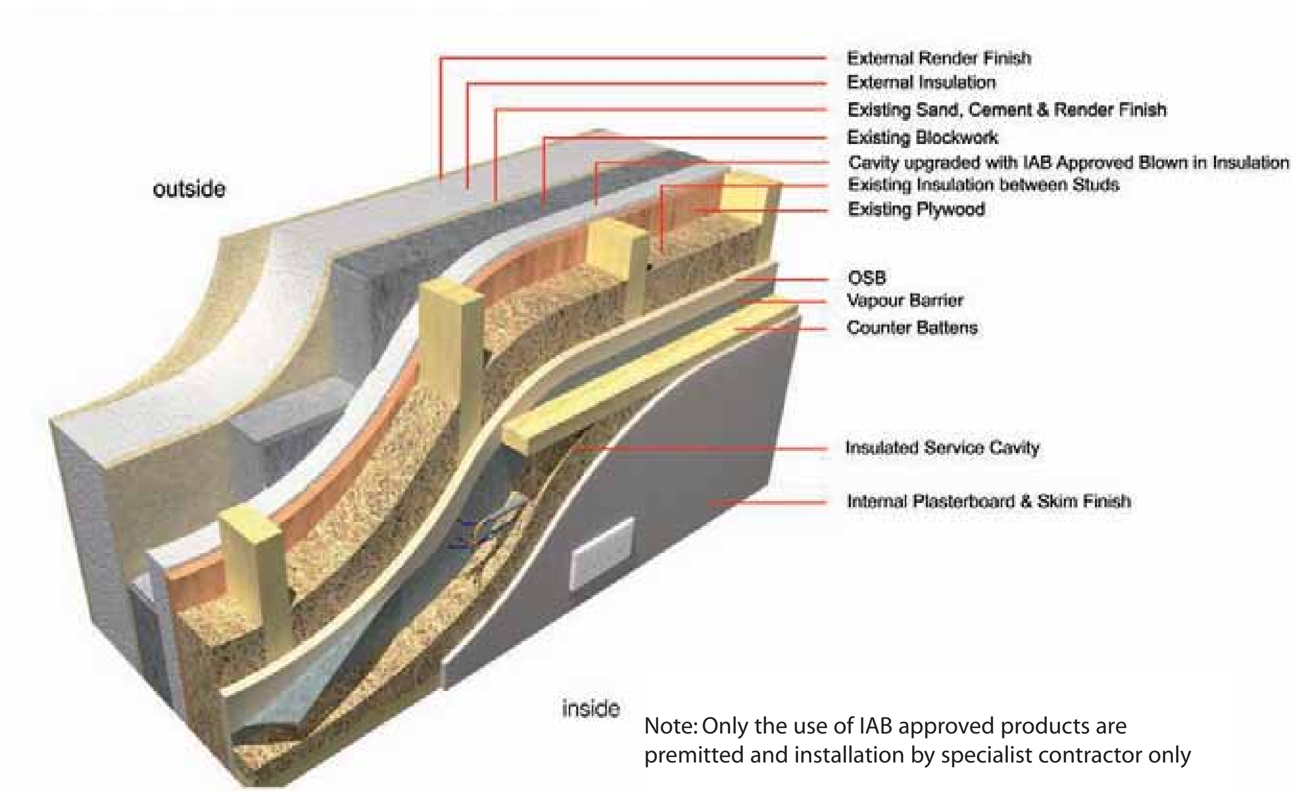
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Timber Frame Exterior Wall Upgraded to Passivhaus Standard - External "Loose" Insulation

Source: MosArt Architecture

Existing Standard Timber Frame Exterior Wall



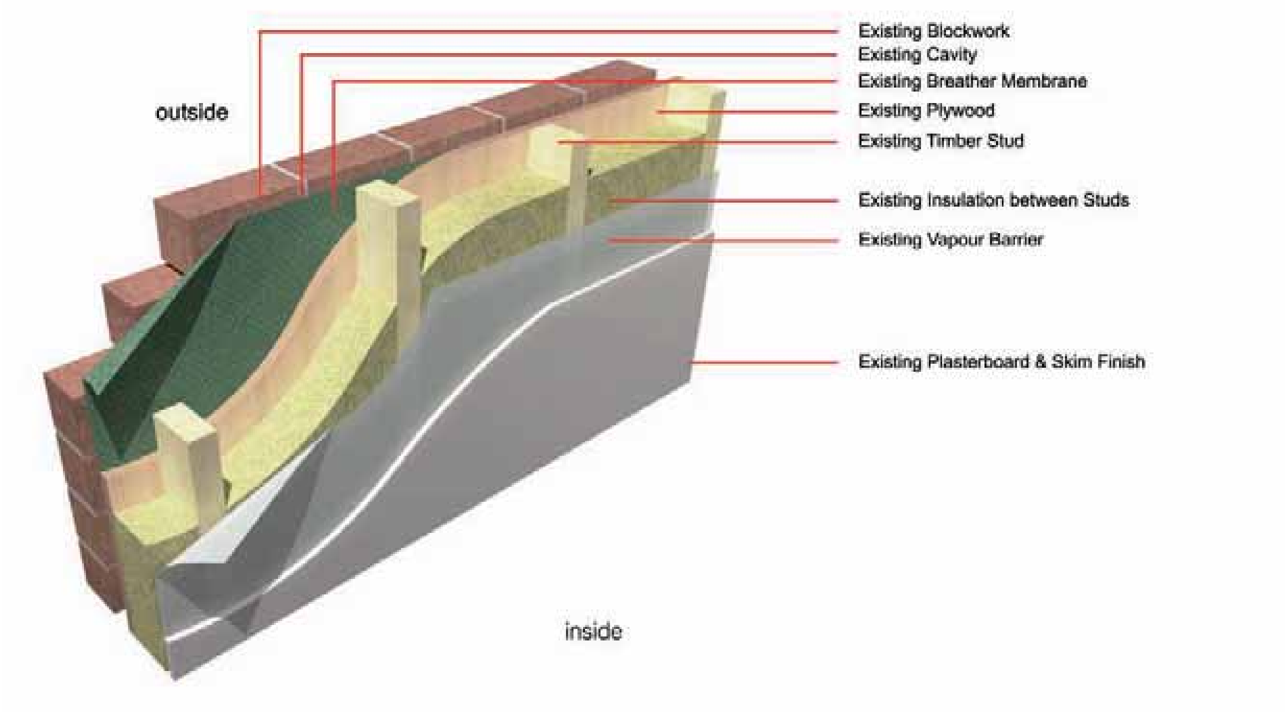


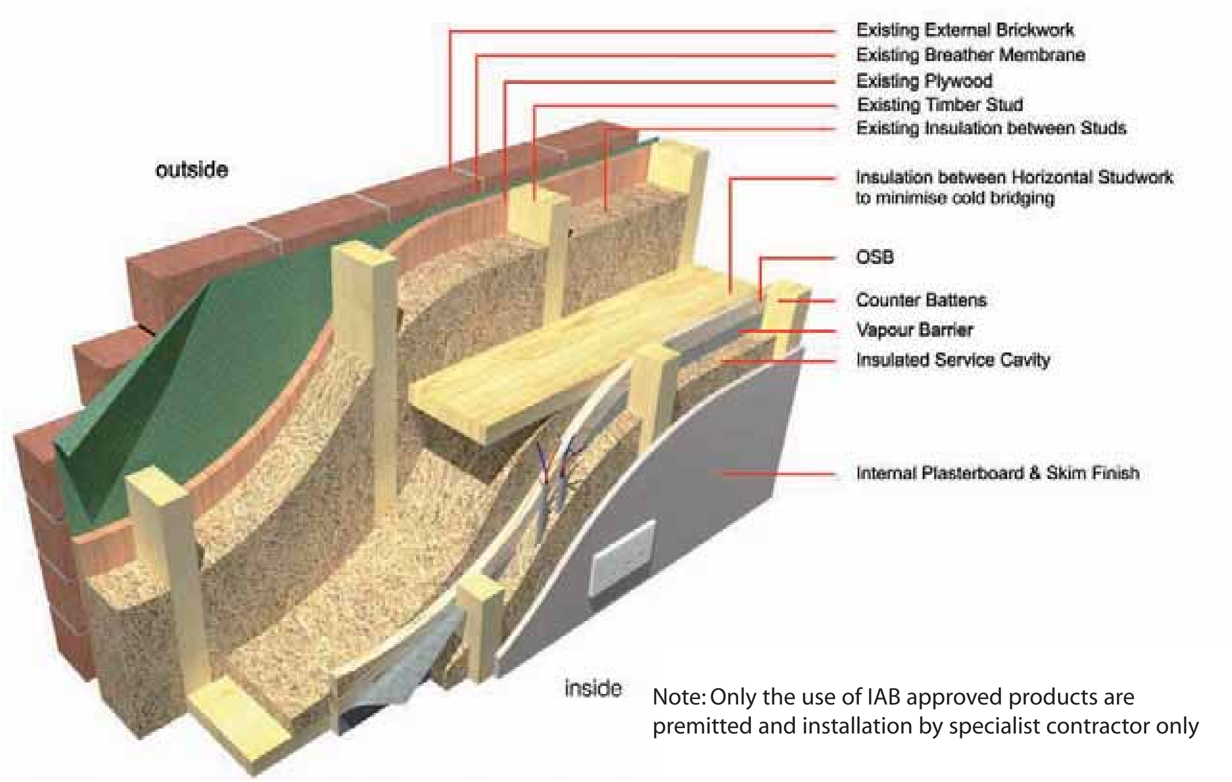
Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Timber Frame Exterior Wall Upgraded to Passivhaus Standard - External "Rigid" Insulation

Source: MosArt Architecture

Existing Standard Timber Frame Exterior Wall





Note: Only the use of IAB approved products are premitted and installation by specialist contractor only

Timber Frame Exterior Wall Upgraded to Passivhaus Standard - Internal "Loose" Insulation

Source: MosArt Architecture

floor or concrete floor with a screed finish. The thermal performance of these is typically not sufficient to achieve the Passivhaus Standard and will thus require upgrading. Unfortunately, floor constructions are difficult to upgrade because most often the finished floor level cannot be changed (considering clear heights at doors, first steps at stairs, height of balustrades etc.).

