SUSTAINABLE ENERGY AUTHORITY OF IRELAND

DESIGN GUIDELINES

Non-Domestic Passive House Projects

Sustainable Energy Authority of Ireland

The Sustainable Energy Authority of Ireland was established as Ireland's national energy authority under the Sustainable Energy Act 2002. SEAI's mission is to play a leading role in transforming Ireland into a society based on sustainable energy structures, technologies and practices. To fulfil this mission SEAI aims to provide well-timed and informed advice to Government and deliver a range of programmes efficiently and effectively, while engaging and motivating a wide range of stakeholders and showing continuing flexibility and innovation in all activities. SEAI's actions will help advance Ireland to the vanguard of the global green technology movement, so that Ireland is recognised as a pioneer in the move to decarbonised energy systems.

SEAI's key strategic objectives are:

- Energy efficiency first – implementing strong energy efficiency actions that radically reduce energy intensity and usage
- Low carbon energy sources – accelerating the development and adoption of technologies to exploit renewable energy sources
- Innovation and integration – supporting evidence-based responses that engage all actors, supporting innovation and enterprise for our low-carbon future

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Guidelines prepared by SEAI Renewable Energy Information Office and MosArt Architecture

Foreword

The Sustainable Energy Authority of Ireland, SEAI, operates programmes and activities to advance the Government's ambition for Ireland to become a world leader in sustainable energy, 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, agreement on the recasting of the Directive, substantial improvements in Building Regulations energy standards and requirement for the use of renewable energy systems, we have seen significant strengthening in the energy performance required of new buildings.

The PassivHaus standard is recognized in Europe as a progressive and advanced benchmark for building energy performance. In 2008 SEAI published 'Guidelines for the Design and Construction of Passive House Dwellings in Ireland' which have been very well received, with some 8,000 copies in circulation. Companion guidelines on 'Retrofitted Passive Homes – Guidelines for Upgrading Existing Dwellings in Ireland to the PassivHaus Standard' which extend the available support and information for the upgrading of existing dwellings to achieve the ambitious PassivHaus Standard were published by SEAI in 2009.

The wide range of building types presented here as case studies demonstrate that the PassivHaus standard is just as applicable to schools and factories, supermarkets and clinics, and churches and sports halls. Originally a German Standard, this is now finding application in different countries as a brand for thermally efficient and well-constructed buildings which deliver good comfort conditions during both winter and summer.

We hope these guidelines will be helpful in increasing awareness and understanding of key principles and technologies for designing, constructing and operating modern low- energy buildings.

Prof J Owen Lewis
Chief Executive
Sustainable Energy Authority of Ireland

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Introduction

1. Introduction

1.1 Definition of Passive House

The Sustainable Energy Authority of Ireland has previously prepared guidelines on the Passive House for both new-build and retrofitted single family dwellings. This document presents guidance for what is loosely referred to hereafter as 'non-domestic' Passive House projects, including buildings such as schools and offices as well as multi-residential apartment projects. The term Passive House is perhaps, at face value, somewhat misleading insofar as it implies that this standard of construction pertains only to 'houses' (or single family dwellings). Nothing could be further from the truth, however, as will be well illustrated in these guidelines. In Section 4, for example, a very broad range of case study Passive House projects will be presented, including not just offices and schools, but also a large Irish supermarket, a church, sports hall, factory and veterinary clinic. It would appear that the principles of Passive House can be applied to just about any building type.

A Passive House is an energy-efficient building with all year-round comfort and good indoor environmental conditions without the use of what might be regarded as 'conventional' space heating or cooling systems. The space heat requirement is reduced to the point at which there is no longer any need for a conventional heating system; the air supply system essentially suffices to distribute the remaining heat requirement. A Passive House provides very high levels of thermal comfort and provision of whole-building even temperature if so desired. The concept is based on minimising heat losses and optimally using heat gains, thus enabling the use of simple building services. The appearance of a Passive House does not need to differ from conventional buildings and living or working in them does not require any lifestyle changes or specialist training. Passive House buildings are typically light and bright due to large glazed areas designed to optimise solar gains, as well as healthy buildings in which to work due to fresh air supply through the ventilation system.

The Passivhaus Standard is a construction standard developed by the Passivhaus Institut in Germany (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 as will be illustrated in these guidelines.

The Passivhaus Standard is a specific construction standard for buildings with good comfort conditions during winter and summer. Typically this includes optimised insulation levels with minimal thermal bridges, very low air-leakage through the building, utilisation of passive solar and internal gains and good indoor air quality maintained by a mechanical ventilation system with highly efficient heat recovery. Renewable energy sources are used as much as possible to meet the resulting energy demand, including that required for the provision of domestic hot water (DHW). It should be noted that the primary focus in building to the Passivhaus Standard is directed towards creating a thermally efficient envelope which minimises both space heating and space cooling requirement. There is also a limitation on the amount of primary energy that can be used by a Passive House building for such uses as cooling DHW, lighting, electrical appliances (such as computers or fridges).

Plate 1.1.10 generally reducing cooling demands leaves roof space for renewable technology (in this case PV cells are being retrofitted to the roof of a commercial project)

Structural air-tightness (reduction of air infiltration) and minimal thermal bridging are essential. A mechanical heat recovery ventilation system (MHRV) is used to supply controlled amounts of fresh air to the building. 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 or indeed to radiators as was found to be the case in a number of the case studies visited.

The energy requirement of any building built to the Passivhaus Standard is as follows:

- Maximum15 kWh/m^2 treated floor area (TFA) per year for space heating and cooling demand.
- The upper limit for total primary energy demand for space and water heating, cooling, ventilation, electricity for fans and pumps, all electrical appliances, and lighting not exceeding 120 kWh/(m^{2}a), regardless of energy source.
- Additionally, the air-leakage test results must not exceed 0.6 air changes per hour using 50 Pascal over-pressurisation and under-pressurisation testing.

In order to maintain high comfort levels in any building, heat losses must be replaced by heat gains. Heat losses occur through the building fabric due to transmission through poorly insulated walls, floor, ceiling and glazing as well as from uncontrolled cold air infiltration through leaky construction and poorly fitted windows and doors. In a typical building, such heat losses have to be balanced by heat gains mostly contributed by a space heating system. In the case of some non-domestics Passive House projects, the internal heat gains from occupants and other sources such as computers (in the case of offices) can be quite significant and can contribute a relatively high proportion of the total overall space heating need. In fact, with certain project types, the internal heat gains might be so great as to necessitate an active cooling system combined with high thermal mass. In every Passive House project, however, the heat losses are reduced dramatically and the internal heat gains are minimised in order that there are major savings to be made both in terms of space heating as well as space cooling.

1.2 Challenges and Opportunities Presented by Non-domestic Passive House Commercial and Public Buildings

The design of non-domestic Passive House projects typically follows many of the general principles used for single family dwellings as presented in SEAI's previous Passive House guidelines. The principles listed below are equally as relevant to single family dwellings as they are to larger commercial or public building projects:

- Highly insulated building envelope, including thermally efficient windows;
- Air-tight construction;
- Southern orientation to maximise passive solar gain coupled with shading to prevent overheating outside of the heating season;
- Compact form to reduce surface to volume ratio;
- Minimised (or fully eliminated) thermal bridging;
- Reduced heat load enabling the delivery of back-up heating through the ventilation system; and
- Minimised primary energy consumption through the use of energy efficient lighting, appliances and mechanical plant.

Outside of the above general principles, it might be expected that there are some very considerable differences in the detailed design of non-domestic Passive House projects compared to single family dwellings, as highlighted below:

- **Larger treated floor area**, which could be 100 times greater than for a typical single family dwelling, impacting on the sizing of mechanical plant;
- **Significantly increased internal heat gains**, whether from computers (in the case of office projects) or from humans (in the case of schools) often requiring incorporation of thermal mass to reduce daily fluctuations;
- Typical requirement for **external sensor controlled shading** in order to reduce unwanted solar gain and glare and yet maximise natural daylighting;

Plate 1.2.1. The size of ventilation equipment for non-domestic projects can be considerable

Plate 1.2.2. Shading devices are generally required to reduce overheating

- **Periodic occupation**, limited to office hours, school hours and semesters or even opening hours in the case of retail projects;

Plate1.2.3. Classrooms are often empty for extended periods during which mechanical plant is often shut down

- **Constraints imposed by Building Regulations**, tending to place greater demands on the design team in terms of, for example, fire protection;
- **Additional thermal-bridge-free detailing,** required as a result of using parapets, balconies and basements which are not typical to single family dwellings in Ireland;
- **Use of common space and circulation zones** (for example in apartment buildings) which might not require heating and which thus might need to be thermally separated from the occupied spaces;

Plate 1.2.4 Stairwells can be designed as integral or separate to the thermal envelope

- **Common need for lobby space**, especially for projects where there is a large amount of people entering and leaving the building such as in a shopping centre (continuous activity) or school (periodic);
- **Lift shafts are** typically required which can have implications in terms of ventilation and smoke extraction;
- **Challenging ventilation requirements**, including high volume flows in commercial kitchens and science laboratories, reduced flows in expansive gymnasia and periodic sensor-controlled operation in offices and schools;

Plate 1.2.5 Commercial kitchens present a challenge in terms of ventilation

- **Possible preference for different temperature zones** as might be required in supermarkets (separating the bulk storage area from the offices, for example) or in gymnasia (cooler temperatures in the sports hall, with warmer temperatures in the changing and shower rooms);

Plate1.2.6 Bulk storage in supermarkets are usually kept at cooler temperatures than the retail area

- **Extended period of 'settling-in'**, taking typically about one year for the building occupants to become fully familiar with the various nuances involved in operating the Passive House (for example when to leave windows open or closed, when to operate the ventilation equipment and how to optimise the use of the external blinds);
- **Possible requirement for more than PHPP** in the design of the building, for example where dynamic simulation might be required (see below for more details);

1.3 Emergence of Passive House Non-Domestic Buildings

The first ever Passive House project (built entirely to the Passivhaus Standard) was the four terraced-house project in Kranichstein, near Darmstadt, Germany, in 1992. Since then the Passivhaus Standard has been applied to several large scale projects including schools, offices, commercial properties as well as apartment buildings in Continental Europe as well as a World 1st in Ireland with the completion of the first ever completed Passive House supermarket by Tesco in Tramore, Co. Waterford.

An EU wide database on completed Passive House projects is underway and due to be launched this year (see www.pass-net.net/database/index.htm). Ahead of this database being completed, it is difficult to ascertain how many non-domestic Passive House projects have been completed. The database developed by the IG Passivhaus Deutschland (see www.passivhausprojekte.de) currently has the most comprehensive listing of such projects (but certainly includes all completed projects), including the following:

Office / Commercial / Administration building:	32
Apartment developments:	25
Mixed office and residential:	19
Kindergarten / day care:	12
School / campus / university:	11
Sports centre / recreation centre:	6
Public building / church:	3
Nursing home:	3
Factory / Industrial Building:	2
Fire station:	1

From this table it can be seen that the most popular Passive House development types recorded on the register referred to above are offices and apartment projects. Following this, there has been quite a number of schools and kindergartens also completed, with fewer examples of other building types such as sports centres, public buildings, churches, nursing homes, factories, fire stations or supermarkets. It is for this reason that these guidelines provide a special focus on offices, schools and apartment buildings, both in the section providing generic guidance (Section 3) as well as the featured case studies (Section 4). Aside from these, Section 4 showcases other case studies (in order to illustrate the broad variety of building types that can be built to the Passivhaus Standard. It would appear that almost any building can be built to the Passivhaus Standard.

Policies promoting Passive House

There are a growing number of regional and trans-European policies and resolutions supporting the Passivhaus Standard which are providing the basis for this standard to be 'the norm' in some areas and creating the impetus for the development of more and more projects. This in turn is creating employment opportunities in the research, development and manufacture of new Passive House products, as well as in design services and construction. The Passivhaus Standard is thus contributing to both economic and environmental sustainability. Some of these policies are listed below:

- In February 2003 the City Parliament of Frankfurt decreed that all new schools and kindergartens have to be built to the Passivhaus Standard.
- In 2006, the City Parliament of Frankfurt extended the requirement for Passivhaus Standard from schools and kindergartens to all new 'city' buildings. In March 2007 it was decided that all municipal administration, urban institutions and corporations and all buildings in the framework of PPP for the city of Frankfurt will be built and designed accordingly the Passivhaus Standard.
- In 2007 / 2008 in Belgium it was decided that all new schools should be built to the Passivhaus Standard.

Article 9 of the recast on the Energy Performance of Buildings (EPBD) and nearly zero-energy buildings states that Member States shall ensure that:
- By December 31 2020, all new buildings are nearly zero-energy buildings; and after December 31 2018, new buildings occupied by public authorities are nearly zero-energy buildings.

Member States shall draw up national plans for increasing the number of nearly zero-energy buildings. These national plans may include targets differentiated according to the category of building. The national plans shall also include inter alia a number of elements including:-
- The Member State's detailed application in practice of the definition of nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator or primary energy use expressed in kWh/m^2 per year. Primary energy factors used for the determination of the primary energy use may be based on national or regional yearly average values and may take into account relevant European standards.
- Since 2006 / 2007 the Passivhaus Standard is required in the German Cities of Leipzig, Wiesbaden, Aschaffenburg. Also in Austria, the Vorarlberg Government will only provide benefit for residential buildings that meet the Passivhaus Standard.

In addition to policies and resolutions, there are also a growing number of subsidy and grant schemes across the EU which specifically support the Passivhaus Standard, including those listed below (reference www.pass-net.net):

- **In Belgium** at a Federal level an index linked annual tax break of €790 for ten years is allowed on certified Passive Houses. On a regional level in Brussels €100 per m^2 of net useable space up to 150 m^2, and €50 for each additional m^2 is given for certified Passive Houses. Other examples include in the Walloon region a grant of €6,500 for a newly built certified Passive House, €3,000 in the City of Turnhout and €5,000 in the city of Bilzen.
- **In the Czech Republic** a subsidy programme commenced on April 7th 2009 supporting newly built single and multi-family Passive Houses and use of renewable energy sources.
- **In Germany** the KFW Bank Passive Houses are funded for either "Energy Efficient Construction" and/or "Energy Efficient Retrofits" with low, fixed interest loans with no repayment on principal required during the first several years Up to EUR 50,000 per housing unit for energy efficient construction and up to EUR 75,000 housing unit for energy efficient retrofits
- **In Slovenia** financial supports are provided for what is referred to as residential buildings with "low energy or passive technology (LEH/PH)". The performance of the building has to be verified in PHPP and there are certain minimum standards which have to be met, including, for example, heat recovery ventilation efficiency of 80%. Grants of between €75 / m^2 (for synthetic materials) and €125 / m^2 for natural materials are provided for a maximum of 200m^2 for a single family dwelling and 150m^2 for a two-family dwelling, with a maximum grant of €25,000.
- **In the Swedish Western Götaland region** a Programme for Energy Efficient Buildings was established in the spring of 2007 with a fund of approximately €2.5 million. The form of support includes information spreading about energy efficient and passive house buildings in order to gain more interested actors (the focus is directed towards politicians, entrepreneurs, architects and consultants).

Passivhaus Projektierungs
Paket 2007

PHPP
2007

Plate 1.4.1 The PHPP software is an essential design tool for Passive House projects

1.4 Use of the Passive House Planning Package (PHPP) Software - the Essential Passive House Design Tool

The Passive House Planning Package 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. Verification requires 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 project is proposed (for Ireland, climate data is available for both Birr and Dublin). The validity of the result from this process is, of course, highly dependent upon the validity of the data entered. The PHPP software is available for purchase from the Sustainable Energy Authority of Ireland Renewable Energy Information Office - www.seai.ie/bookshop

Despite the significant differences between single family dwellings and non-domestic Passive House projects as highlighted in Section 1.2 above, PHPP can still be used as the primary design tool for these latter larger-type projects. There are however several specific conditions provided for in the 2007 Version of PHPP for commercial projects, discussed in outline under the following headings:

- Initial PHPP Set Up;
- Special Considerations Using Standard Worksheets ;
- Specific 'Non-Domestic' Worksheets;

The PHPP is constantly being updated by the Passivhaus Institut to incorporate new research findings, especially in relation to climate data and non-residential Passive Houses.

1.4.1 Initial PHPP Set Up

At the very outset of the input process, there are some special cells in the Excel sheet that have to be selected depending upon the project type. Examples of these are provided below for the purpose of illustration.

Selection of 'Building Type'

In the second Excel sheet in the 2007 Version of PHPP titled 'Verification', there is a pull-down tab under the button 'Building type' used in the calculation of electricity and internal heat gains with the two options of selecting either 'Residential' or 'Non-Residential'.

Selection of 'Utilisation Pattern'

In the same Verification sheet, there are a number of options to be chosen concerning 'Utilisation Pattern'. If the 'Residential' option under 'Building Type' above is selected, the user can choose between the utilisation patterns of 'Dwelling', 'Assisted Living' or 'Other'. If on the other hand the 'Non-Residential' building type is chosen, then a choice is provided between 'Office', 'School' or 'Other' under utilisation pattern. Both this and the 'Building Type' options above determine the internal heat sources which are thereafter automatically calculated.

Selection of 'Types of Values Used'

If designing a building with deviating heating loads (for example a non-typical office use in a fire station which is ONLY used in an emergency case) or for buildings in the 'Other' category above, then the user should select the 'PHPP Calculation' option under the 'Types of Values Used' pull down tab. In this case, internal heat sources can be entered directly into the IHG ('Internal Heat Gains') or IHG Non-Dom (Internal Heat Gains for non-domestic projects) worksheets.

Selection of 'Number of Occupants'

The standard occupancy rate used in PHPP is 35m² per person. This standard can be overridden, however, by manually entering the foreseen number under the pull down tab 'Planned Number of Occupants', also in the Verification Sheet.

1.4.2 Special Considerations Using Standard Worksheets

In non-domestic buildings, there are often special circumstances presented which require the designer to input non-standard values into some of the worksheets. An example of this includes the 'Ventilation' Worksheet wherein the designer can specify whether the ventilation system is working on a permanent 24 hour basis (as it would be in residential projects) or whether is it working intermittently (as it might in a school or office project) where the building is periodically unoccupied and where there is no need for the system to be running continuously.

1.4.3 Special 'Non-Domestic' Worksheets

In addition to the above options that are chosen when setting up the PHPP file for the project, there are other specific sheets that have to be filled in for non-domestic projects. A non-exhaustive list of these is provided and described in outline below:

- **Electricity Non-Domestic**, where it is possible to enter the electricity demand from lighting, electronic devices (computers, servers, fax machines and copiers) as well as kitchens and other uses.

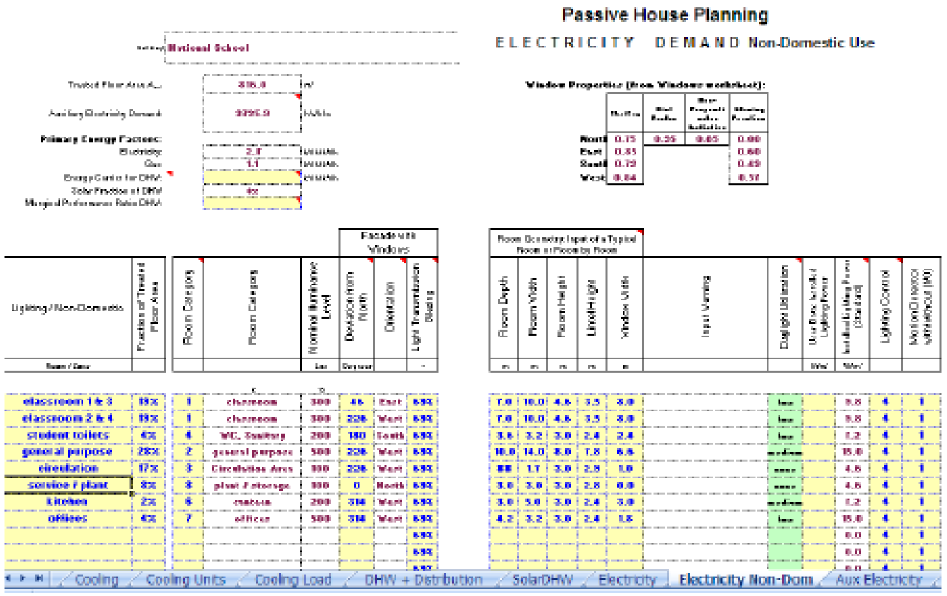

Plate 1.4.3.1 Electricity demand in non-domestic projects can be accurately calculated in the PHPP software

- **Internal Heat Gains Non-Domestic**, where it is possible, for example, to calculate the average heat emitted per person by entering the number of occupants, their utilisation pattern, their age category (up to 10 years old or greater than 10 years old) and activity level (whether sitting or standing / doing light work). Internal heat gains from electrical devices are summarised in the second section of this worksheet.
- **Use Non-Domestic**, where individual user profiles can be entered which define the typical use patterns in any given section of a building. Practical examples of the kind of input in this worksheet include the typical starting and ending time of occupation, number of occupied days per year, illumination level required and average occupancy.

Additional Software Analysis

In certain circumstances additional energy assessment and dynamic simulation modelling might be required in parallel with PHPP analysis as part of the design process. According to the Passivhaus Institut, however, this is mostly relevant in the case of research work on 'unusual' building types calculated in PHPP for the first time including swimming pools, for example, or when dealing with different climate zones. The amount of input parameters is significantly higher for dynamic simulations, potentially leading to incorrect outputs. Accordingly, the Passivhaus Institut recommends using stationary assessment methods for most projects.

In special cases where additional assessment is warranted, examples of the kinds of software used, as well as their functions, are listed below:

- CFD Simulations, for example Fluent or Comis;
- Simulation programs for subsoil heat exchangers, for example PHLuft or Gaea;
- Daylight simulation software, for example based on Radiance (calculation engine – 'Rechenkern' in German);and
- Dynamic building Simulation, for example Dynbil or Trnsys.

1.5 Passivhaus Standard and Building Energy Rating

The Passivhaus Standard and Building Energy Rating (BER) are different methods for evaluating energy performance of buildings based on calculated energy consumption. The Passivhaus Standard is a voluntary standard whereas BER is mandatory when new buildings are constructed or when new and existing buildings are offered for sale or rent. Input parameters and outputs are similar but specific definitions and the way in which the two assessment methodologies calculate outputs can be significantly different. It should not be expected that both tools would predict precisely the same energy consumption for any given project, therefore. It is possible that a Passive House project might not achieve an A rating according to BER, especially if the systems used for heating, cooling or ventilation are primary energy intensive. Likewise, it is possible that a Passive House project could achieve an A1 BER if there sufficient use of renewable energy technology.

The Non Domestic Energy Assessment Procedure (NEAP) is the methodology for demonstrating compliance with specific aspects of Part L of the Building Regulations. NEAP is also used to generate the BER and advisory report for new and existing non domestic buildings. NEAP calculates the energy consumption and CO_2 emissions associated with a standardised use of a building. The energy consumption is expressed in terms of kilowatt hours per square metre floor area per year (kWh/m2/yr) and the CO_2 emissions expressed in terms of kilograms of CO_2 per square metre floor area per year (kg CO_2/m^2/yr). NEAP allows the calculation to be carried out by approved software packages or by the default calculation tool, Simplified Building Energy Model (SBEM) and associated interface iSBEM, which is based on CEN standards and has been developed by BRE on behalf of the UK Department of Communities and Local Government.

Some of the key differences between both the PHPP and NEAP inputs are highlighted below:

Heating Times / Comfort Provision.
PHPP assumes comfort temperatures are maintained at all times throughout the heating season of 205 days. NEAP calculates the energy demands of each space in the building according to the activity within it. Different activities may have different temperatures, operating periods and lighting requirements.

Internal Temperature.

PHPP assumes 20°C throughout the entire building during the heating season. In NEAP buildings can be divided into a number of activity areas e.g. an office building may include a reception area, open plan office, cellular offices, circulation spaces and toilets. The heating and cooling set points for open plan offices are 22°C and 24°C respectively. The set back temperature set point is 12°C.

Building Geometry - Envelope.

PHPP uses external dimensions for determining the area of the elements forming the envelope, therefore fabric heat loss will be amplified for a passive design as the external elements, i.e. walls and roofs, will have a much greater thickness than standard buildings because of the increased levels of insulation. In NEAP the floor area is calculated using the internal horizontal dimensions between the internal surfaces of the external walls.

Building Geometry – Floor Area.

PHPP uses internal dimensions for the calculation of floor area as does NEAP. However, PHPP excludes space taken up by items such as internal partition walls and chimneys and treats the calculation of floor area differently where the ceiling height is less than 2m.

Included / Excluded Energy Consumption.

PHPP focuses on delivered energy for space heating with limiters for all other energy consumption including white goods and water heating. NEAP focuses on primary energy for space heating and cooling, ventilation, hot water, pumps, fans and lighting but does not consider non-fixed electrical using appliances computers and office equipment which can be responsible for significant primary energy use.

Occupancy.

In verification mode, PHPP uses 35 m^2/person (can be overridden within limitations), e.g. 100 m^2 = 2.86 people, 200 m^2 = 5.71 people. In NEAP the occupancy is determined by the activity assigned to each zone or part of the building. For an open plan office the people density used in 0.11 per / m^2 i.e. 100m^2 = 11 people.

Product Accreditation Standards.

PHPP requires the substantiation of input data but is perhaps less prescriptive than NEAP in terms of accreditation. An example of this that is particularly relevant to passive non domestic buildings is mechanical ventilation heat recovery system data certified by the Passivhaus Institut. The acceptance of certification data is likely to cause quite marked differences between the outputs of the two methodologies.

Primary Heating System.

The approach taken for entering heating system efficiency differs in PHPP and NEAP, most notably in the case of biomass boilers where a better result can be achieved using PHPP. In NEAP the effective heat generating seasonal efficiency is calculated by adding the heating efficiency credits, where applicable, to the heat generator seasonal efficiency. The heat generator seasonal efficiency is the ratio of the useful heat output to the energy input over the heating season.

Thermal Bridging.

PHPP uses external dimensions for thermal bridging calculations and it is also possible to carry out visual analysis of whether linear thermal bridges occur. NEAP requires information on the two types of thermal bridge; repeating and non-repeating. Repeating thermal bridges should be taken into account when calculating the U-value of a construction element. Non repeating thermal bridges can arise from a number of situations, but NEAP is only concerned with those arising from junctions between envelope elements, windows, and doors which are in contact with the exterior. For each type of junction, you can enter a Psi value (W/mK) or leave the default values. For junctions not involving metal cladding, you can also tick a box indicating whether or not that type of junction complies with the relevant standards.

Primary Energy Factors.

PHPP only considers the non-renewable part of non-fossil fuels, e.g. processing and transport and therefore the primary energy factor used for wood and pellets is 0.2. In NEAP the primary energy includes the delivered energy, plus an allowance for the energy "overhead" incurred in extracting, processing, and transporting a fuel or other energy carrier to the building. NEAP uses a value of 1.1.

2

Key Principles

Many of the key principles presented in SEAI's previous Passive House guidelines for single family dwellings pertain to non-domestic projects. As presented in Section 1.2 above, however, there are a number of specific issues that need to be dealt with when designing non-domestic Passive House projects. This Section will outline some of the key aspects to be considered.

2.1 The Building Envelope

2.1.1 Thermal Insulation and Thermal Bridging

Similar U-values to those recommended in the guidelines for single family dwellings will be required for non-domestic projects, in the order of 0.15 W/(m²K). The precise insulation levels required will ultimately depend on an analysis of the building design in the PHPP software, so the above value should not be taken as any kind of 'standard' for commercial Passive House projects. The key difference between non-domestic projects and single family dwellings, however, is that the former often comprise more challenging building elements not found in the latter, including the following, for example:

- Basements (perhaps used for car parking, or for plant or storage);
- Parapet walls;
- Curtain wall systems (which might have externally ventilated rain screens); and
- Warm non-ventilated roofs externally sealed for weather protection

Solutions have been developed for all or most of these design challenges as outlined below.

2.1.1.1 Basements

When considering the insulation of basements, there are two choices, namely:

1. Create a thermal separation in the basement ceiling (i.e. create a cold' basement which would be quite appropriate for car parks, for example); and
2. Incorporate the basement into the thermal envelope, and insulate externally to that basement (ie. create a 'warm basement' appropriate where it is used as part of the habitable or used space and where normal indoor temperatures are required).

The designer must decide at the outset whether the basement will be cold or warm and draw a continuous 'red-line' defining the thermal envelope. This will help to identify where critical thermal bridges may arise and where additional detailing will be required. This advice might sound somewhat obvious and therefore unnecessary, but experience has proven time and time again that if basic fundamentals are overlooked at the early stages in the design process, then costly mistakes can be made which could easily have been avoided.

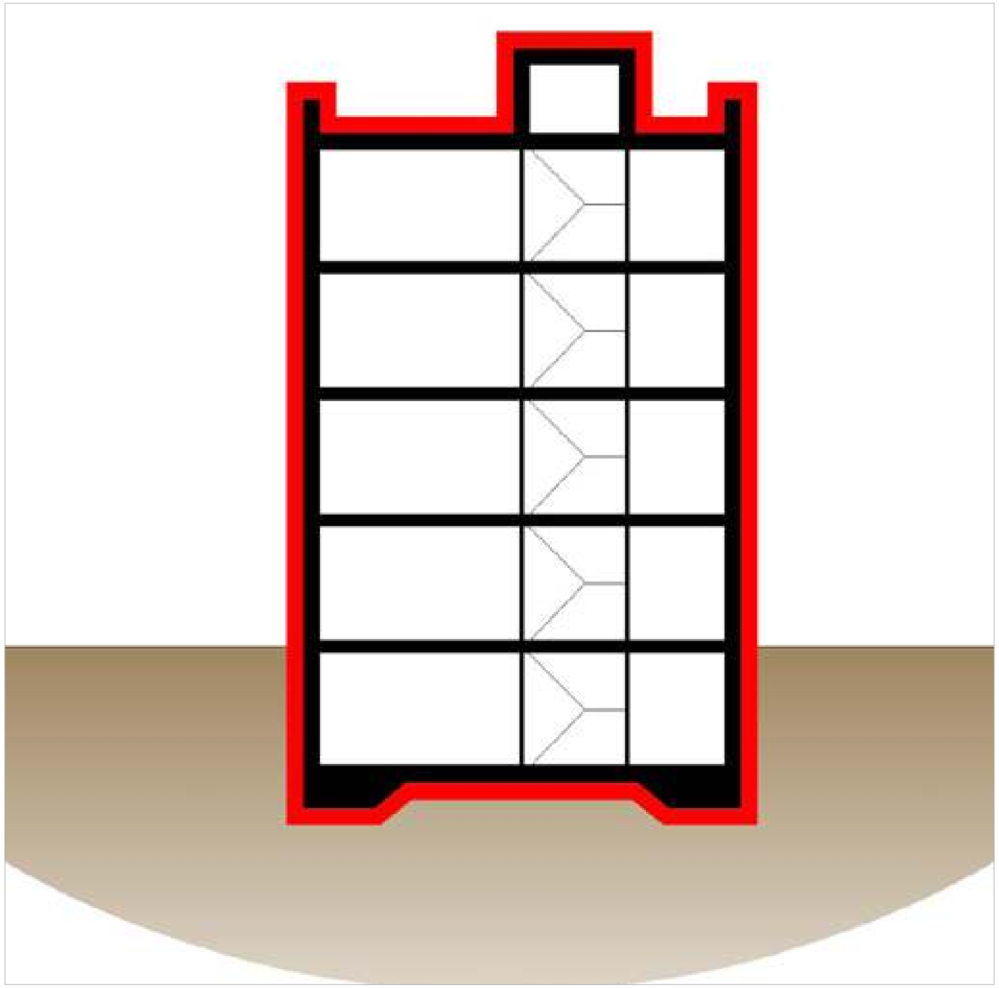

Plate 2.1.1.1.2 Definition of thermal envelope with a warm basement

Whether a cold or warm basement is used, both present their own challenges.

