

# Passivhaus (Passive House) in Australian Climates

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## ABSTRACT

Passivhaus (also known as Passive House) is a low-energy and high-thermal-comfort design, construction, and operational methodology for buildings, developed by the Passivhaus Institute in Germany. Although initially developed for a Central European climate, the Passivhaus concept is touted as being applicable to any climate. Passivhaus is beginning to make headway in the Australian building industry, with several projects recently completed and many more in the design or construction phase. Although the general concepts and targets proposed by Passivhaus may be applicable in all climates, some of the traditional European-centric design philosophies may be modified to better suit the climates of Australian population centres.

Through use of the Passivhaus Planning Package (PHPP) energy modelling tool and climate data for Australian population centres, various design iterations were tested and compared for a test case multi-dwelling residential building. With particular emphasis on a Sydney climate, this modelling resulted in a new set of five “Passivhaus Principles” for warm (cooling dominated) Australian climates. These principles are typically less onerous than their European counterparts and more familiar to both designers and builders in the Australian construction industry.

## INTRODUCTION

Passivhaus is a high-occupant-comfort, low-energy design, construction, and operation standard, which, although developed in Central Europe, is beginning to gain traction in Australia. This paper assesses the viability and degree of difficulty in design and development of buildings to Passivhaus standards in the climates of major Australian cities, with a focus on Sydney, New South Wales. A test multi-residential building was modelled for several Australian climates using the Passivhaus Institute (PHI) certified energy model, Passivhaus Planning Package (PHPP). Shortcomings in the building design were addressed to achieve the Passivhaus standard in a Sydney climate. Moreover, this work provided a test as to whether the five core Passivhaus principles (refer Figure 1) are strictly applicable in Australian climates.

## BACKGROUND

### Passivhaus

Passivhaus (also known as Passive House) is a building design, construction, and operation methodology to provide for high levels of occupant thermal comfort at low levels of energy consumption. An established methodology, the first Passivhaus was launched in May 1988 in Darmstadt, Germany, developed jointly by Dr Wolfgang Feist and Prof. Bo Adamson<sup>8</sup>. The Passivhaus concept is beginning to gain traction in the Australian market, with several single-dwelling Passivhaus projects and many larger Passivhaus developments at various stages.

For a building to be certified as a Passivhaus it must meet six quantitative criteria related to<sup>1</sup> heating and<sup>2</sup> cooling demand,<sup>3</sup> frequency of overheating and<sup>4</sup> excessively high humidity,<sup>5</sup> airtightness, and<sup>6</sup> primary energy demand. Several qualitative

criteria must also be satisfied, primarily related to occupant comfort and controllability. These qualitative criteria have not been considered as part of this work. All criteria are climate-independent, with the exception of the cooling demand criterion, which includes an allowance for dehumidification based on the treated floor area of the development. As an example, quantitative Passivhaus criteria for a 2,500m<sup>2</sup>, 12 apartment multi-residential development in Sydney, Australia are 15kWh/m<sup>2</sup>a for heating demand and 18kWh/m<sup>2</sup>a for cooling demand, which includes a 3kWh/m<sup>2</sup>a climate dependent allowance for dehumidification.

The Passivhaus Institute states that five basic principles apply to the construction of Passivhaus, shown in Figure 1. This paper explores the applicability of these five principles in Australian climates.