For bungalows it is worth thinking about high performance vacuum insulation (see performance details below) plus a new build up on top of the screed. The knock-on effects of rising the finished floor level has to be considered very carefully. Internal doors may have to be cut at the bottom and special detailing would be required at the threshold of external door(s).

Suspended floors are the easiest to deal with and can be upgraded by removing the floor covering, insulating between the joists, fixing a vapour control layer and covering this with a new floor finish. Make sure that the vapour control layer is not penetrated.

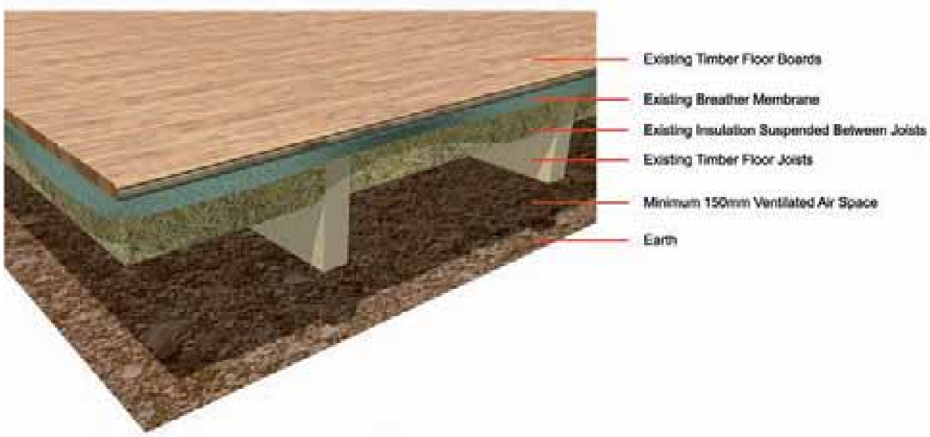
An option of upgrading concrete floor slabs with a screed finish is to take off just the screed and insulation and exchange the existing insulation with a better performing insulation. Vacuum insulation, for example, has a thermal conductivity (λ) value of 0.004 W/mK, i.e. approximately 10 times more efficient than either mineral wool or cellulose. For more information please visit the following website: http://www.vip-bau.de/e_pages/start_e.htm

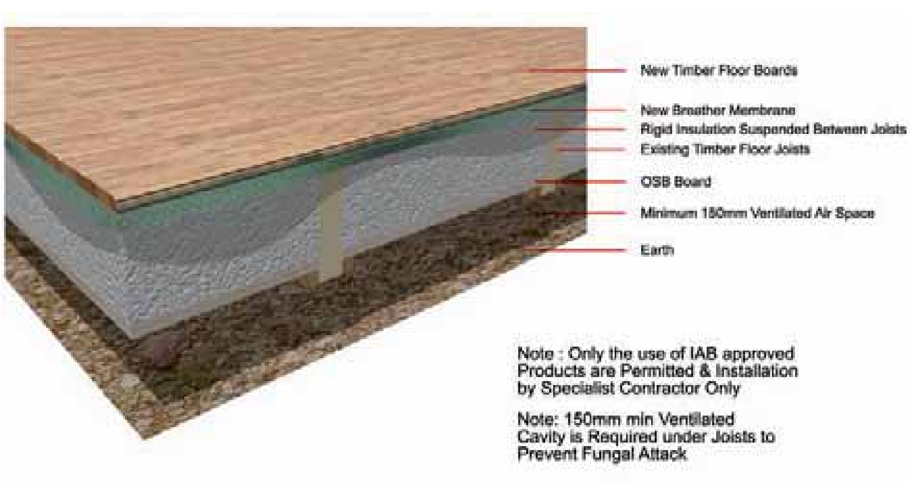
Vacuum insulation has to be handled with extraordinary care (like glass). If the foil wrapping of the boards is penetrated the thermal conductivity will increase up to approximately 0.02 W/mK. It should be noted that at the time of print this product does not have Agrment certification.

If the U-value of the above upgrade options is still not low enough (as determined by the PHPP software) or if there is a power floated concrete floor slab it is worth thinking about completely replacing the floor construction with highly insulated floor slab as described in Section 4.3.1.2.

The installation of a radon barrier should completed in accordance with the Irish Building Regulations.

Existing Standard Suspended Timber Ground Floor





Suspended Timber Ground Floor Upgraded to Passivhaus Standard

Source: MosArt Architecture

Existing Standard Concrete Ground Floor

Note: Excavation Required to allow for additional Thickness of Insulation to Engineers Detail.

Note: Only the use of IAB approved Products are Permitted & Installation by Specialist Contractor Only

Concrete Ground Floor Upgraded to Passivhaus Standard

Source: MosArt Architecture

5.3 Roof

5.3.1 Cold Roof / Insulated at Ceiling Level

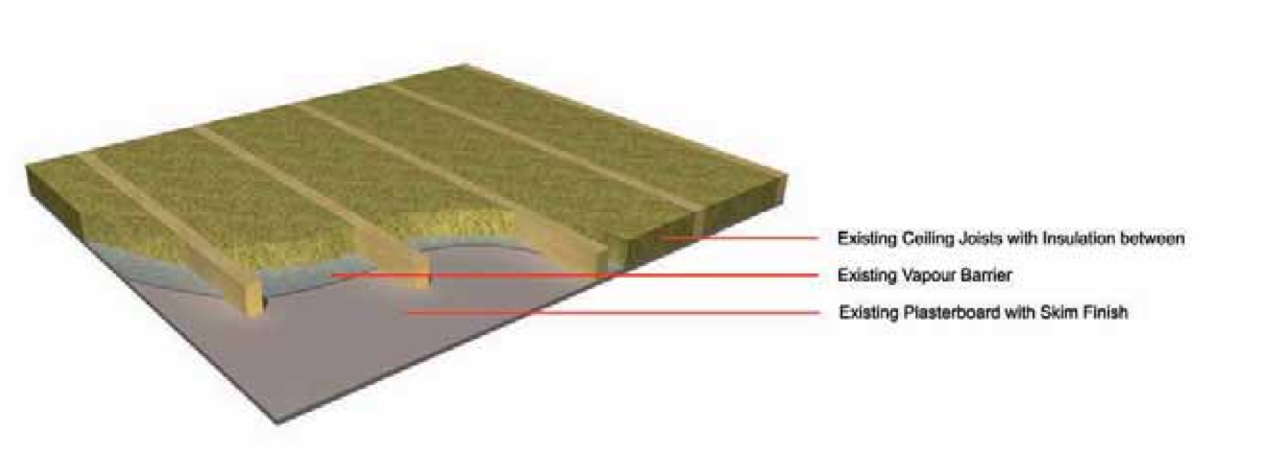
Where there is a cold unused attic space the insulation will typically be found within the joists just above the plasterboard ceiling to the attic.

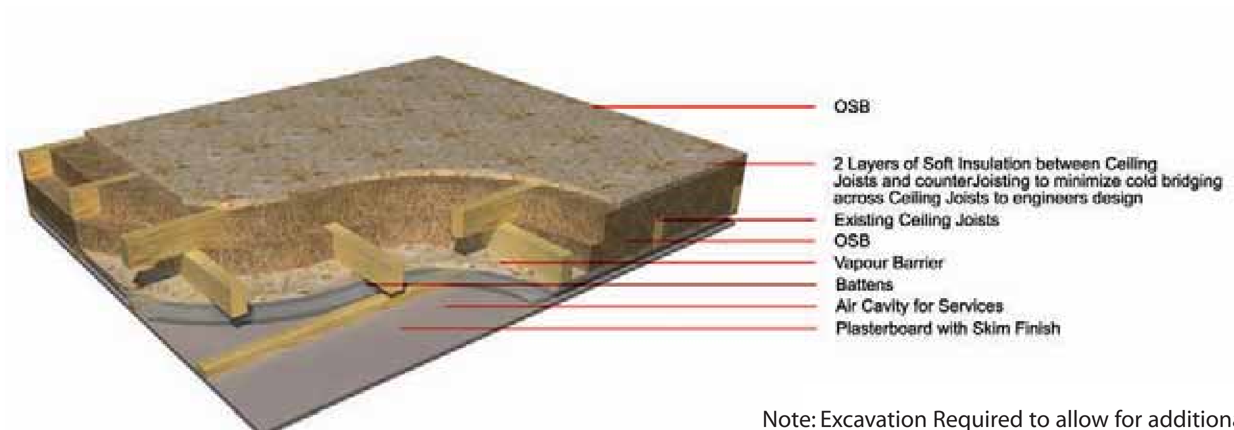
As suggested earlier, in the long term the homeowner might consider converting the attic space to a living space or might be used to locate some of the passive house mechanical plant which should be sited within the thermal envelope, such as the ventilation system. In these cases it is recommended in terms of cost and good building practice to create a 'warm' attic which means that the sloped section of the roof is insulated (see Section 5.3.2).

Usually the airtightness layer (or rather the vapour control layer) - if existent – will not be installed correctly to achieve the Passivhaus Standard. For example, the joints between different sheets will typically not be taped. The first task, therefore, is to remove the existing plasterboard and exchange it with a layer of OSB. On the internal face of the OSB a vapour control layer has to be fixed. Installing this vapour control layer is difficult work as the membrane needs to be seamless under the entire insulation layer. In the case of houses with masonry internal walls, each room can be sealed individually as the membrane can be taped to the four walls which are, themselves airtight. In situations where partition walls are constructed of timber, however, the creation of a full seal is more challenging. The membranes in all individual rooms need to be properly connected – otherwise, while each room itself might have a sealed ceiling, the partition walls will severely compromise the overall airtightness of the dwelling. Alternatively, it might be possible to install the airtight layer on top of the joist which is an easier option. If choosing this option, however, be aware that the insulation must be installed above this membrane which will reduce the available head height in the attic space.

A service cavity should thereafter ideally be created by battens and plasterboard on the internal side of the airtight layer. This will lower the ceiling height, however, and it has to be clarified by the designer if this is acceptable to the occupants.

Existing Standard Ceiling to Attic Space with Insulation on the Flat





Note: Excavation Required to allow for additional Thickness of Insulation to Engineers Detail.