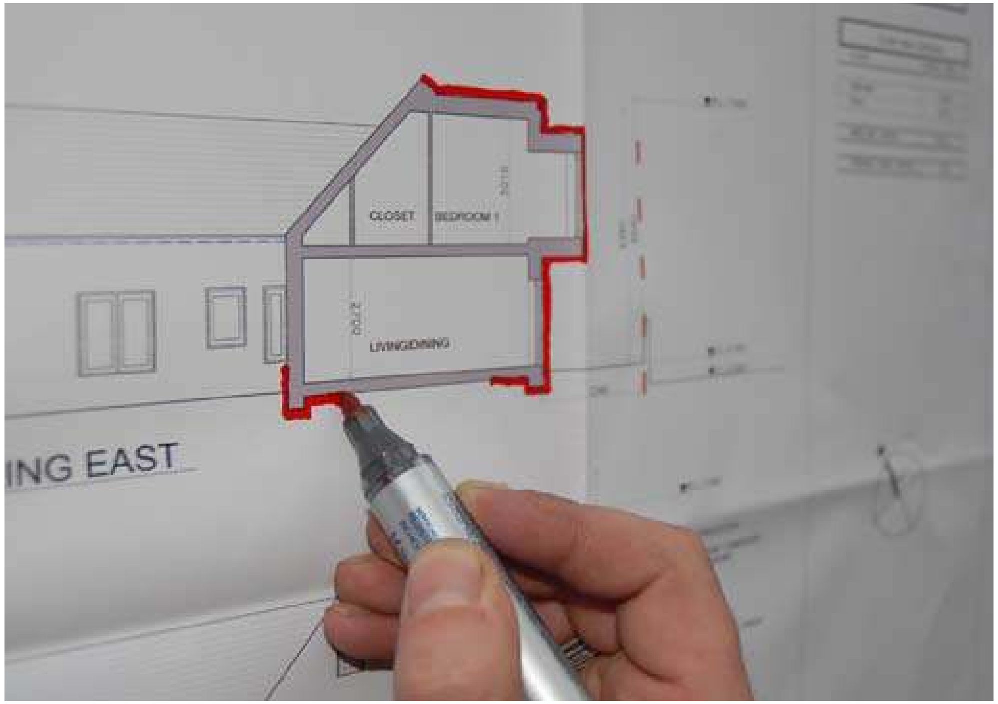

Plate 2.1.1.1.1 Take the time to carefully define the extent of the thermal envelope early on in the design process

Cold Basement – External Structure

In the case of a cold basement, a thermal break will be required in the external structural envelope which overlaps with the layer of insulation fitted to the underside of the basement ceiling. This thermal break can be provided using a variety of means, but is often achieved using a continuous layer of insulating blocks, a variety of which are available such as those depicted below . Consideration needs to be directed not just to the insulation value of those products, but also to their load bearing strength which will generally need to be high in projects which might involve several storeys. In the table below, it will be noticed that with reducing vertical thermal conductivity, the thermal bridge effect is lessened. However, in parallel with this, there is also a reduction in load bearing capacity. In other words , thermally optimal products are not always the best considering structural integrity. In some projects, the designers use a kind of hybrid system whereby a highly efficient thermal break is created (for example using foamglass) with intermittent structural support using concrete spuds as illustrated in the image across.

Plate 2.1.1.1.5 Hybrid thermal break used in masonry multi storey apartment projects.

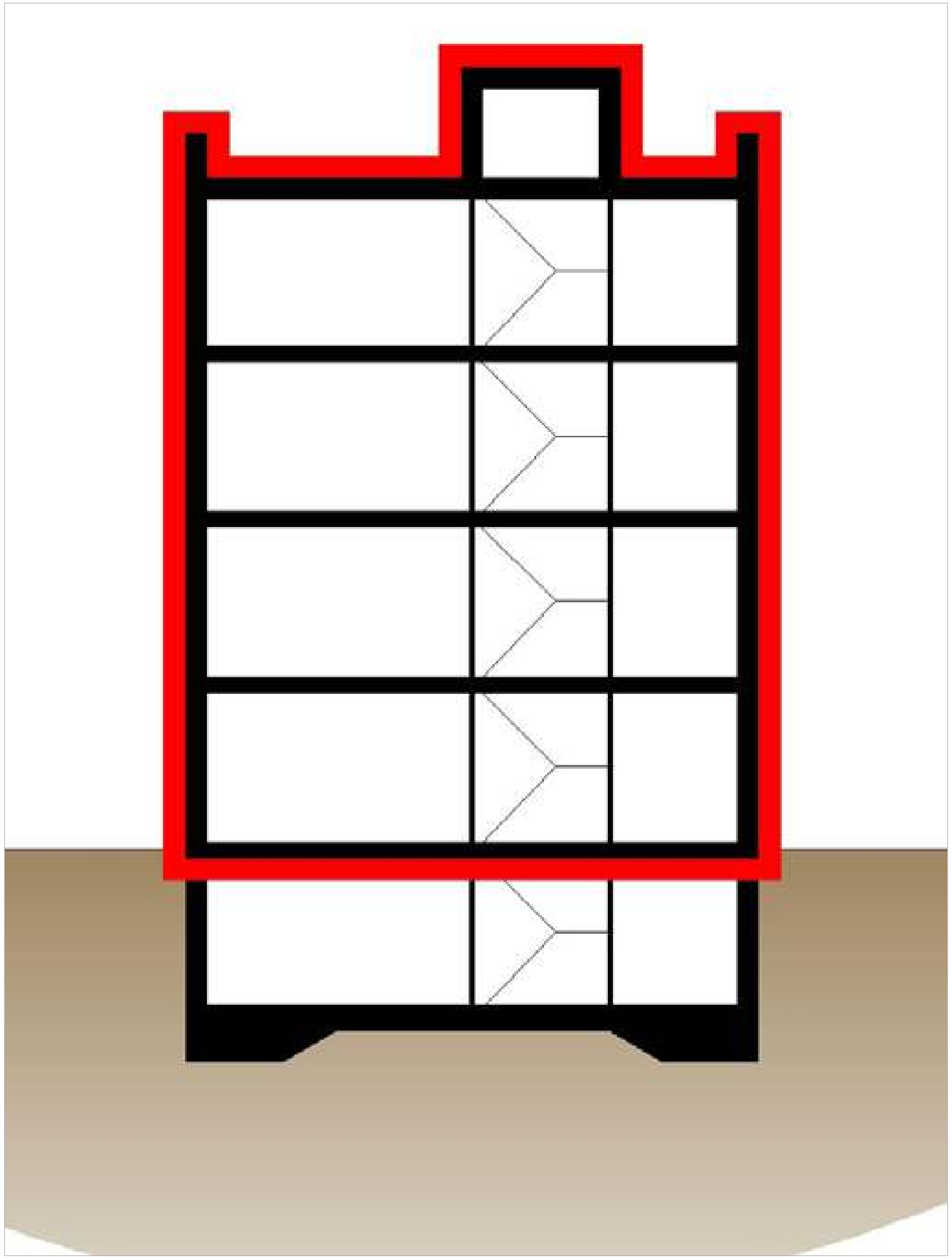

Plate 2.1.1.1.3 Defining the thermal envelope of a building with a cold unheated basement

Thermal Break Material	Thermal Conductivity			
	Horizontal	Vertical	Load Bearing (kN/m^2)	Psi value (W/mK)
Light concrete	0.088	0.286	2400	0.192
Lime-sandstone	0.33	0.33	1900	0.218
Porous concrete	0.21	0.21	1500	0.144
Light concrete	0.083	0.189	1200	0.129
Porous concrete	0.13	0.13	1000	0.086
Bricks	0.09	0.139	900	0.093
Foamglass	0.055	0.058	600	0.026
Porous concrete	0.09	0.09	400	0.053

Table reproduced with permission from the Passivhaus Institut, Darmstadt. Note that the thermal bridging (Psi) values above are indicative only and not to be used for design purposes. Further, they relate to external junctions, as per the norm when calculating heat losses for Passive House projects. The convention in Ireland using DEAP, on the other hand, is to calculate thermal bridging along internal junctions which tend to be higher in heat transfer but shorter in length. Calculation of thermal bridges is an integral part of the design of Passive House projects.

Cold basement – Internal Support Structures

Aside from the above details concerning the (external) building envelope, there will also typically be internal elements connecting through the basement ceiling which support the overall structure. Such support can be provided through walls or columns and the choice between these can have a significant effect on thermal bridging as illustrated below. The Passivhaus Institut presents the following scenarios regarding the thermal breaks created by basement supports:

- A reinforced concrete wall in the basement penetrating through the thermal envelope with no thermal break will result in heat losses of +90% when compared to an undisturbed basement ceiling.
- Replacing the above continuous wall with reinforced columns at 6m grid intervals would reduce the heat losses to +17% for 1 – 2% steel content and to +28% for 9% steel content. This is clearly a marked improvement on the above continuous wall.
- If the whole column is insulated down to ground level, the heat losses are further reduced to +13%. This is the most efficient method of reducing thermal bridge effects in cold basement scenarios.
- Walls in the basement which are non-structural should be thermally separated from the ceiling with low conductivity materials such as those presented in the earlier table.

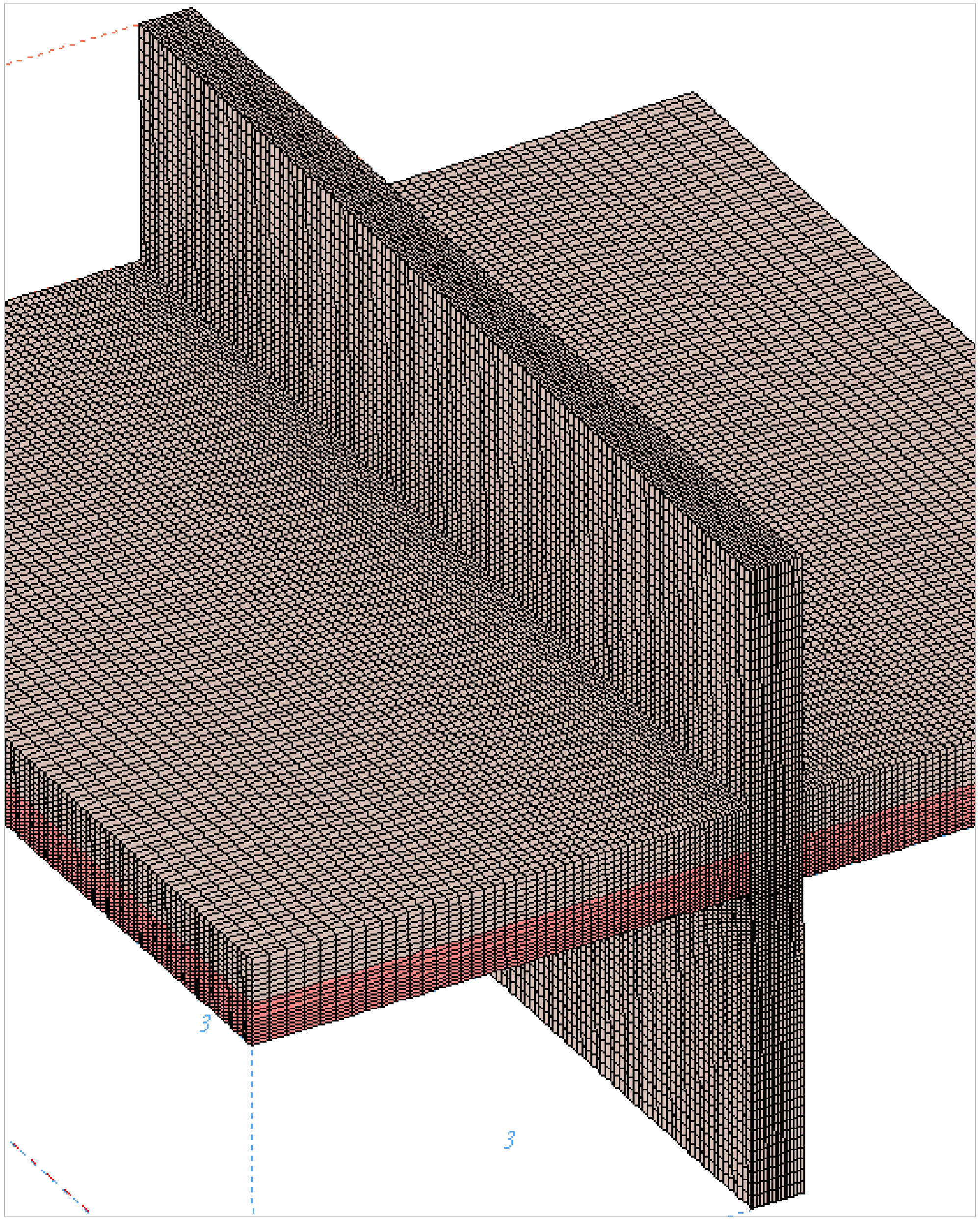

Plate 2.1.1.1.6 Re-inforced masonry walls penetrating cold basements ceilings will result in significant thermal bridging

Source: Passivhaus Institut Dr. Wolfgang Feist - Protokollband Nr. 35

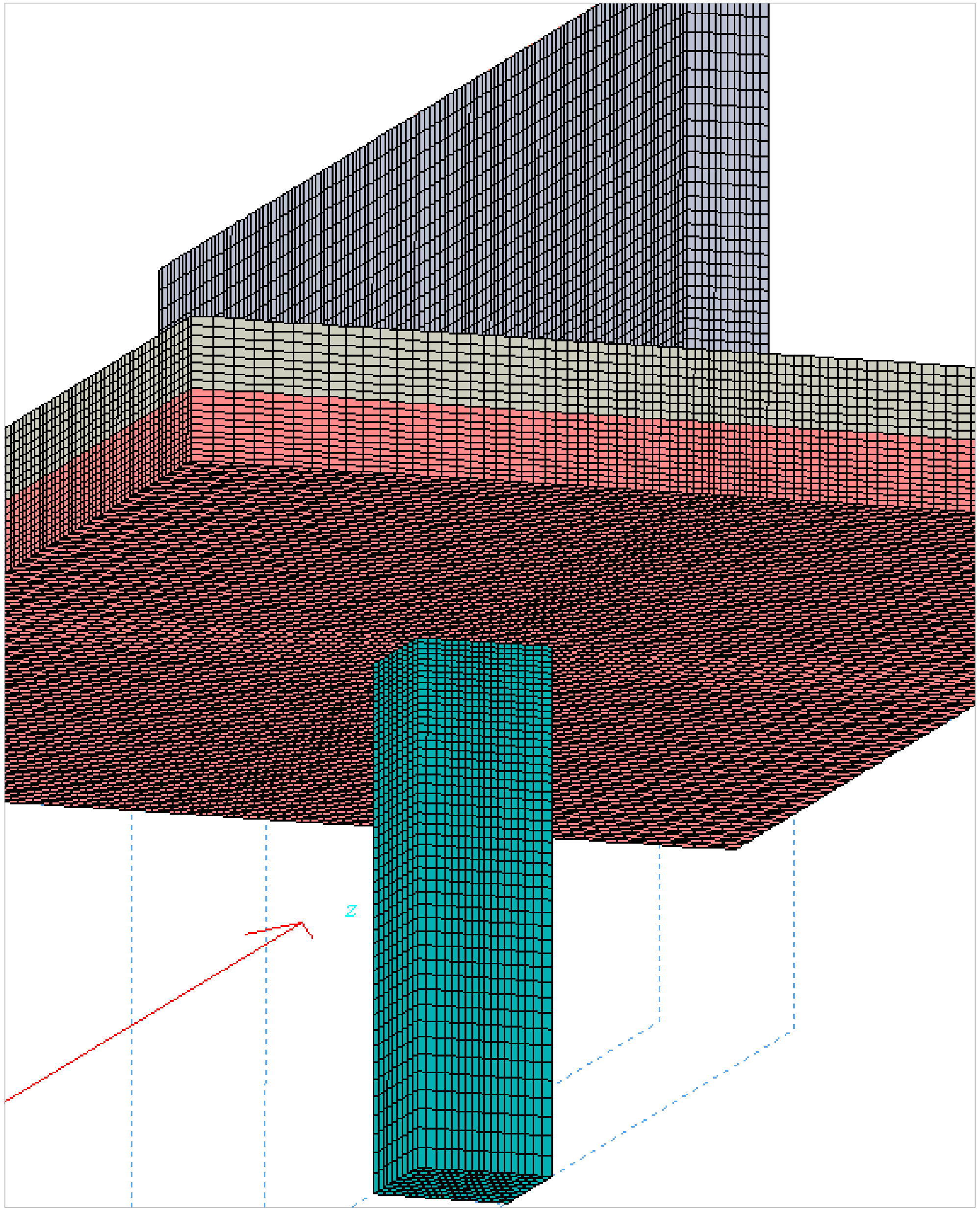

Plate 2.1.1.1.7 Replacing a wall with Columns will help to reduce heat loss through thermal bridging

Source: Passivhaus Institut Dr. Wolfgang Feist - Protokollband Nr. 35

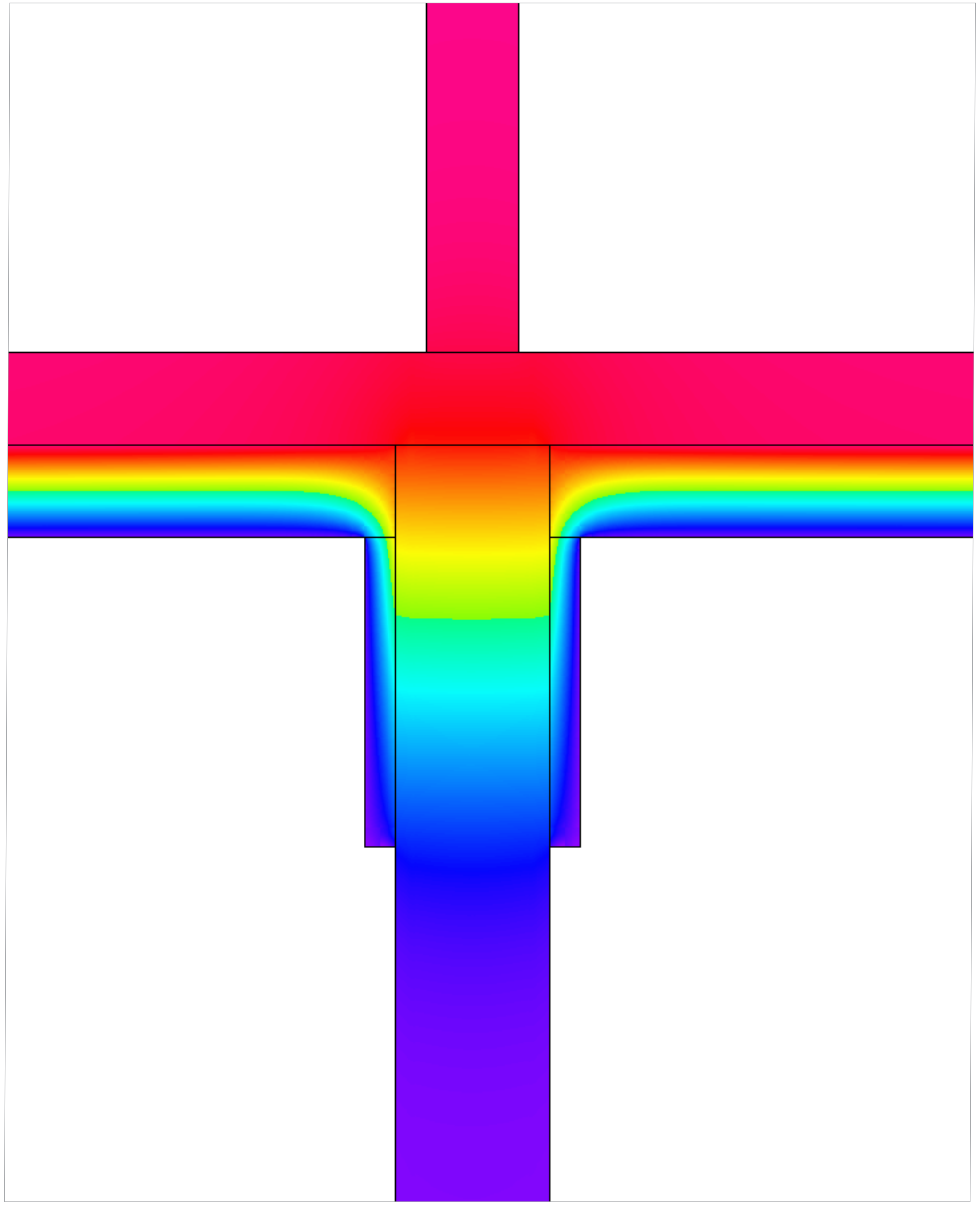

Plate 2.1.1.1.8 The thermal optimal solution is to use columns which are at least partially insulated

Source: Passivhaus Institut Dr. Wolfgang Feist - Protokollband Nr. 35

Warm Basement

As illustrated the key challenge in achieving a warm basement is to completely externally insulate the basement walls, foundation and floor slab .In this situation there is no need to create a thermal break for internal support structures such as columns.

The feasibility of insulating underneath the building will depend on the foundation design (whether strip foundation, or structural slab on grade), the load bearing pressure of the soil and the sensitivity of the building to settlement. As highlighted by the Passivhaus Institut, German regulations dictate that any insulating material used under load bearing structures must display long term pressure resistance (total displacement of insulation material ≤ 2% after 50 years). Some examples of materials used for this purpose are included in the table below.

Material	Thermal Conductivity (W/mK)	Max Admissible Pressure (kN/m^2)
High density expanded polystyrene	0.042	250
Crushed foam glass	0.14	180
Foam glass	0.05	380

Table reproduced with permission from the Passivhaus Institut, Damstadt

Plate 2.1.1.1.9 Structural foamglass insulation for use under floor slabs

If external insulation is deemed not possible underneath the floor slab or foundation, it might be required to insulated the basement internally. Care should be taken to avoid the risk of condensation on the floor slab in such circumstances. When exploring all various means of insulation, full thermal bridge and condensation risk analysis should be carried out for each connection and the former input to the PHPP software so that heat losses can be accurately calculated for the overall project.

2.1.1.2 Parapet Details

Treating parapet walls is similar in approach to that of cold basement walls, where the choice is either to create a thermal break between the exposed 'cold' section of the parapet wall, or alternatively, to fully clad the parapet wall externally with insulation as depicted in the image across

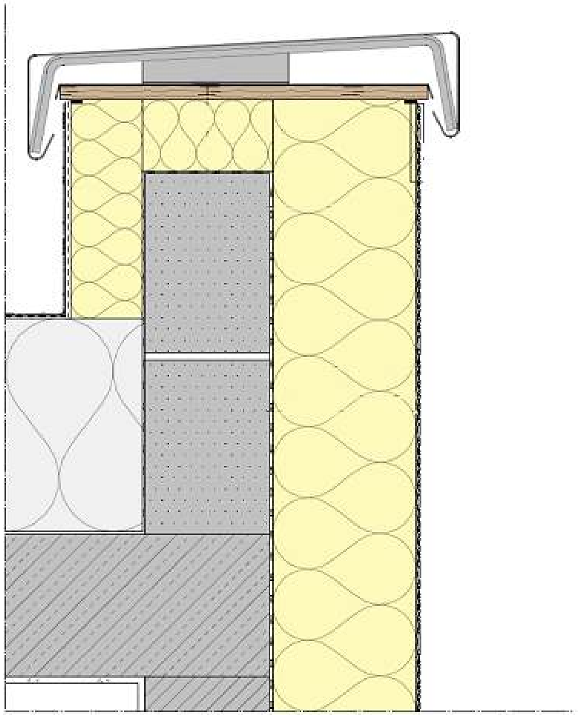

Plate 2.1.1.2.1 Parapet walls should be designed to avoid thermal bridging, in this case externally insulation *(Source :PHI)*

2.1.1.3 Curtain Walls

Curtain walls are quite typically used in commercial Passive House projects, where the external facade system is supported through the external insulation layer back to the structural layer (which is often constructed of concrete). These curtain wall systems may or may not have naturally ventilated external cladding or rain screens. The key issue for consideration with curtain walls is the potential thermal bridge effect created by the fixings used to support the external insulation or cladding system. The materials used for such fixings as well as their anchoring method and frequency of use will determine the thermal bridge effect created. Some examples of different kinds of systems used are illustrated below.

2.1.1.4 Non-Ventilated Warm Roofs

Most commercial Passive House projects will have flat or mono-pitch roofs of low gradient which are completely waterproofed externally. In the case where these roofs are of wooden construction and have no ventilated cavity over the insulation layer, it is vital that an 'intelligent' vapour control layer is used on the warm side of the structure which (a) minimises risk of condensation migrating into the structure and (b) if moisture does enter the structure that it can migrate safely back out to the living space. This strategy is being used at the WohnArt apartment development currently under construction in Darmstadt, Germany.

2.1.2 Windows

The same thermal performance of glazing and frames as has been discussed in SEAI's Passive House Guidelines for single family dwellings is required for commercial projects, namely:

- Triple glazing with U_g (U-value of glazing) ≤ 0.8 W/(m²K) and U_f (U-value of frame) ≤ 0.8 W/(m²K);
- Ψ_{spacer} (thermal bridge heat loss coefficient of the glazing spacer) ≤ 0.04 W/(mK) and $\Psi_{installation}$ (thermal bridge heat loss coefficient of the installation detailing) ≤ 0.04 W/(mK);and
- g-value (solar energy transmittance) 50 – 55%.

What is interesting about the use of windows in non-domestic Passive House projects is they tend to perform more functions than in single family dwellings, as discussed in outline below:

- **Providing balanced high comfort in both summer and winter** is especially important in non-domestic projects such as schools or offices where students or workers may have their desks located close to the window. Consider the case of a conventional building, with a large radiator underneath a poorly insulated window where the person is perhaps too hot when the radiator is on, and too cold when it is off in the heating season. Such imbalances do not occur in Passivhaus Standard buildings, and this is primarily due to the high performance of the glazing.
- **Night cooling** is often required in commercial projects due to the high internal heat loads (this is found to be especially the case with schools, for example). Openable windows can play a significant role in cooling strategies, automatically opening at night as controlled by thermostatic sensors.
- **Balancing day lighting requirements with glare avoidance** is very important in schools and office projects where large open windows bring daylight deep into rooms but can also cause unwanted glare at people's desks. External shading is usually found in such projects to achieve the correct balance between these two requirements (discussed in more detail below).
- **Reducing risk of overheating** is also an important role of windows in non-domestic projects, again assisted with the use of external blinds. It should be remembered that the enhanced thermal performance of Passive House windows has the added benefit in summer of reducing unwanted solar heat gains from outside.
- **Control of heating systems** is also common place in non-domestic projects, where a sensor is fitted to the window and which automatically shuts off the heating system if the window is opened in order to conserve energy.

2.1.3 Air-tightness and Infiltration

It is a requirement for Passive House certification that the following level of air-tightness is achieved:

- *≤ 0.6 air changes per hour using 50 Pascal over-pressurisation and under-pressurisation testing ($n_{50} \leq 0.6\ h^{-1}$).*

In Ireland, air-tightness is tested and measured using q_{50} rather than n_{50} (required by the Passivhaus Standard) and this has lead to some considerable confusion on projects in this country. An overview of both measurement systems is provided below:

- n_{50} is a measure of the air change rate in terms of volume of air moved per hour at 50 Pascal (the mean air leakage rate) divided by the internal volume of the building ((volume per hour) / volume) and expressed in the following format: n_{50} = X.X h^{-1}.
- q_{50} is a measure of the volume of air passing through the external envelope per hour also at a pressure of 50 Pascal. It is a measure of permeability and is expressed in the following format: q50 = X.X $m^3/h/m^2$ where m^2 is a measure of the envelope based on internal dimensions including the floor area.

It is possible to make a general comparison between n_{50} and q_{50}. For most large buildings, the area to volume ratio (A/V ratio) is approximately 0.5, whereas for small buildings, the area to volume ratio is typically in the region of 1.0. Therefore, the n_{50} value of 0.6 air changes per hour equates to an air permeability, q_{50}, of 1.2 for large buildings (0.6/0.5) and an air permeability of 0.6 for small buildings (0.6/1). If the building is very compact (as recommended for Passive House buildings), the A/V ratio might even be lower than that mentioned above, for example, 0.3. In that case, the n_{50} value of 0.6 air changes per hour would approximately equate to an air permeability of $2m^3/h/m^2$ (0.6/0.3). These examples are provided for illustrative purposes only and should not be used as a basis for definitive comparison of n_{50} and q_{50}.