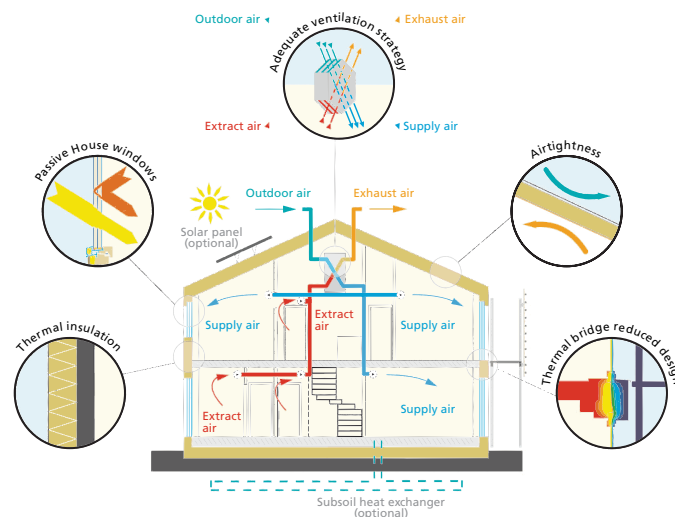


Fig. 1 A schematic of a Passivhaus demonstrating the five principles<sup>9</sup>

## Thermal comfort

The fundamental concept of Passivhaus is provision of thermal comfort with very low-energy utilisation. It is therefore worth considering the concept of human thermal comfort and how buildings are designed to provide a thermally comfortable environment for occupants.

Thermal comfort is defined by Fanger<sup>3</sup> as “that condition of mind which expresses satisfaction with the thermal environment”. The predicted mean vote (PMV) index developed by Fanger<sup>4</sup> and adopted by the International Organisation for Standardisation (ISO)<sup>6</sup> and the American Society for Heating Refrigeration and Air-conditioning Engineers (ASHRAE) is based upon the concept of satisfying the thermal comfort requirements for the majority of occupants. It is acknowledged that due to individual differences it is impossible to specify a thermal environment that will satisfy all occupants<sup>5</sup>. The PMV index is influenced by four “design dependent” parameters and two occupant-controlled parameters, as summarised in Figure 2.

The PMV method has received some criticism for its tendency to underestimate the range of conditions that humans find comfortable. Of note are potential inaccuracies regarding the impact of air movement and humidity on thermal comfort, particularly in naturally ventilated buildings in humid climates<sup>7</sup>. ASHRAE 55<sup>1</sup> has adopted a

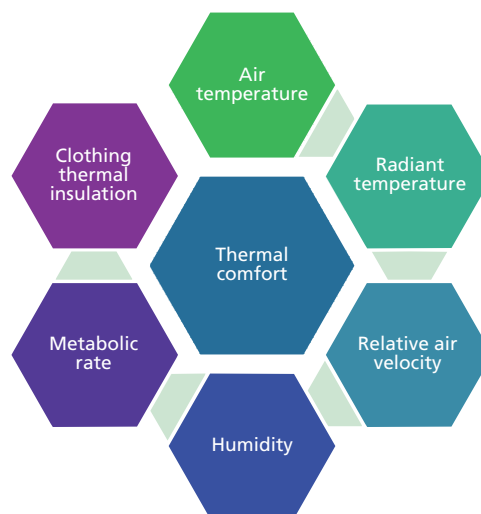


Fig. 2 Thermal comfort parameters

modification to the PMV calculation to better account for thermal comfort due to air movement in naturally ventilated buildings; however, significant work on acceptable thermal comfort conditions in climates around the world is required.

Building designers control occupant thermal comfort through both active measures and passive climate aware design. Active measures utilise energy to cool, heat, dehumidify, or

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otherwise improve thermal comfort levels. Passive design is cognisant of the building, its surrounds, and its climate, and utilises holistic climate-aware design to maximise occupant thermal comfort. It is worth noting that a well-designed thermal comfort control methodology allows for the four design-dependent parameters to be occupant controlled. This provides occupants with a high level of control of their thermal environment, resulting in significantly greater thermal comfort satisfaction levels<sup>12</sup>.

### Sustainable design in practice

The architect's approach to environmentally sustainable design (ESD) is that it be integral rather than accessory; ESD is tightly interwoven throughout the design process through all building elements. The aim is to achieve building performance that not only reduces its environmental impact, but decreases energy and service costs, improves comfort and well-being of occupants, and achieves long-term sustainability.

