

Passivhaus: The pathway to low energy buildings in Australasia

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Cover image: Wade Institute of Entrepreneurship, Ormond College by Lovell Chen is the first education project in Australia to utilise Passivhaus (Image: John Gollings) - timber curtain wall locally manufactured by Passive House Pty Ltd - Bautechnik www.bautechnik.com.au

Abstract

The Passivhaus, or Passive House, standard is a rigorous, voluntary and performance-based standard, with fundamental objectives of thermal comfort and energy efficiency.

Originally from central Europe, Passivhaus is finding traction in the Australasian market. Proponents of the standard seek key outcomes of excellence in indoor environment quality, energy efficiency and occupant health and wellbeing. As climate change remains a global issue of urgent concern, and as fuel costs continue to rise, there is also a strong ethical and economic case for increasing the efficiency and thermal comfort of buildings.

Whilst Passivhaus is currently expanding across the single and multi-unit residential and education markets, Australia will soon also see projects realised in the social housing, commercial and aged care sectors, with many others to follow. Adoption of the fundamentals of Passivhaus is set to accelerate, with the principles being recognised in major rating tools and programs, as well as the National Construction Code (NCC).

This note will outline the criteria and general requirements for Australasian projects to achieve the standard, recent developments in the standard, the impact for a typical project, and demonstrate how it is actually easier to achieve Passivhaus in the relatively mild climates of Australia than in central European climates.



Figure 1. The Four Pillars of the Passivhaus standard (Image courtesy of Australian Passive House Association, APHA)

Introduction

While there are a multitude of tools available in the Australian market for low-energy standards, Passivhaus is the strongest yet to ensure the realisation of a high-performance building. Many design stage tools and codes, including NatHERS, the NCC and NABERS, have shortfalls, including idealised assumptions and no guarantee or sufficient checks of the built product matching the design (State of South Australia, 2014). Although Passivhaus uses what many would regard as 'just an Excel tool' (Microsoft), the basis of the Passive House Planning Package (PHPP) is in pure building physics and there are numerous case studies (Feist 2007, Oram 2011) that have verified the predicted result as being a precise representation of the as-built product.

Passivhaus garners a mixed response from those both inside and outside the building industry. Many reactions are, however, underpinned by misconceptions of the delivered product and its methodologies. This note will endeavour to clarify the standard and outline how to achieve a Passivhaus building in Australasia, while also celebrating the many projects that have done so to date.

Rising concern over climate change, as well as confidence in the quality and performance of building stock, continue to place increasing demands on both the quality and energy efficiency of our buildings. High performance buildings that provide optimal internal comfort without adding further pressure on environmental resources require innovative design solutions from architects, designers and allied professionals. The Passivhaus standard, a design and construction methodology that promotes internal comfort and energy efficiency, was formalised over a quarter of a century ago and is based on research into past and present high performance structures.

Imagine a building standard that provides energy efficiency, thermal comfort, occupant wellbeing and a return on investment (figure 1).

The Passivhaus design standard is effectively a guarantee of build quality, and being an 'as-built' standard (certified once the building is complete) it has marked benefits over the often applied design-only standards prevalent among Australian building codes and tools. The end result is the only one that matters so it is paramount that the whole process is managed smoothly to ensure success.

Passivhaus and its origins

Passivhaus, a methodology that addresses these issues, originated in Europe in the late 1980s. In 1992 the first Passivhaus building was opened by Dr Wolfgang Feist in Darmstadt Kranichstein, Germany.

Dr Feist's team designed and constructed a building in which the full potential for passive design initiatives were maximised, including optimal orientation, shading, good insulation, high performance glazing, airtight construction and mechanical ventilation. The row of four terrace houses achieved excellent internal comfort without the use of any major heating and/or cooling equipment. In Germany's climate, with average winter temperatures well below zero, this is no mean feat. The ultimate view of the team was that any required air-conditioning systems (including heating) were indicators of building defects; signs that the design and construction standards were not sufficiently carried out.

Since this pioneering research project, the Passivhaus design principles have been developed and applied across many European cities. In parts of Germany and Belgium, application of the standard has even been incorporated in local building regulations.

In English literature on the subject, you will commonly see both Passivhaus and Passive House used. The English translation of Passive House can cause some confusion, with the literal translation to 'house' not picking up the implied meaning of 'building', and the common misconception that it is the same as passive solar design.

Based around the principles of the international thermal comfort standard ISO 7730, Passivhaus is known as an ultra-low energy standard, aimed at providing optimal thermal comfort and minimum energy consumption.

In Europe, a Passivhaus building consumes up to 90% less energy for heating and cooling compared to typical buildings (Passivhaus Institute, 2017).

Applicable to new and refurbished buildings of any type, the core concept of Passivhaus is providing a truly energy efficient and comfortable building while maintaining a focus on affordability. With good design achieving so much in efficiency for any building, there is no real limit to the scope and size of a Passivhaus building. Indeed, there is an economy of scale that might be achieved for larger buildings with low surface area to volume ratios, which is one of the most limiting factors for small buildings. The standard tends to be more easily achieved with compact designs; less than compact designs are likely to require an increased building fabric specification to achieve the standard.