Note: Only the use of IAB approved Products are Permitted & Installation by Specialist Contractor Only

Ceiling to Attic Space with Insulation on the Flat Upgraded to Passivhaus Standard

Source: MosArt Architecture

5.3.2 Sloped Roof

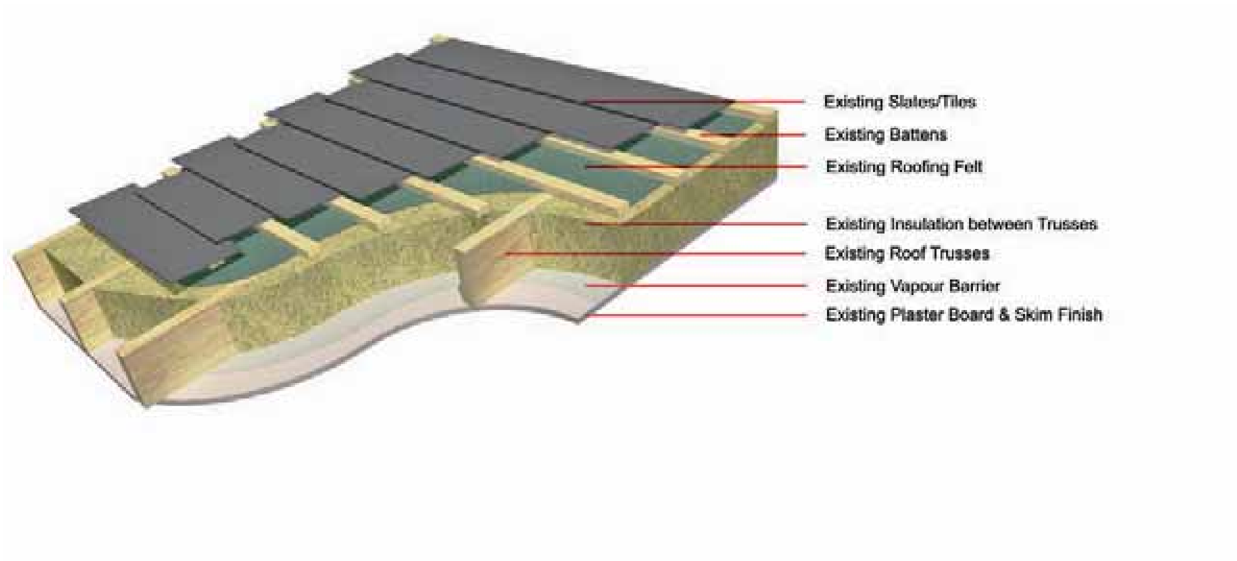
If it is necessary to insulate the sloped section of a roof there are two options, either insulation on top of the rafter (externally) or below the rafter (internally).

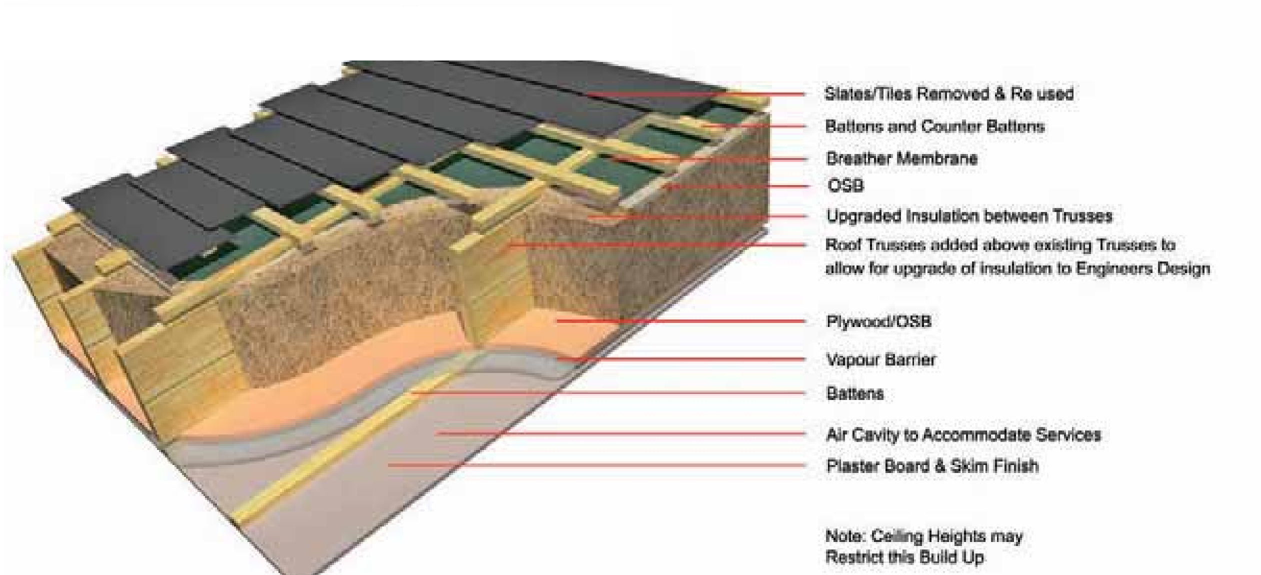
If the roof slates or tiles as well as external weathered parts of the roof construction are in poor condition it is probably wise to replace these as part of the upgrade. In this case external insulation is recommended. The rafters have to be increased in size by adding another rafter on top of them. On top of that an OSB or wood fibre board is fixed and then battens, counter battens and slates are added.

Insulation will also be placed between the rafters and internal to this will be an OSB layer, vapour control layer, battens to create a service cavity and, finally, plasterboard.

When the external parts of the roof are in good condition the insulation could be added to the inside. The build up is in principle the same as the external insulation except that there is no OSB or wood fibre board on top of the rafter. Note that an additional internal build up will reduce the clear head height and with it the usable floor area.

Existing Standard Pitched Roof With Insulation on the Slope





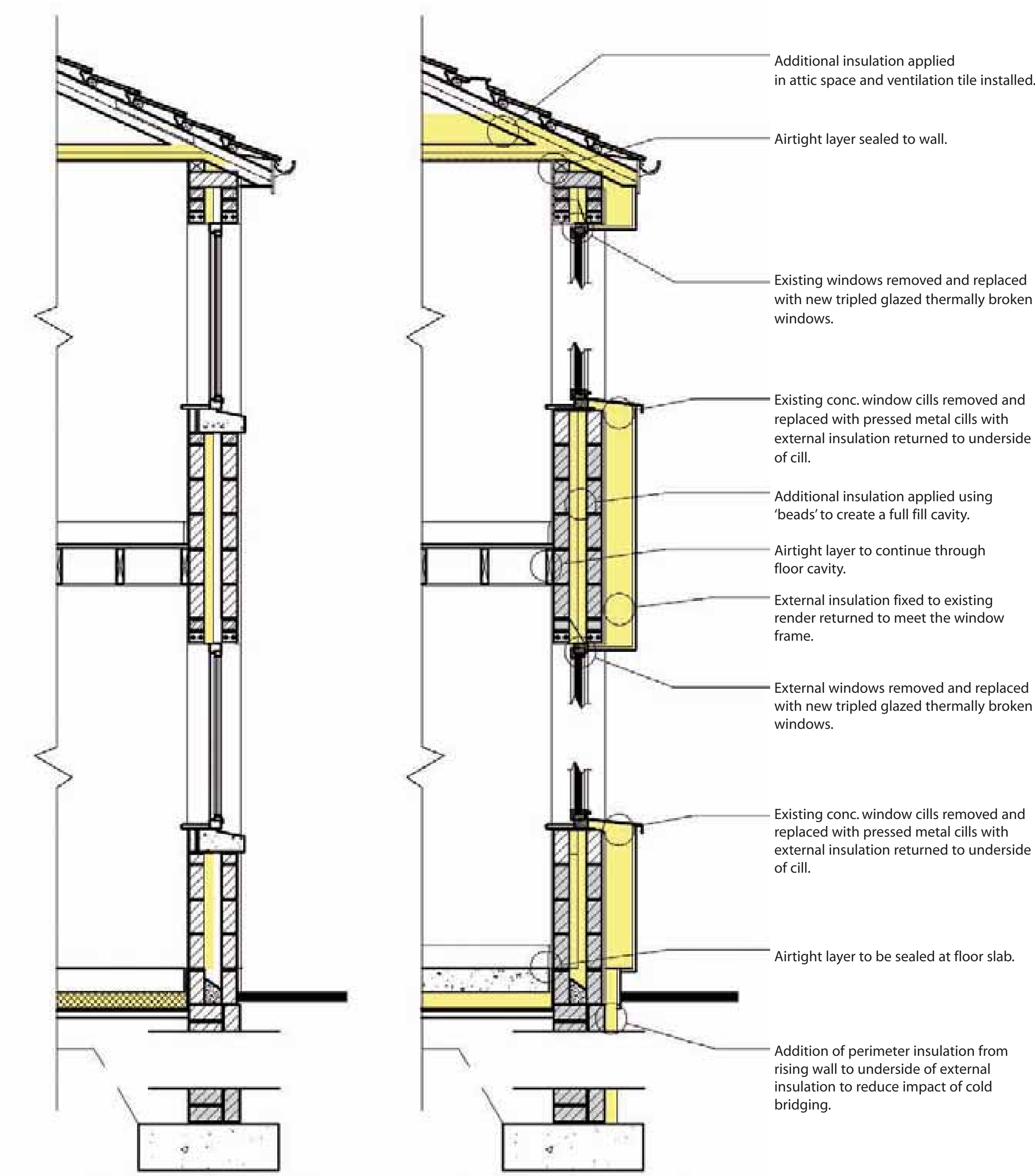
Note: Ceiling Heights may Restrict this Build Up

Pitched Roof with Insulation on the Slope Upgraded to Passivhaus Standard

Source: MosArt Architecture

The thermal performance of buildings is not only dependent on carefully designed build up of walls, roof and floor slab. When retrofitting buildings to the Passivhaus Standard the correct design of junctions in terms of insulation, thermal performance, airtightness and costs also have to be considered. There are many options and strategies that can be used to retrofit to the Passivhaus Standard and to show every single option for the upgrade of the building envelope would go beyond the scope of these guidelines.

The following two sections show possible solutions for the upgrade of a block work and timber frame wall construction.