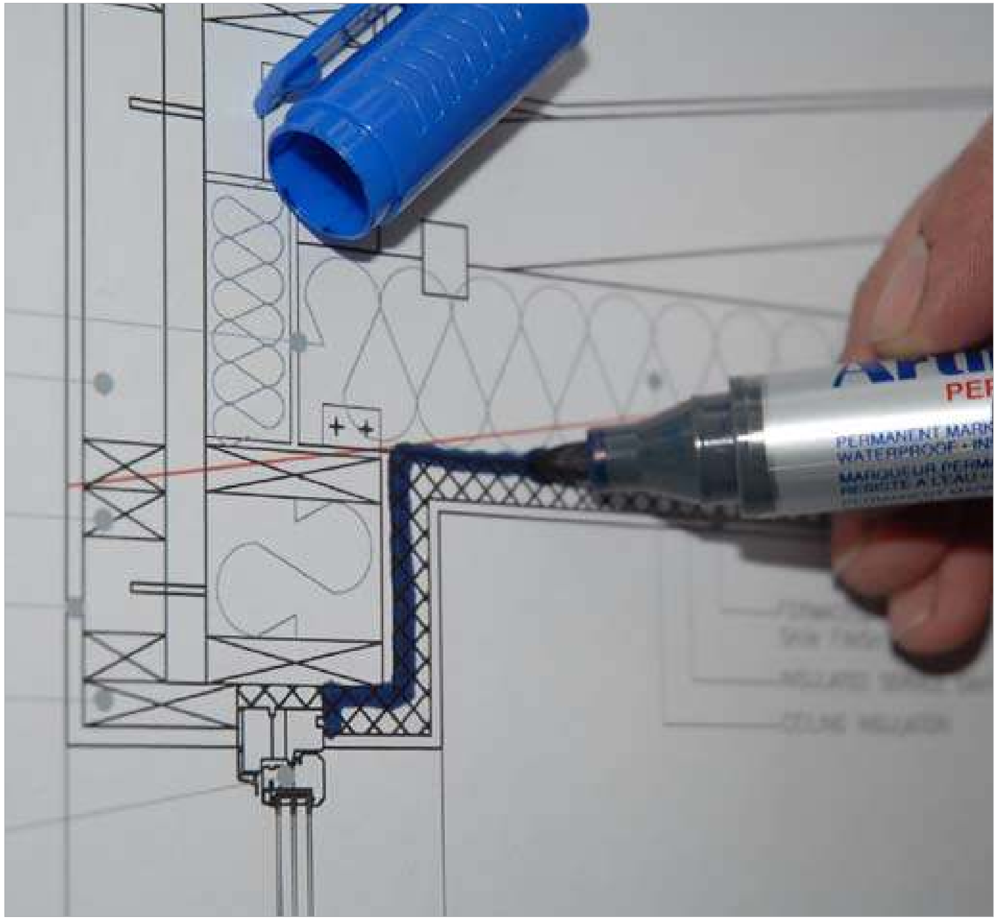

Plate 2.1.3.1. Use a blue marker to define precisely the air-tightness layer

In the early stages of design development, a blue marker should be used to trace an unbroken line where the airtight envelope will be created. This same strategy (albeit with a red marker) was recommended above in relation to identifying the exterior of the thermal envelope. Such seemingly 'elementary' exercises will save a lot of headaches on-site at a later stage.

It will be seen later in these guidelines that this level of air-tightness is typically well surpassed in completed non-domestic Passive House projects in continental Europe. There is not the same level of experience in achieving such standards in Ireland, however, so it is especially important that both the design team as well as the craftsmen are acutely aware of the detailing and high quality workmanship required. The number and length of junctions that have to be detailed and sealed on-site is significantly greater for non-domestic projects than for single family dwellings, so there is a greater potential margin for error. It is best practice to hold a project workshop for all parties involved to explain the importance of achieving a high level of air-tightness. This will undoubtedly focus the minds of the entire team and has been found to be strongly motivating especially for craftsmen.

The most common mistake made with inexperienced construction teams is that the air-tightness test is performed too late in the construction process when opportunities to find and fix leaks have passed. If at that stage the required level of air-tightness has not been achieved, it will likely be very difficult, disruptive and expensive to get it right.

Some practical examples of frequent oversights in creating and achieving an airtight envelope are listed below:

- **Entry and exit points for building services**, including for example ducts for the heat recovery ventilation unit, waste pipes and electrical cables;
- **Breaks in plastered masonry walls**, such as can occur at sockets and other electrical boxes located on external walls;
- **Not plastering to the floor**, in the case of masonry buildings resulting in air leaks behind the skirting boards;
- **Unplastered sections of external masonry walls**, which can sometimes arise if wall mounted mechanical services are fitted at an early stage of the construction process ahead of the skim coat;
- **Not providing an internal service cavity** in the case of timber frame projects and where the airtight barrier is penetrated by a multitude of internal mechanical and electrical services; and
- **Not installing an overlapping airtight membrane** between different floors in timber frame projects where the floor cassette is sandwiched between upper and lower walls.

Plate 2.1.3.2 It would be impossible to make the above construction airtight – this is a result of poor planning

Plate 2.1.3.3 In masonry construction where there is no service cavity, it is important to make any penetrations for services as airtight as possible, in the above case used by bedding the fixings into wet plaster

Plate 2.1.3.4 Note how the rear of this fixing for wall mounted services was plastered in advance of installation, ensuring air-tightness

Plate 2.1.3.5 Providing an internal service cavity will ensure protection of the air-tightness barrier in timber frame construction

Testing Procedures

Depending on the design of the building, it might make sense to test various sections of the project on a phased basis as they arrive at the relevant stage in the construction process, rather than waiting to carry out the very first test on the whole building. Furthermore, due to the significantly larger volumes of commercial projects, the testing equipment typically used for single family dwellings will be inadequate.

Air Infiltration at Entry Zones

The lobbies of non-domestic projects are typically used intensively. This can be limited to peak times in the case of, say, offices and schools, but would be more evenly spread throughout the day in the case of supermarkets or banks. It might be expected that the use of entry and exit points compromises the performance of Passive House projects due to drafts caused in the heating season. The Passivhaus Institut have completed comprehensive research on the implications of additional infiltration arising at lobbies in a case study school (the Kalbacher Höhe Primary School, Frankfurt), however, and found that any additional heat losses are not significant[1].

The PHPP 2007 handbook provides guidance on how to deal with heat losses at entry zones in public buildings, recommending using an infiltration rate between 1.5m^3 and 4.5m^3 per person and event, the former for entrances with porch and door closers, the latter without porch but still with closers.

2.2 Orientation and Massing

The low space heating and cooling demand achieved by the Passivhaus Standard is determined not only by the thermal performance of the envelope as outlined above, but also by the extent of solar heat gains as well as the overall compactness or massing of the building. The ideal orientation and massing would be a compact building (with a surface to volume ratio of < 0.4) with a south facing aspect in terms of glazing.

2.3 Mechanical Systems

The design of mechanical systems for commercial Passive House projects is influenced by a huge variety of factors and providing specific or prescriptive recommendations is outside the broad scope of these guidelines. As one can imagine, there is a vast array of possibilities for heating, cooling, ventilating and providing hot water for non-domestic Passive Houses. The intention in this section is to provide an overview of the most common approaches used across the broad spectrum of non-domestic projects. Further detail is provided later in Section 3 for a number of different building types and examples of systems used in case study projects are described in Section 4.

Minimum Performance Standards

There are no prescribed minimum performance standards for mechanical systems used in Passive House projects. However, the maximum thresholds set for both space heating and cooling demand as well as primary energy demand will ensure that highly efficient plant has to be used. A list of certified Passive House products can be found on the Passivhaus Institut website (www.passiv.de – click on the tab 'Certification'). In the case of mechanical heat recovery ventilation units, if the equipment is not officially certified by the Passivhaus Institut then the manufacturer's stated efficiency has to be reduced by 12% in order to err on the safe side in terms of performance.

2.3.1 Heating

It is sometimes reported that Passive Houses require no heating whatsoever. However, heating is in fact required in every Passive House (albeit much reduced compared to conventional standards) and the design of the heating system, especially for non-domestic projects, requires the specialist input of Mechanical and Electrical Engineers. The design of the heating system should not be treated casually, therefore, as every Passive House project must provide excellent comfort at all times in the worst possible weather.

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[1] Kah, O. and Pfluger, R.: Air change and energetic consequences of door opening processes in a school entry zone. Conference Proceedings for the 2007 International Conference on Passive Houses. Passivhaus Institut.

A key factor to consider in designing the heating system for a commercial Passive House project will be the **space heating load**, a measure of the output of the heat provision system (for example a boiler) required to generate and distribute sufficient heat to maintain internal temperatures of 20ºC in the most challenging weather conditions (expressed in Watts per m^2). Taking an office measuring 10,000m^2, for example, a typical Passive House heat load might require a 100kW boiler (10,000m^2 multiplied by 10W per m^2). The heat load is determined in PHPP by calculating the maximum possible difference (planning for worst case scenario) between heat losses and heat gains. The software takes into account the two contrasting weather conditions of (a) very cold yet clear sunny weather with high solar radiation and (b) moderately cold but overcast and with little solar radiation.

The PHPP software also calculates the maximum heating load that is transportable in the supply air and will indicate to the designer whether or not the mechanical ventilation system can be used to deliver the required heat. As a rule of thumb, if the heat load is below 10Watts per m^2, then it is very likely that the ventilation system can be used. The Excel sheet 'Heating Load' in PHPP will calculate whether it is possible to deliver the required amount of heating simply through the ventilation air or whether an alternative method (for example through radiators) would be required.

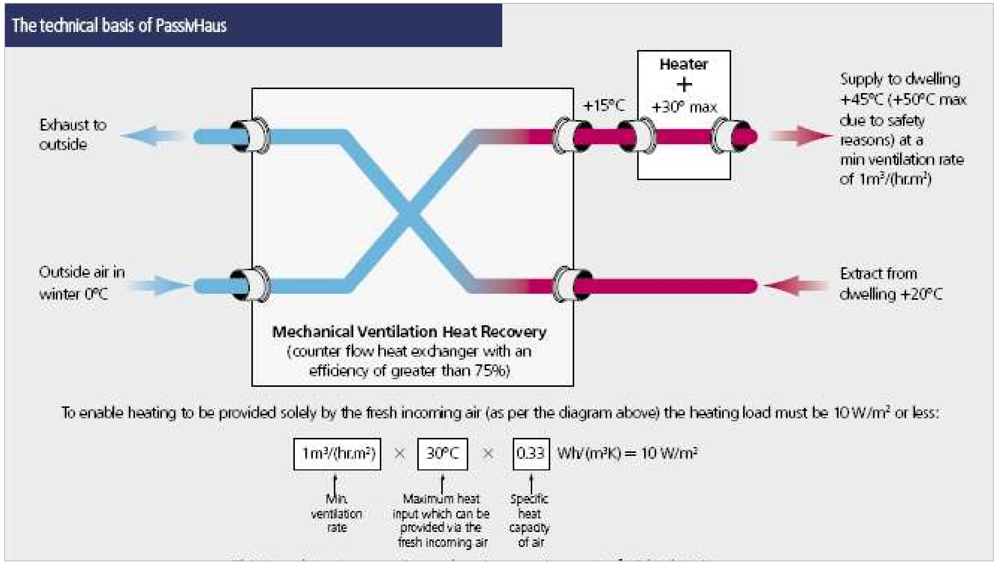

Plate 2.3.1.1. Schematic of low heating is typically delivered using the mechanical heat recovery ventilation system *Source:* www.passivhaus.org.uk

The above diagram above does not take into account the impact of external and internal relative humidity levels and the influence this has on the amount of useful heat that can be recovered. The specific heat capacity of water is higher than air and the external relative humidity levels in Ireland are generally higher all year round than in Central Europe.

Heating Via the Ventilation System

If using the supply air to heat the building, then some kind of post-heater is required to heat the air once it has passed through the heat recovery section of the mechanical ventilation system. There are a number of options available in this regard, including the following:

- Water to air heat exchanger (the hot water can be heated using a combination of solar and biomass or natural gas boilers, for example);
- In-line electrical heat element; and
- Heat pump.

If it is desired to have individual temperature control in each room (for example in each classroom in the case of a school), then a thermostatically controlled post-heater would be required at the point of entry of supply air to each room. This would significantly increase the cost of the system.

Use of Radiators is OK

In Passive House projects it is not necessary to use the supply air to distribute heat throughout the building. In visiting the case studies for these guidelines, the authors were surprised to find that a number of the projects use conventional radiators to provide the required space heating (most people do not associate radiators with Passive Houses). The project designers in these cases emphasise that using such 'traditional' methods of heating are readily accepted by the occupants, provide flexible means of managing temperature on a room by room basis and are relatively inexpensive to install. It has also been pointed out that using such a traditional method of heating means that the building can be kept warm even in circumstances where the heat recovery ventilation system is not operating. Separating the heating and the ventilation system is especially advantageous in schools because it enables the students and teachers to regulate the heating of their individual classrooms.

2.3.2 Cooling

When designing single family dwellings to the Passivhaus Standard, the PHPP software will indicate on the Verification Sheet the likely frequency of overheating (defined as over 25°C). In Ireland's climate, this is unlikely to be a significant problem for such small-scale domestic projects and even if overheating does arise, the occupants can easily cool the building by opening the windows at night or using the summer-bypass option in the ventilation equipment. In the case of non-domestic Passive House projects, however, some further consideration of the risk of overheating and the need for active cooling is required.

The critical difference between single family dwellings and some non-domestic projects is the significant internal heat loads in the latter arising from people and / or equipment. Consider a classroom with 25 students collectively generating 2kW of heat, combined with 10m^2 of south facing glass with a solar yield of another 2kW, totalling 4kW of 'free heat'. The same classroom might have transmission losses of just 0.5kW, eliminating the need for any supplementary heating during class hours[2]. In fact, in this situation, the temperature of the classroom may gradually rise during the day to a point where night cooling is required in order to return classroom to normal comfort levels. Just as with schools, offices also typically have to deal with significant internal heat loads not just from occupants from also from computers, office equipment, servers and kitchens. In all of the case study projects visited for preparation of these guidelines, no air conditioning was used for cooling with perhaps with the exception for computer server rooms.

2.3.3 Ventilation

The table below presents recommendations for ventilation of different building types (offices, schools, sports halls and apartment living rooms) and compares the Chartered Institute of Building Services Engineers (CIBSE) Design Guide A rates with those recommended in the PHPP software. The units recommended by CIBSE are generally litres per second per person (l/(s*P)) whereas the PHPP uses cubic metres per person per hour (m^3/(P*h)). In the table below, the CIBSE units l/(s*P) have been converted to m^3/(P*h) to enable direct comparison with the PHPP recommendations.

It can be seen for offices that there is relatively little difference between the CIBSE and PHPP recommendations (36 and 30 m^3/(P*h) respectively). For schools, however, the PHPP recommendation is approximately half of that recommended by CIBSE but the converse is true for sports halls, where the PHPP rate is approximately double that of CIBSE. In the case of schools, research by the Passivhaus Institut has demonstrated that providing 15 – 20 m^3/(P*h) fresh air ensures good quality air as measured comparing indoor CO_2 concentrations to ambient CO_2 levels. In the case of sports halls, a higher rate is recommended by PHPP than by CIBSE to ensure very high indoor air quality for people engaged in physical exertion. Lastly, concerning apartment living rooms, the unit 'air changes per hour' (ACH) is used both by CIBSE as well as PHPP, the former recommending a range of 0.4 to 1.0, the latter recommending an average of 0.4. It will be noticed that for three of the four building types, PHPP recommends a lower air change rate. The ventilation rates outlined above in existing Passive House schools may be regarded by some observers as low. However, the following factors must be bourne in mind when considering these rates: (a) carbon dioxide production by young people sitting in class is lower than would be the case for adults engaged in normal daily activities – hence the need for fresh air is less in schools (especially primary schools) (b) a one-hour intense flushing ventilation phase both before school opens as well as on school closing is typically used which greatly supplements the lower background ventilation; (c) it has been the practical experience in many Passive House schools that windows are left open by teachers during breaks, even in the heating season, which also increase the background ventilation rate; and (d) as presented elsewhere in this document (Figure 3.2.2.1) the air quality in Passive House schools is well proven. Irrespective of these comments, a CO_2 level of 700ppm is recommended as a maximum for good indoor air quality and each system should be designed to deliver this for all building types.

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[2] Axel, B. Benefits of the Passive House Standard in Schools: cost-effectiveness and user convenience. Conference Proceedings for the 2009 International Conference on Passive Houses. Passivhaus Institut.

Comparison of Ventilation Rates Recommended by CIBSE and PHPP

Building Type	Offices	Schools	Sports Hall	Apartment living rooms
Suggested CIBSE Air Supply Rate	10 l/(s*P)	10 l/(s*P)	10 l/(s*P)	0.4 – 1.0 ACH
Conversion from CIBSE to PHPP units	36 m^3/(P*h)	36 m^3/(P*h)	36 m^3/(P*h)	
Recommendation as per PHPP	30 (m^3/(P*h)	15 – 20 (m^3/(P*h)	60 (m^3/(P*h)	0.4 ACH

Source: CIBSE Environmental Design Guide A

Technical Guidance Document Part F of the 2009 Irish Building Regulations deals with Ventilation and was published in early 2010. Section 1.2.3 of Part F deals with mechanical ventilation with heat recovery in the residential sector and specifies the minimum of either 5 l/s plus 4 l/s per person or 0.3 l/s per m^2 of internal floor area. The rate of 5 l/s plus 4 l/s per person for a house with four persons converts to approximately 19m^3 per person per hour, which is 60% of the ventilation rate of 30m^3 per person per hour recommended in the Passivhaus Standard. Having said that, the above ventilation rate assumes an Air Permeability of 5m^3/(h.m^2) which would typically be far exceeded in a Passive House. The alternative method for calculating the ventilation rate using 0.3 l/s per m^2 of internal floor area would equate to 35m^3 per person per hour for a 130m^2 house for four persons (0.3 l/s X 3.6 (to convert to m^3/h) = 1.08 m^3 per hour x 130m^2 = 140m3 per hour / four persons = 35m^3 per person per hour. This rate of ventilation is closer to the recommended rate of 30m^3 per person per hour in the Passivhaus Standard. Further recommendations are provided for non-residential buildings in TGD Part F, referring to guidance found in CIBSE documents such as that presented in the table above.

2.3.4 Hot water

The demand for hot water in non-residential projects is generally much lower than that in single-family dwellings due principally to their reduced hours of use as well as (typically) no demand for either showering or bathing. The PHPP software recommends using the default hot water consumption of just 12 litres per day per person in an office, compared to twice that (25l/P*d) for residential projects. The Department of Education and Skills in Ireland estimates that hot water consumption in primary schools is approximately 3l/P*d. Coupled with this reduced demand is the potentially very long circulation pipes that would have to be used if a central thermal store is used, with distribution pipes to outlying bathrooms. Combining low demand with a lengthy distribution system can result in significant energy losses.

Avoiding Risk of Legionella

Legionella can result in bacterial contamination of domestic hot water and is therefore a risk to human health. It grows best in temperatures of between 30ºC and 45ºC, so one preventative solution is 'thermal disinfection' achieved by heating the water to at least 60ºC every day. This will obviously result in considerable distribution and stand-by losses which in turn increase the primary energy demand. Instant under-sink water heaters operating on a timer basis practically eliminate circulation losses and also greatly reduce risk of Legionella. Other technologies are also coming on the market, including special membranes and UV-light are also options to consider.

Reducing losses

Distribution heat losses in hot water can be considerable if there is insufficient insulation of the pipes, and only 45% of any losses can be used even if the pipes are placed inside the thermal envelope. The thickness of insulation should generally be a minimum of twice the nominal pipe diameter (Volume 28 of Research Group Cost Efficient Passive Houses: Heat Transfer and distribution losses in Passive Houses. Passivhaus Institut, Darmstadt 2004). Heat losses can be accurately calculated in the PHPP sheet 'DHW+Distribution' wherein the designer can enter pipe lengths and diameters, thickness and thermal conductivity of insulation, location of pipes in relation to the thermal envelope (whether inside or outside), design temperatures and storage losses.

2.3.5 Lighting

Lighting typically accounts for up to 40% of the energy consumption of commercial buildings, with inefficient lighting possibly adding to the risk of overheating and adding to cooling requirement. The focus of the Passivhaus Standard is not just directed towards space heating requirement, but also to Primary Energy Demand where the maximum use is set at 120 kWh/(m^{2}year). It is important to carefully consider the lighting strategy, therefore, and to maximise the amount of natural daylighting where possible as discussed previously. There are no minimum performance standards for lighting systems in Passive House projects *per se*, as long as they do not contribute towards exceeding the above primary energy threshold.

The PHPP software has three input Excel sheets which deal with lighting requirements for Passive House projects, with data being entered typically in the following sequence:

1. 'Use Non-Dom' sheet (dealing with use patterns for non-domestic projects) – in this sheet the designer specifies the different room types in the building (for example, offices, WS, circulation space, plant rooms), their hours of use, the illumination level required and the height at which that illumination is delivered (for example desk height = 08m);
2. 'Electricity Non-Dom' sheet (dealing with electricity for non-domestic projects) – in this sheet the orientation and g-value of typical rooms is entered along with width of windows and room dimensions which allows an estimation of daylight utilisation. After this, the designer specifies the degree of lighting controls provided (whether manual, automatic or using a bus system, with our without motion detectors). PHPP then uses these data entries to estimate the electricity use for lighting as well as the primary energy demand.
3. 'IHG Non-Dom' sheet (dealing with internal heat gains in non-domestic projects) – this sheet is connected to the above sheet (Electricity Non-Dom) where the average heat released internally from lighting requirements is specified (no-input required, automatically brought forward from the above sheet).

2.3.6 Fire protection

For all construction projects, fire protection is of paramount importance and the separation of fire compartments must not be compromised by any Passive House elements. The issue generally of greatest concern is the ventilation ducting which may pass through different fire compartments and which must be designed in order to prevent both spread of flame as well as smoke. There are various products on the market presently which can be used to separate fire compartments, such as fire-dampers which are triggered to close automatically either due to an increase in temperature (at 72^{o}C) or via external smoke detectors. Access to fire dampers has to be ensured in order to enable periodic visual inspection and maintenance, so their positioning has to be carefully considered.

Plate 2.3.6.1 Fire dampers are essential in ventilation ducting where there is separation between different fire compartments

Shutters for cold smoke can also be used to prevent cross-flow of smoke if the central ventilation unit is powered off. They are especially critical in multi-residential buildings with a centralised ventilation system.

2.4 Shading

External shading can be provided by either brise soleil or retractable blinds. The former type present the advantage of having no moving parts (and therefore require less maintenance) but they are not as effective as blinds in keeping out low level light especially from the west and east. Furthermore, if optimally designed, they would differ in their depth according to different orientations (for example, absent on the north elevation and deep on west and east elevation). Such variation might be regarded by the architects as detracting from the overall aesthetic of the building design.

The latter type of shading, retractable blinds, appear to be preferred in the German Passive House office projects visited by the authors. They are designed according to the following strategy:

- Strike a balance between minimizing glare and overheating for office workers while also maximizing natural day lighting and reducing primary energy consumption.
- Not be so 'sensitive' or reactionary to external solar irradiation patterns such that they are constantly moving up and down causing unnecessary irritation to the office workers. Some systems have a delay mechanism such that they only change their position after a predetermined phase of a given exterior condition.
- They should be capable of varying the amount of light penetration at different heights, for example fully closed at the bottom to eliminate glare at the desks and workstation level, with more open towards the top allowing light penetrate deep into the office.
- It should be possible for the building occupants to override the system such that they have control over their own workspace. It is typically in such instances, however, that the building management system will return the blinds to the programmed position after a certain period (for example two hours).
- Linked to a wind monitoring station such that they retract in period of heavy wind in order to avoid damage.

Plate 2.4.1 The shading blinds on this office building, when fully extended, remain open at the top to allow daylight deep into the office but are closed at the bottom to reduce glare at desk level

Plate 2.4.2(a) and (b) Retractable shading can be fitted to the external facade and controlled either manually or automatically

Plate 2.4.3 These retractable opaque blinds are restrained by guide wires but would have to be carefully considered in windy or exposed locations

Plate 2.4.4 Shading can be provided which still provides filtered views of the surroundings

There does appear to be difficulties with shading in some of the Passive House projects visited in preparing these guidelines. In one project, the wind monitoring device was programmed to retract the blinds at very low (too low) wind speeds. In another project, the programming system was not working correctly and the shades were not reacting adequately to external weather conditions. Despite such 'teething' problems, however, retractable shades appear to be working well on most projects.

A variation on the external retractable shade is a system whereby the shade (a perforated metal foil) is located between the panes of glass. This system avoids any concerns about wind damage but the cost differential would need to be careful analysed. If considering using this system, ensure that the blinds pull from the bottom towards the top (and not vice versa) to reduce glare at desk level as discussed above.

3

Key Guidance for Different Building Types

SECTION CONTENTS CONTENTS

3.1 Offices

3.1.1 Key Design Considerations

Plate 3.1.1.1 The proportion of glazing in office projects is optimised to create a balance between maximising solar gains in winter and minimising risk of overheating in summer

High risk of overheating

Whereas Passive House buildings are renowned mostly for their low heating energy requirement, a key challenge in constructing Passive House office buildings is to avoid the risk of overheating in summer, otherwise requiring active cooling. This is normally caused by excessive areas of glazing without adequate shading. In addition, there are significantly greater internal heat gains in offices compared to residential projects resulting from high occupancy rates as well as computers, lighting and computer servers which all generate heat. A Passive House office must not only be comfortable in the heating season, but also in the 'cooling' summer season.

Flexibility of Layout

Many office projects are built speculatively and without prior knowledge of how the building might be subdivided as tenants take occupancy. The impact that this has for Passive House design is in the planning of the mechanical systems including ventilation, heating and cooling, the layout of which should be designed in such a way as to cater for different configurations that might be required. There should generally be a sufficient number of ventilation units, for example, to cater for a large number of sub-divisions.

Varied Occupational Patterns

Offices are typically used during normal working hours and outside of that might well be completely empty. It is important to design the mechanical systems such that they can automatically respond to these changing use patterns and reduce their energy consumption when the building in not in use. One method of achieving this is to install CO_2 sensors which determine the volume of airflow in the ventilation equipment. In the morning, as the offices become occupied, the sensors will increase the rate of ventilation, and the opposite happens in the evening when the demand for fresh air reduces.

Point Source Hot Spots

Typically office buildings will require special rooms for computer servers which are at risk if they overheat and thus must be kept cool. This places a high energy demand for those spaces compared to the remainder of the building, albeit over a confined floor area. Energy efficient methods for cooling server rooms must be an integral part of the planning of Passive House office buildings, including the re-use of 'waste' heat generated in such rooms elsewhere in the building.

Fire Protection

There are special fire protection measures that are necessary for office buildings which can affect the Passive House design approach. Most critically, fire protection of ventilation ducting must be provided to minimise risk of spread of flame and smoke between different fire compartments.

Shading

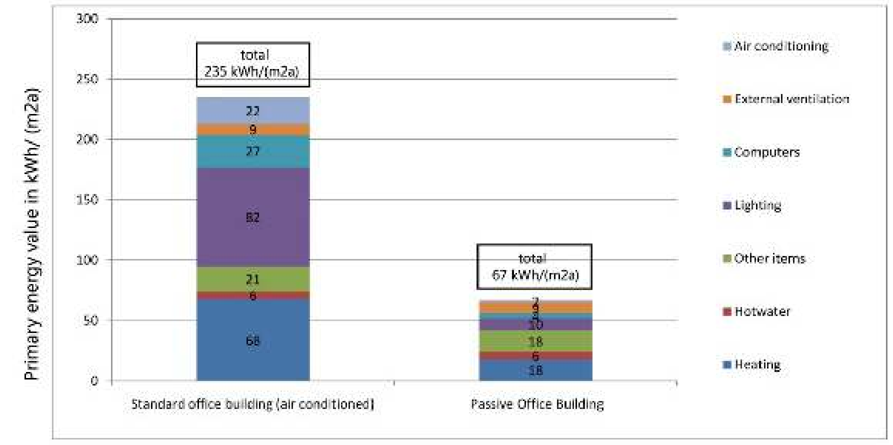
Shading is an essential factor in office buildings in order to prevent overheat through solar gain. The proportion of glass to be used should be determined by day lighting requirements (don't build a glass house!). Otherwise, windows create a great challenge for the building designer because they can lead to overheating in the summer and excessive heat losses in winter. This applies even to triple glazed Passive House windows. There is thus a balance to be held in deciding upon the proportion of glazing compared to opaque elements.

Cooling

The Passive House envelope, which is highly insulated and highly airtight, requires much less cooling than conventional construction. Concrete core activation is typically used in Passive House office buildings, minimising the need for 'active cooling' (especially in the relatively benign Irish climate).

Comparison of Passive House and Conventional Office Construction

A comparison is made below between the primary energy use of standard air-conditioned offices with those built to the Passivhaus Standard. In total, 'standard' offices use approximately 3.5 times the amount of primary energy compared to Passive House offices. There is a negligible difference between both approaches in terms of hot water production, external ventilation and what are referred to as 'other items'. There are very significant differences in terms of air conditioning, lighting, computers and heating with the standard office using 11 times, 8 times, 7 times and 4 times the amount respectively compared to Passive House. The reason for the dramatic difference in terms of air conditioning is not simply due to reduced solar gains through shading, but also reduced internal heat gains arising from more efficient lighting and computers. A net benefit of focusing on reducing the primary energy for lighting and computers, therefore, has a considerable impact on the extent of cooling required.



Typical Primary energy usage for a Standard and Passive Office Building

Adapted from the German Passivhaus Insitut Publication 'Protocollband Nr31' - Energy efficient cooling, Table 6, Page 152.

PASSIV HAUS INSTITUT Dr. Wolfgang Feist

Figure 3.1.1.1

Comparison of Built Passive House Projects

A comparison of a selection of Certified Passive House offices is provided below to illustrate the range of approaches that have been realised. The last of these represents a refurbishment project, the others being new-build. Some of the key issues worth considering for prospective projects are listed below:

- The size of projects completed has steadily been increasing in recent years, culminating in the Luteco Offices in Ludwigshafen, Germany, at almost 10,000m^2 (Plate 3.1.1.2). There would appear to be no limit as to the size of office facility that can be built to the Passivhaus Standard, therefore.
- In terms of construction type, most (but not all) projects comprise a concrete shell, some of which are clad with timber frame facades.
- The cost of construction is regrettably not available for many of the projects. For the two largest projects, however, that there was no additional cost in building to the Passivhaus Standard compared to the conventional standard. Furthermore, it is perhaps interesting to note that the refurbishment cost for the office in Tübingen was in the order of €1,000 per m^2.