A Passivhaus building must meet a number of fundamental performance criteria to be eligible for certification, with the three key criteria being:

- a minimised demand for heating and cooling
- an air tight thermal envelope, and
- significantly reduced whole building energy use.

A Passivhaus is typically certified upon build completion; with the airtightness test, commissioning report and photographic evidence verifying build quality, though there is no time limit. In its purest technical terms, Passivhaus is defined by the independent research institute for Passivhaus, the Passivhaus Institut, as a building meeting the meeting the criteria in Table 1 below:

Notes for Table 1

¹ The criteria and alternative criteria apply for all climates worldwide. The reference area for all limit values is the treated floor area (TFA) calculated according to the latest version of the PHPP Manual (exceptions: generation of renewable energy with reference to projected building footprint and airtightness with reference to the net air volume).

² Variable limit value for the dehumidification fraction subject to climate data, necessary air change rate and internal heat and moisture loads (calculation in the PHPP).

³ The steady-state cooling load calculated in the PHPP is applicable. In the case of internal heat gains greater than 2.1 W/m² the limit value will increase by the difference between the actual internal heat gains and 2.1 W/m².

⁴ The requirements for the PER demand and generation of renewable energy were first introduced in 2015. As an alternative to these two criteria, evidence for the Passive House Classic Standard can continue to be provided in a transitional phase by proving compliance with the previous requirement for the non-renewable primary energy demand (PE) of QP ≤ 120 kWh/(m²a).

Heating		Criteria ¹			
Heating demand	kWh/ m ² a	≤ 15			
Heating load	W/ m ²	≤ 10			
Cooling					
Cooling + dehumidification demand	kWh/ m ² a	≤ 15 + dehumidification limit ²			
Cooling load ³	W/ m ²	≤ 10			
Airtightness					
Pressurisation test result, n50	h ⁻¹ at 50Pa	≤ 0.6 air changes per hour			
Renewable Primary Energy (PER) ⁴			Classic	Plus	Premium
PER demand	kWh/ m ² a	≤	60	45	30
Renewable energy generation (reference to the building footprint)	kWh / m ² a	≤	-	60	120

Table 1. Passivhaus criteria [version 9f] (Source: Passivhaus Institut, 2016). Refer 'Notes for Table 1' above

Certification types

In 2015, the Passivhaus Institut extended the classification of Passivhaus buildings to allow for recognition of ultra-high performance buildings beyond the established scope of the tool. Retaining the existing Passivhaus standard as Passivhaus Classic, there are now further ratings of Passivhaus Plus and Premium:

- Passivhaus Plus, in which additional energy is generated (such as by photovoltaics (PV) to produce approximately as much energy as the building consumes, meets an approximate net zero calculation across a typical year.
- Passivhaus Premium certification recognises projects that go well beyond net zero projects and contribute significantly more energy than the building consumes.

Both certifications require advancements in the project's base energy efficiency as well as renewable energy generation; the certification cannot be achieved by renewable energy contribution. Calculations also consider the time of energy demand versus its supply, e.g. seasonal demands for heating and PV contribution.

Primary Energy – Quantifying sustainability

In the most recent iteration of the tool, version 9 released in 2015, the Passivhaus Institut has sought to establish a lasting and accurate determination of the energy impact of a building, whilst also recommending and recognising future pathways for energy grid infrastructure.

The primary energy demand determines the impact on the environment. To be more exact, it includes:

1. The total primary energy demand from non-renewable energy sources that is supplied to the building; and
2. all energy uses arising in the building.

This definition wraps the energy boundary around the total project, including all energy uses within. This departs from many approaches, which set no limits nor bring into consideration the energy use of occupants and their systems and appliances.

The outcomes

While Passivhaus represents a significant undertaking for most project delivery teams, the considerable lifetime benefits outweigh the added imposition in the design and construction phases. Learning outcomes for students, health impacts for aged care or social housing occupants, and long-term carbon and economic benefits for all, diminish arguments too often focused solely on capital cost considerations.

Though there are no requirements to consider sustainability of materials or embodied energy, a project that targets holistic sustainability may include these elements, alongside complementary factors such as water, transport and biodiversity.

Among the number of Passivhaus projects internationally, significant projects include the world's first high-rise office building, the RHW.2 building in Vienna, Austria (figure 2), and The House at Cornell Tech in New York (figure 3). The RHW.2 building, completed in 2013, houses 900 staff for the Austrian Raiffeisen-Holding Group and maintains many of the design principles typical for high rise office buildings, such as full-height glazing and open plan offices. The clever energy strategy for the building includes canal heat rejection and reticulation of waste heat from the company's data centre.

Cornell Tech's student residence is set to house 350 staff and students from mid-2017, and will be the tallest Passivhaus building in the world on completion. Many apartments have been designed to be heating-free year-round, with only those on the north side of the building to have small heaters in the harsh mid-winter. The building uses a prefabricated facade to envelop the structure and significantly speed up construction.