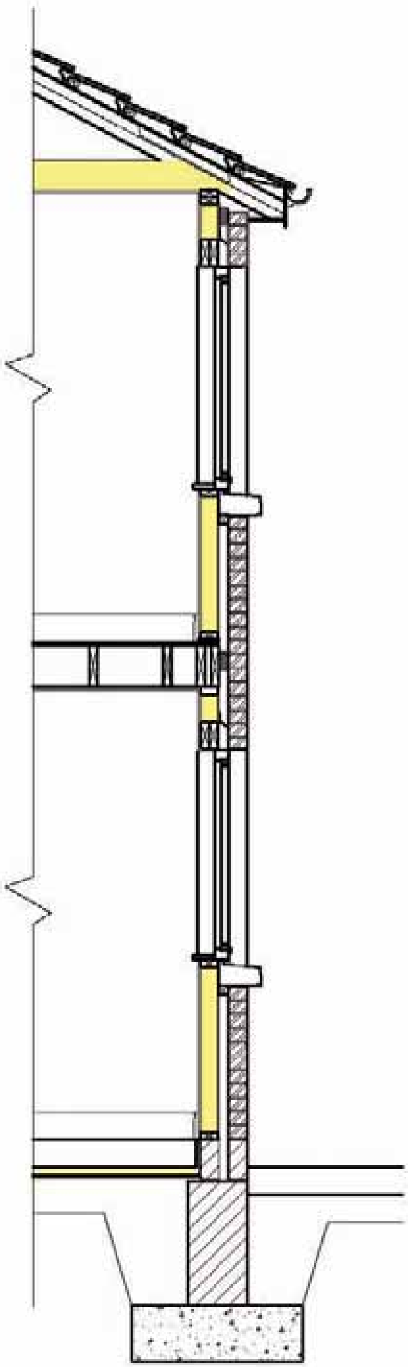


Standard Cavity Wall Construction

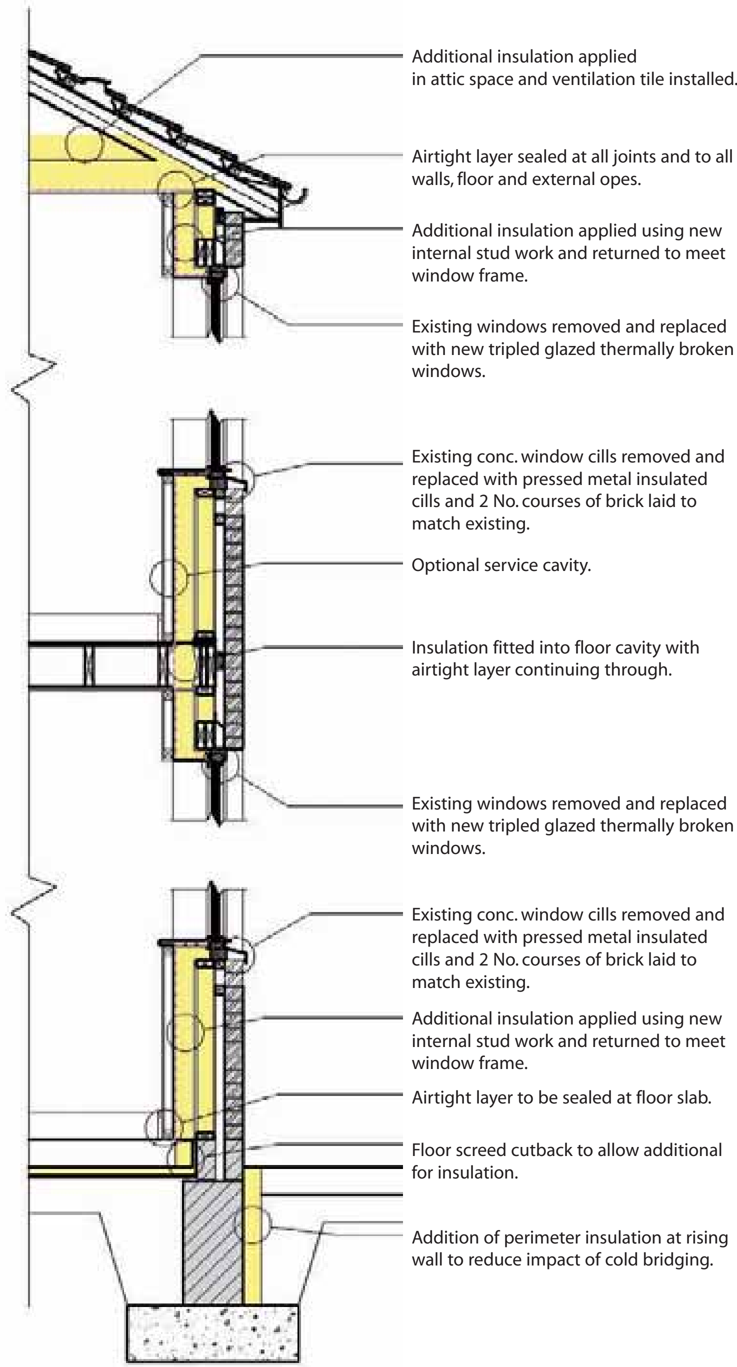
Retrofit for Cavity Wall Construction

Source: MosArt Architecture

NOTE:
Only the use of IAB approved products is permitted & installation by specialist contractor only.



Standard Timber Frame Construction



Retrofit for Timber Frame Construction

Source: MosArt Architecture

NOTE:
Only the use of IAB approved products is permitted & installation by specialist contractor only.

Section Six

Case Study Retrofit Building - Theoretical

Case Study Retrofit Building - Theoretical

This Section will illustrate a theoretical case study in how to approach the upgrading of a semi-detached house to the Passivhaus Standard. A description of the construction type and thermal performance of the property will first be provided. Thereafter, it will be shown how the specialist software PHPP was used to determine such critical issues as the level of insulation required for the Passivhaus Standard along with sizing of mechanical systems and prediction of annual space heating requirement. Schematic drawings are included in order to illustrate various means of achieving a highly efficient thermal envelope as well how to deal with challenging issues such as thermal bridging and excellent air-tightness. An approximate estimate will be provided of the projected savings in terms of energy for both heating and DHW production.

Dwelling Description

The dwelling chosen as a case study is a semi-detached / terraced house built in the late 1970's and located in north County Dublin.

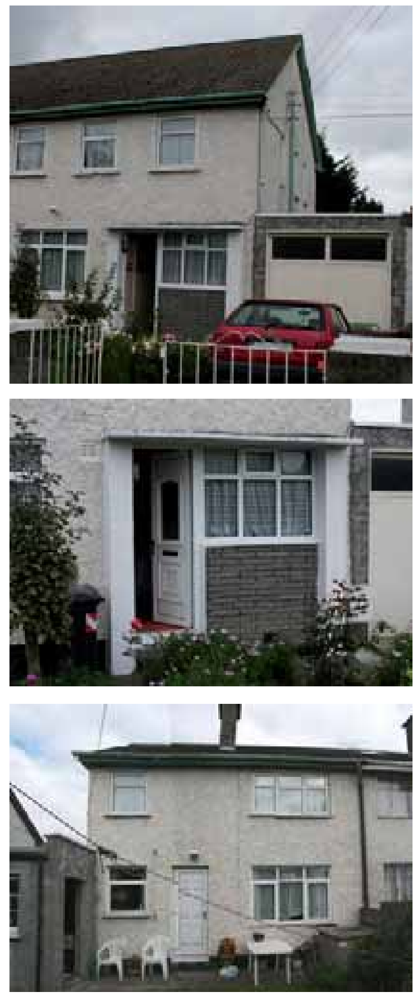
The house comprises three bedrooms and one bathroom upstairs with an entrance hall, sitting room, kitchen and dining area at the ground floor level. The total accommodation comprises 83m^2. In addition to this is an unheated, externally accessed, single storey, flat roofed garage attached to the western side of the dwelling.

In terms of aspect, the front of the house faces north and the rear of the house faces south. There are no east facing windows but three windows which face west.

The construction of the walls, floor and ceiling is summarised in the Table below. The windows were replaced in 2004 from single glazed units with wooden frames to double glazed PVC. Attic insulation was also fitted in 2004 which added considerable comfort to the dwelling.

Thermographic images of the house were taken at pre-dawn in late September 2008, with an outside temperature of 11 degrees C and an internal temperature of 18 degrees C. The low energy performance of the building fabric can be easily appreciated from these images, highlighting uninsulated external walls with thermal bridging, heat loss through ventilation grills, uninsulated external door, poorly insulated hot water pipes connecting to radiators and inadequately sealed attic hatch.

A blower door test was also carried out on the same day to determine the level of airtightness of the dwelling. The result of this test was 6.39 air changes per hour at 50 Pascal, or 6.6m^3/(hm^2). The principal weakness of the envelope in terms of airtightness is the ground floor, comprising wooden flooring on timber joists over a ventilated void. According to the occupant, there are often severe drafts



Source: MosArt Architecture

CURRENT BUILDING ENVELOPE DETAILS (FROM INTERIOR TO EXTERIOR)

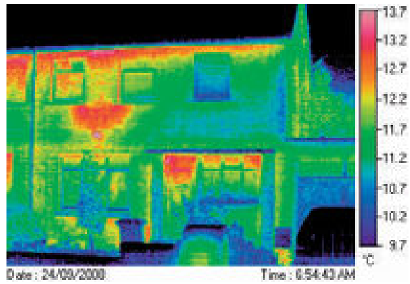
Walls	Floor	Ceiling	Windows and Doors
100mm inner concrete block	25mm wooden floor covering	12mm plaster board	
40mm cavity uninsulated	150mm joists uninsulated	100mm ceiling joist with 100mm mineral wool insulation	
100mm exterior concrete block	150+ mm open ventilated space		
Overall U-value = 1.69 W/(m^{2}K)	Overall U-value = 1.47 W/(m^{2}K)	Overall U-value = 0.43 W/(m^{2}K)	Overall U-value of windows = 1.85 W/(m^{2}K) and doors = 3.0 W/(m^{2}K)

blowing up from the open space below the ground floor creating severe thermal discomfort. A number of the windows and both external doors are insufficiently sealed as can be seen from the smoke test carried out during the blower door test. Other weaknesses include wiring which passes from the first floor through to the attic space as well as a poorly sealed attic hatch.