Plate 3.1.1.2 Entrance to the Luteco Offices in Ludwigshafen, Germany

- All of the projects reached impressive levels of air-tightness, many down as low as n_{50} 0.2 air changes per hour @ 50 Pascal, including the refurbished office building in Tübingen (even though the limit for certification is somewhat higher at 0.6 ACH).
- Space heat requirement for all projects is less than or equal to 15 kWh/(m²/a) (delivered energy). There is a significant difference between the projects in terms of primary energy requirement, some as low as 68 kWh/(m²/a) and with an average of 93 kWh/(m²/a).
- Heating systems vary from project to project with most using either heat pumps or condensing gas boilers.
- Lastly considering U-values, the average for walls is in the order of 0.13 W/(m²K), with 0.18 W/(m²K) for floors and 0.11 W/(m²K) for roofs. It must be remembered that these values are designed for cold Continent climates, so it is likely that less insulation would be required in order to meet the Passive House Standard in Ireland (subject to design and testing in PHPP).

	Ludwigshafen	Energon Ulm	Stadl-Paura	Unterhaching	Bremen	Tübingen refurbishment
Year of construction	2007	2002	2003	1999	2001	2003
Treated floor area	9,823	5,412m²	2000m²	1,074m²	902m²	838m²
Construction type	Masonry	Masonry and timber	Timber	Masonry and timber	Masonry	Masonry
Construction cost per m²	N/A	€1,300	N/A	N/A		€967
Air-tightness	0.2/h	0.2/h	0.4/h	0.2/h	0.49/h	0.2/h
Space heat requirement (kWh/(m²/a) (delivered energy)	12	12	14	9.2	15	15
Primary energy requirement (kWh/(m²/a)	102	68	N/A	96.4	N/A	107
Heating / cooling method	Concrete core - geothermal probes.	Concrete core - district heating & geothermal for cooling	Geothermal	Condensing gas boiler, 15kw	Central gas boiler	Gas condensing boiler with radiators
U-value of wall / floor / roof (W/(m²K)	0.14 / 0.23 / 0.11	0.13 / 0.21 / 0.12	0.11 / 0.13 / 0.11	0.13 / 0.15 / 0.11	0.13 / 0.16 / 0.09	0.14 / 0.18 / 0.14

Source: www.passivhausprojekte.de/projekte.php

3.1.2 Mechanical Systems

Ventilation

The table below is derived from EN 13779 and was summarised by PHD (www.passivhaus-info.de) in preparation of their CEPH training material. In this table different indoor air quality (IDA) levels are presented, from IDA 1 (excellent quality) to IDA 4 (low quality). IDA 3 is regarded as sufficient for office projects, whereas IDA 4 is regarded as adequate for schools. In any event, the quality of indoor air has firstly to be agreed with the Client. It should be noted that typical concentrations of CO_2 in outdoor fresh air is approximately 400-500ppm, implying that IDA 3 below for offices would achieve an indoor CO_2 level of approximately 900 – 1500ppm.

Classification of Indoor Air Quality (IDA) According to CO_2 levels in Non-Smoking Areas.

Classification if IDA	Fresh Air Flow	Increase in CO_2 compared to external fresh air
IDA 1 – Excellent Quality	>54m³/h/Person	<400ppm
IDA 2 – High Quality	36 - 54m³/h/Person	400 – 600ppm
IDA 3 – Medium Quality	22 - 36m³/h/Person	600 – 1000ppm
IDA 4 – Low Quality	>22m³/h/Person	>1000ppm

Source: www.passivhaus-info.de

As highlighted above, the overall design of the ventilation system will be greatly affected by whether a centralised (whole building) system is used or whether a decentralised system is used. The latter would enable easy subdivision division of the building into smaller letting units should this be required and thus guarantees greater flexibility of building use in the future.

The ventilation system will typically be shut down when the offices are not in use, requiring a pre-'flushing' phase prior to opening the next day to clear the air of any contaminants. Further details on this flushing phase is provided later when dealing with schools.

Heating and Cooling

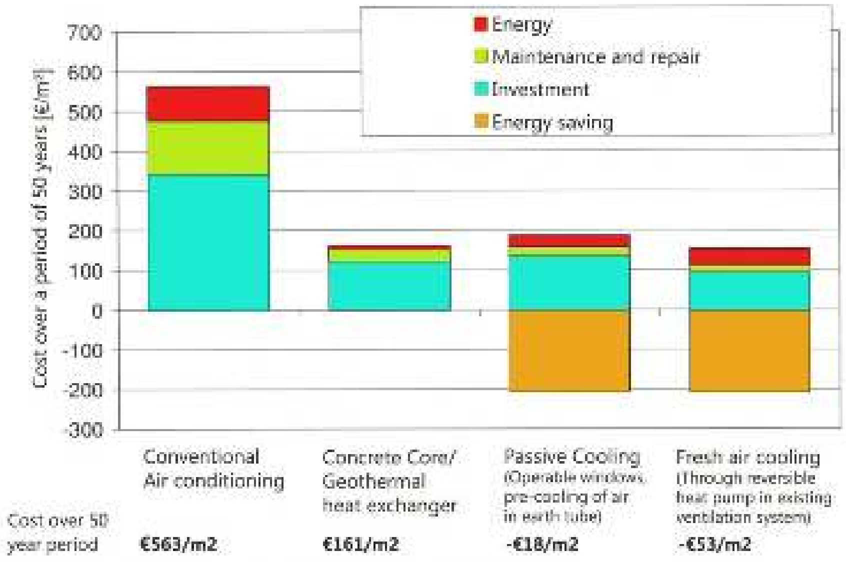
Heating and cooling of office projects is dealt with simultaneously in this section due to their typically using the same system.

Plate 3.1.2.1 The decentralised ventilation system provides flexibility of internal layout options

Offices present a special case in terms of Passive House design due to the high internal heat gains resulting from high occupancy rates and use of heat generating devices such as computers and other electrical equipment and appliances. Internal heat gains in offices and administrative buildings according to PHPP are approximately 3.5W/m², compared to just 2.1W/m² for residential projects and 2.8W/m² for schools. Only assisted living residences, at 4.1W/m², are specified in PHPP as having higher internal heat gains than offices. As result of these high internal heat gains, the demand for space heating tends to be relatively lower for office projects.

The choice of heating system is, ironically perhaps, typically determined by the optimal method of cooling. There is little point in using traditional radiators for heating in the winter if the same appliances cannot be used for cooling in the summer. In the case of office projects, heating is thus often provided through a hydronic system of heating the concrete floor slab(s) using geo-thermal earth probes which can then be used in reverse in summer for cooling.

There should be no need for air-conditioning in Passive House office projects, except perhaps for server rooms where temperatures of 16ºC are typically required. It is best to cluster the servers in one part of the building in order to minimise the number of separate air-conditioning units required. In any event, the roof of a Passive House office building will typically look quite barren compared to typical office buildings in terms of the amount of air-conditioning kit involved, leaving more room for renewable energy technology if deemed appropriate.



Long term cost comparison of Cooling Systems for Office buildings.
Note that in each case the mechanical ventilation cost is included in the investment costs.

Adopted from the German Passivhaus Insitut Publication 'Protocollband Nr31' - Energy efficient cooling, Table 15, Page 183.

Figure 3.1.2.1

Offices built to the Passivhaus Standard can be cooled using a variety of means, whether using air-conditioning (not at all common) or using a more typical Passive House approach such as with fresh air at night. The above figure highlights the difference in costs and performance of different cooling systems for an office of 10,000m² built to the Passivhaus Standard and can be summarised as follows:

- Conventional air conditioning is by far the most expensive method of providing cooling, in terms of energy consumption, maintenance and capital investment costs.
- Concrete core cooling using a geothermal heat pump brings about very significant savings in comparison to air conditioning but nevertheless does not bring about any energy saving potential compared to the two methods presented below.
- Night cooling using openable windows and cooling fresh air intake in earth tubes requires marginally higher capital costs that concrete core cooling, but also achieves significant savings.

- Fresh air cooling using a reversible heat pump to cool the fresh air delivered in a mechanical ventilation system was found to be the optimal system from an economic perspective given the net savings over the lifetime of the building.

3.1.3 Shading

As mentioned in the introduction to this section on Passive House office projects, a careful balance has to be held between (a) use of glass for solar gain in the heating season to minimise space heat demand and (b) avoidance of overheating through excessive solar gain in the summer. The optimal approach is to provide sufficient glazing to achieve the space heating target of 15 kWh/(m^{2}a) (delivered energy) whilst providing some means of shading the windows in the summer to prevent overheating (defined as greater than 25°C for more than 10% of the year. Retractable blinds are used extensively in Continental Europe for this purpose, withdrawn when there is a low risk of overheating and when solar gain can contribute positively towards the overall energy balance, and extended to provide shading when there is a likelihood of overheating (Plate 3.1.3.1). Shading mechanisms are most usually controlled by solar irradiation sensors as well as wind anemometers, the latter retracting the blinds if structural damage to the blinds is a risk. The automated control of external blinds can be designed to enable complete control by office occupants if so desired. However, the automated controlling system usually overrides manual settings after a prescribed period to ensure that an optimal energy balance is maintained.

3.1.4 Building Management

Contemporary office developments are typically managed by sophisticated building management systems, controlling lighting, ventilation, heating and cooling along with other important functions. The Passivhaus Standard is no different in that regard, and there are significant energy savings to be made with carefully programmed building energy management systems. The primary objective in any Passive House project is to maintain a balance between heat gains and losses, whilst also ensuring high indoor air quality as well as thermal comfort. In the non-domestic sector, this balance can only be realistically achieved through the use of relevant building management systems.

Plate 3.1.3.1 Shading mechanisms are most usually controlled by solar irradiation sensors as well as wind anemometers, the latter retracting the blinds if structural damage to the blinds is a risk.

3.2 Schools

Plate 3.2.0 The renowned certified Passive House doors in the Aufkirchen Montessori School

3.2.1 Key Design Considerations

Internal Heat Gains

The key challenge in the design of Passive House schools is the very high occupancy at certain times of the day and certain times of the year (Plate 3.2.1.1). Despite the high number of occupants, however, the resulting substantial internal heat gains are insufficient to provide heat for the entire school as there will not be students in all rooms at all times.

Plate 3.2.1.1 Internal heat gains from pupils is accounted for in the PHPP software

Outside of the heating season, especially in spring and autumn, there is a risk that the building might overheat if not designed correctly. The thermal comfort levels during the summer months should be maintained so that internal temperatures do not exceed 25^{0}C for more than 10%, (ideally 0%), of the occupancy time of the school. The frequency of overheating is one of the outputs of PHPP in the verification sheet, and the designer can adjust the design to achieve the above recommendation.

The Importance of Thermal Mass

Thermal mass is very important in schools, modulating temperature fluctuations which might otherwise be significant. The Passivhaus Institut recommend that the total effective, floor area specific, thermal storage capacity of room enclosure components should be $c_{effective}$>150 Wh/m^{2}K in relation to the class room floor area. This can be achieved in a variety of ways and does not necessarily imply that the entire structure need be constructed of heavy 'massive' materials. It is possible, for example, to use a timber frame external shell combined with masonry floors and internal walls (so called 'mixed' construction). If the above thermal mass is not possible to achieve, alternative additional cooling methods must be considered (see below).

In the graph below the beneficial effects of thermal mass in a school can be readily appreciated. Whilst all three construction types are seen to fluctuate in response to external conditions, the peaks in temperature in the lightweight construction is noticeably higher than either mixed or solid construction. Using mixed or solid construction in schools is beneficial, therefore, in terms of modulation of internal temperatures.

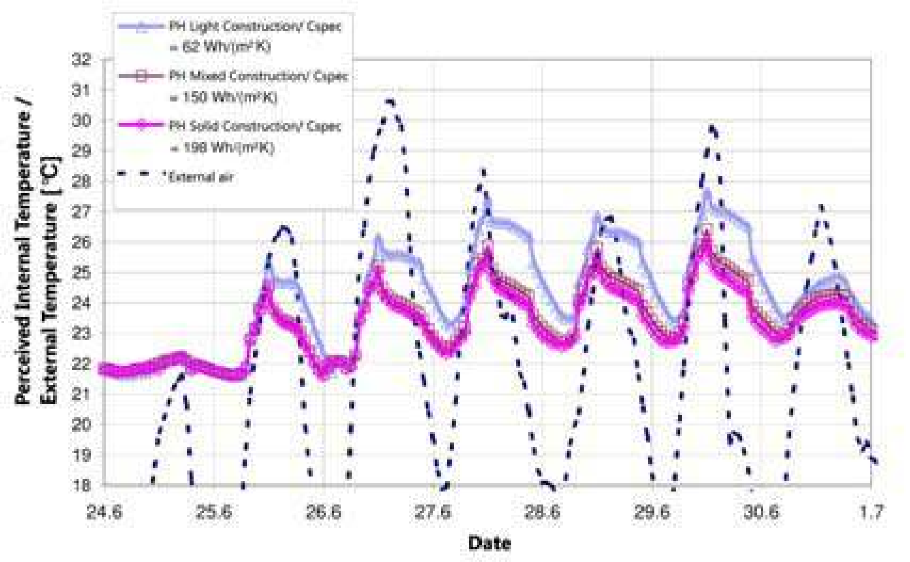


Figure 3.2.1.1
(Source: Volume 33 of Passivhaus Institut Research group cost-efficient Passive Houses: Schools)

Easy to plan for Educational Spaces

The advantage presented by the scheduling of classrooms is that the occupancy of different spaces is typically predictable. The occupancy is therefore known in advance making it easier to plan the heating and ventilation system. It is more difficult to plan for other spaces, however, such as staff rooms where occupancy varies throughout the day.

The school will also feature standard low energy design systems which are standard on all new Irish schools such as:

- T5 lighting with daylight dimmers set to off and absence detech
- Individual digital temperature room controls
- Rainwater recovery
- Low flush toilets
- Percussion taps

Please visit www.energyeducation.ie for updates on the project and other DOES projects.

Complexity of room types and functions

Most schools have teaching spaces which are quite different to typical classrooms in terms of internal heat gains as well as the need for fresh air ventilation. Such rooms would include, for example, multi purpose rooms, learning support rooms, specialist subject rooms, general purpose halls, libraries, computer rooms, laboratories (Plate 3.2.1.2) or sports halls. The exact amount will vary from primary to post primary schools. This can be overcome by specific ventilation and heating strategies for each of these room types.

Plate 3.2.1.2 Schools typically have a variety of rooms with specific functions that need to be carefully considered when designing the mechanical systems

3.2.2 Mechanical Systems

Ventilation Rates

In PHPP the typical ventilation rate used is $30m^3$ per person per hour. However, in the case of schools, this is generally reduced to 15 to $20m^3$ per person per hour due to the frequency of breaks during the day when the room is unoccupied. Such ventilation rates will typically achieve CO_2 concentrations of between 1,200 ppm and 1,500 ppm. This rate of air exchange is significantly lower than for residential or offices buildings due to the high density of occupation during school hours. Of course, a CO_2 concentration of < 1,000 ppm would be better. Achieving such air quality would increase the ventilation rates and therefore the electrical power used as well as increasing the size of plant, ducting required and operational costs. It would also result in decreasing the relative air humidity in winter. According to the Passivhaus Institut, it is the experience of Passive House schools in Germany that the air quality is significantly higher than in conventional (non-mechanically ventilated) schools, but still not the absolute best as this would require too much energy. In terms of efficiency of the heat recovery system, this should be at a minimum of 80%, otherwise there would be significant heat losses during the heating system.

Note that the above ventilation rate of 15 to $30m^3$ per person per hour should be increased marginally for secondary schools where the average age of students is higher.

Fresh air ventilation only through opening windows is generally not provided in Passive House schools. However, openable windows are generally recommended and sometimes needed to prevent overheating.

Comparison of Window Ventilation with Mechanical Ventilation

A comparison study of ventilation using only manually openable windows compared to that with mechanical ventilation is provided below (prepared by the Department of Architecture, City of Frankfurt). As can be seen from the graphs below, the schools which only use window ventilation tend to experience high level of CO_2, and therefore lower air quality. Schools with mechanical ventilation, on the other hand, experience much reduced CO_2 levels.

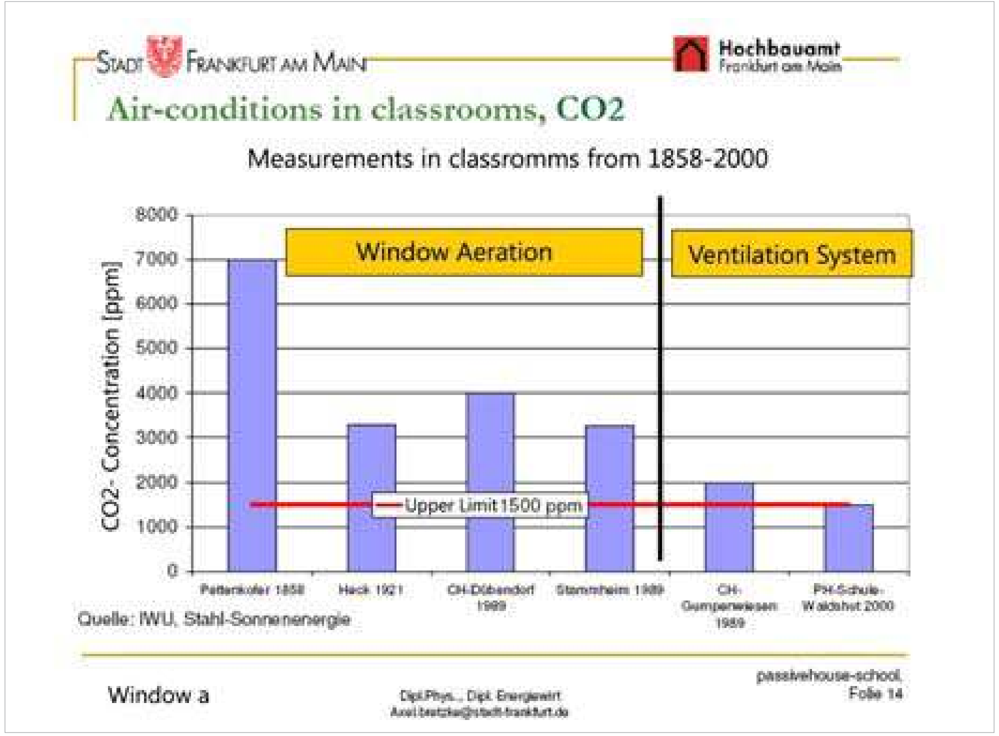


Figure 3.2.2.1 Comparing the effectiveness of window versus mechanical ventilation of schools

Periodic Switching off the Ventilation System

The schedule school days are 183 primary school and 167 post primary, they are therefore left unoccupied for very long periods during which is it typical to switch off the ventilation systems or operate it a much reduced levels (for example at night or during the holiday season) in order to reduce primary energy consumption.

Best (Passive House) practice is to run the ventilation system in a kind of 'temperature-threshold-operation' which involves ventilating the building at a reduced rate so that the temperature never falls below 17°C. The Department of Education and Skills recommend the heating frost protection system which uses pumps and heating systems to ensure 12°C is maintained in order to protect the building fabric. Then, heating-up following closure can be done relatively fast (1 hour), even when using supply air heating without radiators (one hour pre-flushing is necessary anyway to allow for a sufficient ventilation to flush all unwanted odours out of the school before the pupils arrive). If using this method for heating-up the school, it is important to correctly dimension the heating load.

Where the system is being shut down completely, it is important that there is an automated system for complete drying of the air filters before the ventilation switches off so that there is no risk of mould growth in the filters which might be moist with potential risk to human health. This can be easily achieved by re-circulating the air at the end of each usage period.

The periodic switching off of the ventilation system is a fundamental difference between residential projects where the system is in operation on a continuous basis. Operation of ventilation rates at reduced levels during opening hours can also be controlled by occupancy sensors, CO_2 sensors or other air quality indicators.

Pre and Post 'Flushing'

As suggested above, where the ventilation system is shut down (whether overnight, at the weekend or during school holidays) it is beneficial to carry out what is referred to as 'flushing' for an hour or so before and after the operational period. This flushing requires operating the ventilation systems at the maximum flow rate possible, drenching the building with surplus fresh air at the beginning and end of the school day.

Filter Quality

Different quality of filters can be used depending on the specific application and the separation rate required. In the table below, a filter classification is provided according to EN 779 (collated by passivhaus-info.de). For hygienic reasons, a minimum F7 filter quality should be used in the supply air duct

Filter Classification	Separation Rate (%)	Suitable Application
G1, G2 and G3	<65, 65 - <80 and 80 < 90	Coarse dust filter: Pre-filter for coarse and fine dust
G4	> 90	Passive House extract filter
F5 & F6		Fine particle filter: pre-filter for suspended particles for use in restaurants, clinical rooms and clean rooms
F7, F8 and F9		Passive House fresh air filter
EU 10 – 17	> 85 to 99.99	Highest standards of air purity for operating theatres and clean rooms

Fire Protection

The use of a centralized ventilation system may have implications for fire protection measures. Therefore, it is best to keep the design of the ventilation system as simple as possible, with minimal ducting connecting / interlinking different teaching spaces. It would also be necessary to take into account acoustic issues, such as cross talking when interlinking different teaching spaces with the ventilation system.

Separate Ventilation Systems

Schools will typically require separate ventilation systems according to different room functions, as follows:

- Classrooms, toilets, circulation spaces and common areas;
- Staff rooms and servaries;
- Science laboratories and fume cupboards.

Plate 3.2.2.1 Fume cupboards in laboratories will need separate extract systems

Heat Distribution

Research by the Passivhaus Institut on best practice European case studies has proven that there should be no difficulty in heating schools through the supply air and that the systems should be designed in such a manner that the flushing phase can heat-up the building after periods when the building is unoccupied. In the case of the two Passive House schools visited in preparation of these guidelines, both used traditional radiators as their means of delivering additional heating to the classrooms. In both cases, the radiators were not positioned under the windows. The recommendation of using such 'traditional' methods of heating will likely come as a surprise to many readers, but it has been found that allowing the teacher direct control of the heating of individual rooms using the all-familiar radiator is very successful. In the case of Passive Houses schools these radiators have quite a low output and therefore and quite slim and are non-intrusive in terms of useable floor space.

Maximise Natural day lighting

Irish classrooms are typically 7m maximum deep plan and two storey therefore require high windows to maximize the availability of natural day lighting for the whole room. However, it is not necessarily recommended to have floor to ceiling glass throughout as this could lead to over-heating through external solar gains. It is best to adopt a moderate approach therefore and not use glazing excessively. Note: Department of Education and Skills do not provide floor to ceiling glass but do require a daylight factor of 4.5 in technology spaces.

Avoiding Temperature Asymmetries

It is important to avoid temperature asymmetries which can arise near the windows of classrooms and this can be achieved by using high quality Passive House windows with an overall combined U value for glass and frames of <0.85W/ (m^2K) inclusive of installed thermal bridges. Furthermore, while the Passive House Standard requires an n_{50} air-tightness level of 0.6 ACH @ 50 Pascal, it is recommended to improve this to < 0.3 ACH @ 50 Pascal if at all possible.

3.2.3 Shading

There are a number of considerations involved in designing a shading system for Passive House classrooms, namely :

- Minimise unwanted external solar heat gains in summer;
- Maximise solar heat gains in the heating season;
- Maximise natural daylighting; and
- Minimise risk of glare and visual irritation.

In terms of control, it is best to employ a system that can be controlled directly by the teacher in each room, for example roller blinds with an open weave factor of 5%.

3.2.4 Building Management

As with all Passive House projects, the simpler the mechanical systems used the easier it will be to manage the operation of the building. Ideally the system should be set up such that the principal can operate and control the ventilation and heating systems independently.

As mentioned in the introduction, the key challenge concerning schools is to deal with the variation in building occupancy as this has a significant effect on the ventilation rates and heating system.

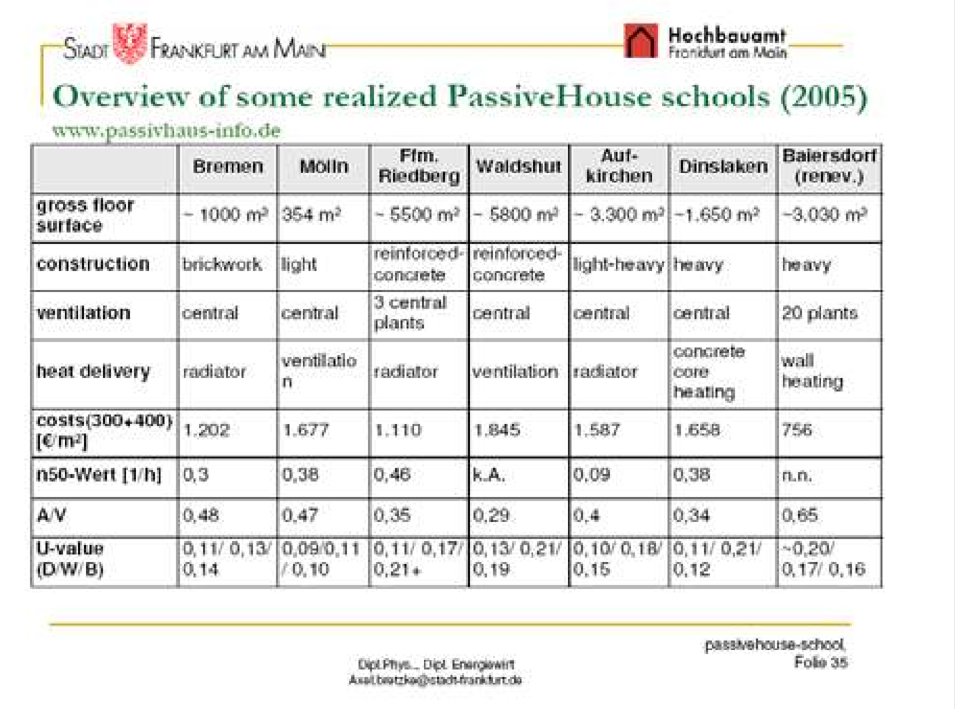
Night Cooling

In order to maintain thermal comfort in periods of hot weather during the spring months (ie. to minimise overheating) night cooling might occasionally be required. This can be achieved using a variety of means. One mechanical method is to operate the ventilation system using what is referred to as the 'summer bypass' where the cool night air is not heated up by the exhaust air, but instead passes directly through the building. Another method is to have openable windows or vents in the rooms which are thermostatically operated, opening and closing during the night as required in order to achieve the required temperature. Care needs to be taken that this method does not compromise any internal alarm sensors that might be activated by moving elements in the interior. Note: Security at the building would need to be taken into account with this approach.

Comparison of Completed Passive House School Projects

The overview table below was prepared by the Architectural Department of the City of Frankfurt and provides a useful overview of six new-build and one retrofit school project completed up to 2005 in Continental Europe. Some key issues relating to Passive House design are summarized in bullet form below:

- The Passive House standard can be achieved irrespective of the size of the school.
- All the new-build projects use a central ventilation system, with the retrofit project using a decentralized system, likely due to difficulty in integrating ducting throughout an existing school.
- Just two of the projects deliver the space heat requirement through the ventilation system, with the others using radiant heat (whether radiators or through the concrete core).
- Costs vary hugely from project to project, with an average build cost for the six new-build projects of approximately €1,500 per m². The cost of refurbishment of the project at Baiersdorf was approximately €750 per m², or 50% of the average cost of new-build.
- The level of air-tightness achieved varied from project to project, but the average for the schools for which results are available is in the order of n_{50} 0.3 ACH @ 50 Pascal. Readers will note that this is considerably better than the requirement of 0.6 ACH @ 50 Pascal required for Passive House Certification.
- Larger schools tend to have lower surface to volume ratios which makes it easier to achieve the Passivhaus Standard.
- Lastly, reference to the U-values used is not that relevant to Ireland given that all of these projects are built in climates with much colder winters. What is interesting, however, and bearing in mind the above highlighted difference in climates that U-values for the floors (new build) average at approximately 0.15W/ (m²K) and for walls averaging at 0.17 W/ (m²K). It is likely that higher U-values (ie. > .15 W/ (m²K)) could therefore be used in Ireland which would not be too onerous in terms of cost. The average U-value for roofs is found to be considerably lower at approximately 0.11W/ (m²K), highlighting that the insulation of the roof is considerably more critical than the floors.



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Overview of some realized PassiveHouse schools (2005)

www.passivhaus-info.de

	Bremen	Mölln	Ffm. Riedberg	Waldshut	Auf-kirchen	Dinslaken	Baiersdorf (renev.)
gross floor surface	~ 1000 m²	354 m²	~ 5500 m²	~ 5800 m²	~ 3.300 m²	~1.650 m²	~3.030 m²
construction	brickwork	light	reinforced-concrete	reinforced-concrete	light-heavy	heavy	heavy
ventilation	central	central	3 central plants	central	central	central	20 plants
heat delivery	radiator	ventilation	radiator	ventilation	radiator	concrete core heating	wall heating
costs(300+400) [€/m²]	1.202	1.677	1.110	1.845	1.587	1.658	756
n50-Wert [1/h]	0,3	0,38	0,46	k.A.	0,09	0,38	n.n.
A/V	0,48	0,47	0,35	0,29	0,4	0,34	0,65
U-value (D/W/B)	0,11/ 0,13/ 0,14	0,09/0,11 / 0,10	0,11/ 0,17/ 0,21+	0,13/ 0,21/ 0,19	0,10/ 0,18/ 0,15	0,11/ 0,21/ 0,12	~0,20/ 0,17/ 0,16

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passivehouse-school,
Folie 35

Notes on the above table:

The build cost above includes all structural elements, the building envelope and all mechanical and electrical services (and does not include fit-out).

For U values, D = roof, W = wall and B = floor

3.3 Gymnasia and Sports Halls

3.3.1 Key Design Considerations

Preference for Two Temperature zones

The preferred temperature in a sports hall proper is between 18ºC or 19ºC. Higher temperatures would be too warm given the high level of physical activity engaged in by the users. The temperature in the changing rooms and showers, on the other hand, needs to be warmer, perhaps as high as 22ºC. Differences in temperature can be achieved using different means of delivering the required heating.

Plate 3.3.1.1 The ideal temperature in any gymnasium sport hall is 18ºC or 19ºC which is marginally less than that used for the majority of Passive House projects, ie. 20ºC

Plate 3.3.1.2 Warmer temperatures are generally desired in changing rooms, ideally 19ºC.

Requirement for Separate Ventilation Zones

Just as the changing rooms and shower areas require higher temperatures than the sports hall, so too do they require significantly higher air change rates in order to ensure high air quality considering both moisture levels as well as odours from sports clothing and footwear. Furthermore, the volume of space to be ventilated in the changing rooms will be considerably smaller than that of the sports hall.

Alternatively, sports hall ventilation can be used as supply air to changing rooms.

High insulation Reduces Vertical Temperature Stratification

In the case of conventionally insulated high spaces such as sports halls there can often be pronounced vertical temperature stratification, equating to approximately 1°K per 1m height[1]. This results in a 'heat cushion' just below the ceiling which in turn can lead to exaggerated heat losses through the roof. In the case of highly insulated Passivhaus Standard buildings, on the other hand, very even temperatures are found to exist at all heights. The CFD simulations prepared by the Passivhaus Institut below illustrate this effect.