The response to sustainability may be understood from five key design principles:

1. Eco-system designs that productively connect with and sustain their environment
2. Temporal design that sustains quality over time
3. Production; a design that can be produced in a way that reduces waste, emissions and resource demand
4. Operational design that provides for the ability to operate and sustain activities and events while reducing waste and resource demand
5. End-of-life design that has the ability to be dismantled, recycled, renewed or re-used.

In best practice sustainable architecture, a mixture of passive and active design measures is usually implemented. However, these days a large proportion of work comes from institutional clients who are becoming savvier when it comes to environmental design initiatives, and many now have their own requirements in place. Although these clients look for some passive design measures, many tend to be active solutions. The most common passive design measures utilised on projects to date include:

1. Passive cooling (natural ventilation)
2. Passive heating in winter through increased thermal insulation
3. Consideration of siting of buildings to maximise/minimise environmental factors
4. Solar shading and window system specification to minimise solar gain and heat loss
5. Integrated BMS systems.

## METHODOLOGY

### Overview

The methodology of this study was to conduct energy modelling for a proposed multi-residential building (23 Wills Street) using the Passivhaus Planning Package (PHPP) and PHI-approved climate data for Australian population centres. Alterations to

the building design were then made to bring the design to a Passivhaus standard for a Sydney climate.

### The Passivhaus Planning Package (PHPP)

The PHPP is a spreadsheet-based energy modelling tool that calculates key Passivhaus certification parameters (e.g., space heating demand, space cooling demand, primary energy demand, and airtightness). The PHPP utilises climate data certified for use by the PHI. Similar to many other energy model climate data filed, the PHI certified data is typically collated from local weather station data, processed, and formatted.

The results of the PHPP calculation are fundamental to the Passivhaus certification process, during which all documentation provided to the Passivhaus certifier is used to support data entries in the PHPP. The PHPP methodology is primarily based on ISO standard calculations.

Compared to dynamic energy models used in the buildings and infrastructure industry (IES-VE, EnergyPlus, ESDL Tas, etc.,) the PHPP makes two key simplifications:

- Utilising a monthly energy balance method rather than a higher resolution (e.g., hourly) dynamic simulation.
- Treating the entire thermal envelope as a single zone rather than splitting individual areas, rooms, and apartments into zones and assessing the energy balance for each zone.

For a comparison of the PHPP to a Passivhaus specialised dynamic energy model (WUFI Passive), see [11]. The PHI provides the following justification for the above simplifications<sup>10</sup>:

- Data inputs are simplified, as compared to a dynamic model
- Calculations are visible and transparent, noting that the PHPP is annotated in German (this author has successfully traced key calculations with heavy use of online translation tools).
- PHPP has increased calculation resolution and higher accuracy for key factors which significantly affect the energy balance of low energy buildings

The above justifications may prove correct for Passivhaus buildings designed for a heating-dominated climate (such as Germany). However, the increased accuracy may not apply for Passivhaus buildings designed for a cooling dominated or dehumidification dominated climate.

On review of documentation provided by PHI regarding the PHPP calculation method it is generally unclear whether this is the case. With the increased uptake of the Passivhaus standard worldwide it would be greatly beneficial for the PHI to address this question.

### Project description

23 Wills Street is a five-storey mixed-use development situated in Bendigo, Victoria comprising of 18 apartments and retail and other tenancy uses at ground and first floor. The outer skin is a mixture of glass reinforced and precast concrete, and provides a modern reinterpretation of Bendigo's civic sensibility. This outer skin with its punched windows and apartment decks and balconies assists in providing both solar



**Fig. 3 Architectural render  
(viewed from the north) – 23 Wills Street**

amenity and shading while maintaining visual privacy between the development and neighbouring properties.

