Chifley Passive House: Two years of performance data

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Abstract

Three years ago, the first wave of certified Passive House residences were built in Australia. Half of these houses were built in Canberra where the climate has long cold winters and dry hot summers, the ideal place for high performance buildings.

This paper focuses on one certified Passive House in Canberra and presents two years of collected performance data. It reinforces the notion that Passive House principles are universally applicable, in particular to non-European climates. It also adds to the growing body of knowledge of what works in the Australian context and what doesn't.

The solar-passive attributes of the house like thermal mass and cross flow ventilation were assets. Temperature and humidity data show the indoor environment stayed mostly within comfortable ranges despite needing virtually no heating in winter and no cooling in summer.

Indoor air quality data show the effectiveness of the mechanical ventilation and heat recovery (MVHR) system in moderating CO_2 and moisture levels even with the windows closed.

The overall energy use of the house was 64% less than other similar households and the actual energy use was 13% better than predicted, thus cementing Passive House as the premier comfort and energy efficiency standard.

1. Background

Despite there being six certified Passive Houses in Australia, there is still little performance data on them. To begin to address this issue, this paper presents measured data for a single-family home located on a suburban site in Chifley, Canberra, shown in Figure 1. Chifley Passive House was constructed and certified to the Passive House standard in 2014 and data has been gathered since, with the aim of informing house designers, builders and potential homeowners. It is home to a family of four including one author of this paper.

Figure 1: Front exterior and living room of the Chifley Passive House

1.1 Climate

The house is located 599m above sea level in a warm-temperate climate where the summers are as warm as those in Melbourne and the winters are as cold as those of Christchurch. Figure 2 shows the long-term average temperatures for Melbourne, Canberra and Christchurch (PHPP, 2016a) as well as the hourly temperatures for a Canberra Typical Meteorological Year (TMY) (NatHERS, 2016).

The measured performance data spans the years 2015 and 2016, so it is instructive to compare the actual temperatures of those years with the climate data used in the Passive House Planning Package (PHPP). Figure 3 shows this comparison. The summer of 2015 was 1.2°C warmer than the PHPP typical year and the winter was 0.2°C colder. The summer of 2016 was 1.8°C warmer than the PHPP typical year and the winter was 1.1°C warmer.

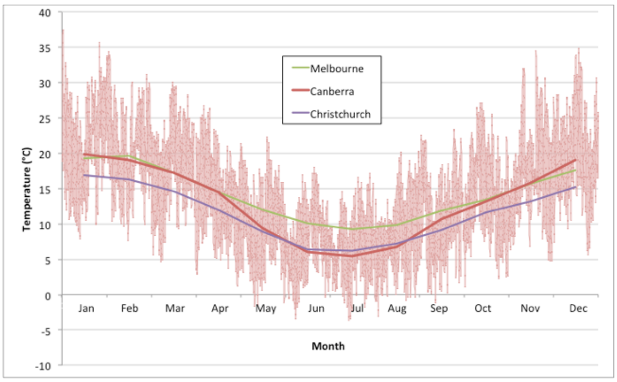


Figure 2: Climate for Melbourne, Canberra and Christchurch

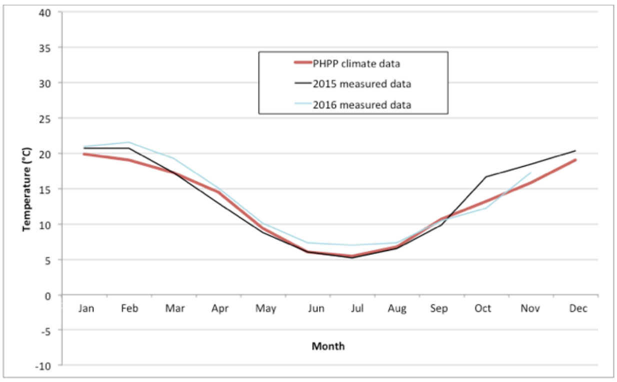


Figure 3: Comparison of PHPP climate data against locally measured climate data

2. Building Details

The house is a single storey building with a 127m^2 treated floor area (TFA) that is small compared to most new Canberra houses. It is oriented 15 degrees east of north and experiences little overshadowing. It relies on extensive north facing glazing, thermal mass and operable windows to achieve extremely low energy use. The floor plan is shown in Figure 4.

Most of the glazing (81%) faces north and provides light and heat to living areas and bedrooms. The floor consists of 150mm of XPS foam insulation under a 100 mm concrete slab and dark porcelain tiles. The walls are made from prefabricated timber structural insulated panels (SIPs), and the roof is made from steel SIPs. Non-passive house certified double glazed uPVC framed windows and doors are used throughout. Figure 5 shows the major building components and their U values.