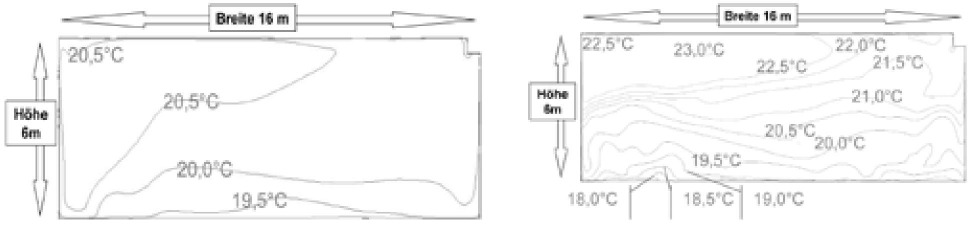

Figure 3.3.1.1 Vertical cross-section through a simple sports hall heated with supply air from the ventilation system. Temperature isolines are shown for a sports hall with a Passive House building envelope (left) and another sports hall built to the German EnEV 2007 ('low energy') standard (right). In the Passive House sportshall, temperature distribution is very even. Assumptions: outside temperature 0°C; heating with supply air from the upper left

Source: Passivhaus Institut Dr. Wolfgang Feist – 'Conditions and planning aspects of Passive House gymnasiums'. Oliver Kah, Jürgen Schnieders in Conference Proceedings of 13th International Passive House conference, Frankfurt, Germany

Benefit of Thermal Mass

High thermal mass is beneficial in gymnasia in terms of modulating the effects of solar gains and internal peak loads and will reduce temperature fluctuations more so than would a light-weight construction. The effect of this is illustrated in the graph below. The Passivhaus Institut notes that the benefit of high thermal mass in gymnasia is less beneficial than in schools (due to the lower internal peak loads in the former).

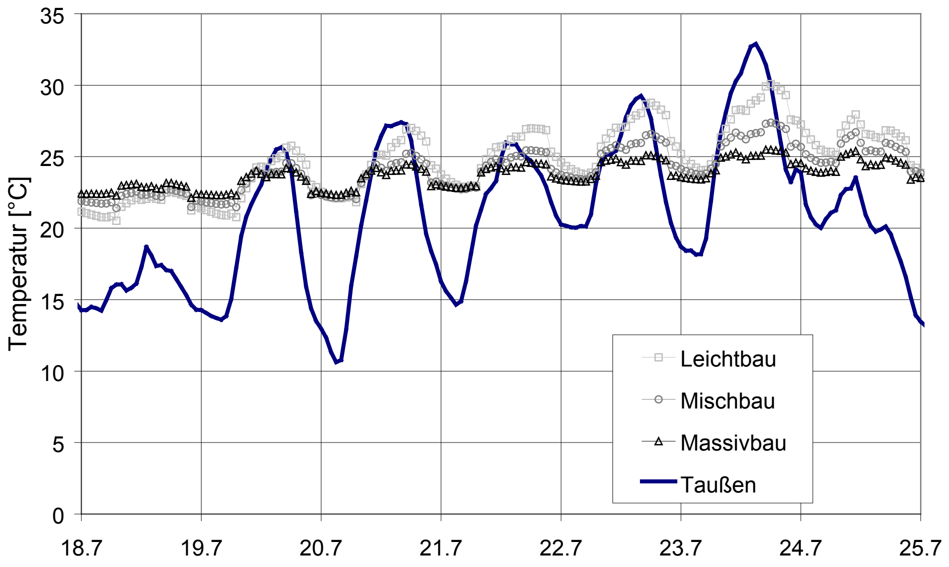

Figure 3.3.1.2 room temperature over time for heavy construction, mixed construction, and lightweight construction in a Passive House gymnaisum during a hot week. External sun shades and night ventilation can be used to maintain comfortable temperatures in the summer

Note: 'Leichtbau' = lightweight construction, 'Mischbau' = mixed construction and 'Massivbau' = thermally-massive construction

Source: Passivhaus Institut Dr. Wolfgang Feist – 'Conditions and planning aspects of Passive House gymnasiums'. Oliver Kah, Jürgen Schnieders in Conference Proceedings of 13th International Passive House conference, Frankfurt, Germany

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[1] Some of the specific recommendations in this text are derived from the paper titled Conditions and planning aspects of Passive House gymnasiums, written by Oliver Kah and Jurgen Schnieders of the Passivhaus Institut and published in the Proceedings of the 13th International Passive House Conference, 17th to 18th April 2009

Speed of Construction

Sports halls and gymnasia are often built on the grounds of schools or universities where disturbance by noise and vibration as well as health and safety concerns strongly favour the use of a rapid construction approach, perhaps using off-site systemised techniques.

Cost Considerations

If it is being considered to use a sports hall for other purposes such as a community centre or for occasional theatre or such-like events, a well designed acoustic system will be required which would add significantly to the typical cost of construction.

3.3.2 Mechanical Systems

Sizing of Ventilation System

It is important to size the ventilation equipment appropriately to the typical demands by users. Consider the case where sports halls are also used as community centres for public gatherings. If the ventilation system is sized for potential full occupancy, say catering for 300 persons, the equipment required would be very substantial and would add a significant cost to the project. Besides, such events might represent a small percentage of typical use. In such instances, it would be possible to provide additional ventilation using zero energy ventilation strategies such as openable windows which are triggered by Co_2 levels. The ventilation systems can therefore be sized for typical user numbers, perhaps in the range of 30 to 40 persons depending on the circumstances.

Plate 3.3.2.1 The windows in the top section of this glazed facade can be opened if necessary to provide for cooling when needed

Single or Dual Ventilation Systems

An important distinction has to be made between the air exchange rates in the sports hall section of the gymnasium and that in the changing and shower area. The former is typically of very large volume, requires lower temperatures (perhaps 18^{0}C) and a modest air change rate of perhaps 0.7 times per hour during use. The volume of the latter is considerably smaller, but requires higher temperature (perhaps 22^{0}C) and much higher air exchange rates, perhaps 5 to 10 times during their use, due to the high humidity. A choice has to be made as to whether to use a single MHRV system covering both spaces (sometimes referred to as 'flow-through') or to use two separate systems, one for each space.

In the two Passive House Gymnasia visited by the authors, the former flow-through system was used in the Kalbacher Höhe Primary School, Frankfurt, with the latter used in the sports hall at Unterschleißheim. The advantage of the single system is that there are likely to be cost savings in terms of mechanical plant. However, the air in the gymnasium which is at 18°C might have to be heated up as it passes through to the changing area or, if not, additional radiant heat provided to compensate for the flow-through of the slightly cooler air. If the flow-through concept is used, it is important to consider any requirements of fire regulations.

Positioning of Supply and Extract Grills

The positioning of the fresh air ducts in the sports hall must also be considered as they are typically high ceilinged (7m at lowest point). In the Unterschleißheim project, dynamic modelling carried out in the design phase suggests that the fresh air would typically drop off gently from the point of entry, eventually hitting the floor perhaps five to six metres from the ventilation grill. Accordingly, the fresh air grills in that project were placed at approximately 2.5m above the floor with the extract air grills placed close to floor level to provide maximum turnover of fresh air in the zone where people need it most. In the sports hall at the Passive House Kalbacher Höhe Primary School, Frankfurt, the fresh air is delivered at ground level and drawn through the hall through vents at a higher mezzanine level.

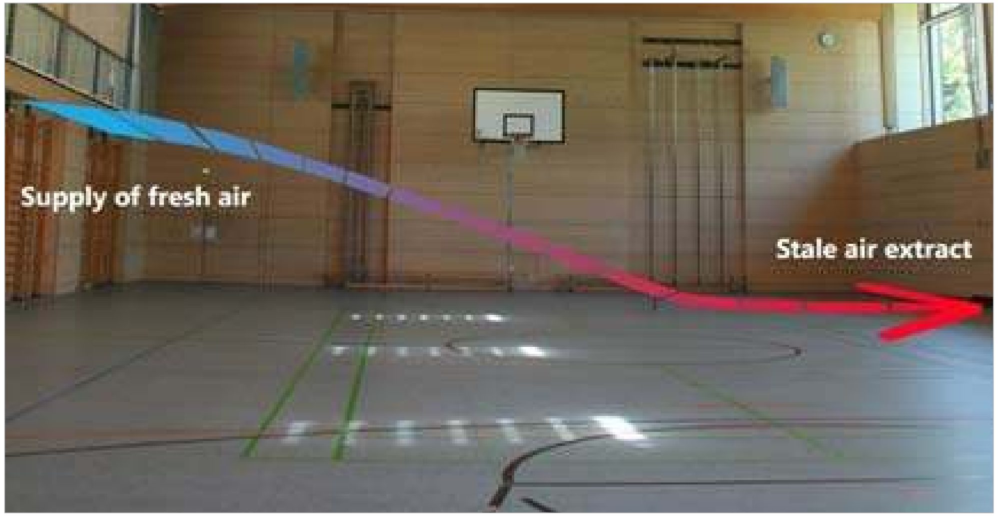


Plate 3.3.2.2 In this sports hall, fresh air is delivered at mid-height of the main hall, and extracted at floor level

3.3.3 Shading and Glare Avoidance

The enjoyment of sports can be significantly compromised if there is too much glare created by light of low incidence which typically arises on both east and west elevations when the sun is lower in the sky. Shading might thus be required to reduce glare, depending on the building design and orientation. Both of the gymnasia visited in the preparation of these guidelines use a very clever strategy to avoid risk of glare, placing the playing surface below ground level with the windows at (a higher) ground level delivering light at an ideal position. The use of a semi-basement also helps to integrate the taller sports hall into its surroundings which might be beneficial in terms of planning considerations.

Excessive glazing on east and west elevations can also result in overheating, particularly in summer, so shading may be required not only to reduce glare but also to reduce overheating and the need for cooling. Micro-perforated blinds can be used to reduce glare and overheating. Another possible strategy is to provide reflected light through roof-lights with grills to avoid glare. Lastly, the colour of finishes used internally can also have a great influence on day lighting (with brighter warmer colours reflecting more natural light) which in turn will affect the degree of artificial lighting used and, accordingly, the primary energy use of the building. The use of such design strategies will be greatly determined by the specifics of the project design as well as site characteristics.

Plate 3.3.3.1(a) and Plate 3.3.3.1(b) External shading can be extended or retracted to control glare for sports activities and to minimise risk of overheating

Plate 3.3.3.2 Natural daylighting can also be provided through energy efficient rooflights, coupled with bris-soleil to reduce overheating when the sun is high in the sky

Plate 3.3.3.3 The internal wooden finish of this gymnasium was finished with a white wash to reflect more natural light within the building

3.3.4 Building Management

Periodic Operation of the Ventilation System

The operational hours of the ventilation system needs to be carefully considered. It would be a waste of energy to have the ventilation system running at full capacity when the building is not occupied (as compared to a dwelling where the system runs 24/7). The ventilation can thus be either shut down completely when the building is not occupied or, preferably, can be run at a very low level reducing energy consumption whilst also providing some minimum air change rate. When considering such strategies, great care must be taken to ensure that there is no risk of mould growth in the filters. The risk of this is higher if the system is completely shut down. The equipment can be automatically programmed to completely dry the filters before shut down, eliminating any risk of mould and therefore reduced air quality. Sports halls are typically used according to a regular and predictable schedule and so the ventilation system can be programmed in advance with minimal manual operation required.

Pre-Flushing

As recommended earlier in relation to schools, in cases where the ventilation system is periodically turned off or reduced in terms of air change rates it is important to operate a pre-flushing phase which will help to (a) freshen up the space in terms of indoor air quality and (b) re-heat the building which might have dropped slightly in temperature. Re-heating the building using such pre-flushing implies that the heat demand is delivered through the MHRV and not through the use of radiators (which is also an option that can be considered). This flushing phase should ideally provide at least 2 complete air changes prior to occupation.

3.4 Apartment Complex

Plate 3.4.0 In this development near Darmstadt, large apartment complexes are being built to the Passivhaus Standard

3.4.1 Key Design Considerations

Passive House apartments differ from all the other building types presented in these guidelines in so far as they are residential in function. The implications of this in terms of Passive House design include the following:

- They tend to be **occupied on a 24 hour seven day a week basis**, unlike schools or offices which can be left vacant for extended periods. High thermal comfort and good indoor air quality are thus required on a continuous basis.
- Individual residents will **expect to have complete control of the temperature of their living space**, as thermal comfort needs differ from person to person. This contrasts with an office, school or shopping centre where an open plan arrangement is more the norm and where the same temperature is generally delivered over the entire complex. Apartment blocks thus require more temperature controls per m^2 than other building types.
- The **treated floor area will be very significantly smaller** compared to all other project types, typically ranging between $65m^2$ and $125m^2$. The heated volume too will be a fraction of that in commercial or public buildings, with lower ceilings and less unused / common / void space. This can impact on such design aspects as the sizing of ventilation equipment, for example (which will be much smaller for individual units than it would be for a large office building).
- On a practical level, the reduced floor area means there may be little room for bulky plant, such as a large solar tank, or for storage of wood pellets for back-up heating. **Domestic hot water and space heating can be provided through a centralised system, however, freeing up valuable floor space**. Remember too that radiators are typically not used in residential projects, maximising useable floor space and removing clutter from beneath the windows.
- Apartment blocks are occupied, and therefore 'managed', by lay-persons who will typically have **little knowledge of Passive House technology**. This can have implications in the first couple of years of occupancy for the maintenance of the heat recovery ventilation equipment, for example, and the need to change the filters periodically. There are solutions to this potential problem, however, such as having a centralised ventilation system where the filters can be changed by the building management company.
- The **occupancy rates tend to be much lower than for offices and schools**, with the default used in PHPP at $35m^2$ per person. This tends to reduce potential internal heat gains purely on the basis of heat generated by humans. This reduction, however, must be balanced with a higher internal heat gain on average per m^2 from the operation of household appliances and the activities of day to day living, such as cooking and washing. On balance, the internal heat gains in residential projects would be marginally less than for schools and considerably less than for offices.
- There tends not to be the same preference or demand for floor to ceiling glass as there might be in an office or retail project, **reducing potential risk of overheating** through unwanted solar gain. An added bonus of this is reduced heat transmission losses through glazing.

Influence of Solar Gain on Space Heat Requirement

Depending upon the design of the apartment block, there might be individual living units which do not have the benefit of solar gain in the heating season (for example single aspect north facing apartments. While such units may well have the same internal heat gains as their south facing counterparts, they will otherwise clearly be at a disadvantage with regards to overall energy balance. This can be compensated with increased insulation which will reduce transmission heat losses, or perhaps through reducing the size of the units such that the internal heat gains on average per m^2 of treated floor area are higher than for larger units.

Inevitably there will be variation in the space heat requirement of different units with different orientations. The same holds true in terms of the actual space heating energy used by individual apartments, however, with some residents preferring it warmer than others, some preferring to leave their windows open, some people being at home all day long and others out during normal office hours. It is possible to test the influence of variation in the temperature of neighbouring apartments in the Heating Load worksheet in PHPP (Row 36 – 'House/DU Partition Wall' which is linked to Cell E26 in the Areas worksheet). This is a useful exercise as it ensures that all units can maintain adequate comfort even in periods when the neighbouring unit(s) might be colder as might occur when the neighbours are on winter holiday and their heating is shut off. It can also be used to test the influence of being located next to an unheated circulation space. The PHPP software uses a default temperature difference for adjacent unheated spaces of $3^{o}C$ which might be considered low but has been found to be adequate due to the high thermal inertia causing temperatures to decrease very slowly. If the adjacent unit is an existing poorly insulated building, a temperature difference of $5^{o}C$ is recommended.

Irrespective of whether individual apartments receive solar gain in the winter, they will always be much more thermally efficient than a standalone detached single family dwelling which suffers the same lack of external solar gains due to the reduced surface area in apartments exposed to the elements.

Regarding design and certification of Passive House apartment projects, it is the entire or overall project that is certified, rather than individual units as per certification criteria on www.passiv.de/07_eng/phpp/Criteria_Residential-Use.pdf.

Maximise Natural Daylighting

In single aspect apartment developments (where a central corridor provides access on both sides to individual apartment units), it is preferable to provide natural daylight to circulation spaces which can also spill-over to the apartments. This will enhance the quality of space for residents and also reduce primary energy consumption with artificial lighting. The Passive House student accommodation complex in Vienna (need to get the name of the Architects) provides a clever example of this, where large roof windows provide daylighting to the corridors in each of the five floors through a series of light shafts as depicted below.

Plates 3.4.1.1(a), (b) and (c) Light shafts in apartment blocks can be designed to provide daylighting for both semi-private circulation space as well as private living space

3.4.2 Mechanical Systems

Centralised versus Decentralised Space Heating and Domestic Hot Water Systems

The majority of non-domestic case studies presented in these guidelines use centralised systems for heating, hot water and mechanical ventilation. In the case of apartments, however, there is a choice to be made as to whether each individual apartment has their own separate system (decentralised) or if a centralised system can be used.
A cost benefit analysis will help to determine whether or not it makes sense to use centralised or decentralised mechanical systems. In continental Europe, district heating is commonplace in which case centralised systems for space heating and domestic hot water generally makes more sense due to the benefit of not requiring a boiler or storage facilities on-site. District heating is less common in Ireland currently, however, so there is not the same automatic presumption in favour of centralised systems.

Consider the scenario presented below between centralised versus decentralised heating systems. In the case of a decentralised system, 50 individual heat generating devices (such as a boiler or a heating coil) would be required, whereas a centralised system would require just one or perhaps two or three modulating heat generating devices for different zones.

Heating system	No. of apartments	Treated floor area	Heat Load	Design No. and size of boilers required
Decentralised	50	100m^2	10 W/m^2	50 no. 1 kW heat generating devices
Centralised	50	100m^2	10 W/m^2	1 no. 50 kW heat generating device

The following factors will have an influence on whether to use a centralised or decentralised system for space heating:

- **Number of living units** – the more units there are in an apartment complex, the more economically viable it is to use a decentralised system (decisions in this regard will be project specific). There may come a point with very large developments, however, where the length of heating pipes is so great that there are significant heat losses. In such cases, it would likely make sense to sub-divide the complex into a number of different zones, each served by a separate modulating heat generating device. Alternatively, the form or shape of the apartment complex might dictate the number of devices to use. In an L-shaped development, for example, two might be used each serving its own zone.
- **District heating** – where available, a centralised heating system would likely make more sense due to the potential to avoid the use of any boilers whatsoever in the project.

- **Delivery of space heating** – there is a choice to be made as to whether to deliver the space heat requirement via a hydronic radiant system using radiators or under floor heating (not common in Continental Europe) or, alternatively, using the mechanical ventilation system. If using the latter system, there are further choices to be made, including whether to use an electrical heat pump or a water to air heat exchanger. A third choice can involve a hybrid system where radiant heat is provided in the bathrooms (for example with a small radiator for extra comfort) in combination with heat provided via the mechanical ventilation system. In all of the above cases with the exception of where a heat pump is used in the mechanical ventilation system, a centralised hydronic heating system is likely to be preferred. These scenarios are presented in the table below. The advantage of using a heat pump in combination with the mechanical ventilation is that there is no need for any external hot water heating system. In this case, each apartment can have total and independent control over its own heating system using, for example a so-called 'compact unit' which incorporates a DHW tank, the mechanical heat recovery ventilation system and a heat pump for heating both DHW as well as heating the air passing around the apartment when needed.
- **Heat exchangers** – if a centralised heating system is being used, heat exchangers will be required irrespective of whether the means of delivering that heat is via radiators, under floor heating of warm air systems.

Plate 3.4.2.1 Compact units such as that depicted above are well suited to apartment projects where space might be limited for more bulky plant

Space heating system	Options for space heat delivery	Likely preferred scenario
1. Hydronic system for radiant heat	Radiators or under floor heating	Centralised
2.Mechanical ventilation system	Water to air heat exchanger	Centralised
	Electric - typically air to water heat pump	Decentralised
3. Hybrid (combination of hydronic and mechanical ventilation)	Radiant heat in the bathroom and elsewhere using the mechanical ventilation system	Combination of both centralised and decentralised

Be aware that option to use individual air source heat pumps must be carefully considered in light of relatively poor efficiencies and the resulting large primary energy overhead.

Domestic Hot Water

The PHPP software uses a default value of 25 litres per person per day for consumption of domestic hot water in residential projects (compared with 12 litres per person per day for office projects). As with space heating demand, the supply of DHW can be provided on a centralised or decentralised basis and using a variety of means of production, including a boiler, heat pump or solar collectors. If using a solar collector system, the Passivhaus Institut recommends designing a system to provide approximately 50% of the anticipated annual demand. While it is technically possible to size a system to provide a higher contribution, the usability of the excess produced in summer is fairly restricted. The recommendation provided in PHPP is to specify approximately 0.5m^2 of south facing solar collectors per person, with a storage tank of 50 litres per person.

Centralised versus Decentralised Mechanical Heat Recovery Ventilation

There are much more factors to consider in choosing between centralised versus decentralised mechanical ventilation systems compared to the above discussion on space heating and domestic hot water. The latter tend to be used predominantly, but there are situations where a centralised system might be considered, the advantages of which are listed below:

- **Centralised management** – with a centralised approach, the entire ventilation system for all living units can be managed and maintained at one location and by one suitably qualified person. This removes the responsibility on individual home owners to maintain their own system, including the periodic replacement or cleaning of filters. This scenario might be especially relevant in social housing projects or in student accommodation or hostels where there might not be the same interest on the part of the occupants to change the filters when needed. There is some concern in the case of social housing apartment projects that residents might even turn off the ventilation equipment as a means to saving money on electricity. A centralised system would remove any risk of this happening.
- **Potential space saving in individual apartments** – heat recovery ventilation systems for apartments will tend to be quite small in size (some of which can even be placed in a ceiling void) but nevertheless do occupy space which might otherwise be saved if a centralised system were used. Any space saving in individual apartments must be considered in light of the significant amount of space needed for a large centralised system, however. The efficiency of smaller MHRV units is improving over time and the advantages concerning space saving is likely to diminish as new and improved products come on the market.
- **Reduced primary energy consumption** – A single MHRV system for multiple living units will use less primary energy than multiple individual systems. This is especially the case for very small living units (such as student accommodation facilities) where the individual air flow volumes might be very low and where one large plant could easily provide the needs for the entire complex.

Plate 3.4.2.2 Decentralised MHRV system in apartment ceiling void during construction

Plate 3.4.2.3 Bulky centralised MHRV systems require considerable floor space

The disadvantages of a centralised MHRV system may well outweigh the advantages, as listed below:

- **Fire compartmentalisation** – if a centralised mechanical ventilation systems is used, there must be special fire protection measures in order to eliminate risk of spread of flame or smoke between each living compartment (depicted below). Such measures can significantly increase the cost of the overall system.

Plate 3.4.2.4 Fire compartmentalisation devices in centralised ventilation systems

- **Additional controls** – despite their being a centralised MHRV plant, each individual homeowner must still be given control of their system such that they can alter the flow rate depending on their needs (for example, low rate when they are on holidays, high rate if they have a lot of guests or otherwise medium in normal circumstances). The cost of providing these controls might well offset any savings made on using one centralised plant.
- **Sound attenuation** – there is likely to be an increased complexity in the design of the system to ensure that sound does not travel between individual living units, adding further to the cost of the system.

3.4.3 Shading

The Passive House design considerations for apartments in respect to shading will generally be quite similar to that recommended for single family dwellings. However, in situations where an apartment has just one external façade, there will be probably be a need to maximise the proportion of glazing in order to provide sufficient day lighting for the residents. The area of glazing must, of course, be considered in respect of maximising solar gain and natural daylighting while also minimising overheating and transmission heat losses. The PHPP analysis will guide the designer into optimising these considerations.

It is often easier to accommodate shading to apartment complexes than it is to other building types such as offices or schools due to the typical need for balconies as amenity space or for external access on dual aspect units (see examples below).

Plates 3.4.3.1 Balconies often serve dual purpose in providing both access to external space as well as providing shading to south-facing windows

In situations where balconies are not possible or appropriate, there are other means of providing shading such as using blinds which have been shown earlier in relation to offices (but which are not commonplace in Ireland), or using external shutters such as on the Vienna student accommodation complex depicted below.

In many situations, there will not be a need for any shading and this will be accurately predicted by the PHPP analysis.

Plates 3.4.3.2(a) and (b) Sliding copper shutters manually operated from inside add a dynamic character to this Passive House student accommodation complex in Vienna city

3.4.4 Building Management

Management of apartment buildings is considerably different to that of, for example, offices or schools insofar as they are used as accommodation for families or individuals on a 24 hour basis. Each living unit must generally provide individual control of the key services required for optimising comfort, including space heating and mechanical ventilation. It has been explained earlier that these services can be provided either on a centralised or decentralised basis, with the former placing responsibility for management and maintenance with the facility manager and the latter being operated directly by the occupant. In the case of social housing or student accommodation, it might be beneficial to use a centralised system that is managed by a third party, whereas private accommodation might well be best managed by the home owners. In any event, the management of Passive House apartments will tend to be simpler than for public buildings such as schools or offices due to the lower internal heat gains and their use on a 24 hour basis (without the need for shutting down systems at night such as happens in offices and schools).

The key design challenge for management of Passive House apartment buildings is to make the operation of the Passive House extremely simple for the homeowner. The controls should be user friendly. The control depicted below, for example, allows the homeowner to set the temperature of the apartment as well as the ventilation rate and will also indicate when the filters need to be changed and if there is a high concentration of $C0_2$.

Plate 3.4.4.1 Typical control unit for MHRV in an apartment which will inform the home owner when the filter needs to be replaced

Circulation Space

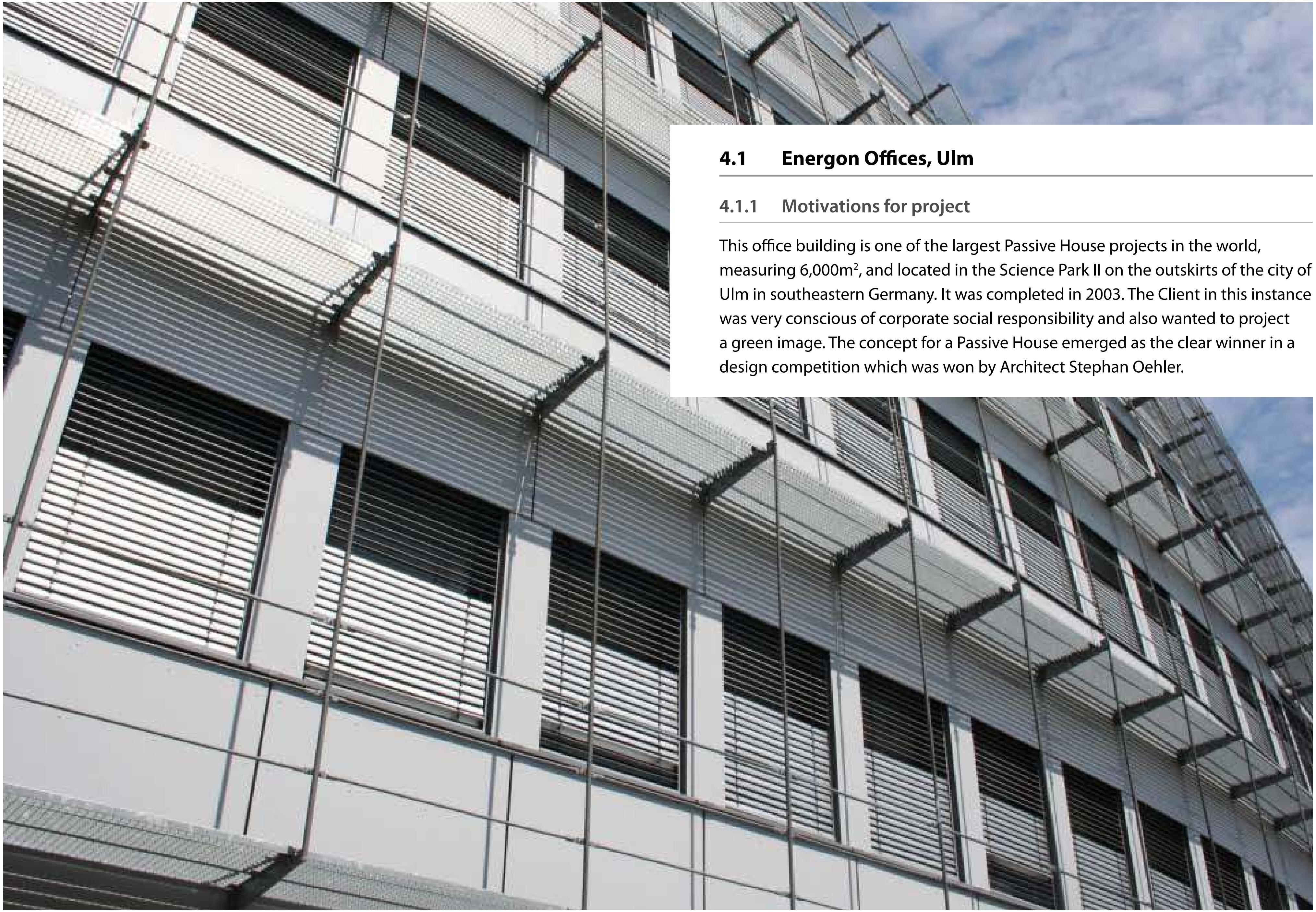
An important issue to consider in apartment buildings is the maintenance and management of circulation spaces. In many projects, stairwells and lift shafts are left out of the Passive House envelope and are treated as external areas in terms of heating and ventilation (this is true also in some Passive House office buildings). In other words, they are neither heated nor mechanically ventilated. If this strategy is employed, it is crucial that the adjoining accommodation space is thermally separated from these other 'cooler' spaces in order not to create thermal bridging, drafts or exaggerated heat losses. This approach will not suit every project, but it should be considered as an option at the concept design stage as it will reduce considerably the energy use of the overall development. Due to the compactness of apartment buildings, such unheated spaces tend not to get too cold and so are regarded as acceptable buffer zones by the residents.