Figure 2. Raiffeisen-Holding Group (RHW.2) building, high rise office, Austria by ARGE Atelier Hayde Architekten and Architektur Maurer (Image: Lukas Job [CC BY-SA 3.0] via Wikimedia Commons)



Figure 3. The House at Cornell Tech University, Roosevelt Island, New York (Image: Handel Architects)

The Bushbury Hill Primary School is one of the first Passivhaus schools to be built and certified in the UK (Figure 4), while the Enterprise Centre at the University of East Anglia is the UK's first university project (figure 5). Both are examples of providing excellence in learning outcomes for building occupants, as well as achieving low embodied energy design. The Enterprise Centre was carefully designed to include renewable and local materials, resulting in an embodied energy reduction of approx. 75 - 80% (Architype, 2017). The building is considered the greenest in the UK, and one of the most sustainable in Europe. The University considers the legacy of the project as key to its purpose, and utilises it to educate both building teams and the general public.

Bushbury Hill houses 120 primary school students, a kindergarten for 30 children, and serves children from one of the area's toughest housing estates. The project met the Passivhaus criteria with a strict fixed budget, focussing on optimising a simple design. The outcomes for the client have been credible and genuine, with the principal reporting excellent occupant satisfaction and beneficial learning outcomes (Architype, 2012).



Figure 4. Bushbury Hill Primary School, Wolverhampton, England, 2011, by Architype (UK)
(Image: ©Leigh Simpson Photography)



Figure 5. The Enterprise Centre, University of East Anglia, England, 2015, by Architype (UK)
(Image: ©Photo by Darren Carter, Morgan Sindall)

Passivhaus in Australasia

Design teams have adapted their techniques to different building types and climate zones across the globe, drawing on Passivhaus principles. What makes this standard so successful and what can be learned from an Australasian perspective?

The 2nd South Pacific Passive House Conference in Melbourne, 2016, celebrated new projects and case studies of buildings in climates as diverse as Perth, Canberra, Toowoomba, Melbourne and Darwin. While the Australian climate has broad variation across its length and breadth, the Passivhaus standard finds application across these diverse climate zones. Key variables are economic product availability and professional services delivery. These are being overcome in many parts of the region, and services and products are now widely available in many parts of Australia and New Zealand. Indeed, there are now certified products being manufactured locally in both countries, and many more being directly imported due to demand. Local suppliers report strong demand, even for non-Passivhaus projects.

The message for comfortable, healthy and efficient buildings has been sold.

Following successes in Europe, Passivhaus buildings are also starting to take hold in hot climates such as Spain, Mexico, Greece and Indonesia. These are climates where temperature extremes make life very uncomfortable, and buildings need to provide refuge and relief. In much of the populated area of Australia, where the climate is mild to temperate, comfort can be achieved with ease when compared to more extreme climate zones. The temperature differential – or the difference between the outdoor and desired indoor temperatures, and that which our air conditioning and heating systems must abate – is on average around 10 - 15°C, whereas in places such as Germany and Scandinavia this can be in excess of 45°C.

The Passivhaus tool is applicable across all climate zones, from Antarctica to Indonesia. At the Princess Elisabeth Station, a zero-carbon Passivhaus research station in Antarctica, there is no active heating system. Temperatures at the site vary between -50°C to -5°C, while temperatures inside are maintained at a comfortable 20°C (International Polar Station, 2016).

At the time of writing there are in excess of 80,000 Passivhaus buildings worldwide (IPHA, 2016). However, the real number is unknown; only around 10,000 have attained the official Certified Passivhaus tag, with the majority functioning without the official stamp of approval. Indeed, many of the more pioneering buildings have been left uncertified. At the time of writing, there are now seven certified projects in Australia (IPHA, 2016), with many more in the pipeline. Upcoming projects include student accommodation, education buildings and a number of single and multi-residential dwellings.

Case study: 30 Research Way, Monash University, Victoria, Australia

Housing the Monash Facilities and Services Division, this adaptive re-use project refurbished an existing steel-framed warehouse to create a new, open plan work place (Figure 6 and 7). The Monash Sustainability team advised on a Passivhaus 'inspired' refurbishment of the 40-year-old storage warehouse. With its holistic design approach, this building aims to redefine how Monash campus buildings are developed in order to significantly reduce energy consumption.

The insulated, air-tight building is flooded with natural light on most days (Figure 7), reducing the need for energy intensive systems such as heating, cooling and lighting. The Passivhaus design has also benefitted staff by providing a 'creative, comfortable and productive office space' (Monash University, 2016).

During 2015 - 16 the building was able to draw almost 70% of its total energy requirements from the 70kWp rooftop solar array. Further building tuning and behaviour change measures are anticipated to enable an energy reduction that will see the building achieve the status as Monash's first 100% solar powered building (Monash University, 2016).

The project has helped inspire the university to further its commitment to ultra-high efficient buildings as they strive towards zero emission buildings for their campus. The upcoming Technology and Engineering building will be designed to be fully Passivhaus, the very first of its kind outside Europe and a very significant project for the region.



Figure 6 and 7. 30 Research Way, Monash University by McGlashan Everist Architects, completed December 2014
(Images: Lisbeth Grosmann)

Case study: The Wade Institute of Entrepreneurship, Ormond College, The University of Melbourne, Victoria, Australia



Figure 8. The Wade Institute of Entrepreneurship, Ormond College by Lovell Chen (Image: John Gollings)

'The power of a space comes from the people who occupy it', Kai Chen (Lovell Chen, 2017).

The Wade Institute of Entrepreneurship at Ormond College, Melbourne, is the first education project in Australia to utilise Passivhaus to deliver two efficient, flexible and agile teaching and learning spaces for its Masters candidates.