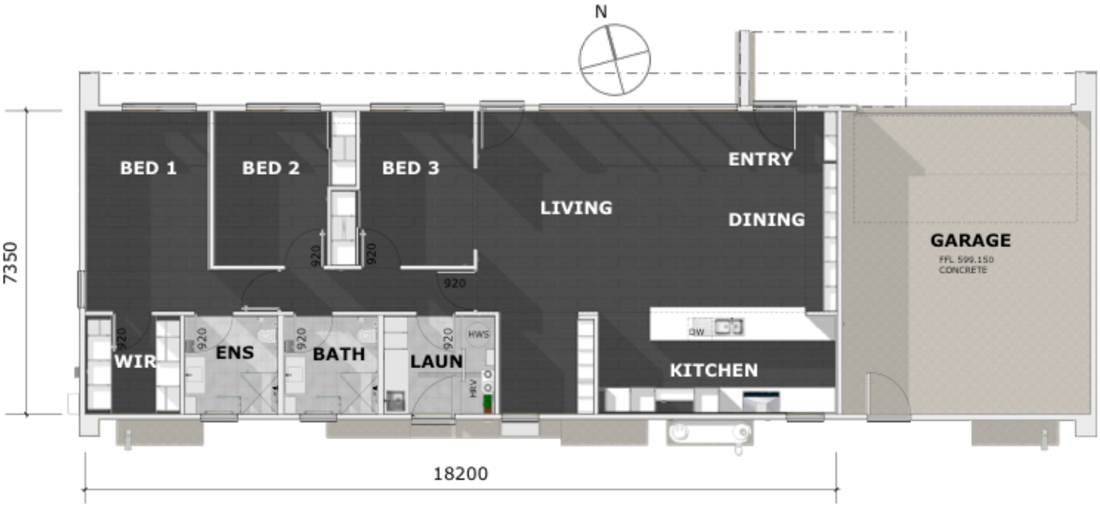
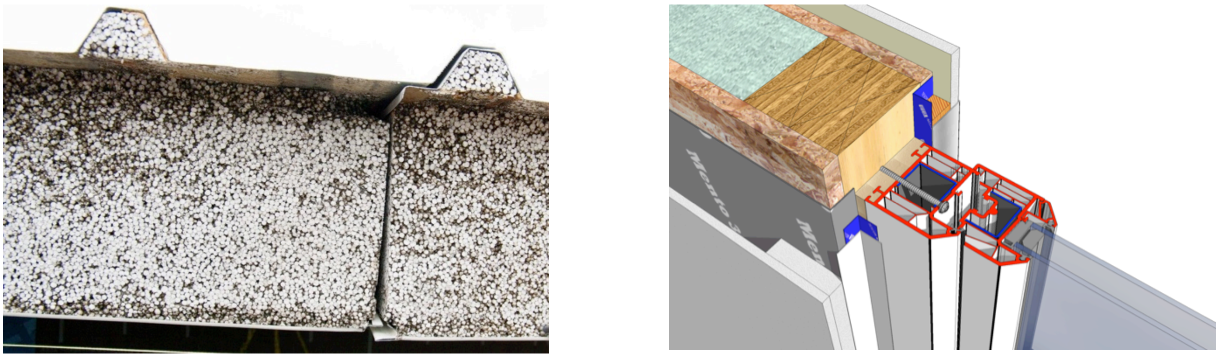


Figure 4: Floor plan

XPS floor insulation (150mm, U = 0.21 W/m2K)

PIR wall insulation (90mm, U = 0.29 W/m2K)



EPS roof insulation (200mm, U = 0.20W/m2K)

uPVC window frames with double glazing (Uw = 1.45W/m2K)

Figure 5: Typical floor, roof, wall and window details.

The airtightness layer comprises a Pro Clima Intello membrane on the interior side of the SIPs wall panels. The membrane is taped to the concrete slab and to the windows frames. For the roof, the steel underside is taped at joints to complete the airtightness layer. The house achieved a blower test result of 0.1 h^{-1} @ 50 Pa, which is extremely low compared to new houses in Canberra that have an average air leakage rate of 15 h^{-1} @ 50 Pa (Ambrose and Syme, 2015).

Motorised roller blinds with 71% block-out fabric protect the north facing windows from the summer sun as do 900mm eaves. The mechanical ventilation and heat recovery (MVHR) system is a Zehnder ComfoAir 200 with semi-rigid ducting. The only heat sources are an inline 1.2kW electric heater in the MVHR system and a 100W heated towel rail in one bathroom. No active cooling devices are installed in the house. A Sanden heat pump with a 315- litre tank located in the laundry provides domestic hot water.