Common Areas

In many apartment buildings there will be common areas (such as reception space, toilets, lobbies, corridors, crèche, meetings rooms and leisure facilities) which will need to be heated, lit and mechanically ventilated using systems separate to that of the individual residences. These spaces must all provide a high level of thermal comfort and good air quality. It is best to cluster such spaces if at all possible (whether horizontally beside each other, or vertically above and below each other) so that the heating and ventilation services can be provided on an efficient zoned basis. This will reduce the number of individual mechanical systems that have to be maintained and managed. Some of these spaces will be infrequently used, and the ventilation system can be controlled by presence detectors or by a Co$_2$ sensor instead of them constantly operating and wasting energy. In such spaces, it might be preferable to provide the back-up heating required using radiators which are familiar to most people and are easily controlled to provide an instant boost of temperature if required.

4

Completed Case Study Projects



4.1 Energon Offices, Ulm

4.1.1 Motivations for project

This office building is one of the largest Passive House projects in the world, measuring 6,000m^2, and located in the Science Park II on the outskirts of the city of Ulm in southeastern Germany. It was completed in 2003. The Client in this instance was very conscious of corporate social responsibility and also wanted to project a green image. The concept for a Passive House emerged as the clear winner in a design competition which was won by Architect Stephan Oehler.

4.1.2 Key design features

Contemporary Facade

The building is designed in a compact triangular shape (Figure 4.1.2.1 (plan) and Figure 4.1.2.2 (section)) consisting of three curving facades (Plate 4.1.2.1) with a central atrium (Plate 4.1.2.2). The facades curve in section also (Plate 4.1.2.3), creating a relaxed massing. Whilst the external wall system is constructed of timber frame, it is finished with metal cladding which gives a high-tech contemporary appearance, entirely suited to the innovative research and development work that is carried out there.

Contemporary and kinetic facade

Unlike many modern offices which comprise floor to ceiling windows throughout, the proportion of glazing to opaque façade is tightly controlled in this building to optimize the balance between maximizing natural daylighting and minimizing overheating and the need for cooling. A dynamic external shading system helps to keep the building cool and changes the appearance of the building throughout the day. The offices on each floor have a single aspect either with an external window or an internal window opening onto the atrium.

4.1.3 Mechanical Systems

Dynamic shading system

As has been discussed in Section 2 above, the principal challenge for most offices is to minimise the cooling load due to overheating in summer by a combination of internal heat gains and external solar gains. The highly insulated envelope, triple-glazing and airtight construction go a long way to reduce unwanted external heat gains. However, a clever shading system is also used on this project which reduces unwanted solar gain. The shading is automatically controlled by solar irradiation sensors on each facade. When fully extended, the shades are partially open at the top but fully closed at the bottom (Plate 4.1.3.1). This strategy provides natural light at a high level deep into the office, whilst also eliminating glare at the desk level. The automated system can be overridden by the office occupants, but will revert to the optimally programmed position after a pre-determined time (in this case two hours).

Figure 4.1.2.1 (plan)

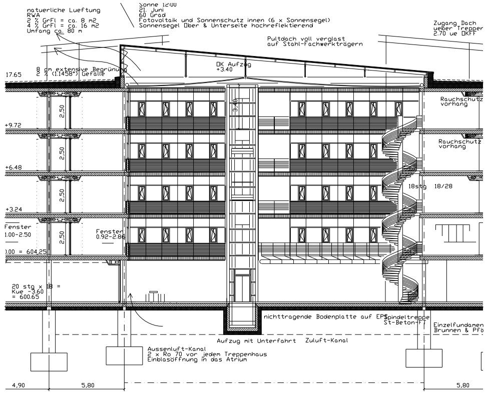


Figure 4.1.2.2 (section)

Plate 4.1.2.1

Plate 4.1.2.2

Plate 4.1.2.3

Plate 4.1.3.1

Concrete Core conditioning (CCC) using geothermal boreholes

This office building is cooled using a series of 40 geo-thermal boreholes which deliver 'cool' water (18°C) to the concrete floors at each level. The ground temperate at an average of 10°C cools the circulating water to 15°C which in turn is mixed with warm water to 18°C before entering the concrete core so that there is no risk of condensation. The cooling demand for the entire office is provided just by one 3.5kW pump (Plate 4.1.3.2) used to power the concrete cooling system.

Minimal heating requirement

In terms of heating, if the external temperature is greater than 5°C, there is no need for active heating. If the external temperature goes between 5°C and –5°C, the waste heat from the server rooms and kitchen extract is sufficient to heat the entire building. If the external temperature goes below –5°C heating is provided by connection to the district heating system.

Ventilation strategy

The fresh air demand for this building is so huge (28,000m^3/hour at full occupancy, reduced to 4,000m^3/ hour when unoccupied) that it is possible to walk upright inside the air intake duct! The majority of fresh air is delivered centrally to the atrium space which also serves internal offices (Plate 4.1.3.3) through louvered vents (Plate 4.1.3.4). Offices located on the external facade have their own 'active' decentralised supply. All extract air from the building is drawn from the central corridors at each floor.

Plate 4.1.3.2

Plate 4.1.3.3

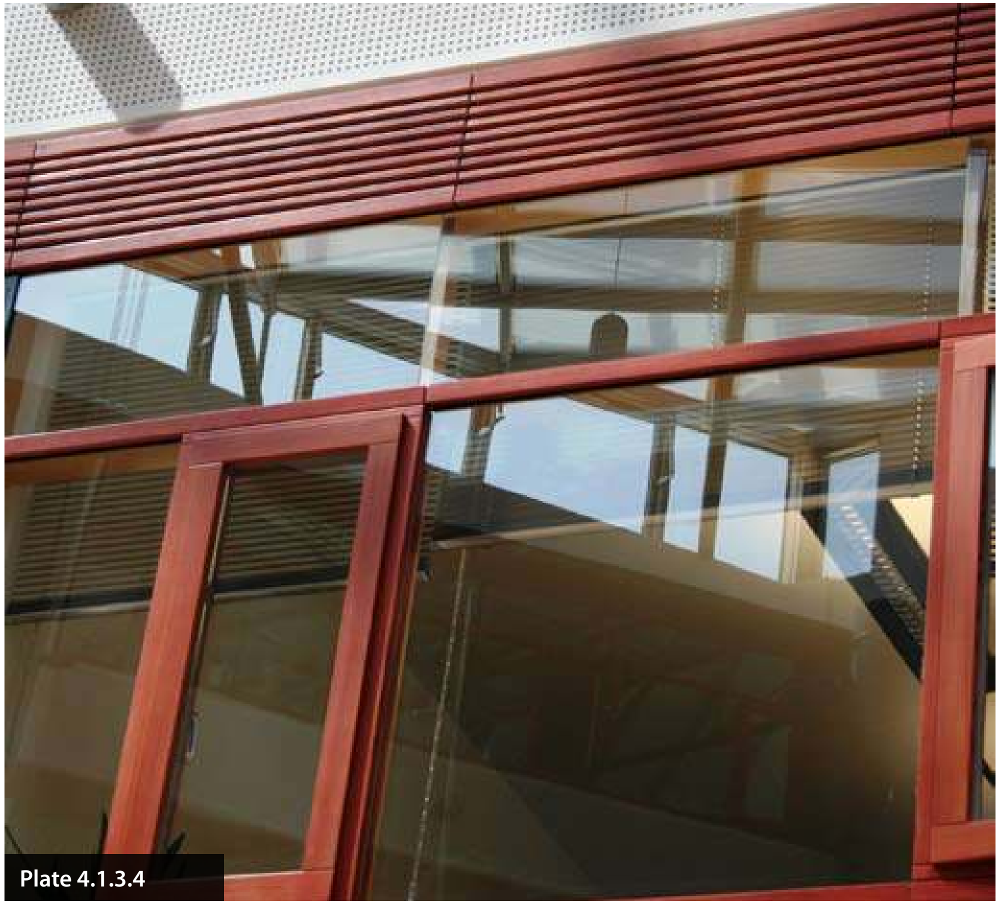


Plate 4.1.3.4

4.1.4 Perceived Benefits of the Passive House Standard

The energy savings being experienced at this project are hugely impressive. Heating and cooling costs for conventional buildings in this region are approximately €10 to €15 per m^2 per year. In the case of this office, however, the cost is between €2 to €3 per m^2 per year, representing a saving of approximately 80%. The total build cost for the office was approximately €1,650/m^2 which is 20% less than the average cost for offices at the time when it was built.

> ***"The payback from this project was from day 1 – the owner will never build 'normal' again"***

4.1.5 Lessons learned and guidance for future projects

This building was originally designed for a single occupant, with a staff complement of 400 persons all engaged in typical office duties. As a result of this, the design consisted of a single heating and cooling zone for the entire building. In practice, the building is used by a number of different companies, some of which are engaged in research and development with the result that different floors have different heating and cooling loads. A more flexible system with separate cooling and heating zones would thus be advisable in future projects.

The wind speed sensor controlling the external shading has tended to be a little overly 'sensitive', retracting the shades when perhaps they could safely be left extended. Lastly, the air handling system used by the kitchen and canteen represents approximately one third of the total air volume for the building. In the future, perhaps there will be more efficient means by which kitchens can be ventilated as a proportion of the entire building (Plate 4.1.5.1). In some non-domestic projects, the kitchens are used only for reheating food that has been cooked elsewhere and which may not require separate air-handling systems. In cases where a fully operational kitchen is required, then separate heat recovery is important perhaps using an induction hood (which works with lower volumetric flow rates).

Plate 4.1.5.1

Factual summary overview:

Project type	**Office**
Treated floor area in PHPP	5,692m^2
Annual heat requirement (delivered energy)	PHPP = 12.5 kWh/(m^2a)Measured = 17 kWh/(m^2a)
Year of construction	2003
Project Team	
Architects	Stefan Oehler, Bretten Ebok Tubingen, FP7 Stuttgart
Mechanical Engineers / Building Services Planning	Ebok Tubingen, FP7 Stuttgart
Other important design team members	Passivhaus Dienstleistung GmbH
Construction Details	
Construction type (for example, timber frame, concrete…)	Concrete skeleton with timber frame facade
Exterior wall U value insulation thickness and type	0.13 W/(m^2K), 350mm of mineral wool type
Roof U value insulation thickness and type	0.12 W/(m^2K), 400 – 700mm of cellulose
Floor U value insulation thickness and type	0.22 W/(m^2K), polyurethane
Glazing details	U_g = 0.7 W/(m^2K) g-value = 50%
Ventilation Details	
Air-tightness	n_{50} = 0.20h
Ventilation equipment used	Air is preheated in earth tube (42% efficient) and heat recovery from waste air is 64% efficient
Ventilation rate:	Centralised distribution of fresh air through the atrium
Means of controlling ventilation rate	Time clock
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	Unknown
Type of back-up heating system used	District heating powering a concrete core heating system (26°C)
Cooling load per m^2	Unknown
Method of cooling used	Chilled concrete floor powered from geothermal tubes (18°C)
Domestic hot water production	From district heating (only required in the kitchen)
Renewable energy production	Photovoltaic panels producing 850 kWh per year
Construction and Energy Costs	
Cost of construction (not including cost of land)	€1,680 / m^2
Estimate on additional ('extra') costs over conventional cost for construction	Lower! Approximately 80% of ordinary office buildings
Typical annual energy costs (only for space heating and / or cooling)	€2.50 / m^2

4.2 Lu-Teco Offices Ludwigshafen

4.2.1 Motivations for project

The office facility based near the banks of the Rhine in Ludwigshafen is the largest Passive House building in the World, measuring approximately 10,000m^2 in floor area (Plate 4.2.1.1).

Photo 4.2.1

4.2.2 Key design features

Overall form

These offices consist of three blocks each connecting to a lateral spine on the northern side (Figure 4.2.2.1 (plan) and 4.2.2.2 (section) and Plate 4.2.2.1 and Plate 4.2.2.2). Two south facing courtyard spaces are created between the three blocks (Plate 4.2.2.3), with green canopies protect the south-facing glazed areas from overheating. This design strategy reduces the area of south facing glass and creates overshadowing for a high proportion of the windows, reducing unwanted solar gain.

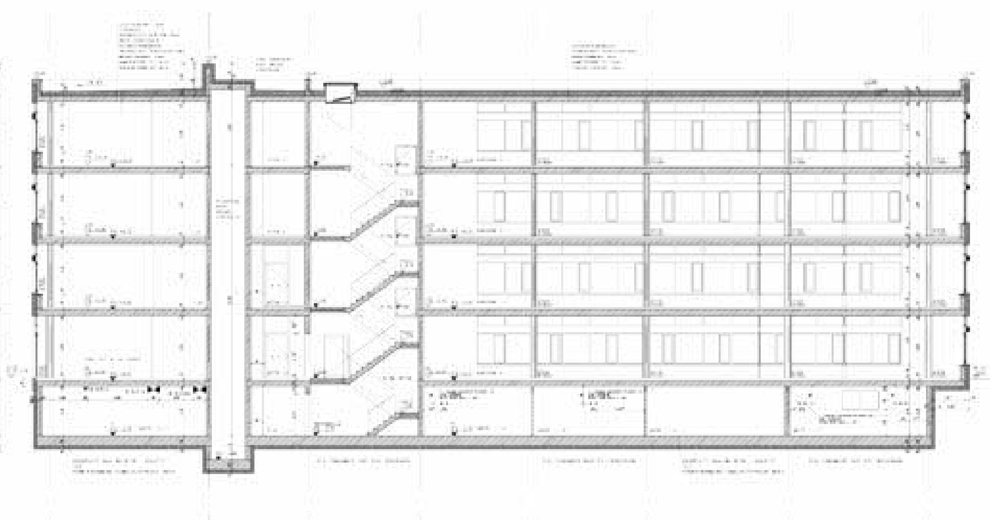
Flexible occupancy layout

This office was purposely designed in order to cater for different tenancy occupation arrangements. Mechanical services were installed so that each floor could be subdivided in a number of layouts while still ensuring that individual tenants would have control of the ventilation, heating and cooling of their own space. This flexible approach is critically important when designing office buildings.

Cost efficient finishes

The overriding influence on the planning of this project was achieving the Passive House standard within the budget of a typical office block. The design team focused on investing in energy efficient design rather than on exorbitant finished and materials. That said, the quality of finished is very high and there is no sign of compromise having been made anywhere.

Figure 4.2.2.1 (plan)



4.2.2.2 (section)

Plate 4.2.2.1

Plate 4.2.2.2

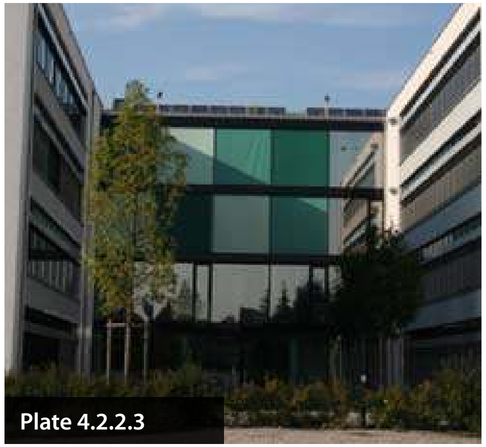


Plate 4.2.2.3

4.2.3 Mechanical Systems

Geothermal concrete heating and cooling

Each of the three blocks are heated and cooled in a similar way to the Energon offices described above using ground source heat pumps located in the basement. Each of the heat pumps is served by 13 boreholes.

Decentralised ventilation system

In terms of the mechanical ventilation system, a decentralised approach was used on this project, different to that used in the Energon building which was centralised. The ventilation equipment for each space is positioned on an external wall, and can be identified externally by the intake and extract vents (Plate 4.2.3.1). The ducting system was left exposed in most of the office spaces (Plate 4.2.3.2) to reduce costs and to facilitate easy access if required.

The air flow rate in each office is controlled automatically by CO_2 sensors, eliminating the need for manual or time-clock control.

Server rooms

The only air conditioning required in the building is for the server rooms. The amount of cooling units involved is a tiny fraction of that typically required for conventional air-conditioned offices (Plate 4.2.3.3).

Vacuum insulation panels and solar shading

Very thin yet highly efficient vacuum insulation panels were used in the glazing section of the exterior fabric to the rear of the housing for the retractable shading device (Plate 4.2.3.4). Above this is a high level shallow window with no shading (allowing light to penetrate deep into the office). Below this, the glazed section can be protected from excessive solar gain by variable louvered shading. The operation of the louvers is automatically programmed by an external solar sensor (Plate 4.2.3.5).


Plate 4.2.3.1


Plate 4.2.3.2


Plate 4.2.3.3


Plate 4.2.3.4

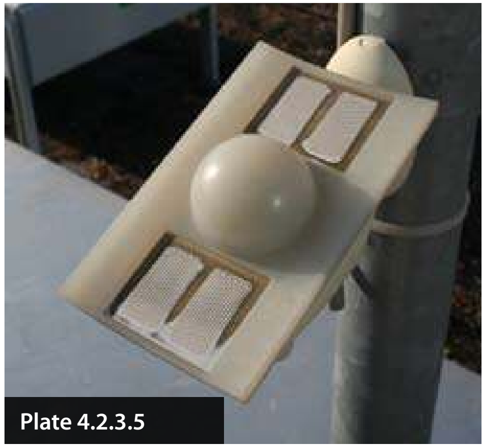


Plate 4.2.3.5

4.2.4 Perceived Benefits of the Passive House Standard

The Lu-Teco offices are fully occupied, despite the trend in the region for vacancy rates as high as 25%. The offices were constructed at no additional cost compared to conventional build, yet save approximately €150,000 per year on heating and cooling costs. Without doubt, therefore, the project has been a commercial success and this is primarily due to the Passive House standard being adopted from the very outset.

> ***"Our tenants love to see the oil price rising!"***

4.2.5 Lessons learned and guidance for future projects

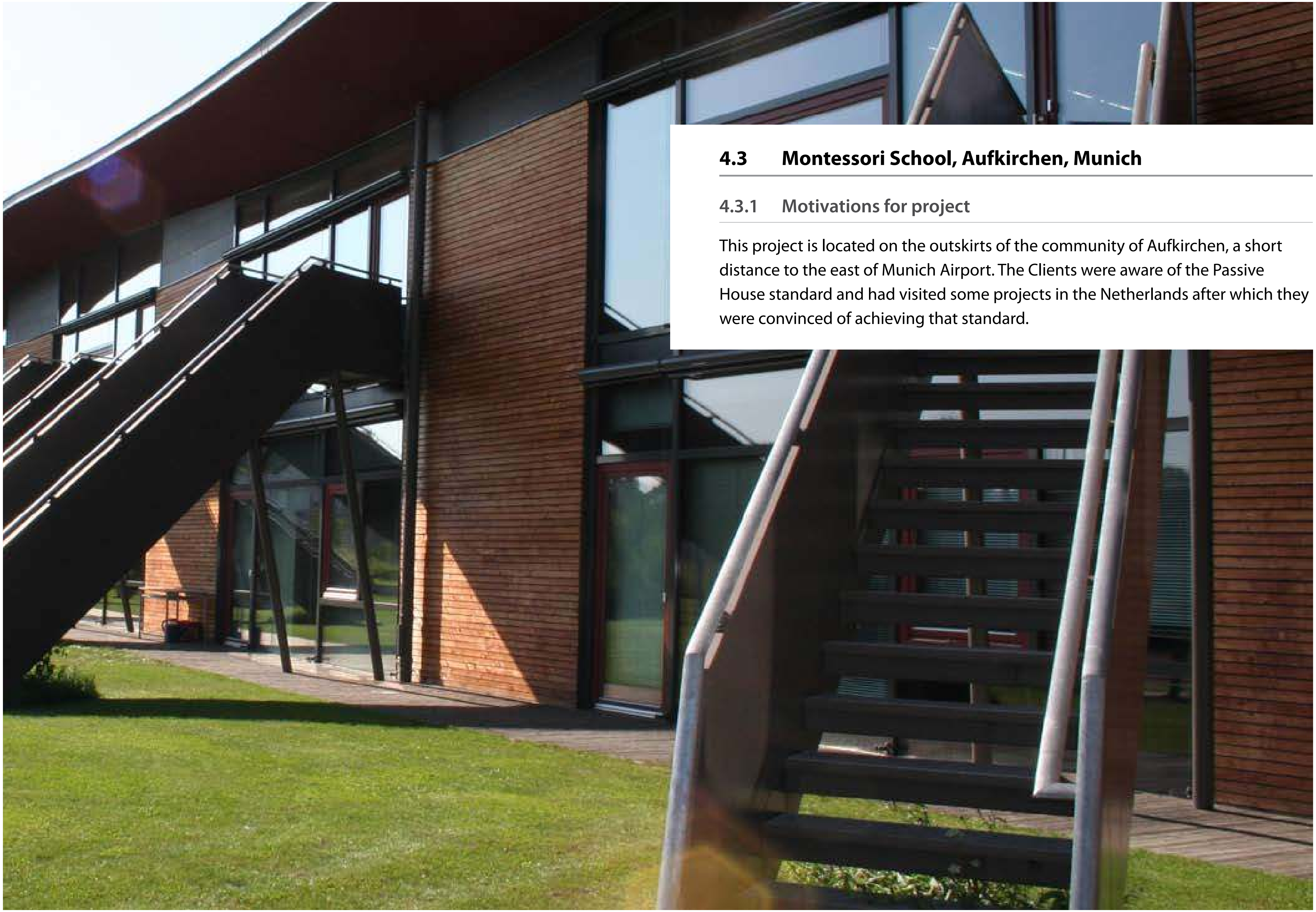
Factual summary overview:

Project Description	
Project type	Office
Treated floor area in PHPP	9,823m^2
Annual heat requirement (delivered energy)	PHPP = 12 kWh/(m^2a)
Year of construction	2007
Project Team	
Architects	Architekturbüro Lutz Laier
Mechanical Engineers / Building Services Planning	IBB Büro Baumgartner
Other important design team members	Passivhaus Institut
Construction Details	
Construction type	Masonry
Exterior wall U value insulation thickness and type	0.137 W/(m^2K), 200mm of 0.035 W/(mK) insulation conductivity
Roof U value insulation thickness and type	0.113 W/(m^2K), 300mm of insulation
Floor U value insulation thickness and type	0.226 W/(m^2K), 160mm of 0.044 W/(mK) insulation conductivity
Window frame details	U_f = 0.9 W/(m^2K)
Glazing details	U_g = 0.6 W/(m^2K) g-value =50%
Ventilation Details	
Air-tightness	n_{50} = 0.20/h
Ventilation equipment used	Vallox equipment, heat recovery 75% efficient
Average air change rate	Decentralised system (each zone 200 – 300m^2)
Means of controlling ventilation rate	Decentralised system controlled by CO_2 sensors
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	10W/m^2
Type of back-up heating system used	3 geothermal heat pumps, each with 13 boreholes
Cooling load per m^2	Unknown
Method of cooling used	Chilled concrete floor, additional cooling achieved through shading
Domestic Hot Water production	Centralise hot water system not provided due to low usage
Renewable energy production	Photovoltaic panels producing XXXXkWh per year
Construction and Energy Costs	
Cost of construction (not including cost of land)	XXXX € / m^2
Estimate on additional ('extra') costs over conventional cost for construction	X%
Typical annual energy costs (only for space heating and / or cooling)	XXXX € / m^2
Miscellaneous	

4.3 Montessori School, Aufkirchen, Munich

4.3.1 Motivations for project

This project is located on the outskirts of the community of Aufkirchen, a short distance to the east of Munich Airport. The Clients were aware of the Passive House standard and had visited some projects in the Netherlands after which they were convinced of achieving that standard.



4.3.2 Key design features

The principal architect for this project, Gernot Vallentin, aimed to create a Passive House school which was simple in design and detailing, yet also dynamic and highly expressive and, most importantly, could be built at no greater cost than a conventional school. Each of these objectives was achieved with ease as will be seen from the description and images below.

In terms of overall massing, a compact form was sought which would maximise energy efficiency. In terms of aesthetics, however, a rolling green roof which connects at both ends with the surrounding landscape as well as a curving plan provided the overall concept for the building (Figure 4.3.2.1, Figure 4.3.2.2 and Plate 4.3.2.1). As a result of the above design approach, every classroom room is a different shape creating a strong sense of identity for individual classes.

The architect approached the building design using the classic principles of Passive House, orientating the longest axis of the building to the south. Classrooms in this two storey school face to the south, with corridors, utility rooms and toilets to the north (Figure 4.3.2.2 and Plate 4.4.2.2). From the very outset the overriding objective was to keep the design and detailing very simple, therefore minimizing cost of construction. Thermal mass is achieved using an internal masonry skeleton clad with a timber frame exterior shell.

An interesting design feature of this school is the individual external stairs provided from each of the first floor classrooms directly to the school garden below (Plate 4.3.2.3). Incorporating these stairs resulted in very significant savings in terms of fire protection measures that would otherwise be required. Note: Strategies such as this need to be verified for compliance with Building Regulations in force in each jurisdiction.


Figure 4.3.2.1

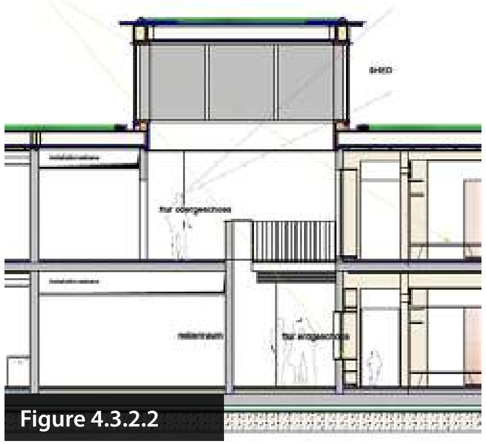


Figure 4.3.2.2


Plate 4.3.2.1


Plate 4.4.2.2


Plate 4.3.2.3

Natural daylighting is provided to internal circulation space through four massive west facing rooflights (Plate 4.3.2.4 and Plate 4.3.2.5).

4.4.3 Mechanical Systems

The mechanical systems required for this school cost approximately €150,000 less than would be required for a conventional school. The money saved was invested on upgrading the windows to Passivhaus Standard as well as additional insulation.

Heating is provided by a combined heat and power (CHP) unit (Plate 4.3.3.1), the smallest available on the market, in combination with a condensing gas boiler. The heat is delivered to the classrooms using conventional radiators, not something you see in every Passive House. The principal advantage of using radiators was the ease of control by the teacher in each classroom.

In terms of ventilation, each room is provided with fresh air through a long ceiling grill which is positioned overhead the transition from what is the main body of the classroom to a project work space and cloak room (Plate 4.3.3.2). The extract air is drawn from the cloakroom area which helps to keep the air in the room dry on wet days when outdoor clothes might be damp. This extract air is drawn out through a combination of a ceiling grill directly to the MVHR unit ('active') as well as 'passively' through an opening to the central corridor (Plate 4.3.3.3). Using the latter technique, all of the classrooms ventilate through the open space to be extracted at a central point.

A dual shading system is provided on the floor to ceiling glazing in each of the classrooms. The function of the external shading is primarily to reduce potential overheating, whereas the internal blinds are used to prevent unwanted glare for students (Plate 4.3.3.4).

4.3.4 Perceived Benefits of the Passive House Standard

The key benefits for the owners and occupants of the school is the high level of comfort and air quality, not to mention the significant cost savings from reduction of energy use. The mechanical systems were designed so that teachers have full control of the air flow, temperature and daylighting in their classrooms. They thus feel 'connected' with and in control of the building.

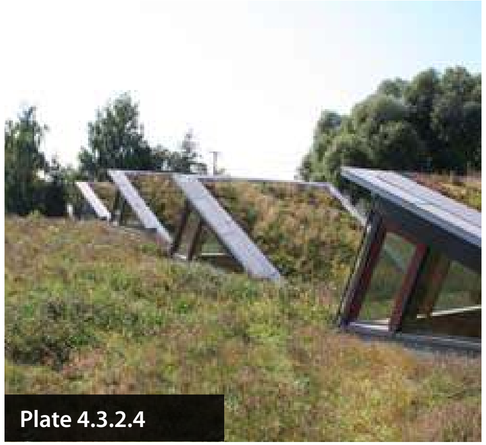


Plate 4.3.2.4

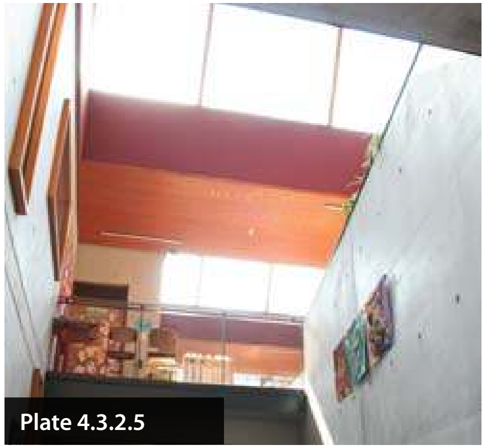


Plate 4.3.2.5

Plate 4.3.3.1

Plate 4.3.3.2

Plate 4.3.3.3

Plate 4.3.3.4

> **“The students no longer complain about the building, they only complain about the teachers! :-)**
>
> School Principal

4.3.5 Lessons learned and guidance for future projects

The Architect is very satisfied with the overall design concept of compact form, southern orientation and simple detailing. There were some difficulties initially with the automated control of the external shading system resulting in occasional overheating. This school was one of the first Passive House schools in Germany (the first was built in Bremen) and as such was somewhat experimental in its design. It was designed and built according to principles of Passive House schools developed by the Passivhaus Institut, is working extremely well, and the occupants are very happy with its performance. The use of thermal massing internally has prevented any need for active cooling. In summary, this project perfectly demonstrates that Passive House projects can be comfortable, expressive and affordable to build.

Project Fact file

Project Description	
Project type	School
Treated floor area in PHPP	3,275m^2
Annual heat requirement (according to PHPP) (delivered energy)	PHPP = 12kWh/(m^{2}a)
Year of construction	2004
Project Team	
Architects	Architekturbüro Vallentin | 84405 Dorfen Architekturbüro Grotz, 85435 Erding Walbrunn Architekten , 85461 Emling Reinhard Loibl, 85345 Freising
Mechanical Engineers / Building Services Planning	Ing. Büro Lackenbauer
Building Physics planning	Fraunhofer Institut, 83607 Holzkirchen
Construction Details	
Construction type	Mixed construction (timber and masonry)
Exterior wall U value insulation thickness and type	0.176 W/(m^{2}K), 280mm of cellulose insulation
Roof U value insulation thickness and type	0.102 W/(m^{2}K), 406mm of cellulose insulation
Floor U value insulation thickness and type	0.146 W/(m^{2}K), 120mm +120 mm of XPS insulation
Window frame details	U_f = 0.805 W/(m^{2}K)
Glazing details	U_g = 0.75 W/(m^{2}K) g-value = 51%
Ventilation Details	
Air-tightness	n_{50} = 0.09/h
Ventilation equipment used	Robatherm manufacturer, rotationswärmetauscher ⌧ 8000 m^3 machine
Average air change rate	30 m^3/h x person when occupied 15 m^3/h x person when not occupied
Means of controlling ventilation rate	Manual setting
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	9,9 W/m^2
Type of back-up heating system used	Combined heat and power unit (12 kW+5 kW electric)+ gas-fuelled condensing boiler (60 kW)
Cooling load per m^2	Not required
Domestic hot water production	Combined heat and power unit
Renewable energy production	Nil
Construction and Energy Costs	
Cost of construction (not including cost of land)	€1,587 / m^2
Estimate on additional (‘extra’) costs over conventional cost for construction	Nil
Typical annual energy costs (only for space heating and / or cooling)	1.92 € / m^2

4.4 Kalbacher Höhe Primary School, Frankfurt

4.4.1 Motivations for project

During a design competition held for primary schools in the Frankfurt Region in 2000 / 2001, a decision was taken to build three schools to the Passive House Standard. Ahead of construction, a cost benefit analysis by both the school board as well as the municipal authorities concluded that the additional cost to achieve the Passive House Standard over and above a 'low energy standard' was likely to be in the order of 5.3% which would be amortised over a 10 to 20 year period. This project at Riedberg was opened in November 2004 and is reported as the first primary school in Germany built to the Passive House Standard (Plate 4.4.1.1 and Plate 4.4.1.2).