A highly innovative structural concept is highlighted for all to see, with the precisely engineered, bright yellow columns internally fulfilling more than an aesthetic purpose (figure 8). Services such as lighting and ventilation are considered components, with concealed, low-energy LED strip lighting and a decentralised, highly-responsive ventilation strategy. Both enable a reduction in energy consumption for what are normally high energy consumers in similar buildings.

Natural, tactile finishes such as cork and leather flooring sit beside the high-efficiency, triple glazed timber windows to complete a highly customised but adaptable learning environment. A high level of natural daylight further reduces the primary energy requirement for artificial lighting, and provides a connection to the outdoors. Delivered by a construction team that included industrial and interior designers; an attention to detail has ensured that the final product is a fine example of the functional and beautiful combination that the Passivhaus standard facilitates.

The perimeter walkway extends around both built volumes and is intended to create further space for students to explore and engage in their studies, acting as external hallways. Full-height glazing to both buildings allows students to be immersed in their natural surroundings, and natural ventilation can be used as desired.

The larger teaching space is designed to be open plan, adaptable to multiple formats or uses. Magnetic, moveable walls can be used to create smaller project spaces, as required. The lecture space utilises a sinkable floor to hold additional seating that enhances the flexibility of the space. The buildings feature triple glazing, decentralised ventilation units and carefully detailed rigid insulation to ensure the building envelope performs to the required level for Passivhaus.

'Fabric first' approach to design

The Passivhaus approach to building fabric is one that is applied without compromise. This is key to ensuring that thermal bridges are eliminated, insulation is continuous and that airtightness is a key concern. No single glazing is accepted and window frames become a critical performing element, i.e. no aluminium framing can be included. Whilst many may imagine some 300mm thick R10 monstrous wall section, it would be a reflection of either extreme climate or poor design should this be needed. In southern Australian climates, it is possible to build a compliant Passivhaus dwelling using a R4 wall, R6 roof and R2 floor, an achievable and marginal increase on the base building code requirement at time of writing.

Windows in a Passivhaus building are often one of the most costly and complex elements to get right. Depending on the expanse of glazing, orientation and available shading, it is likely that the window specification (glass and frame) required will fall somewhere between a U-value of 1.2 and 2.0. Whilst not available from every supplier, it is achievable nonetheless. The local Australian glazing market is catching up, with renewed interest in developing the high-performance end of the window market to overcome the current requirement to import much of the high-spec stock.

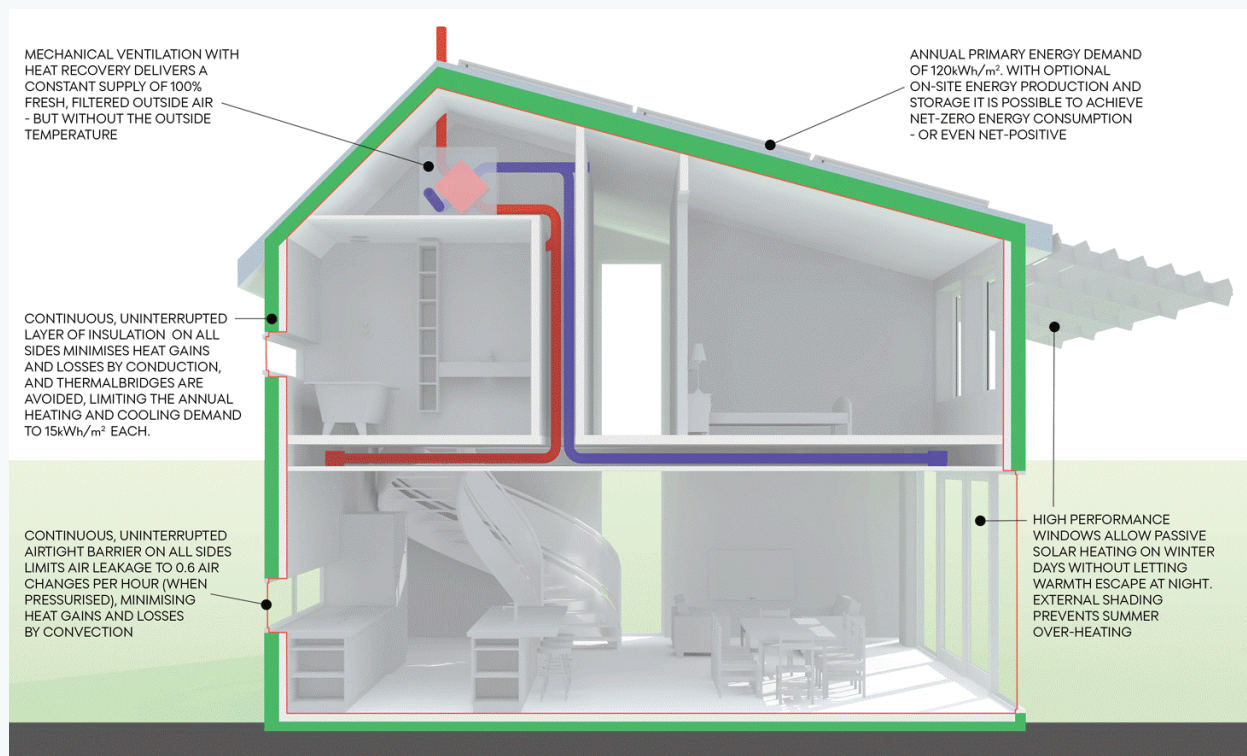


Figure 9. Passivhaus basic construction (Image courtesy APHA)

Passivhaus in different climate zones

The Passivhaus Institut defines climate zones internationally according to a combination of internal research and International Weather for Energy Calculations (IWEC) data files. Figure 10 and table 2 below detail the six climate zones as defined.