Sustainable design has been integrated from the outset: all apartments are naturally ventilated and all bedrooms and living areas have ample natural light. The building will also display intelligent resource allocation, and adopts both passive solar design and ESD principles.

### Thermal design

Key design aspects that influence the thermal performance of the development include:

**Roof insulation:** The roof is very well insulated, at approximately R5.7.

**Shading:** Significant overhang shading is provided by the punched deck areas on the northeast and southwest facades. The overhang provided ranges from 1.0m and 2.0m in extent with a typical extent of 1.5m. This shading reduces solar gain on these facades by 35% to 45% in summer and 25% to 30% in winter.

**Shading:** The northwest façade is completely glazed. However, little shading is provided to the glazing. Perforated metal lateral sun shades are part of the design, yet this level of shading complexity is unable to be directly accounted for in PHPP. This shading was accounted for in PHPP in an approximate fashion, with minor impacts on heating or cooling demand results.

**Glazing:** All glazing for the development was specified to a solar heat gain coefficient (SHGC) of 0.63. This is key to the performance of the development during the summer months. All windows were double-glazed insulating units with a u-value of no greater than 3.4.

**External finishes and solar radiation properties:** External finishes are generally light coloured (white), with a low solar absorptivity. The roof is unpainted metal.

**Wall insulation:** External walls of the development are generally R2.5.

**Airtightness:** The airtightness of the building was assumed to be 15.5 air changes per hour (ACH) @ 50Pa.

This value was derived from [2] and is the mean value of airtightness for residential buildings testing in Australia.

**Thermal bridging:** psi-values for thermal bridges in various parts of the building envelope were assumed based on previous work by the authors on thermal bridging in standard Australian stud wall construction. The most significant thermal bridge runs along the slab edges, with a psi-value of approximately 0.8W/mK.

### Assumptions

Several simplifying assumptions were made regarding the PHPP energy model:

- The ground and first floor of the development are retail and conference areas, respectively. In order to simplify the PHPP calculations, it was assumed that the thermal envelope began at the second floor. Note that for the building to be certified as a Passivhaus, the whole building must meet Passivhaus standards.
- In order to simplify PHPP calculations it was assumed that identical HRV systems were present in both the baseline and modified models.
- It was assumed that the stair and lift cores were not within the thermal envelope. Previous experience with designing to the Passivhaus standard in Sydney indicates that heat losses to core areas are not significant in comparison to other elements of the building envelope.

## RESULTS

### Baseline model

The PHPP model results for the baseline design were 24.4kWh/m<sup>2</sup>a for cooling demand and 23.7kWh/m<sup>2</sup>a for heating demand. This is in comparison to a cooling demand limit of 18kWh/m<sup>2</sup>a and a heating demand limit of 15kWh/m<sup>2</sup>a. Breakdowns on heat gains and losses for cooling and heating are provided in Figure 4.

The modelled cooling demand was approximately 35% greater than the limit required to achieve Passivhaus certification. Non-useful heat gains and solar heat gains were high, which was largely due to the extent of unshaded building envelope (both opaque and glazed) in the development. Heat gain through the 100% glazed and minimally shaded north-western facade was 560kWh/m<sup>2</sup>a, which accounted for 40% of glazing heat gains. The northeast facade had comparable incident solar radiation and glazing area to the north-western facade; however, overhang shading reduced heat gains through this facade by 50% to 284kWh/m<sup>2</sup>a.

Ventilation heat losses, comprising air infiltration and heat-recovery ventilation, accounted for approximately 27% of heat losses. Windows accounted for 21% of heat loss, with 16% and 17% of heat losses occurring through the floor slab and thermal bridges, respectively. These findings may indicate contradictions to generally held Passivhaus guidelines of airtightness, highly insulated (triple-glazed) windows, floor slab insulation, and minimising thermal bridging. The PHPP method provided much more information about heat losses as compared to heat gains.