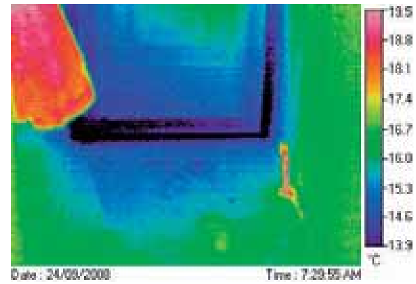
Current Heating and DHW System

The house is currently heated using a relatively new natural gas boiler of approximately 80% efficiency. The boiler heats six radiators (two downstairs and four upstairs) which are controlled by a thermostat located in the kitchen. There is also a wall mounted electrical heater in the upstairs bathroom and a portable electric heater in the living room.

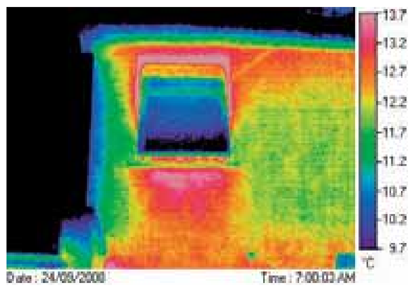
The house currently has no DHW tank. Hot water is provided on demand at the kitchen sink (using electricity) and in the upstairs bathroom with an 'electric shower'. The primary control for heating aside from the kitchen thermostat is a time clock.



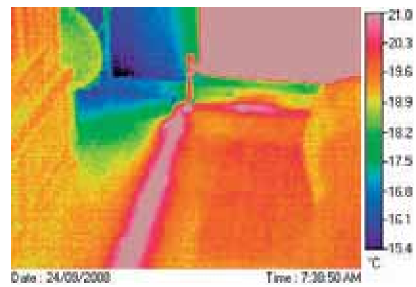
Front (north) elevation illustrating significant heat loss through the upstairs front bedroom external wall (Bedroom 2). The red glow located between the two windows is created by heat loss from a wall mounted radiator at that position.
Source: GreenBuild Building Information Services



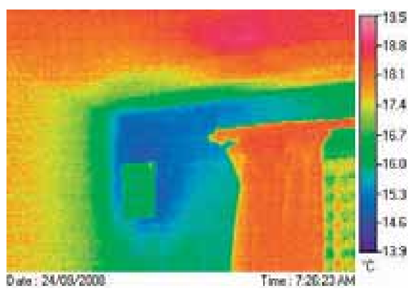
Heat loss depicted in black and blue colouring created by an uninsulated front door. Note how the cold migrates inward along the floor.
Source: GreenBuild Building Information Services



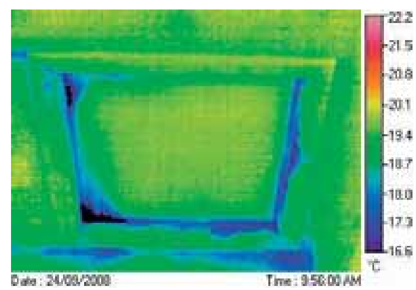
Rear (south) view of Bedroom 3 highlighting in red significant heat losses through the uninsulated external wall from a wall mounted radiator positioned under the window.
Source: GreenBuild Building Information Services



Heat loss (depicted in grey line) from an under floor hot water pipe feeding a radiator.
Source: GreenBuild Building Information Services



Heat loss depicted in blue colouring created by cold air entering the corner of a bedroom through a ventilation grill.
Source: GreenBuild Building Information Services



Poorly sealed attic hatch displaying heat loss around the perimeter (in dark blue colouring).
Source: GreenBuild Building Information Services

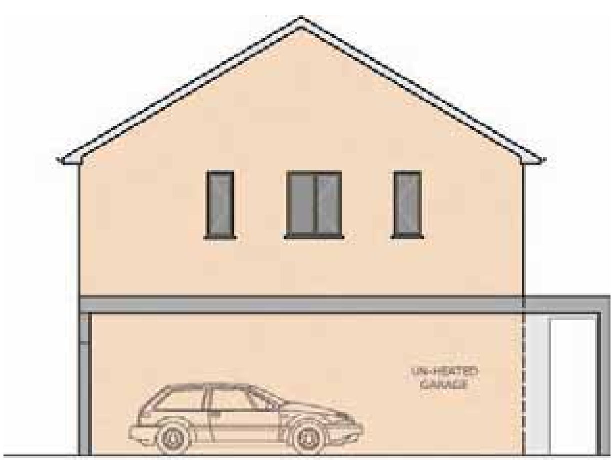
Smoke test clearly highlights poorly sealed windows
Source: MosArt Architecture

Smoke test illustrating air leakages below a window sill
Source: MosArt Architecture

Leaky floor construction
Source: MosArt Architecture

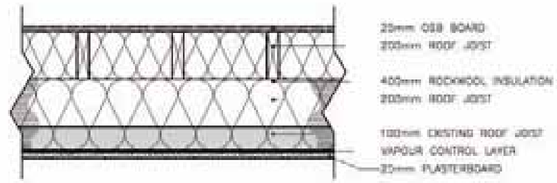
NORTH ELEVATION

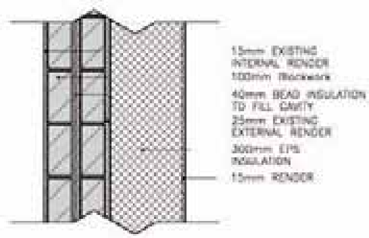
SOUTH ELEVATION

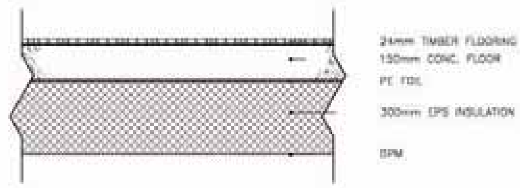


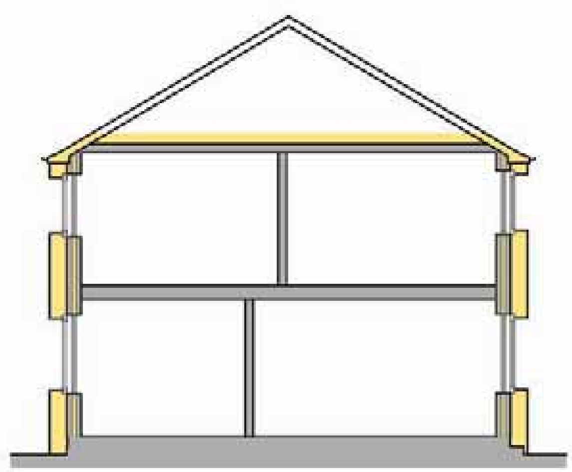
WEST ELEVATION

Source: MosArt Architecture









SECTION

Use of PHPP and DEAP to Prepare Retrofitting Strategy

All the relevant details concerning the existing building dimensions, thermal envelope performance, level of airtightness, orientation and shadowing as well as electrical elements, heating system are entered into both the PHPP and the DEAP software.

As can be seen from the Table above, the dwelling as it is currently constructed has an annual space heating requirement of approximately 14 times that of the Passivhaus Standard. Further, with an existing BER of E2, there is considerable scope for improvement to bring the overall energy efficiency to what would be required by the revised 2008 Part L Building Regulations (a BER of approximately B1).

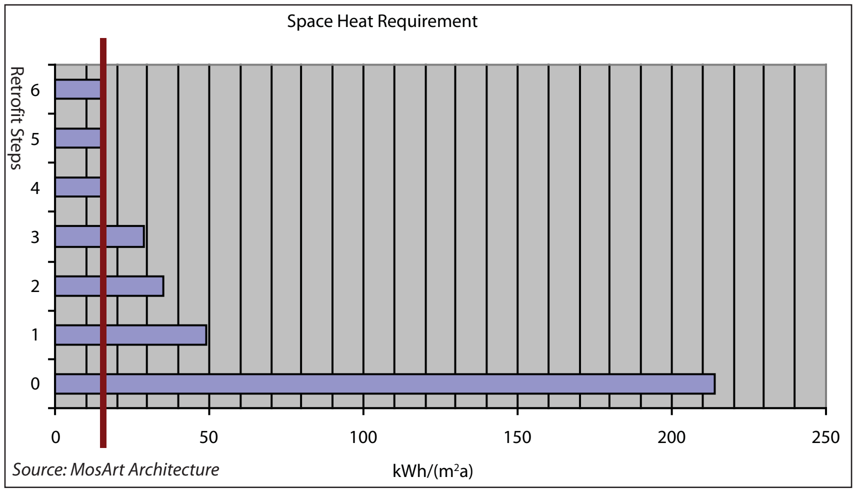
Taking the current annual space heating demand and multiplying this by gas and electrical prices, it should, theoretically (according to the PHPP), cost the owner in the order of €900 per year on gas and €570 per year on electricity, totalling approximately €1,500 per year. This estimation is very close to the actual amount spent on heating by the occupant of the house as determined from a review of their energy bills.

Preparing a Retrofit Strategy

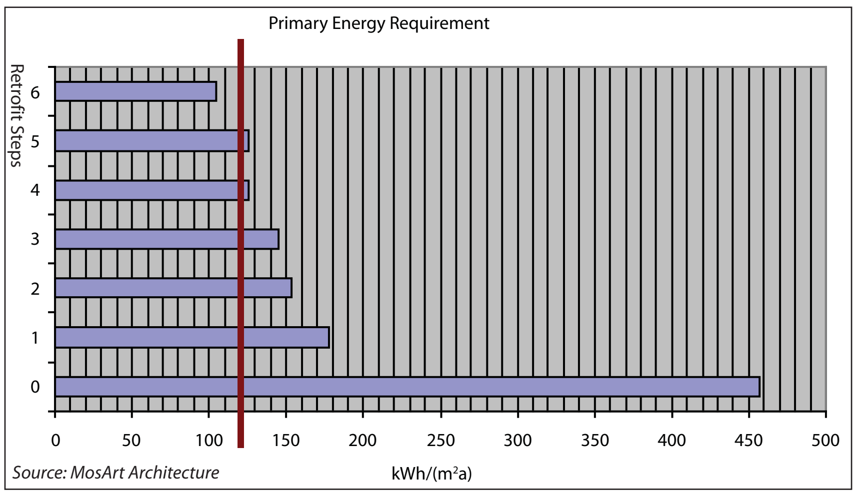
There are quite a number of aspects of the current dwelling that cannot be altered to any significant degree, including, for example, orientation and surface to volume ratio. Other aspects that might be improved, albeit with some difficulty and therefore relatively high cost, include thermal bridges and amount of south facing glazing. The most cost effective means of making considerable improvements to overall energy performance include (a) significantly upgrading the insulation value of the entire thermal envelope, including windows and doors, (b) considerably improving the level of airtightness, (c) installing a mechanical heat recovery ventilation system and (d) fitting renewable energy technologies such as solar collectors for DHW and improving the efficiency of the gas boiler.