3. Measurements

The house was fitted with wireless Aeotec temperature and humidity sensors, a Comet T6540 carbon dioxide (CO_2) sensor and battery operated Wireless Tag sensors for short term temperature and humidity measurements. Results were logged every 10 minutes. The CO_2 sensor is based on a dual wavelength non-dispersive infrared (NDIR) gas sensor that automatically compensates for ageing effects and so only requires calibration every 5 years. Indoor sensors were located in the centre of the house, 1 meter above the ground and away from heat sources, direct sunlight and ventilation grilles (Figure 6). Wireless Tag sensors were located in the bathroom, bedroom and on the slab surface of the living room.

An Aeotec Smart Switch 5 measured duct heater energy usage and the main electricity meter measured total electricity usage.

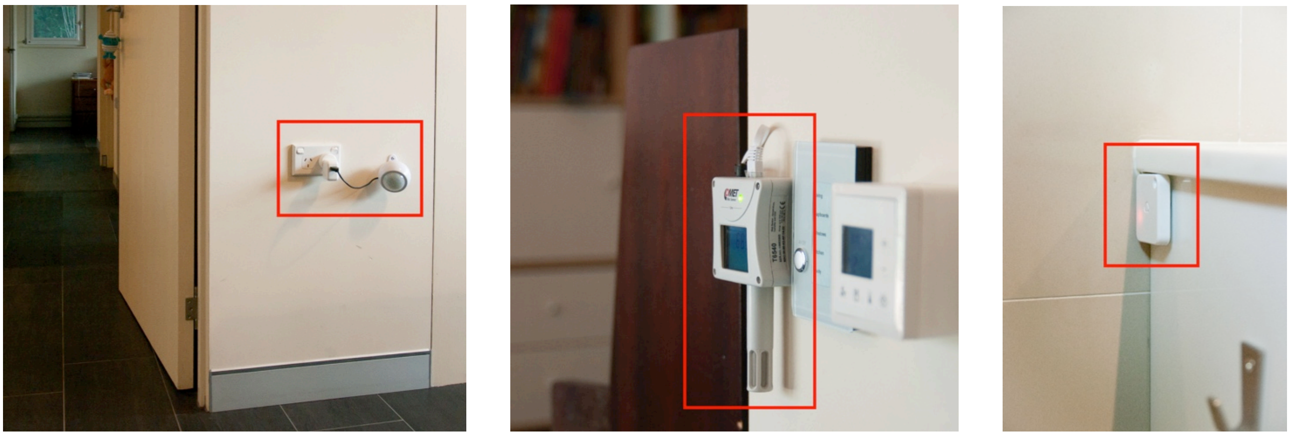


Figure 6: Temperature/humidity sensor, CO_2 sensor and portable temperature/humidity sensor

3.1 Energy consumption

Over the two years 2015 and 2016, the occupants of Chifley Passive House consumed 64% less energy compared to other similar households in Canberra (ACIL, 2015); 75% less energy than Melbourne houses with energy ratings of less than 5 stars (Ambrose et al, 2013); 62% less than Melbourne houses with energy ratings of 5 stars or more; and 57% less than Christchurch houses (Isaacs et al, 2010). Figure 7 shows this comparison. It shows there are significant savings potentials over conventional houses.

The actual energy consumed in Chifley Passive House was 13% less than the PHPP modelling predictions (Figure 8). Although lighting, appliances and domestic hot water consumed 8.5 kWh/m^2/year more energy than predicted, the heaters consumed 14kWh/m^2/year less. This was partly due to higher than predicted internal heat gains from lighting, appliances and domestic hot water offsetting the need for additional heating. In other words, inefficient or higher usage of appliances can keep a Passive House warm in winter instead of a heater. The practice is not advisable because of the unwanted heating effects in summer. There was insufficient data collection to isolate the appliances responsible. Another factor at play was that the winters of 2015 and 2016 were warmer than the PHPP typical year (Figure 3). When the PHPP climate data was changed to reflect the actual climate during the test years, the predicted heating demand changed from 14.2 to 11.9 kWh/m^2/year, bringing the prediction even closer to the measured values.