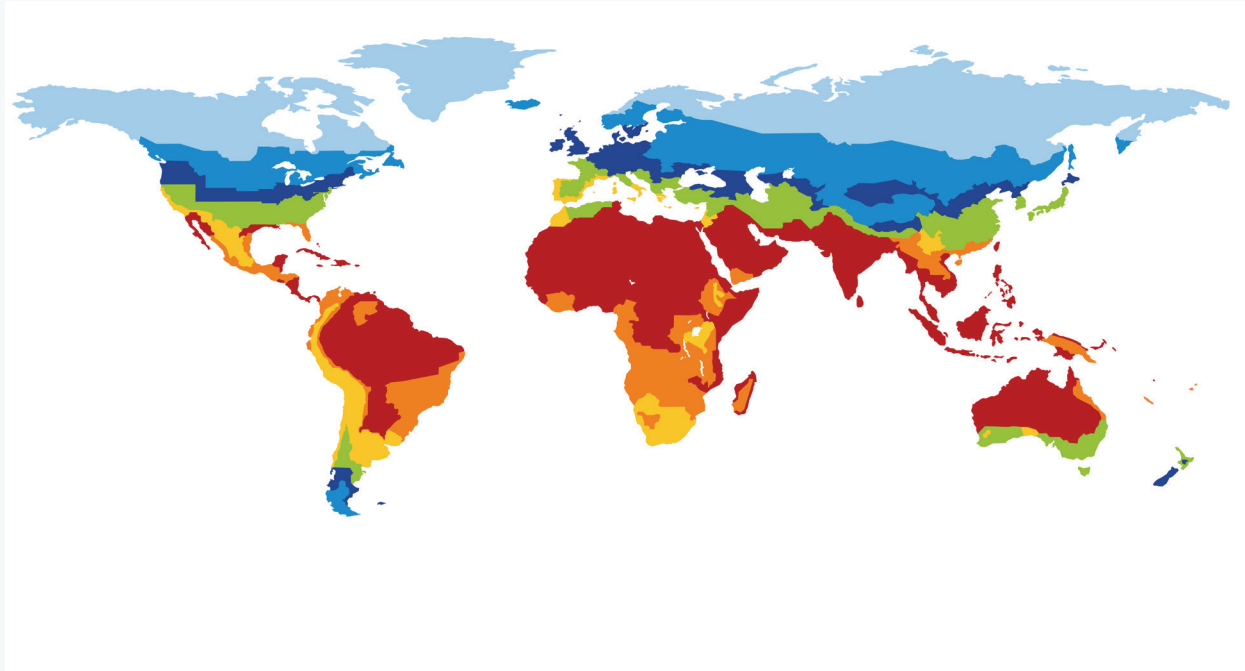


Figure 10. Passive House climate zones (Source: Courtesy of Passivhaus Institut)

Climate zone	Example of country or city	Description
Cold climate	Russia (Yekaterinburg), Sweden	Typically cold winters (e.g. <math><-20^{\circ}\text{C}</math>) but sunny (reasonable solar gains possible). Demands excellent insulation, ventilation and airtightness. Passive heating works very well.
Warm climate	South-west Europe, northern New Zealand, southern Australia	Warm but not hot summers and winters without significant cold periods (annual mean temperature between 15-23°C).
Hot and dry climate	Las Vegas, Central Australia	High diurnal and seasonal temperature variances. Good solar protection necessary, though no dehumidification required (generally).
Hot and humid climate	South-east Asia, Darwin, Cairns	Very high summer temperatures, no heating needed. Shading critical. Outside air rates should be minimised to reduce dehumidification requirements.
Subtropical, mild climates	Brisbane, Tokyo, Shanghai	Warm and humid summers, mild winters (occasional frosts). Both heating and active cooling required. High levels of insolation. Ventilation with heat recovery can eliminate dehumidification requirements.
Tropical climates	Mumbai, Singapore, Mexico	Generally cooling conditions prevail, with moderately warm ambient temperatures between 25-30°C, high rainfall and high ambient humidity. Cooling and dehumidification required most of the year, with no heating. High airtightness required, moderate insulation, cool external colours, good shading, low Solar Heat Gain Coefficient (SHGC).

Table 2. Passive House climate zones (Source: Passipedia, 2017)

Of the three major Passivhaus criteria, the most problematic for local construction is usually the building airtightness. In a leaky building, air infiltration can account for as much as 50% of the heating and air conditioning loads, and accounts for most of the discomfort due to draughts or excessive heat gains. Achieving the Passivhaus standards for airtightness eliminates these problems.

To date, airtightness in Australia has been almost entirely omitted from standard design and construction considerations, with specifications on low-energy buildings only starting to include requirements for building sealing. However, the NCC is expected to include new requirements for measurable targets for building sealing in its 2019 revision.