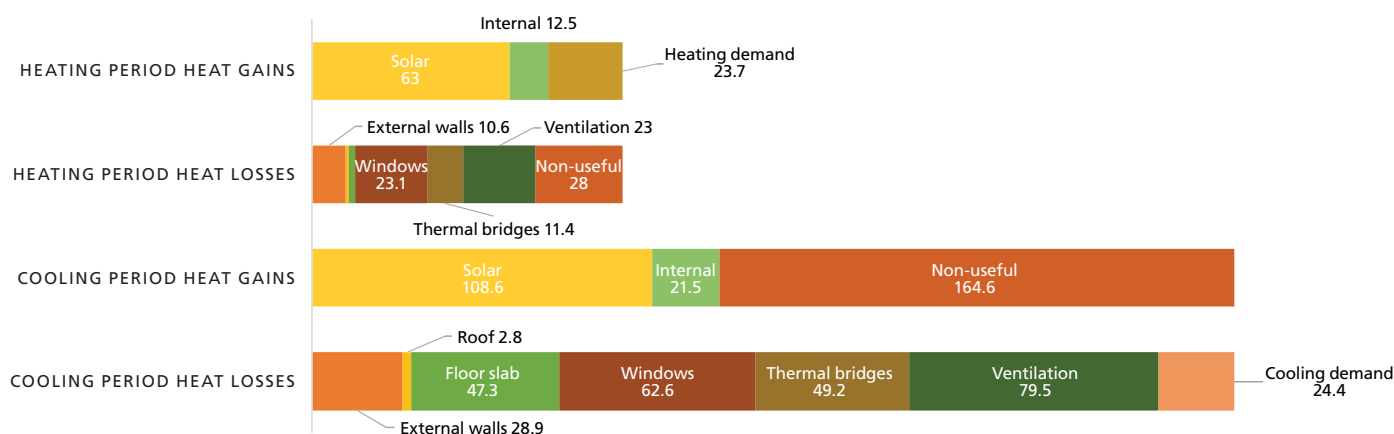


Fig. 4 Heat gains and losses for baseline model, kWh/m²a

The modelled heating demand was approximately 60% greater than the limit required to achieve Passivhaus certification. Heat losses were high for non-useful heat (28%), ventilation (23%) and windows (23%). This finding is consistent with the Passivhaus principles, which appear to be optimised for buildings in cool climates. Window solar heat gain accounts for approximately 64% of winter heat gains. For a Sydney climate, non-useful heat gains are significant even during the heating (winter) months.

The performance of the development in PHPP is aligned with expectations based on key climate variables and design features. Airtightness and ventilation are key factors, as well as properties affecting solar heat gain, including window solar heat gain coefficient and building envelope absorptivity. These factors all have the most direct bearing on the ability of the development to meet Passivhaus requirements for a Sydney climate. Note that these key thermal design features do not necessarily align with the five Passivhaus principles.

### Modified model

To achieve Passivhaus, several alterations were incorporated into the design of the building, producing a “modified” design. These alterations were largely concerned with reducing solar gain into the building without compromising on heating demand, and are listed below:

- Reduce glazing on the northwest facade by 20%
- Colour the roof white to reduce solar absorptivity
- Reduce the SHGC of glazing on the northwest facade to 0.45 (equivalent visible light transmittance approximately 55%)
- Reduce the SHGC of glazing on the northwest facade to 0.51 (equivalent visible light transmittance approximately 55%)
- Change airtightness of the building thermal envelope to permit no more than 0.6 air changes per hour (i.e., marginally meet the Passivhaus criterion of 0.6 ACH @ 50 Pa).

The modified design met the Passivhaus criteria, with the effect of the modifications on heat gains and losses presented in Figure 5 (below) and Figure 6 (overleaf). The PHPP results were 17.9kWh/m²a for cooling demand and 13.5kWh/m²a for heating demand, in comparison to a cooling demand limit of 18kWh/m²a and a heating demand limit of 15kWh/m²a.