The steps used to gradually upgrade the case study dwelling are detailed in the table on page 55. A summary of the

PERFORMANCE OF THE EXISTING DWELLING ACCORDING TO PHPP AND DEAP[7]	PHPP	DEAP
Annual space heating requirement	214 KWh/(m²a)	160 KWh/(m²a)
Annual primary energy use	441 KWh/(m²a) including all household electricity	356 KWh/(m²a) (only includes electricity for lights, pumps & fans)
Building Energy Rating	N/R	E2
CO_2 Emmissions	94 $KgCO_2eq/(m^2a)$	37 $KgCO_2eq/(m^2a)$



Source: MosArt Architecture



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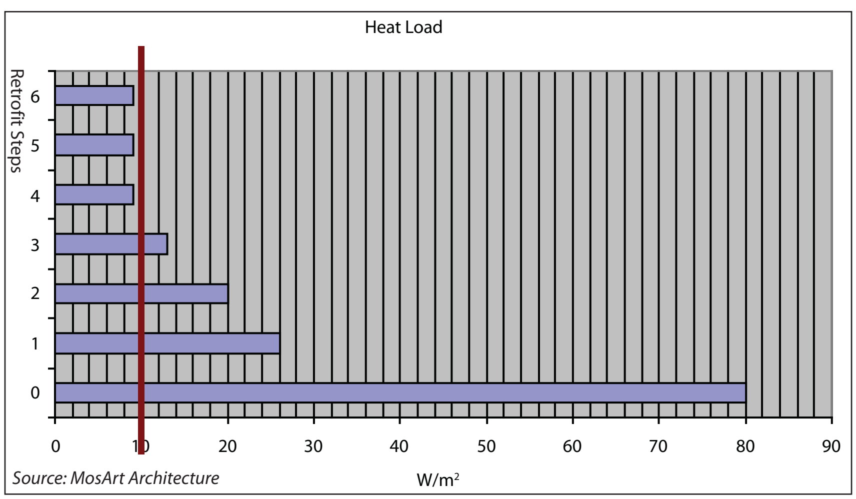


Source: MosArt Architecture

overall result of the upgrading strategy is provided hereunder:

- The space heating requirement target of 15 kWh/(m²a) has been met, reducing the current energy use by 93% from the current level of 214 kWh/(m²/a) according to the PHPP calculations. Referring to DEAP the 'heat use' has been reduced from 160 kWh/(m^2a) to 9 kWh/(m^2a) (also a reduction of 93%)

- Achieving the Passivhaus Standard required very significantly upgrading the U-values of the building envelope. The poorest performing element of the dwelling is the walls (U-value of 1.69 W/(m^2K)) which would need to be upgraded to 0.10 W/(m^2K). The windows and doors would have to be replaced with high performance triple-glazed elements, airtightness improved from 6.39 air changes per hour at 50 Pascal to 0.6 air changes per hour, use of a MHRV system with an efficiency of 85%, increasing the area of south facing glass from 7.38m^2 to 9.05m^2 and replacing the gas boiler with a unit with 90% efficiency and installing 5m^2 of solar collectors (flat plate or evacuated tube) on the south-facing roof.
- The primary energy demand including for DHW, heating, cooling, auxiliary and household electricity was reduced in the PHPP analysis from 457 kWh/(m^2a) to 105 kWh/(m^2a) and in DEAP from 375 kWh/(m^2a) to 55 kWh/(m^2a)
- The heat load for the dwelling was reduced by 90% from the current size of 80 W/m^2 to 9 W/m^2. Taking that the dwelling is 83m^2 in size, the size of boiler required for space heating alone could be reduced from 6.6 kW output to just 0.8 kW.
- Frequency of overheating remains unaltered at 0%.
- Referring to the CO_2 calculations in DEAP, the CO_2 emissions have been reduced from 160 kgCO_2eq/(m^2a) to 12 kgCO_2eq/(m^2a), representing a 93% reduction. In real terms, given the house size of 83m^2, there would be an annual saving in CO_2 emissions of over 12,000 Kg, or approximately 12 tonnes. In 2004, the 'average dwelling in Ireland was responsible for emitting approximately 8.2 tonnes of CO_2. If the case study house was retrofitted to the Passivhaus Standard, it would emit just 1 tonne per year. It is estimated that approximately 750,000 houses in Ireland were built before the first ever Building Regulations. If 25% of those were upgraded to the Passivhaus Standard, there would be a reduction in annual emissions of CO_2 by 2MTCO_2eq/(m^2a).
- Lastly, the Building Energy Rating of the case study dwelling in achieving the Passivhaus Standard would be an A3, a very significant improvement from its E2 BER.

Measures in Detail

As mentioned above all proposed measures have to be checked and be approved for each individual project.

Thermal Insulation

The existing house was built in traditional un-insulated cavity wall construction, with a U-value calculated at 1.69 W/m^2K. A 40 mm fulfilled cavity with blown insulation beads and rendered 300 mm EPS insulation on the outer leaf will bring the U-value down to 0.10 W/m^2K. As shown in Section 5 there are a number of options available to upgrade a wall such as that described above.

The flat ceiling to the attic has to be insulated with 100 mm mineral wool between the joists. Additional insulation will be required, however, in order to achieve the target U-value (if using mineral wool insulation, for example, 400 mm would be required. If other insulation products with lower thermal conductivity (λ) values are being considered, less depth would be needed). In order to keep the attic accessible, it would be advantageous to construct a raised floor above this additional insulation using OSB, for example.

The existing ground floor slab is a suspended floor construction and it would have been extremely difficult to reduce the U-value down to the required 0.10 W/m^2K. It was decided, therefore, that the best option in this case would be to remove the existing floor and construct a new 150 mm concrete floor slab with 300 mm insulation underneath.

Windows and Doors

In terms of glazing, it is proposed to use triple glazed windows with an average U-value (glass and frame) of Uw average=0.9 W/m^2K and doors with a U-value of Ud=0.8 W/m^2K. The windows and doors should be installed in the same layer as the cavity to continue the insulation layer.

Thermal Bridges

In general thermal bridges are reduced by using external insulation. Perimeter insulation should be continued on the outer face all around the building approximately 500 mm to 1,000 mm into the ground, dependent on the depth of the foundation. Furthermore, the frames of windows and doors should be overlapped by the external insulation (at least 60 mm thickness) to reduce thermal losses.

The most significant thermal bridges would occur at the concrete canopy over the front door, the concrete columns on either side of the front door and at the joint of wall and roof of the adjacent garage. It would probably be best to remove the existing concrete canopy as well as the columns. If there is still a need for a canopy it could be constructed as-new, yet structurally separated from the house.

The uninsulated cold wall of the garage should ideally be disconnected from the house and the resulting gap insulated (some means of structurally anchoring the garage wall back to the house will likely be required). The roof of the garage is easier to deal with as it is mainly made from timber and therefore its thermal conductivity is not that high. Besides, additional insulation can easily be fitted above and under the rafters to reduce the thermal bridges.

Thermal bridges can also be created at the party wall with the neighbour if they do not insulate their building. These thermal bridges can be reduced by insulating internally.

Lastly, the hatch to the attic has to be well insulated and sealed airtight.

Airtightness

A continuous airtight layer has to be created in the building. As render is airtight, there is typically no difficulty in achieving airtightness over wall areas. Windows and doors should be taped airtight with a suitable tape to the wall. Following that the reveals can to be plastered.

The layer of foil underneath the concrete floor slab serves two purposes.

The first duty is to prevent the concrete seeping into the gaps between the insulation boards while pouring it. The second function is to create the airtight layer. This foil has to be taped airtight at the edges to the walls.

All joints of joists or rafters to walls have to be taped airtight to the walls. If there is no render in the ceiling level at the walls these spaces have to be rendered or spanned with a vapour barrier membrane.

Underneath the insulation of the first floor ceiling a vapour barrier has to be installed. It is very important to carry out a blower-door-test before the closing the access points to joints and junctions. It will typically happen that the first test result exceeds the 0.6 air changes per hour. During the test leakages can be located and sealed.

Ventilation Heating System

In the case of the example dwelling, the ventilation system and heat recovery unit are located in the 'box room' on the first floor. The ventilation ducts are passed through the ceiling void and supply the fresh air to the habitable rooms such as bedrooms and down to the ground floor in two shafts to the family and living room. The air is extracted in the kitchen, hall, box room and bathroom.

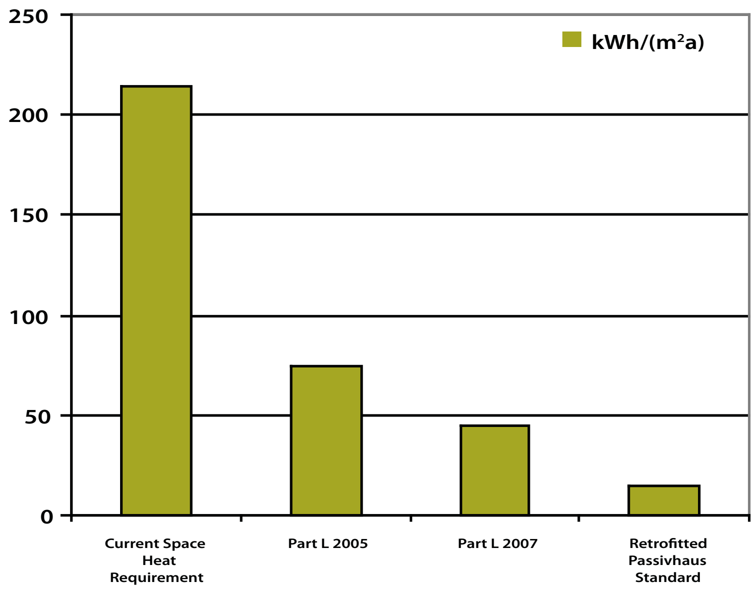
The heat recovery unit is calculated with an efficiency of 85% and as a 'back-up heating' the existing heating system with radiators is retained.