Achieving the Passivhaus level of airtightness may require a construction strategy overhaul such as a change to the staging of various building processes. Building services and their locations must be carefully considered, and the airtightness strategy may require careful specification of appropriate materials such as tapes and/or vapour membranes to form a continuous airtight barrier.

The domestic sector in Australia has seen the most research in the area of building sealing, and the results have been particularly poor. A typical Australian home would likely achieve an airtightness test result in the realm of 10 air changes per hour (ACH), measured in a pressurised building (to 50Pa), and in many homes can be up to and above 35 ACH (Ambrose & Syme, 2015). Data for homes constructed between 2001 and 2011 showed the worst performance (average 15.5 ACH, worst 35 ACH) (Ambrose & Syme, 2016).

Studies on office buildings reveal the average at around 8 ACH (Egan, 2011), although recent tests from high-performance buildings suggests that less than 3 ACH is achievable (AIVAA, 2017). In comparison, the Passivhaus standard requires that the building achieve excellent airtightness of 0.6 ACH – or roughly 10 to 20 times better than current practice.

Importance of eliminating thermal bridges

Generally, insulation of the building fabric is included to resist heat transfer. Insulation is specified based on its R-value, or thermal transfer resistance. A thermal bridge is a localised area of the building envelope where the heat flow is different (usually increased) in comparison with adjacent areas (figure 11). Thermal bridges most commonly occur across window frames, structural members, penetrations of the building fabric (e.g. pipe or ductwork) and at junctions of the building fabric, such as where a wall meets a floor or ceiling. In these areas, there is an inconsistency in the insulation and this results in a localised change in heat transfer.

Thermal bridges are, quite literally, bridges across which thermal energy can flow. In winter the heat pumped into or gained in a building is lost when it flows out across window frames, for example; in summer the reverse happens with heat from outside being transferred inside to counter the work done by air-conditioning systems. These thermal bridges are imperfections in a thermal envelope. When tallied up across a whole building, these small bridges can result in significant energy losses and financial impacts.

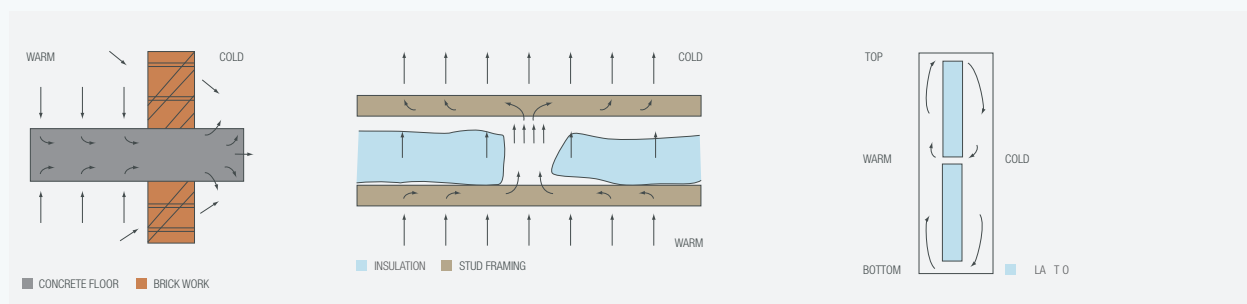


Figure 11. left to right (Source: McGregor, 2012, EDG note 76 - AuSES 1 'Construction Details for Cool Temperate Climates')

- Structural bridge – projecting balcony floor slab
- Air bridge – shrinkage or workmanship creates gaps around parts of the insulation
- Circulation bridge – gaps of a few millimetres can set up convection currents.

Thermal bridges occur everywhere, and can be tricky to firstly track down, and then eliminate. A skilled designer will learn to recognise them. Whilst a small number of insignificant thermal bridges can be inconsequential, the real target for any good building design is to seek and eliminate them. There are a variety of software tools available to analyse thermal bridges in construction details. Developed at Lawrence Berkeley National Laboratory, THERM is a free software that can be used to model heat-transfer effects in building components:

<https://windows.lbl.gov/software/therm/therm.html>

The effects of thermal bridges are:

- Altered interior surface temperatures; in the worst cases this can lead to moisture formation in building components, condensation and mould growth
- Altered, usually increased, heat transfer.

The following thermal images (figure 12) show the 'before' and 'after' of a retrofit program for insulation and thermal bridging measures applied to a terrace apartment building in Frankfurt, Germany. These thermal images are taken from outside on a cold night, with indoor heating operational to ensure high indoor temperatures.

The 'before' images show that a significant proportion of the heat pumped into the building to maintain comfort conditions was simply leaking to the outside, mostly across thermal bridges around windows, doors and at floor-to-wall and roof junctions (all areas shown white, yellow and red). The amount and rate of heat loss was significantly decreased in the 'after' scenario (note all surfaces are 'cold', or blue) and the resulting energy required to maintain a comfortable indoor environment was significantly reduced. The answer was simple insulation and thermal bridge prevention methods, including thermal breaks across fixings and tight air sealing around windows and doors.