Increasing the airtightness of the building was required to meet the Passivhaus criterion. This significantly reduced ventilation heat losses. The effect of this was to increase cooling demand but to significantly reduce heating demand, to the extent where the Passivhaus heating demand criterion was met through this design modification only. As airtight construction reduces sensible cooling due to air infiltration it is essential that airtight

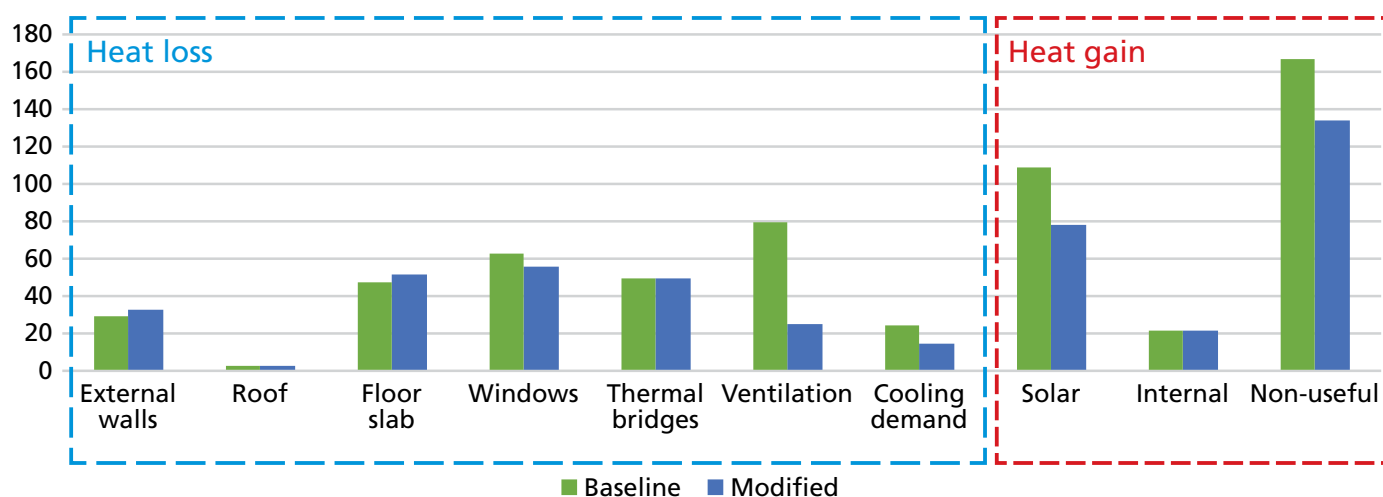


Fig. 5 Heat losses and gains during cooling period, kWh/m²a

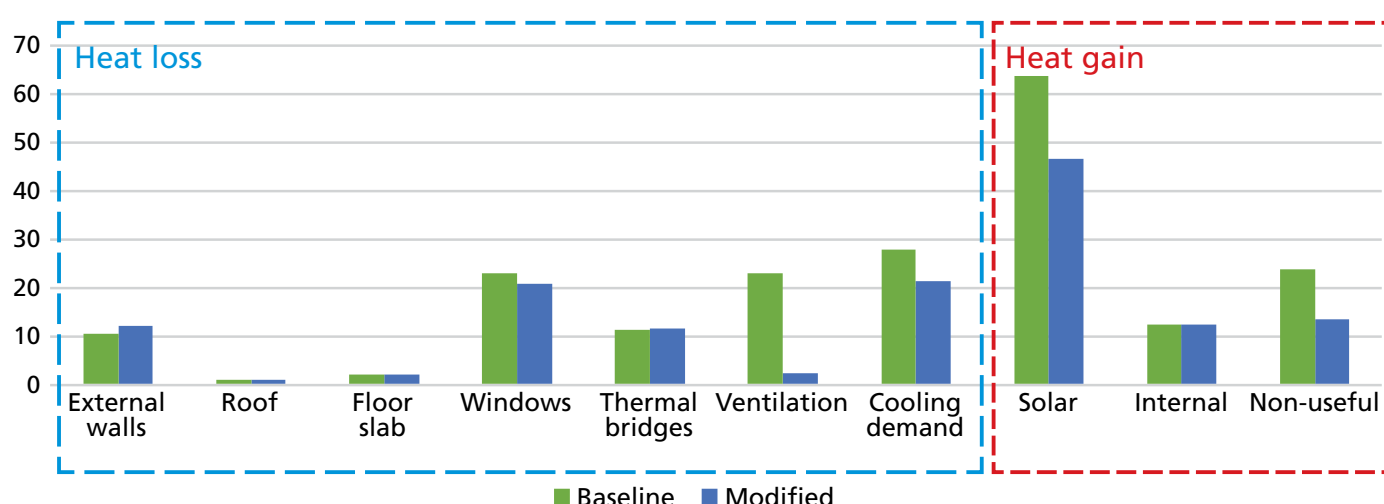


Fig. 6 Heat losses and gains during heating period, kWh/m²a

construction is coupled with an efficient, appropriately sized, and user controllable ventilation system (e.g., HRV system) to provide sensible cooling in summer.

All other design alterations were concerned with reducing solar load in the building. The change with the most significant architectural impact was reducing the glazing area on the north-western façade. This modification was actually considered as part of the original design of the building, and is currently being reviewed as part of the architectural design process. Changing glass types may have a cost impact to the project noting that high performance glass is not uncommon in Australia. A construction cost versus operational cost analysis may be undertaken to calculate the payback period of the high-performance glass.

Operable external shading (such as shutters or screens) is extremely effective in reducing solar gain through windows in summer, while still providing solar gain in winter. However, due to the form of the building this modification wasn't considered appropriate. Operable shading would result in a bespoke design, installation, and maintenance solution, which would negatively impact the project budget and not necessarily complement the architecture.