Plate 4.4.1.1

Plate 4.4.1.2

4.4.2 Key design features

The project comprises a primary school, kindergarten and gymnasium with full commercial kitchen and cafeteria. There are 16 classrooms serving 400 primary school children, with an additional 120 children in the kindergarten and an adult complement of approximately 50. The two storey building is designed in a south-facing horseshoe form enclosing a central courtyard and playground (Figure 4.4.2.1 and Plate 4.4.2.1).

4.4.3 Mechanical Systems

Ventilation

The ventilation system when fully operational delivers approximately 8,000m^3 per hour costing in the region of €500 per year to operate. The ventilation system is only operated during the heating season, which is in the order of 100 days during the year. Outside of this, the MVHR is shut down (with the exception of toilets which have no openable windows) in order to reduce primary energy consumption with fresh air being provided through openable windows and openable vents. The air exchange rate during full occupancy is 2/h. In rooms which are infrequently used (such as staff rooms or the hall) CO_2 or mixed gas sensors control the volumetric flow regulator (Plate 4.4.3.1). Similar to the Aufkirchen Montessori School, a centralised air exhaust system through the corridors is used.

Summer night cooling

Classrooms have high internal (25 students) and external thermal loads (15m^2 of glazing with 15% irradiation producing 60 – 80 W/m^2). The heat thus has to be stored during the day, and dissipated during the night. Each classroom is fitted with two thermostatically controlled night air flaps (Plate 4.4.3.2) which open when required and direct airflow into the corridors and up through roof windows. These flaps (measuring 1m^2 per classroom and opening if the temperature exceeds 26^{0}C) provide night air cooling and can be used in combination with active night cooling using the ventilation system running with the summer bypass in operation. Furthermore, the extract ducts terminate at a high point in the building and can be left open to create a 'passive' stack effect.


Figure 4.4.2.1


Plate 4.4.2.1

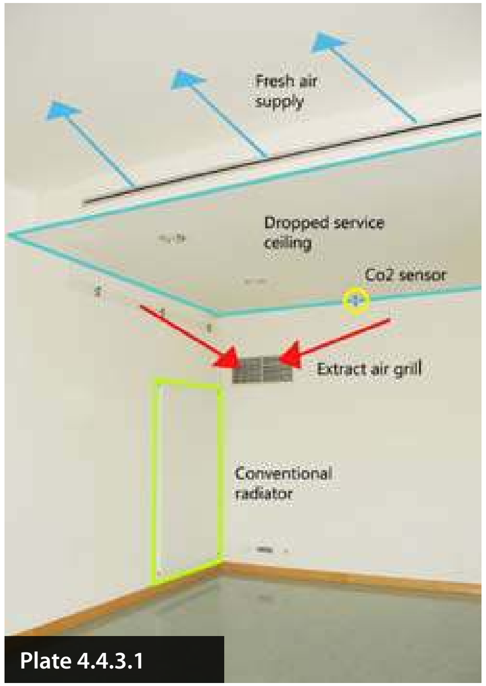


Plate 4.4.3.1


Plate 4.4.3.2

Heating system

Two 60kW wood pellet boilers are used to supply the heating for the entire complex (Plate 4.4.3.3). The system consumes 25 tonnes of pellets per year, and the ash has to be emptied just once annually. A simple system of small but high temperature radiators is used in all the classrooms to provide any backup heating required. These radiators were curiously described to MosArt as a 'placebo' whereby the teachers from day one feel confident that they could control the temperature just as they like in each of the rooms. Circulation spaces are heated only through the exhaust air passing from the classrooms. If the windows are opened, the radiators are automatically switched off via a thermostat.

Lighting

The building uses a clever central lighting control system whereby the lights in all classrooms are automatically turned off at the end of each lesson. It has been the experience of the building managers that the students and teachers often don't bother to turn on the lights again when they return to the room, reducing primary energy consumption.

External blinds

External blinds are provided to each classroom which are automatically controlled. The positioning of the blinds can be temporarily overridden using a key switch. When the blinds are fully extended, the upper one third remain open to provide natural light deep into the room.

Plate 4.4.3.3

4.4.4 Perceived Benefits of the Passive House Standard

The high performance glazing provides high comfort even at the window without the need for a radiator next to the window. The promoters of this schools project maintain that better learning conditions are created for the students as well as enhanced working conditions for the teachers.

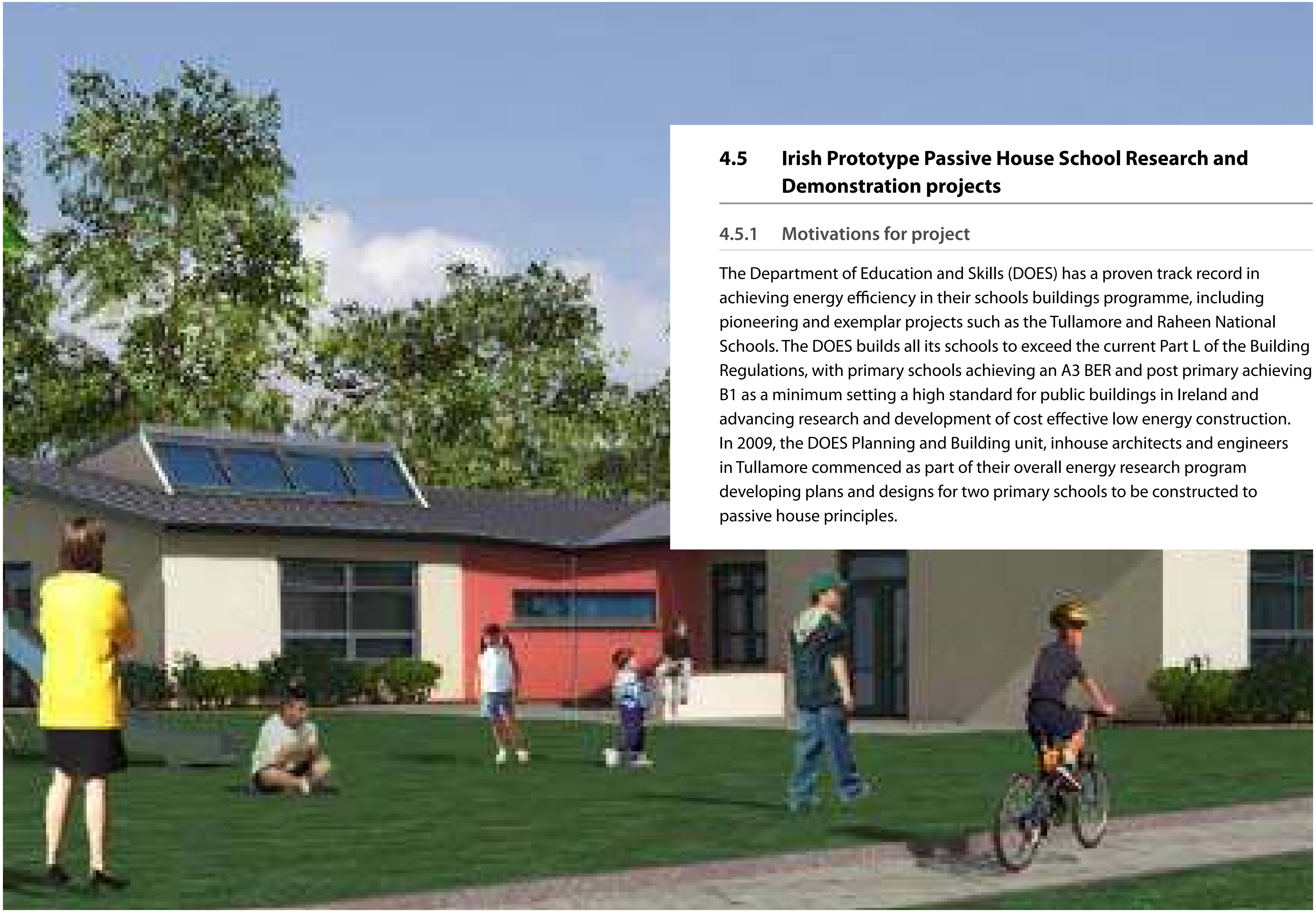
> ***"The heating system was broken for one week and nobody realised it"***

4.4.5 Lessons learned and guidance for future projects

The use of a centralised exhaust air system resulted in an increase in fire safety and noise control measures which increased the cost of the project. In the future, the designers of the project say that they would likely use an exhaust air duct system to each classroom which may be more economical.

Project Fact file for Kalbacher Höhe School, Frankfurt

Project Description	
Project type	Primary school, kindergarten and gymnasium
Treated floor area in PHPP	8,000m^2
Annual heat requirement (according to PHPP as well as measured if available) (delivered energy)	PHPP = 15 kWh/(m^2a)
Year of construction	2003 - 2004
Project Team	
Architects	Architekturbüro 4a, Stuttgart
Mechanical Engineers / Building Services Planning	ICRZ, Hochbauamt Stadt Frankfurt, Ingenieurbüro Rösch, SHL Planungsbüro
Other important design team members	Passivhaus-Institut and Transsolar
Construction Details	
Construction type	Masonry
U value and insulation type and thickness used in exterior wall	0.17 W/(m^2K), 280mm of mineral fibre insulation
U value and insulation type and thickness used in roof	0.11 W/(m^2K), 300mm of insulation
U value and insulation type and thickness used in floor	0.21 W/(m^2K), 20mm sound insulation, 100mm of EPS insulation, 12.5mm plasterboard and 40mm clay pebbles
Window frame details	U_f = 0.8 W/(m^2K)
Glazing details	U_g = 0.6 W/(m^2K) g-value = 45%
Ventilation Details	
Air-tightness	n_{50} = 0.46/h
Ventilation equipment used	Menerga manufacturer
Average air change rate	2/h
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	10.5 W/m^2
Type of back-up heating system used	Two 60 kW pellet boilers
Cooling load per m^2	Not required
Method of cooling used	Night cooling achieved through night flaps
Domestic Hot Water production	Heated using the central heating system. Student bathrooms only have cold water. User facilities > 30m from the central heating system use electric water heaters
Renewable energy production	8 kWp of photovoltaic panels
Construction and Energy Costs	
Cost of construction (not including cost of land)	€1,110 / m^2 net
Estimate on additional ('extra') costs over conventional cost for construction	5.3%
Typical annual energy costs (for space heating and / or cooling)	€1.46 / m^2



4.5 Irish Prototype Passive House School Research and Demonstration projects

4.5.1 Motivations for project

The Department of Education and Skills (DOES) has a proven track record in achieving energy efficiency in their schools buildings programme, including pioneering and exemplar projects such as the Tullamore and Raheen National Schools. The DOES builds all its schools to exceed the current Part L of the Building Regulations, with primary schools achieving an A3 BER and post primary achieving B1 as a minimum setting a high standard for public buildings in Ireland and advancing research and development of cost effective low energy construction. In 2009, the DOES Planning and Building unit, inhouse architects and engineers in Tullamore commenced as part of their overall energy research program developing plans and designs for two primary schools to be constructed to passive house principles.

4.5.2 Key design features

The key design feature of the school is that it is based on a modular footprint that can be easily expanded from a four classroom school to a six classroom school (Figure 4.5.2.1). Considering specifically the Passive House aspect, the building form (of the four classroom school) is compact and in terms of orientation, there is a clear bias in the positioning of the classrooms towards the southeast which will maximise solar gains as well as natural daylighting during the heating season (Figure 4.5.2.2). Less frequently used rooms as well as circulation spaces and plant rooms are logically positioned on the northern side. While there is some stepping in terms of footprint, overshadowing will be minimal.

4.5.3 Mechanical Systems

As has been discussed above under general design guidance for schools, thermal mass is important in order to modulate temperature fluctuations and to minimise overheating arising from significant internal gains. The construction method proposed for the school comprises traditional masonry concrete floors and walls, with the former to be externally insulated.

A centralised mechanical heat recovery ventilation system will be used to deliver the recommended 30m^3 per person per hour, achieving an average air change rate when occupied of 1 per hour for the entire volume. The ventilation system will only be used during school hours, plus a 'flushing phase' of one hour before and after closing. Rooms that require extraction of air (such as WCs) are evenly spread around the building which will make it easier to achieve a 'whole-building' integrated ventilation system.

A wood pellet boiler is proposed for the heating system, to be delivered through radiators located in each of the rooms. Using radiators will enable hands-on control of the heating of individual classrooms by the teachers and has been found to work well in many completed Passive House schools in Continental Europe and this is a standard feature in all Irish schools.

4.5.4 Perceived Benefits of the Passive House Standard

Using a building management system with significant monitoring these schools will be used as living experiments to test various means of heating, cooling and ventilating for future developments in Ireland.

Figure 4.5.2.1

Figure 4.5.2.2

4.5.5 Lessons learned in the Design Process

As part of the design process for these passive house schools, a number of alternative construction scenarios were tested in PHPP to identify the most economical basis for achieving the Passivhaus Standard concerning space heating demand and primary energy demand. These scenarios were tested for the two contrasting Irish climate datasets included in PHPP, namely for Dublin Airport and Birr in County Offaly and are presented below.

- Initial sketch: 120mm phenolic insulation and 225mm Rockwool in roof, 160mm phenolic insulation on external walls and 160mm phenolic insulation in the floor, with triple glazing throughout;
- Option 1: Extra 75mm Rockwool in roof, extra 40mm insulation on the walls
- and extra 40mm insulation in the floor, with double glazing throughout (overall U-value 1.6W/m^2K);
- Option 2: As above, except 300mm EPS under floor insulation;
- Option 3: As above, except triple glazing in clerestory (roof windows) in classrooms;
- Option 4: As above, with all windows in classrooms being triple glazed; and
- Option 5: As above, with all windows triple glazed and doors double glazed.

Key performance criteria calculated using the PHPP are listed in Table 1 below, illustrating how the different scenarios would likely perform. For the purposes of this analysis, the interior temperature is set at 19^{0}C, and night cooling is achieved using passive window ventilation.

Table 1: Comparative Performance of Alternative Scenarios (X/Y where X = Dublin Airport climate data and Y = Birr climate data)

	Space Heat Demand kWh/(m^2a)	Primary Energy Demand kWh/(m^2a)	Heating load (W/m^2)
Initial sketch	10 / 15	35 / 36	11 / 11
Option 1	18 / 23	37 / 38	14 / 14
Option 2	17 / 22	37 / 38	14 / 14
Option 3	15 / 20	37 / 38	13 / 13
Option 4	13 / 18	36 / 37	13 / 13
Option 5	8 / 12	35 / 36	11 / 11

As can be seen from the results in the above table, all options easily satisfy the requirements for primary energy demand. However, only the initial Sketch as well as Option 5 would achieve the Passivhaus Standard for space heat demand according to both the Dublin Airport and Birr climates. If only referring to the Dublin Airport climate, Option 3 and Option 4 would also achieve the required standard.

Factual summary overview (Table)

Project Description	
Project type	Passive House Primary School
Treated floor area in PHPP	816 m^2
Annual heat requirement (according to PHPP) (delivered energy)	PHPP = 15 kWh/(m^2a)
Anticipated Year of construction	2010
Construction Details	
Construction type	Externally insulated masonry walls and floor with timber roof structure,
Exterior wall U value insulation thickness and type	0.133 W/(m^2K), 150mm of phenolic insulation
Roof U value insulation thickness and type	0.087 W/(m^2K), 120mm of phenolic insulation over 300mm of mineral fibre
Floor U value insulation thickness and type	0.90 W/(m^2K), 250mm of phenolic insulation
Window frame details	Majority of windows double-glazed at U_f = 1.60 W/(m^2K), 8 no. clerestory windows with U_f = 0.79 W/(m^2K)
Glazing details	Majority of windows double-glazed at U_g = 1.30 W/(m^2K) and g-value = 64%, 8 no. clerestory windows with U_g = 0.50 W/(m^2K) and g-value = 55%
Ventilation Details	
Air-tightness	n_{50} = 0.60/h (target)
Ventilation equipment used	To be confirmed post tender award
Average air change rate	1.00 /h when occupied 0.45/h average over 24 hours
Means of controlling ventilation rate	To be confirmed post tender award
Design Heating (and Cooling) System and Renewable Energy	
Heat load	11W/m^2
Type of back-up heating system used	Wood pellet boiler (size to be confirmed)
Cooling load per m^2	8W/m^2
Method of cooling used	Night cooling to be provided through ventilation system
Domestic hot water production	Wood pellet boiler
Renewable energy production	Photovoltaic panels being considered
Construction and Energy Costs	
Cost of construction (not including cost of land)	Unknown at time of print
Estimate on additional ('extra') costs over conventional cost for construction	Unknown at time of print
Typical annual energy costs (only for space heating and / or cooling)	Projected at approximately €1 / m^2

4.6 Tesco Supermarket, Waterford

4.6.1 Motivations for project

The Tesco store in Tramore, County Waterford, was completed in October 2008 and is the first Certified Passive House retail outlet in the World (Plate 4.6.1.1). This project is an important case study, therefore, as it demonstrates the diversity of building project types that can be built to the Passive House Standard. The design and development of this Passive House supermarket was identified as the next logical step for the supermarket chain who have been innovating for some considerable time in terms of energy efficiency of their stores. The strategy being deployed is to test which measures are most cost effective on pilot stores and then apply those measures onto existing stores. The Tramore prototype is the 18th such 'experiment' for this retailer worldwide. It is important to highlight that the decision to 'go passive' was made post-planning, so, for example, the orientation of the building is not ideal with regards to solar gain.

Plate 4.6.1.1

4.6.2 Key design features

The Tesco supermarket in Tramore provides just a few hints of its eco-credentials at first glance, including the micro-generator wind turbine, the externally exposed timber frame and cladding and the massive roof lights (Plate 4.6.2.1). Aside from these, the store is very similar in appearance to any other in the same chain across Ireland. What lies beneath, however, are all the traits of typical Certified Passive House projects including triple-glazed windows, highly insulated building fabric, air-tight envelope, optimal daylighting and low energy appliances. The glazed façade addressing the car park is north facing and thus would not generate any solar gain during the heating season. Efforts were made to reduce the extent of heat loss along this elevation through using 6m wide solid walls on either side as well as a 1.2 m opaque section running along the top of the entire façade. Otherwise for marketing purposes, the maximum amount of glass was used which also provides a high level of day lighting along the cashier line (Plate 4.6.2.2). Six very large roof lights provide natural daylight to the store interior, reducing the degree of artificial daylighting required (Plate 4.6.2.3 and Plate 4.6.2.4). The exposed interior structural elements are all laminated timber beams which are unusual in such buildings and create a rather distinct character (Plate 4.6.2.5).


Plate 4.6.2.1

Plate 4.6.2.2


Plate 4.6.2.3

Plate 4.6.2.4


Plate 4.6.2.5

4.6.3 Mechanical Systems

The highest energy demand in a large retail outlet such as that at Tramore is for chilling of fridge and freezer units, equating to approximately 40% of the total energy use (Plate 4.6.3.1). There was a significant focus in this project to introduce innovative measures to reduce this energy demand, therefore. Carbon dioxide refrigeration was used (a first application of this technology in commercial retail for Ireland) which uses CO_2 as the main refrigerant. The use of this gas is carbon neutral (and thus does not affect the primary energy calculations in PHPP) and the specific design application of this technology at Tramore, consumes 15% less electrical energy than conventional 404A HFC refrigerant systems. The electrical demand for the fridge cabinets was further reduced by replacing conventional 32 Watt fan motors with 7 Watt EC motors along with low energy LED lighting and trim heater control. And all the while, these innovations pass unnoticed to the shoppers. The mechanical plant required for cooling is placed external to the building envelope in order that it (the plant) does not contribute towards internal heat gains inside the store which in turn would require additional cooling (Plate 4.6.3.2).

Lighting too consumes a high proportion of the electrical demands of a retail outlet (in the region of 25% of total energy use). The strategy developed for lighting of the main sales area in this case involved using T5 lamps (which are currently the most energy-efficient lighting devices) combined with a DALI (Digital Addressable Lighting Interface) bus system which allows for intelligent control. Artificial lighting thus actively responds to the availability of natural daylight delivered either through the south-facing facade or the large roof lights. Low energy LED lights were used in the fridge cabinets.

Retail outlets are often open on a 24 hour basis, and their front doors are constantly opening and closing with resulting heat losses. Electric hot air curtains are typically used at the front door to keep the cold air from entering the shop. In this case, however, the warm air system is driven by a more efficient hot water system generated by the CCHP or tri-generation plant). An ideal solution would have been to use a large revolving door but this was not practicable on this site. Instead, a purpose designed external lobby was introduced to allow for a buffer zone between external and internal doors (Plate 4.6.3.3). The 2007 PHPP handbook gives some guidance (Page 86) on air infiltration loses arising in such situations, estimated to be in the order of 1.5m^3 to 4.5m^3 per person and event.


Plate 4.6.3.1


Plate 4.6.3.2


Plate 4.6.3.3

In addition to the above energy saving mechanical plant, a roof mounted photovoltaic system (Plate 4.6.3.4) contributes electrical energy to partially power the check-out tills and the wind turbine located in the car park provides power for the LED sign at the front entrance. Furthermore, a tri-generation unit for production of electricity, heating and cooling is used on the site, running on natural gas (neither the PV nor the tri-generation unit are required for the Passivhaus Standard).

In terms of the design of the thermal envelope, the store owners required three different temperature zones according to their function, namely 16^{0}C in the bulk storage area, 19^{0}C in the sales area and 20^{0}C in the back-of-house offices. The concrete floor in each of these three zones thus had to be isolated in order to prevent thermal bridging and resulting risk of uncontrolled heat losses to the (cooler) bulk storage area.

Lastly, considering air-tightness, the average achieved for conventional Tesco stores is $3.0m^3/hr/m^2$. In the case of the Tramore store, the Passive House n_{50} requirement of 0.6ACH @ 50 Pascal equates approximately to q_{50} of $2.7\ m^3/hr/m^2$ which was exceeded to the level of $2.4\ m^3/hr/m^2$. It should always be the objective of building as tight as possible, and not 'just' to the threshold set by the Passivhaus institut.

Plate 4.6.3.4

4.6.4 Perceived Benefits of the Passive House Standard

The average primary energy consumption for Tesco stores in Ireland is approximately 69 kWh/ (m^2/a) . This has been reduced by 40% in the Tramore store, to approximately 43 kWh/ (m^2/a), saving almost 100,000 kWh of energy per year. If this amount of energy reduction were feasible over the entire chain of stores in Ireland (consisting of some 115 stores), the savings in terms of CO_2 as well as operational costs would be very significant. There has also been a positive spin-off in terms of consumer reaction to the many eco-features in the store, assisted by the interactive digital display board in the entrance area (Plate 4.6.4.1).

Plate 4.6.4.1

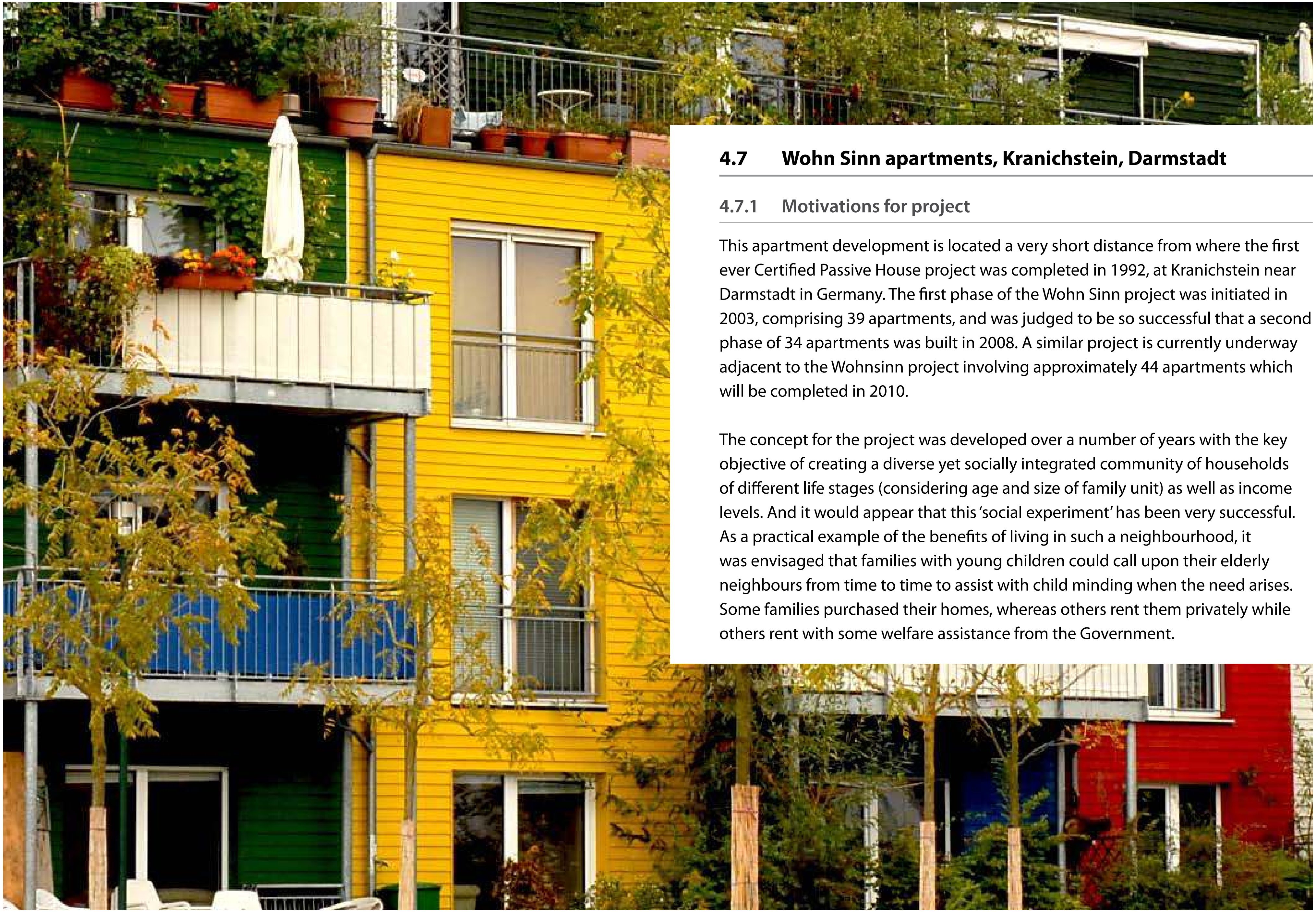
> **“This store is very comfortable to work in, it is like being at home in your own sitting room”**

Quotation from the Store manager

4.6.5 Lessons learned and guidance for future projects

The Tesco Passive House project cost approximately 5% more than conventional stores. As explained earlier, this store was not originally designed as a Passive House, and it would have been more cost effective to do so right from the outset. Areas where possible additional savings could be made for future stores would be to locate the chilled and frozen products in a separate insulated room (like an ‘ice cave’) and reducing the area of expensive triple glazing. Lastly, the detailing and design consultancy required for this project (which represents a very small proportion of the above costs) would be reduced for future projects.

Project Description	
Project type	Supermarket
Treated floor area in PHPP	3,972.2m^2
Annual heat requirement (delivered energy)	PHPP = 15 kWh/(m^2a)
Year of construction	2008
Project Team	
Architects	Joseph Doyle Architects, Dublin
Mechanical Engineers / Building Services Planning	White Young Green, Belfast
Other important design team members	Passivhaus Institut
Principal Construction Contractors	Manning & Son Ltd., Dublin
Construction Details	
Construction type	Timber Frame
Exterior wall U value insulation thickness and type	0.18 W/(m^2K), 150mm prefabricated wall panel filled with PIR foam, aluminium coating (lambda = 0.025 W/(mK))
Roof U value insulation thickness and type	0.15 W/(m^2K), 100mm prefabricated roof panel filled with PIR foam, lambda = 0,025 80mm prefabricated roof panel (PUR-foam - lambda = 0.030 W/(mK))
Floor U value insulation thickness and type	Perimeter insulation only, due to the large size of the building: ground below building acts as a heat storage. 100mm insulation, lambda value = 0.04 W/(mK) at perimeter only: Equivalent u-value = 3.69 W/(m^2K)
Window frame details	Uf = 1.1/1.8/2.5 W/(m^2K) Uw-value 1.08 is the mean value of all vertical and horizontal windows and glass doors.
Glazing details	Ug = 0.6 W/(m^2K) g-value = 43%
Ventilation Details	
Air-tightness	n50 = 0.31/h
Ventilation equipment used	Klingenberg plate heat exchanger with Klingenberg rotary wheel.
Average air change rate	0.30/h when occupied
Means of controlling ventilation rate	CO_2 sensor
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	14.9 W/m^2
Type of back-up heating system used	Gas-fired Tri-generation (heating, electricity, cooling)
Cooling load per m^2	Space cooling = 0 W/m^2, Fridges are cooled with CO_2 refrigerants
Method of cooling used	
Domestic Hot Water production	Gas-fired Tri-generation
Renewable energy production	40 photovoltaic panels producing approximately 8,450 kWh per year
Construction and Energy Costs	
Cost of construction (not including cost of land)	Not available
Estimate on additional (‘extra’) costs over conventional cost for construction	5%
Typical annual energy costs (only for space heating and / or cooling)	Yet to be verified



4.7 Wohn Sinn apartments, Kranichstein, Darmstadt

4.7.1 Motivations for project

This apartment development is located a very short distance from where the first ever Certified Passive House project was completed in 1992, at Kranichstein near Darmstadt in Germany. The first phase of the Wohn Sinn project was initiated in 2003, comprising 39 apartments, and was judged to be so successful that a second phase of 34 apartments was built in 2008. A similar project is currently underway adjacent to the Wohnsinn project involving approximately 44 apartments which will be completed in 2010.