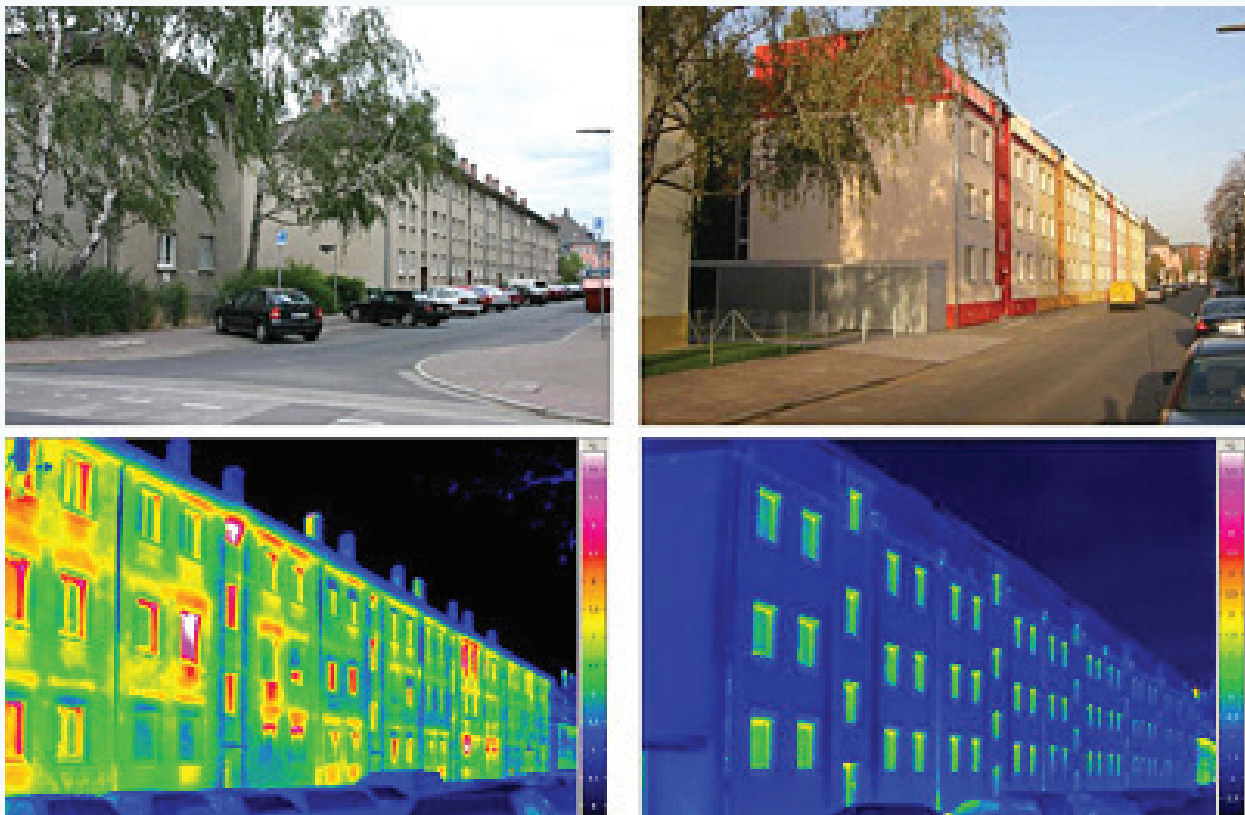


Figure 12. Significant reduction in heat loss due to insulation and thermal bridging retrofit (Image courtesy International Passive House Association)

Ventilation – is there more than one solution?

A Passivhaus building is airtight, necessarily so in order to enhance comfort and efficiency, as previously outlined. In order to ensure the building is habitable, there is a requirement for ventilation to be introduced by some means. A popular and persistent myth surrounding Passivhaus buildings is that they cannot utilise openable windows. Natural ventilation is very much encouraged when conditions are suitable. However, when extreme outdoor conditions make natural ventilation undesirable, the required solution is a mechanical ventilation system.

At least one study has shown that the use of mechanical ventilation with heat recovery (MVHR) is actually more energy efficient than natural ventilation for a thermally efficient house in the UK context, when providing the same levels of thermal comfort (AECB 2009). The MVHR is a simple-to-operate system that ensures good air quality is maintained at all times, regardless of occupant behaviour or presence, eliminating problems such as odour, stale air and excess moisture. For maximum energy efficiency, an air-to-air heat exchanger captures thermal energy – whether heat or ‘coolth’ – from the outgoing air stream, keeping a high proportion of the thermal energy that has been used to condition the indoor environment inside. The system typically uses 100% outside (fresh) air and does not recirculate exhaust air. Filtration (typically F7 filter or better) should also be used to ensure that incoming air does not contain outdoor pollutants or allergens.

Early data from Australian projects, monitoring temperature, relative humidity and CO₂, shows that the indoor environment quality of a Passivhaus dwelling is indeed superior, with multi-year data showing consistent performance throughout diurnal, seasonal and occupational variances (Truong & Garvie, 2016; Besen et al, 2016). This is in agreement with data from international Passivhaus projects, and applies to all building types.

An added benefit of the ventilation system in an airtight building is the exhaust of volatile organic compounds (VOCs) and other toxins that are typically found in buildings, such as those released from common items including furniture and finishes. While it is possible to select low-emission items, in a standard building this may be completely overlooked.