### Other Australian climates

Sydney presents a uniquely mild climate for thermal design of buildings, and is possibly the simplest climate in which to design an Australian Passivhaus while largely using traditional design and construction methods. As demonstrated in Figure 7, all other Australian climates demand a holistic design approach where the Passivhaus designer must work with the client and architect from the beginning to shape the design. Melbourne, Adelaide, Canberra and Hobart all lend themselves toward more traditional Passivhaus design (minimising heat losses) using the five key principles.

However, in Canberra and Adelaide solar gain also must be controlled in summer. Perth demonstrates similar behaviour to Sydney, but the cooling demand limit includes no allowance for dehumidification. Therefore, designing a Passivhaus for Perth must carefully balance heat flux between summer and winter.

Building a Passivhaus in Toowoomba would require an extensive review of building massing and orientation, with changes to components such as exterior finishes, glazing, and shading. Note that achieving the airtightness criterion will likely significantly reduce heating demand for all climates as demonstrated in the modified model for a Sydney climate.

Based on the resulting modified design for 23 Wills St in a Sydney climate, and modelling results for Australian population centres, a new set of five Passivhaus principles for warm Australian climates are proposed:

- **Glazing** – climate-aware glass selection and window-to-wall ratio
- **Shading** – passive and operable shading to minimise solar heat gain in summer
- **Building finishes** – low solar absorptivity to minimise solar heat gain in summer
- **Ventilation** – efficient, appropriately sized, and user-controllable ventilation system
- **Airtightness** – control heat flux throughout the year.

These principles are typically less onerous than their European counterparts, and more familiar to both designers and builders in the Australian construction industry. It is anticipated that these new principles will increase the accessibility of Passivhaus as a standard in warmer Australian climates and encourage further adoption of the Passivhaus concept throughout the country. Note that in cooler Australian climates (e.g., Hobart), the five traditional Passivhaus principles still apply.