The concept for the project was developed over a number of years with the key objective of creating a diverse yet socially integrated community of households of different life stages (considering age and size of family unit) as well as income levels. And it would appear that this 'social experiment' has been very successful. As a practical example of the benefits of living in such a neighbourhood, it was envisaged that families with young children could call upon their elderly neighbours from time to time to assist with child minding when the need arises. Some families purchased their homes, whereas others rent them privately while others rent with some welfare assistance from the Government.

4.7.2 Key design features

The development consists of a three storey south-facing U-shaped layout with some of the units two storey and others single storey (Figure 4.7.2.1, Plate 4.7.2.1 & Plate 4.7.2.2). All of the upper levels are accessed off shared terraces which connect to a lift at the northeast corner. The entire development is thus barrier free in terms of access. All of the homes are dual aspect, with the two north-south blocks having east and west facades, and the connecting east -west block having south and north facing facades. All of the homes located off the ground floor have terraces, many of which have been planted and provide a valuable private and communal amenity (Plate 4.7.2.3).

The corners of the apartment blocks are cleverly used for community purposes, including a day room winter garden (Plate 4.7.2.4) and library to the northwest, sauna, guest apartments and kids den to the northeast and meeting rooms to the southwest.
In the central courtyard is located a well landscaped mound which disguises an underground 'bunker' style room which is used by the community to store food items and bulky non-perishables that require cooler temperatures than would be provided in the Passive House apartments (Plate 4.7.2.5).

The development is just a few hundred metres from an electric tram line which connects with the nearest urban settlement at Darmstadt just a short journey to the southwest (Plate 4.7.2.6).

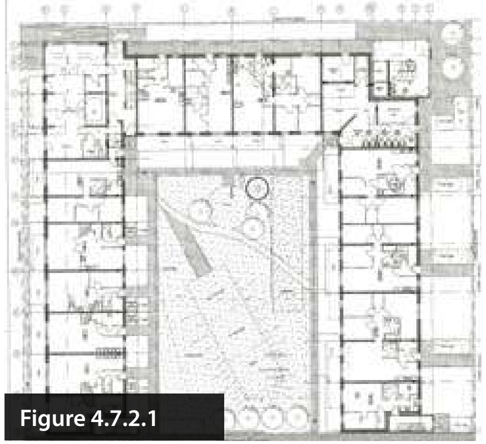


Figure 4.7.2.1


Plate 4.7.2.1


Plate 4.7.2.2


Plate 4.7.2.3


Plate 4.7.2.5


Plate 4.7.2.6

4.7.3 Mechanical Systems

The apartments are heated through the ventilation system using a water to air heat exchanger connected to a district heating system. The district heating is provided by a local incinerator plant (located just a few kilometres from the project (Plate 4.7.3.1)) and the calculation of primary energy demand from this is calculated in a dedicated Excel sheet in the PHPP software titled 'District Heat'.

The avoidance of needing radiators for heating results in space saving which is appreciated by the homeowners. The exception to this rule is found in the bathrooms where a small radiator is used to provide additional comfort and to help with clothes drying.

Each apartment has a separate heat recovery ventilation system, so every household has direct control of their own mechanical system. There are three levels of air exchange rate; namely low, which is used when the units are left unoccupied during holidays, normal, for everyday use, and high, when there is a need for greater air change rate such as during a party or family gathering.

There is no individual metering of heating energy used in the apartments as this was felt to be too expensive given the low space heating demand. Instead, each household is charged a flat rate per square metre on an annual basis for all their heating needs. Consumption of domestic hot water is, however, metered.

All residents have the option to invest in the photovoltaic power plant located on the roof of the apartment complex, which provides an annual return on investment of 3 - 4% (Plate 4.7.3.2).

An adjacent apartment neighbourhood is currently under construction and provides a very useful case study to see the form of construction that is used. The structural envelope of the building is, in this case, masonry which is externally insulated in high density polystyrene (Plate 4.7.3.3). The windows are fitted in advance of the external insulation in order to ensure that an airtight connection between the frame and the shell is achieved. The external insulation is then fitted to provide partial cover of the window frame which reduces any heat losses through thermal bridging.

The mechanical heat recovery ventilation units are discretely fitted to the underside of the ceiling over the entrance hallway (Plate 4.7.3.4) and the drain for condensate is cleverly connected to the cistern for the toilets providing an easy means of disposal.

Plate 4.7.3.1

Plate 4.7.3.2

Plate 4.7.3.3

Plate 4.7.3.4

4.7.4 Perceived Benefits of the Passive House Standard

The benefits typical to Passive House projects all apply to residents at this facility, including low heating cost, high thermal comfort, excellent indoor air quality, bright living spaces and an overall sense of well being attributed to the high level of sustainability. There is an additional and important social benefit in this project that can be attributed directly towards the Passive House Standard, however. The formation of sub-committees to assist in helping the residents to familiarise themselves with living in Passive Houses has contributed to a stronger sense of community spirit. The community is clearly very proud of its achievement in developing what is an excellent model of sustainable living with the Passive House Standard being at the core.

> ***"The first phase of this apartment complex was so successful that it was extended just a few years later"***
>
> Quotation from the owners / tenants / users

4.7.5 Lessons learned and guidance for future projects

In the early days of the project, it took people a while to become accustomed to the subtleties of living in a Passive House. Some families were in the habit of leaving windows open during the heating season, for example, and most were unfamiliar with the use of heat recovery ventilation and the periodic changing of filters. These issues were addressed through the formation of a number of neighbourhood groups who provided advice and assistance to those that needed it. One of these groups visits each household once a year to remind them to change the filters, for example.

If the temperature in the apartment drops, as might happen over a two week vacation during the heating season, for example, it can take a while (about one day) to bring the home up to a comfortable temperature again. This is because the primary heating method is through the use of warm air through the ventilation system. If radiators or underfloor heating was used, the re-heating of homes would be much quicker. This doubling up of systems, however, (ie. ventilation system plus hydronic heating system) would have increased the cost of construction.

Project Description	
Project type	Apartment
Treated floor area in PHPP	3.885 m^2 WohnSinn1, 3.097m^2 WohnSinn2
Annual heat requirement (according to PHPP as well as measured if available) (delivered energy)	PHPP = 15 kWh/(m^{2}a)
Year of construction	2002/2003 WohnSinn1, 2007/2008 WohnSinn2
Project Team	
Architects	faktor10 GmbH, Petra Grenz, Darmstadt
Mechanical Engineers / Building Services Planning	WohnSinn1: Norbert Stärz, Pfungstadt WohnSinn 2: Hans Baumgartner, Mörlenbach
Other important design team members	Passivhaus Institut, Darmstadt for WohnSinn 1
Principal Construction Contractors	WohnSinn1: Tichelmann & Barillas, Darmstadt WohnSinn2: Büro bauart, Lauterbach, Darmstadt
Construction Details	
Construction type	Concrete core made with prefabricated elements with facade comprising a timber frame structure
Exterior wall U value insulation thickness and type	0.12 W/(m^{2}K), either 300mm Styropor insulation on concrete elements or 300mm Isofloc in the timber frame elements
Roof U value insulation thickness and type	0,12 W/(m^{2}K), either 300mm Styropor or 400mm Isofloc
Floor U value insulation thickness and type	0.11 W/(m^{2}K), 300mm perimeter insulation
Window frame details	U_f = 0.78 W/(m^{2}K)
Glazing details	U_g = 0.6 W/(m^{2}K) g-value = 50%
Ventilation Details	
Air-tightness	n_{50} = 0.35/h
Ventilation equipment used	Vallox KWL 90, 75% efficient
Average air change rate	0.4/h when occupied 0.25 – 0.3/h when not occupied
Means of controlling ventilation rate	Manually controlled
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	10W/m^2
Type of back-up heating system used	Fernwärme aus städtischem BHKW (Gas)
Cooling load per m^2	N/A
Method of cooling used	N/A
Domestic Hot Water production	District heating + 25m^2 thermal solar collectors (used on WohnSinn2)
Renewable energy production	250m^2 of photovoltaic panels installed in 2009 – productivity not yet determined Jahr 2009
Construction and Energy Costs	
Cost of construction (not including cost of land)	1.100 € / m^2– WohnSinn1 €1,230 / m^2– WohnSinn2
Estimate on additional ('extra') costs over conventional cost for construction	10%
Typical annual energy costs (only for space heating)	€3.60 / m^2 including maintenance (not metered, flat rate independent of actual use)

4.8 St. Franziskus Church and Community Centre, Linz, Austria

4.8.1 Motivations for project

The main motivation for the construction of this church and community centre (completed in 2004) was "*to protect as far as possible the resources of the World and God's creation in line with the teachings of St. Francis of Assisi without a significant loss in comfort*". The aspiration was to create a building which has a net positive effect on the environment through the production of renewable energy right on the site. The project involved not only the construction of a new Church, but also refurbishment of an existing community facility.

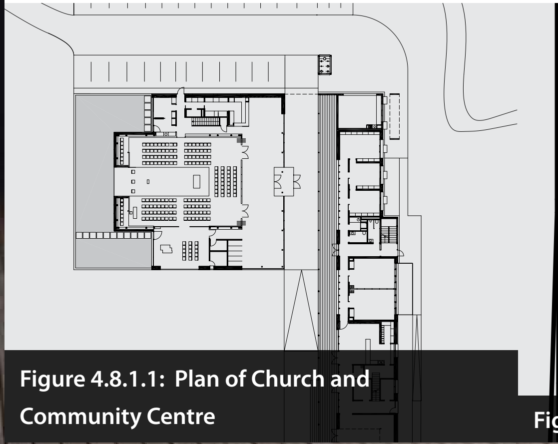


Figure 4.8.1.1: Plan of Church and Community Centre

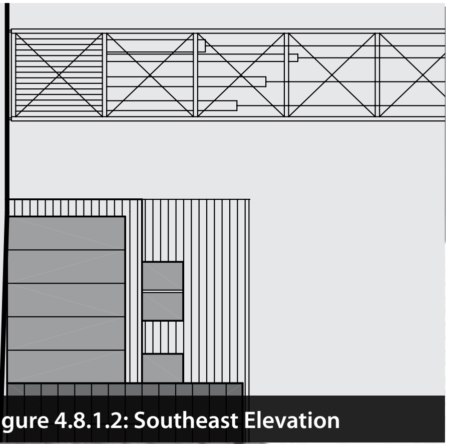


Figure 4.8.1.2: Southeast Elevation

4.8.2 Key design features

The main part of the church proper was designed in a contemporary form, consisting of a mostly opaque cube with a glazed section on the south façade which continues in the roof bringing light from above (Plate 4.8.2.1, Plate 4.8.2.2 and Plate 4.8.2.3). The opaque elements on the southern façade consist of photovoltaic cells which visually serve as a mirror, reflecting the surrounding gardens and integrating the building into it’s surroundings (Plate 4.8.2.4). The altar is located north of centre within the church, with a separate sacristy to the west and a glazed wall identifying a contemplative space to the east. The church combines with separate meeting and social rooms to cater for multiple functions for the local community (Plate 4.8.2.5).

4.8.3 Mechanical Systems

The principal challenge in building a church to the Passive House Standard is the extended periods of time when the building is unoccupied. To deal with this, the external fabric of the church was insulated to such a high degree that the unheated room temperature never drops below 12^{0}C in the even the coldest days of winter (at the time of the authors visiting this project, the external temperature was a numbing minus 25^{0}C). During the design development stage, a separate calculation and simulation was carried out for the building by a specialist firm (GMI) to optimize and test the building shell and ventilation in terms of insulation, temperature consistency and air flow energy efficiency.

The back-up heating for the church and community centre is a wood boiler which delivers the heating both through the ventilation system as well as through hydronic means. The heat load of the church is quite high for a Passive House and this could not be delivered through the ventilation system.

The use of the church is generally scheduled in advance and so the heating system can easily be programmed to deliver the optimal temperature at the times required. An automated shading system comprising a retractable internal canopy is used in both the ceiling and south facing glazed section to reduce any risk of overheating.
The ventilation system is turned off when the building is not occupied and is automatically regulated by a $C0_2$ sensor.

The opaque southern façade is constructed of photovoltaic cells and there are additional cells located on the roof (measuring in total $200m^2$) which generate approximately 15,000kWh per year. Hot water is delivered by $35m^2$ of solar collectors.

Plate 4.8.2.1

Plate 4.8.2.2

Plate 4.8.2.3

Plate 4.8.2.4

Plate 4.8.2.5

4.8.4 Perceived Benefits of the Passive House Standard

The parish identifies itself intensely with this new construction type and sees in it as a contemporary way to implement the message of St. Francis (Plate 4.8.4.1). All future churches in the district of Linz will be built with a heavy focus on ecology and economy.

Completion of the church would not have been possible without the input of the local parish community and the evolution of the project was characterized by different parties learning from each other and by developing solutions through 'collective building'.

> ***This building is described locally as 'God's Power Station'***
>
> Quotation from the owners / tenants / users

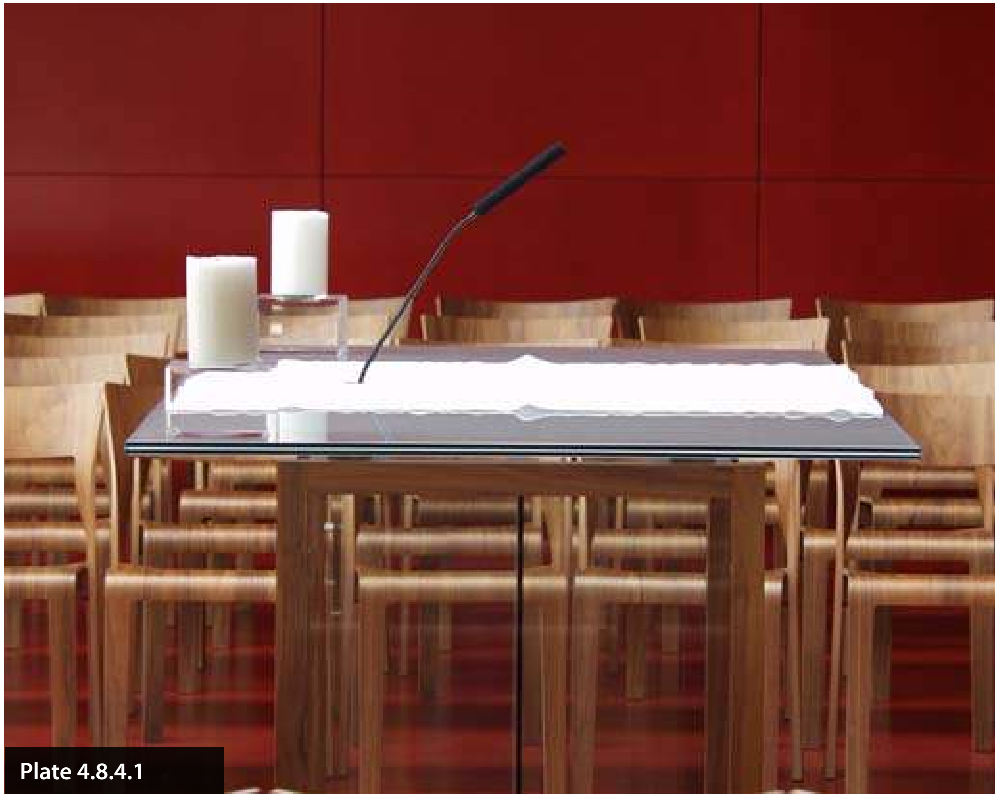


Plate 4.8.4.1

4.8.5 Lessons learned and guidance for future projects

The construction of the building was and still is an experiment and many elements and building parts were used in a prototype like fashion. There is still a certain degree of fine tuning carried out to optimise the energy efficiency.

2. Project Fact file

Project Description	
Project type	Church and community centre, partially retrofitted
Treated floor area in PHPP	1,320 m^2
Annual heat requirement (delivered energy)	PHPP = 17.03 kWh/(m^{2}a)
Year of construction	2004
Project Team	
Architects	Architekten Luger & Maul ZT Gesellschaft OEG
Mechanical Engineers / Building Services Planning	GMI Bernhard Gasser Schulgasse 22 A 6850 Dornbirn
Construction Details	
Construction type	Timber frame with timber cladding
Exterior wall U value insulation thickness and type	0.119 W/(m^{2}K), 350mm of rockwool
Roof U value insulation thickness and type	0.084 W/(m^{2}K), 300mm of EPS Plus 60mm of rockwool
Floor U value insulation thickness and type	0.120 W/(m^{2}K), 300mm of EPS
Glazing details	U_g = 0.68 W/(m^{2}K) g-value = 53%
Ventilation Details	
Air-tightness	n_{50} = 0.12/h
Ventilation equipment used	MHRV with 85% efficiency and capable of delivering 10,150m^3/h
Means of controlling ventilation rate	Combination of CO_2 sensor and clock timer
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	45W/m^2 (the reason this is so high as it also includes the refurbished section of the community centre)
Type of back-up heating system used	wood boiler 85 kW
Cooling load per m^2	
Method of cooling used	Air circulation with earth heat exchanger
Domestic hot water production	35m^2 solar collectors
Renewable energy production	200m^2 of photovoltaic panels producing 15,000kWh per year
Construction and Energy Costs	
Cost of construction (not including cost of land)	2,250 € / m^2
Estimate on additional ('extra') costs over conventional cost for construction	Unknown
Typical annual energy costs (only for space heating and / or cooling)	Unknown

4.9 Sports Hall and Community Centre, Unterschleißheim

4.9.1 Motivations for project

This project was the first Passive House sports hall in Germany. It is located adjacent to a school in the town of Unterschleißheim, a short distance to the northeast of Munich. The brief was to design a building which would primarily serve the needs of the adjacent school (Figure 4.9.1.1), but also be available for use to private sports clubs in the local community as well as serving as a community centre for local events including occasional film screenings and theatre. This building is thus a multi-purpose facility.

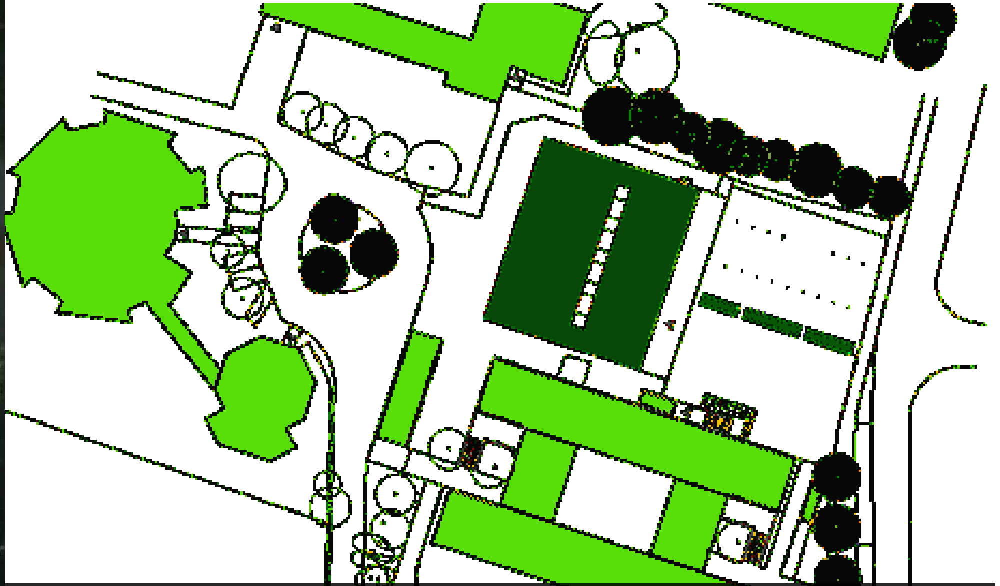


Figure 4.9.1.1: The Sports Hall (in dark green) connects to the adjacent school (below in the above sketch) and creates a courtyard aligned with a church in the distance

4.9.2 Key design features

The sports hall was designed to achieve a clear and simple spatial organization, responding to a strong visual axis created by a church in the middle-distance (Plate 4.9.2.1). Both of the longitudinal facades are entirely glazed thus creating an easy transition from outside to inside (Plate 4.9.2.2). The facility is entered via a foyer at ground level which takes up the entire width of the hall and acts as a spectator stand during sports events (Plate 4.9.2.3). The playing surface is located one level below as depicted in the sectional drawing (Figure 4.9.2.1). It is possible therefore to look outwards and inwards via the fully glazed facades of the ground floor.

In terms of structural elements, the building comprises a post-and-beam arrangement based on a modular design which facilitated pre-fabrication of much of the project. The roof is supported by a series of laminated timber beams tapering towards the ends and supported by visually lightweight posts (Plate 4.9.2.4). The overall impression created is of a lightweight floating roof, despite the fact that it conceals approximately 400mm of mineral wool insulation!

The quality of detailing in this building is impressive, with all services and utilities neatly integrated behind the internal finish of three-layer pine panels (Plate 4.9.2.5) which have been glazed in white to reduce the need for artificial lighting.


Plate 4.9.2.1


Plate 4.9.2.2


Plate 4.9.2.3


Figure 4.9.2.4

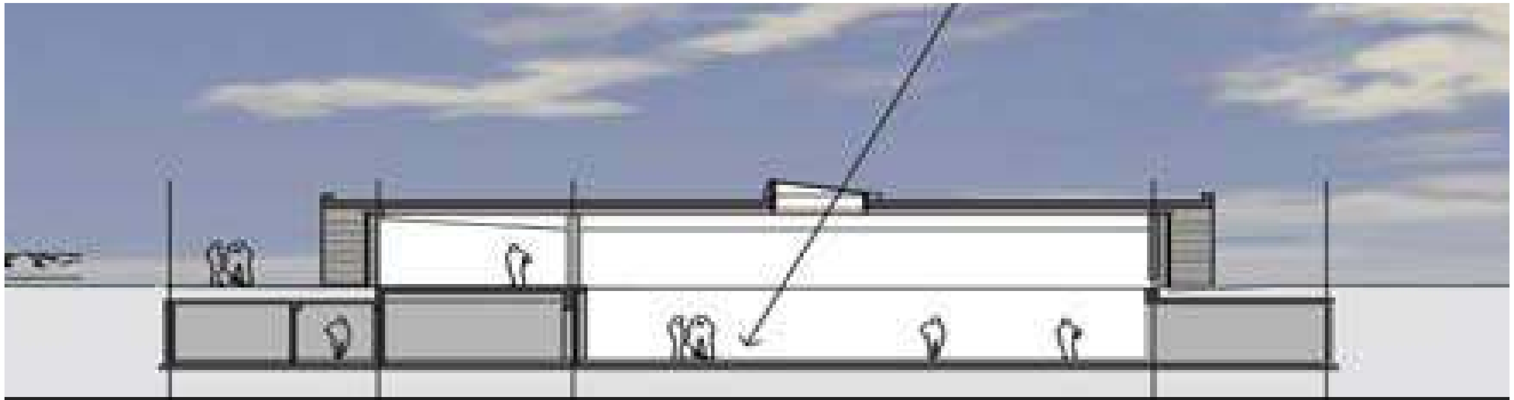


Figure 4.9.2.1: The foyer provides an elevated view over the sunken sports area


Figure 4.9.2.5

4.9.3 Mechanical Systems

The mechanical heat recovery ventilation system was designed to cater for two different zones, the first comprising the shower area which needs warmer temperatures and a higher air change rate, the second in the open sports hall and foyer which needs lower temperatures and a much reduced air change rate (due to the large volume). The supplementary heating required is provided via a renewable energy district heating system (using a geothermic power plant). Window sizing was guided by daylight simulations which strike to achieve a balance between providing sufficient light for the users of the sports hall, whilst also minimising use of artificial lighting. Roof windows are also provided which supplement daylighting but which have louvers which can be used to minimise risk of overheating from solar gain (Plate 4.9.3.1).

4.9.4 Perceived Benefits of the Passive House Standard

The Architect for this project is keen to emphasise that building design must be guided by strong architectural and urban place-making concepts first and foremost, with principles of Passive House playing a secondary role. The combination of these elements has been successfully achieved in this project. The Passive House concept has created a building of extremely low energy use, high comfort levels and superb indoor air quality.

> ***"When you are outside you are drawn inside, and when you are inside you are drawn outside"***

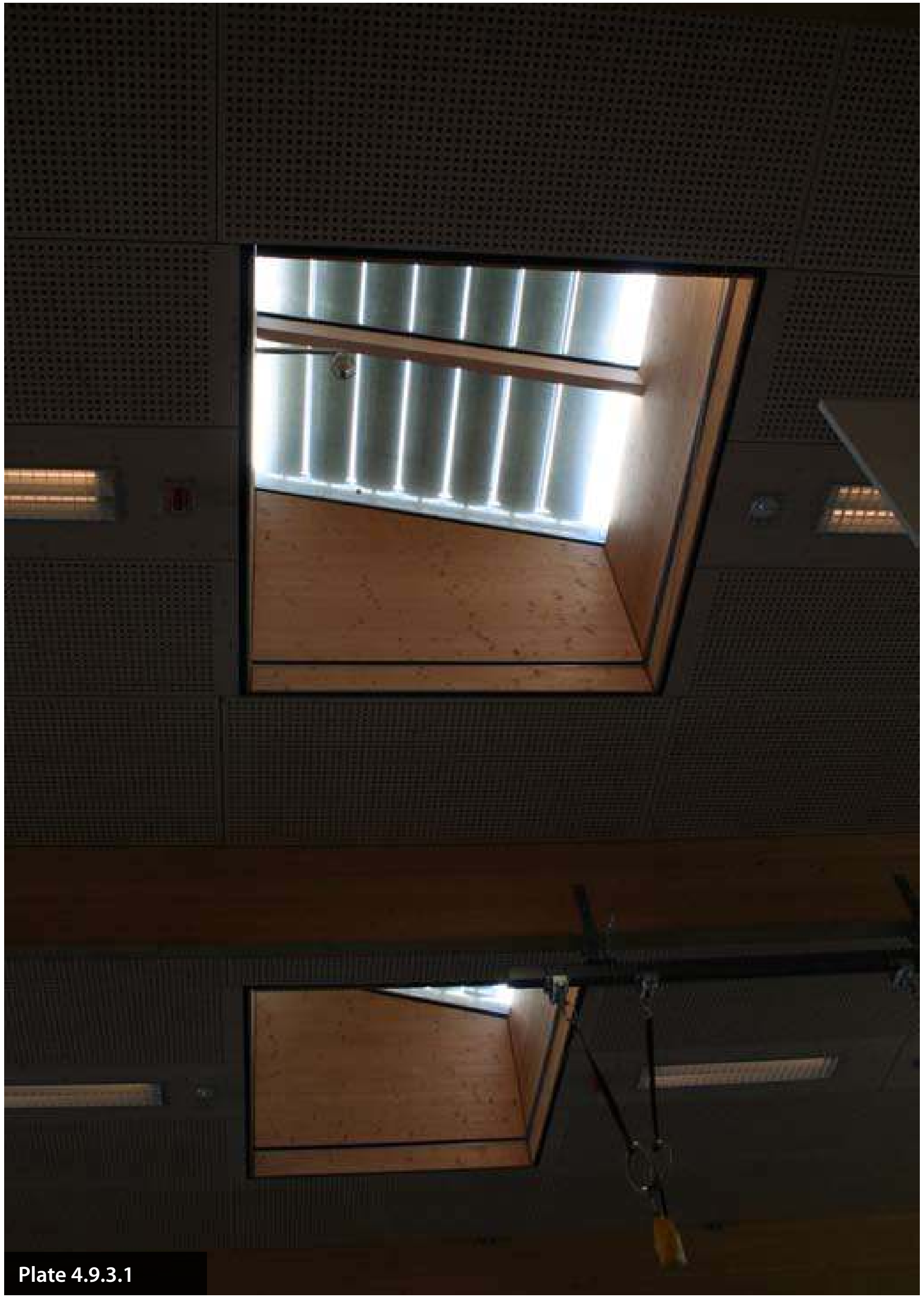


Plate 4.9.3.1

4.9.5 Lessons learned and guidance for future projects

In the design of this project, there was much discussion between the Design Team and the Local Authorities on the sizing of the ventilation system. Due to the fact that the building was to be used not just for small groups playing sports, but also for community events (such as concerts), the Design Team were initially requested to size the ventilation system to cater for the latter larger occupation pattern. However, this would have required very significant ventilation equipment that would only be used occasionally. The solution to this challenge was achieved by providing large openable windows which are used to supplement the MHRV when required. This hybrid system of mechanical and natural ventilation has worked well in practice.

Factual summary overview

Project Description	
Project type	Gymnasium
Treated floor area in PHPP	1,000m^2
Annual heat requirement (delivered energy)	PHPP = 14 kWh/(m^{2}a)
Year of construction	2003
Project Team	
Architects	P S A Pfletscher und Steffan
Mechanical Engineers / Building Services Planning	Ingenieurbüro Bauer, Herr Veeh
Other important design team members (eg. Passivhaus Institut or others?)	Passivhaus Institut
Construction Details	
Construction type	Timber frame
Exterior wall U value insulation thickness and type	0.088 W/(m^{2}K), 400mm of mineral wool insulation
Roof U value insulation thickness and type	0.094 W/(m^{2}K), 400mm of mineral wool insulation
Floor U value insulation thickness and type	0.155 W/(m^{2}K), 240mm of perimeter insulation
Window frame details	U_f = 0.91 W/(m^{2}K)
Glazing details	U_g = 0.6 W/(m^{2}K) g-value = 50%
Ventilation Details	
Air-tightness	n_{50} = 0.20/h
Ventilation equipment used	Menerga Resolair machine, delivering 3,000m^3/h
Average air change rate	Different ventilation rates used for showering area (high air change rate) and for the sports hall (moderate)
Means of controlling ventilation rate	Manual setting and time clock
Design Heating (and Cooling) System and Renewable Energy	
Heat load per m^2	11W/m^2
Type of back-up heating system used	Hybrid system of geothermal heat pumps and district heating
Cooling load per m^2	Not required
Method of cooling used	Not required
Domestic hot water production	District heating provided via a geothermic renewable energy source
Renewable energy production	Not applicable
Construction and Energy Costs	
Cost of construction (not including cost of land)	€2,400 / m^2 net
Estimate on additional ('extra') costs over conventional cost for construction	Unknown
Typical annual energy costs (only for space heating and / or cooling)	Unknown

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