Integrated design and quality control

Unlike many building rating and certification tools, the ultimate aim of building to the Passivhaus standard is not necessarily the final certification, but rather

to achieve exactly what the standard promises to deliver: a comfortable, high quality, healthy building that costs very little to run. The certification is the guarantee of quality, and a verified and marketable result, but is not mandatory. It has been well-demonstrated that Passivhaus developments make economic sense (Burrell, 2016, Hines, J, 2016); the new frontier is achieving local market recognition of its benefits, whereby the capital investment becomes worthwhile given an identifiable return. Primarily, though, the recognition of additional value beyond financial measures is a more critical conversation and will result in sector change to better serve building occupants.

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The key to achieving Passivhaus on any building is much the same as any holistic measure: it must be integrated from day one. Sustainability, in any form, cannot be an ‘add-on’. For the client, this means getting expert advice early, and for the design team, this means getting everyone together from the concept stage to ensure that the aesthetics, functionality and constructability do not conflict.

A certified Passivhaus is a guarantee of quality and the Passivhaus Institut works hard to ensure that the stamp that bears the name upholds its integrity. The Institut has established individual certifications for Passivhaus professionals to assist building owners and designers to realise projects with ease. The following certifications are available for Passivhaus professionals and building components:

- Certified Passive House Designer or Consultant
 - Design professionals, likely an architect or engineer, with ability to work with the PHPP.
- Certified Passive House Tradesperson
 - Builders and tradespeople who have been trained to apply the exacting requirements.
- Certified Passive House Components
 - High performance building components including window frames, glazing, skylights, external doors, curtain walling, wall panels, insulation, heat pumps and ventilation systems.
- Certified Passive House
 - A completed building that has been certified as meeting the Passivhaus standard.

It should be noted that a Passivhaus building can be realised and certified without the use of certified designers, consultants, tradespeople or products. These certifications have been established to provide clear direction in the market, but are not prerequisites to success. Additionally, many of the certified components, including fabric components such as windows and insulated panels, have been certified with central European climates in mind and will likely exceed requirements for milder climates such as those in most of Australia. The engagement of a Certified Passive House Designer and/or Tradesperson would be an added benefit to any project, with such professionals having demonstrated the required knowledge and expertise to prepare and execute a design according to the stringent requirements of the standard.

Cost and ease of build

Reported costs for Passivhaus projects vary across a substantial range, but it is difficult to distinguish in most cases the true cost of Passivhaus measures. Additionally, many clients are hesitant to share data. The available cost data, at the time of writing, indicates a range of \$2,200 to \$5,500 – a range that makes this information difficult to assess. What does hold true, though, with a view of the lower end of this range, is that it is possible to deliver Passivhaus within a reasonable budget and on par with traditional building projects. With many of the pioneering residential projects sitting at the ‘luxury’ end of the market, it is difficult to equate this to a typical dwelling. Upcoming projects in the education and social housing sectors will demonstrate a dedicated interest in implementing the standard in line with typical budgets.

Long-term but now slightly outdated, tracking data from Europe, as part of the Passive-On project, shows that a residential Passivhaus project is likely to require between 3 - 8% more in upfront costs (Passive-On Project, 2007); however, many projects have been completed with no additional investment (Architype, 2012; Burrell 2016). Any additional costs are quickly recouped through lower operating costs, usually within around five years or less. The additional investment in materials such as insulation is partially offset by the significant reduction, or even elimination, of heating and air-conditioning systems, for example. With the health, wellbeing and comfort measures introduced by the stringent build quality, there are also many benefits that cannot easily be quantified through direct analysis. Applications of the standard in healthcare, education, aged care and social housing have been shown to have widespread, long-term societal and public infrastructure benefits (Vidal, 2013; Burrell, 2016). Australian research into the benefits of Passivhaus principles in social housing design include social, financial and environmental value (Moore et al., 2015).

The development of the Australian, in particular, and New Zealand markets has been pronounced, with both local manufacturers and existing international suppliers escalating their supply of products to the building industry. Regional manufacture is also proliferating: New Zealand and China now manufacture certified Passivhaus windows and ventilation units, two key components. The number of skilled professionals has accelerated, with over 55 certified designers and consultants and 25 certified tradespeople in Australia, and three building certifiers in the region (two in Victoria and one in New Zealand), at time of writing. Local education has been ramping up, and many more opportunities are available to local practitioners looking to advance their knowledge in the field. Highly specialised practitioners are now operating nationally. However, demand for Passivhaus practitioners currently exceeds supply, with the move from residential to education and commercial projects demanding a new set of skills.

Conclusion

Any good building is designed around providing not just an aesthetically pleasing structure, but the essential provisions of comfort, shelter and a healthy indoor environment. As we move into a more sustainable future, the use of technological fixes for poor building practice, coupled with the associated substantial energy bills and greenhouse gas emissions, needs to be considered. When adopted as part of an integrated approach, the Passivhaus standard ensures comfort, energy efficiency, excellent air quality and low operating costs through just three major areas of focus – insulating right, good building sealing and reducing total electrical loads.

The standard is about the very basic elements of building well and, with the core elements based in physics, is backed up by decades of research and real world, exemplar projects. With advantages including an enhanced quality of life and future-proofing from energy price escalation, Passivhaus has established itself as the leading international standard for comfortable, healthy and affordable low-energy buildings, by both scale and diversity of application.

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