## CONCLUSION

A multi-residential building was modelled for several Australian climates using the Passivhaus Institute-developed energy model, Passivhaus Planning Package (PHPP). The building design was then modified to meet the Passivhaus heating and cooling demand criteria for the climate of Sydney, New South Wales. The design modifications were generally non-architecturally obstructive and largely related to solar gain control, indicating that the mildness of the Sydney climate may be favourable to Passivhaus design. Other Australian climates are generally

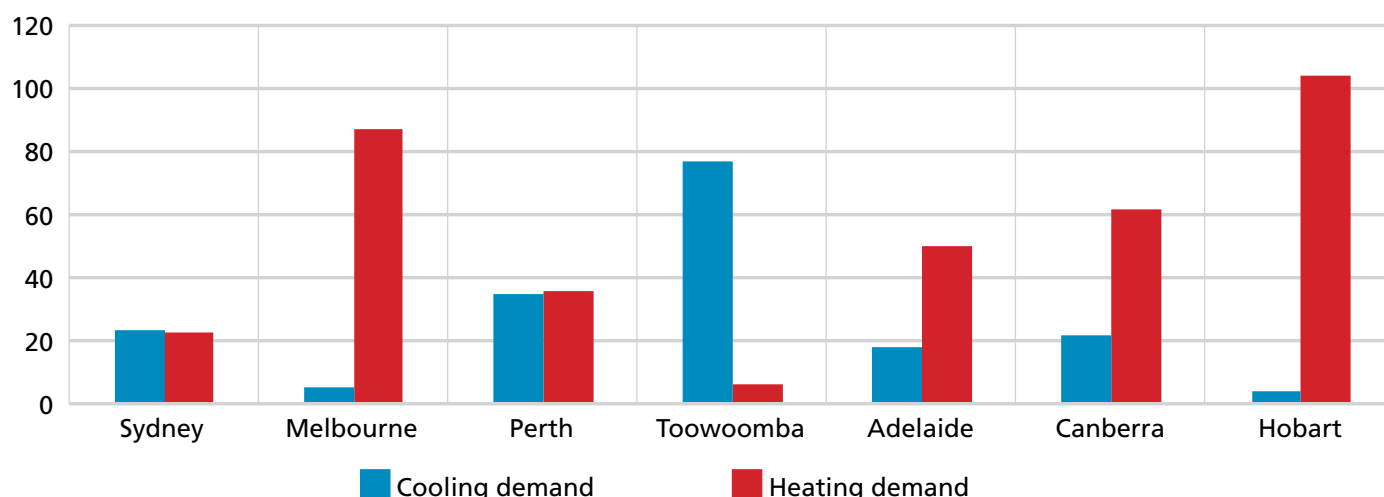


Fig. 7 Cooling and heating demand of the baseline model for Australian cities, kWh/m²a

less forgiving for Passivhaus design, and require collaboration between the architect and Passivhaus designer from a very early design stage. In particular, Melbourne, Hobart, and Toowoomba showed high heating and/or cooling demand.

Building airtightness was found to be key in reducing heat losses during both warm and cool periods. Although beneficial during cool periods (as heating demand is reduced), airtight construction was required to be balanced with an appropriate ventilation system and solar heat gain control to avoid overheating during warm periods. Based on the analysis for Australian climates, and especially the detailed analysis for a Sydney climate, the following five Passivhaus principles for warm Australian climates were proposed:

- **Glazing** – climate-aware glass selection and window to wall ratio
- **Shading** – passive and operable shading to reduce heat gains in summer
- **Building finishes** – low absorptivity to reduce solar heat gain in summer
- **Ventilation** – efficient, appropriately sized, and user-controllable ventilation system
- **Airtightness** – control heat flux throughout the year.

This work demonstrates the holistic nature of climate-aware design, and provides key guiding principles for warm Australian climates. ■

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