Room temperatures are controlled with time control, external temperature sensors and thermostats.

Cost of Retrofitting

The cost of the above proposed works has not been estimated for this 'theoretical' case study. However, experience on Continental Europe suggests that retrofit costs to the full Passivhaus Standard typically equate to approximately 60% of what it would cost for to build the same dwelling completely from new. It must be stressed that such works are most economically viable when dealing with an old dwelling which, irrespective of energy performance, needs to be completely upgraded. The case study dwelling presented in the following chapter is an example of where such an overhaul was needed. In that case, the extra over costs to reach towards Passivhaus Standard (i.e. over the above costs of new kitchen, extension, conventional builder's work and so forth) was in the region of 14%.

Until such time as more projects get underway in Ireland, it is difficult to estimate what retrofit costs will be.

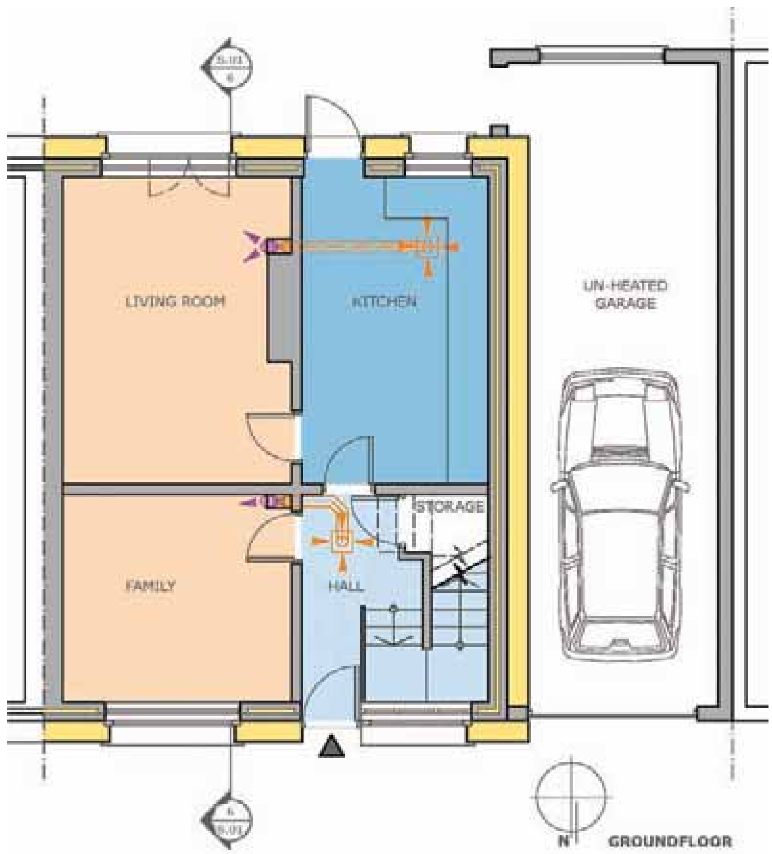


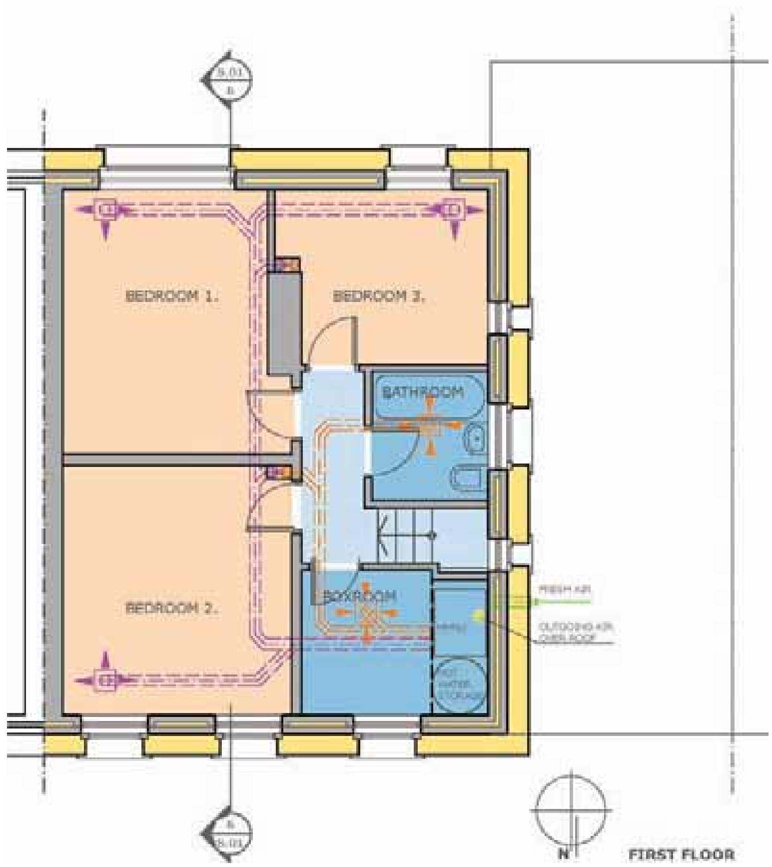
Space heating energy comparison, Current use in case study dwelling, Building Regulations (TGD) Part L 2005 and 2007 and the Passivhaus Standard. Source: MosArt Architecture

		PHPP CALCULATIONS				DEAP CALCULATIONS			
Step	Description	Space Heat Requirement	Primary Energy (DHW, Heating, Cooling, Auxiliary and Household Electricity):	Heat Load	Frequency of Overheating	Primary Energy	Heat use (Space Heat Requirement)	CO_2 emissions	Building Energy Rating
	Units of Measurement	kWh/(m²a)	kWh/(m²a)	W/m²	%	kWh/(m²a)	kWh/(m²a)	$kgCO_2eq/(m^2a)$	
	Passive House threshold	15	120	10	10	-	-	-	-
	Current performance	214	457	80	0	375	160	79	E2
1	Insulation of building fabric (walls, ceiling, floor), reduction of thermal bridges - improve U-value walls from 1.69 to 0.10 W/(m²K), U-value ceiling from 0.43 to 0.09 W/(m²K), U-value floor from 1.47 to 0.10 W/(m²K)	49	178	26	4	177	51	39	C2
2	Change from double to triple glazed windows, change doors -improve average U-value windows from 1.85 to 0.91 W/(m²K), U-value doors from 3.00 to 0.80 W/(m²K)	35	154	20	5	153	38	34	C1
3	Airtightness - improvement from 6.39 to 0.6 airchanges per hour @ 50 Pascal	29	145	13	15	125	22	28	B3
4	Balanced whole-house-ventilation system, with Heat Recovery Unit, efficiency 85%	16	126	9	0	108	9	25	B2
5	Increase window sizes of south facing windows,from 7.38 to 9.05 m²	15	126	9	0	108	9	25	B2
6	Condensing Gas boiler for heating and DHW- efficiency of 90%, DHW not electric anymore, 5 m² Solar panels, 300 l hot water storage	15	105	9	0	55	9	12	A3

Source: MosArt Architecture

Externally Insulated Building Envelope and Heat Recovery Venilation System in Retrofitted Dwelling





Source: MosArt Architecture

Passive House Verification

Photo or Drawing

Building:	Example Building
Location and Climate:	IRL - Dublin
Street:	
Postcode/City:	
Country:	Ireland
Building Type:	Semi-detached, residential building
Home Owner(s) / Client(s):	
Street:	
Postcode/City:	
Architect:	MosArt Architects Ltd.
Street:	Block 5, Broomhall Business Park
Postcode/City:	Wicklow, Co. Wicklow, Ireland
Mechanical System:	
Street:	
Postcode/City:	

Year of Construction:	1970				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	308.8	m^3	Internal Heat Gains:	2.1	W/m^2
Number of Occupants:	2.4				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area:	82.9	m^2			
	Applied:	Annual Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	**214**	**kWh/(m²a)**		**15 kWh/(m²a)**	**No**
Pressurization Test Result:	**6.4**	**h^{-1}**		$0.6\ h^{-1}$	**No**
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	**457**	**kWh/(m²a)**		120 kWh/(m²a)	**No**
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	419	kWh/(m²a)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kWh/(m²a)			
Heating Load:	80	W/m²			
Frequency of Overheating:	0	%	over	25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)		15 kWh/(m²a)	
Cooling Load:	0	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:

Copy of the PHPP 2007 verification sheet for theoretical case study pre retrofitting

Passive House Verification

Photo or Drawing

Building:	Example Building
Location and Climate:	IRL - Dublin
Street:	
Postcode/City:	
Country:	Ireland
Building Type:	Semi-detached, residential building
Home Owner(s) / Client(s):	
Street:	
Postcode/City:	
Architect:	MosArt Architects Ltd.
Street:	Block 6, Broomhall Business Park
Postcode/City:	Wicklow, Co. Wicklow, Ireland
Mechanical System:	
Street:	
Postcode/City:	

Year of Construction:	late 1970's				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	308.8	m^3	Internal Heat Gains:	2.1	W/m^2
Number of Occupants:	2.4				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area:	82.9	m^2			
	Applied:	Annual Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	**15**	$kWh/(m^2a)$		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):	**105**	$kWh/(m^2a)$		120 $kWh/(m^2a)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	69	$kWh/(m^2a)$			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		$kWh/(m^2a)$			
Heating Load:	9	W/m^2			
Frequency of Overheating:	0	%	over	25 °C	
Specific Useful Cooling Energy Demand:		$kWh/(m^2a)$		15 $kWh/(m^2a)$	
Cooling Load:	6	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.

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Copy of the PHPP 2007 verification sheet for theoretical case study post retrofitting

SECTION SEVEN

Case Study of Completed Retrofitted Project

Case Study of Completed Retrofitted Project

This project is one of the first in Ireland in retrofitting a conventional built dwelling towards a Passivhaus Standard. The clients visited MosArt's demonstration passive house 'Out of the Blue' in 2006 and were inspired to convert their home to the same standard of comfort and energy efficiency.

The existing external walls were constructed as a standard cavity wall with a 100 mm brickwork outer leaf, 100 mm cavity and 100 mm concrete blockwork inner leaf. Upon inspection the cavity was found to have no insulation installed and the walls had been dry lined internally with timber studs with rock wool insulation between, polyethylene vapour barrier and plasterboard with skim finish.

As the exterior leaf was brickwork we were restricted in how we could upgrade the fabric to the Passivhaus Standard. We achieved this by fully filling the cavity with blown in insulation, the existing dry lining was removed internally and replaced with larger timber studs and higher density insulation between, a higher quality airtight vapour barrier was installed and taped on all joints with specific care taken to junctions at floors, ceilings and around windows and doors and new plasterboard and skim finish was installed. All existing wall vents were blocked up internally and a MHRV unit was installed throughout the house.

The existing double glazed windows were replaced with thermally broken triple glazed windows throughout and triple glazed roof lights were installed in the roof.

The existing roof was a standard tiled roof with pre-fabricated timber trusses with insulation on the flat. As the alterations to the existing house included an additional bedroom in the roof space the insulation had to be changed to on the slope to accommodate this. Additional timber rafters were installed to accommodate additional higher density insulation in the roof space between the timbers, airtight vapour barrier was added and new plasterboard with skim finish.

The existing heating system was replaced with a MHRV unit and heat pump with a gas condenser boiler as back-up and solar collectors to the roof for hot water supply.

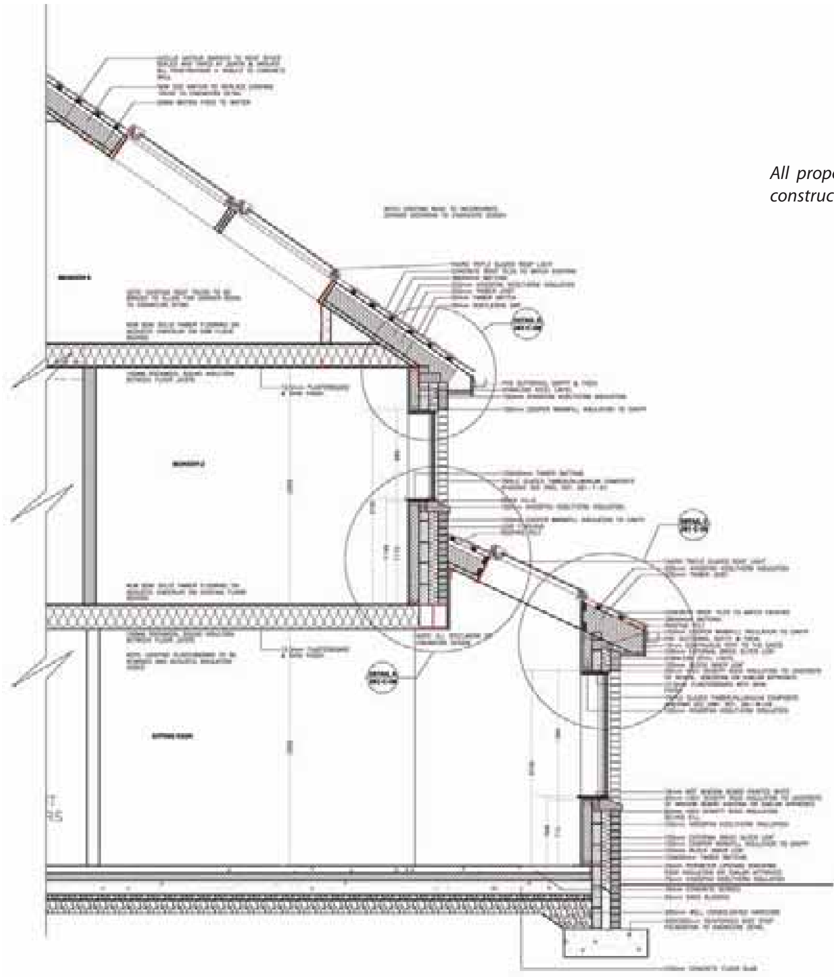
It is important to note that the programme for a passivhaus build differs to that of a conventional build. Time should be allowed for the installation of the airtight layer, this airtight layer should then be tested (blower door test) for leaks prior to any plasterboard being installed. Should any leaks be detected they should then be rectified and the airtight layer should be re tested until the required level of airtightness is achieved. Testing with a thermal imaging camera is also available. This can detect any cold bridges in the external fabric of the building. Strict on site supervision is required throughout the construction works by the designer. The site foreman or main contractor should also be made aware of the importance of strict on site supervision by them of all trades to achieve an airtight building. On completion the house should have one final blower door test.

The retrofitted building was occupied in May 2008 and at the time of print, the heating season is approximately 50% complete. The actual annual energy consumption cannot be verified before May 2009 at the earliest. A comparison between the modelled and achieved improvement of the energy performance of this project is yet not possible, therefore it is anticipated that the annual space heating requirement will be reduced by 80%.

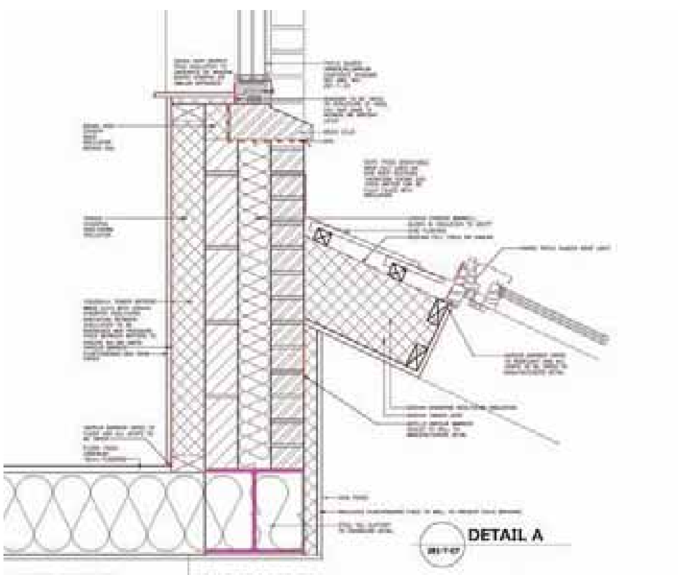
The extra-over cost to achieve the Passivhaus Standard according to the cost plan on this project was 14%. It should be borne in mind that this house underwent a major retrofit and extension programme and thus the above percentage extra over costs should in no way be taken as a general guide for retrofit projects.

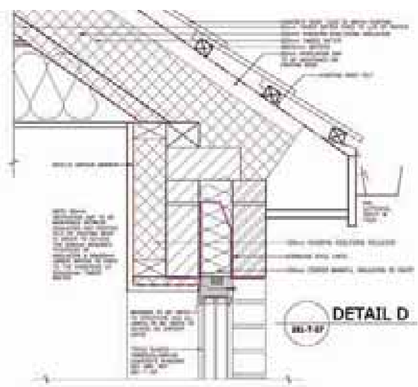
Improvement of U-values

Envelope elements	Pre-retrofit U-values	Post retrofit U-values
External cavity wall	0.28 W/(m^{2}K)	0.19 W/(m^{2}K)
Floor slab	0.58 W/(m^{2}K)	0.18 W/(m^{2}K)
Roof	0.13 W/(m^{2}K)	0.11 W/(m^{2}K)
Windows	2.90 W/(m^{2}K)	0.81 W/(m^{2}K)

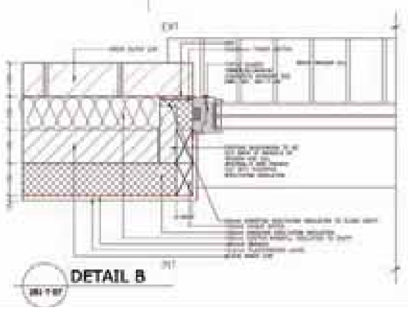


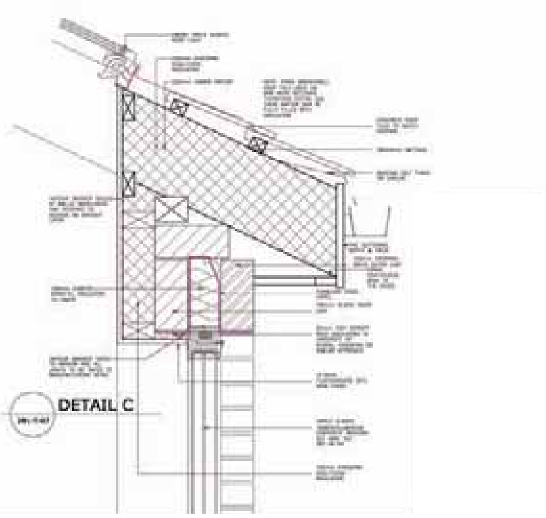
All proposed retrofit measures must be properly detailed to enable construction and well as to verify performance in the PHPP software





NOTE: ANY PENETRATIONS FOR SERVICES THROUGH VAPOUR BARRIER TO BE PROPERLY SEALED





Before commencing any retrofit works, a full survey will be required to establish current insulation standards

While the red brick facade remained untouched, all the windows were upgraded to triple-glazed Passivhaus Standard units (U-value of 0.81 $W/(m^2K)$ for entire window)

These special triple glazed roof lights were used on the south facing rear elevation (U-value of 0.91 $W/(m^2K)$ for entire window)

Retrofitting to reduce energy consumption also provides a valuable opportunity to enhance the aesthetics of the interior

The mechanical heat recovery ventilation system was installed in an accessible part of the warm attic space

This water to air heat pump is connected to a low-temperature under-floor heating system and is anticipated to provide 85% of the space heat requirement (COP = 3.4)

The existing building envelope was dry-lined internally with high performance insulation

Locations such as this where large services exit the building envelope are very difficult to seal properly in terms of airtightness

The south facing rear of the house on completion, with 15m^2 of flat plate solar thermal collectors which are expected to contribute 65% of DHW demand

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