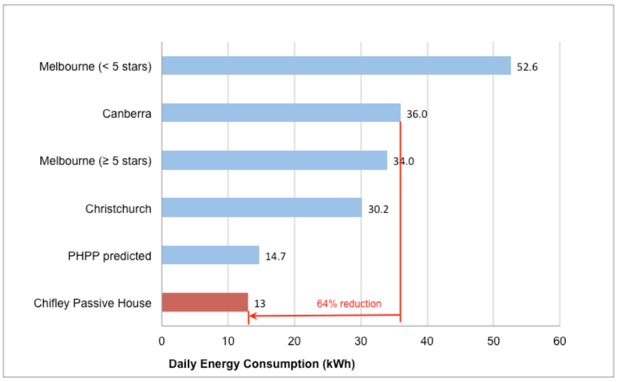


Figure 7: Energy consumption comparison with other cities

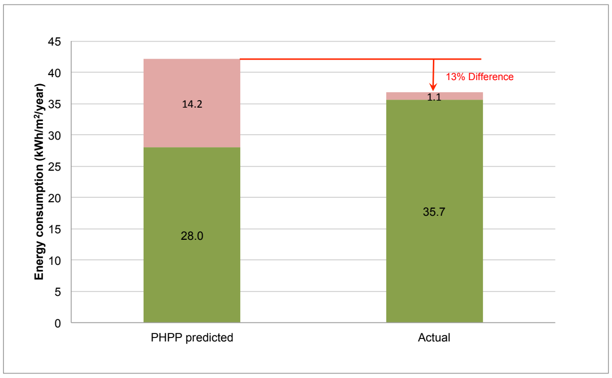


Figure 8: Comparison of predicted and measured energy consumption

3.2 Winter performance

Figure 9 shows measured temperatures for a typical winter week with clear skies and frosty mornings below 0°C and daytime maximum temperatures of 8°C. Despite the cold conditions and despite the inline duct heater not being used, the readings show the indoor temperature did not drop below 19.8°C during this week. To achieve this, the occupants kept the windows shut and the blinds fully open to maximise the amount of heat stored in the floor slab during the day. One consequence was that the indoor temperature sometimes exceeded the 25°C comfort level; however, the occupants felt that the temperatures were still comfortable. A second consequence was that the extra heat in the slab kept temperatures at a comfortable level at night and through to the following morning.

Temperatures during a partially overcast week are presented in Figure 10. Although there was minimal solar gain through windows, the outdoor temperatures were warmer than those of the preceding week (Figure 9) and so the indoor temperature remained above 20°C, evidence of the slow loss of heat through the building envelope. If the cloudy weather was to have continued for several more days, then the indoor temperature would have dropped below 20°C and the inline duct heater would have been required to maintain comfort.

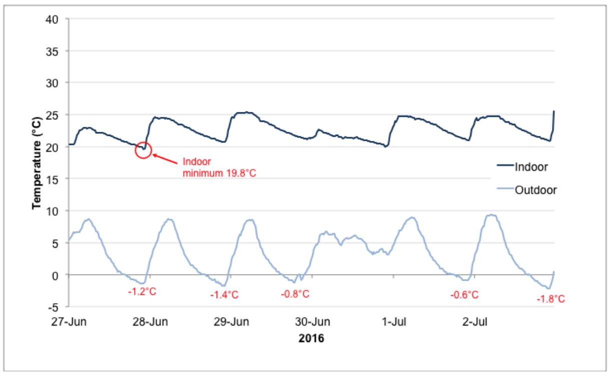


Figure 9: Temperature readings for a cold clear week in winter without heating

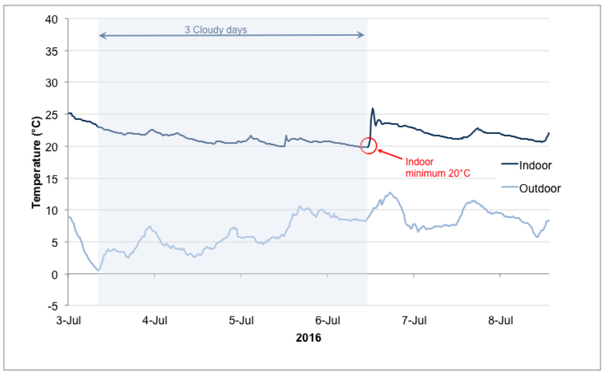


Figure 10: Temperatures readings for a cold cloudy week in winter without heating

Figure 11 shows a histogram of all the measured temperatures for 2015 and 2016. It shows that the house remained warm for most of the winter, not just for the weeks shown in the previous graphs. The percentage of time below the comfort limit of 20°C was 3% in 2015 and 1.5% in 2016 with the coldest recorded winter living room temperatures being 17.8°C in 2015 and 19.6°C in 2016. A run of cold days in July 2015 prompted the occupants to install the duct heater but the heater was only used over a period of 10 days that year and not used at all in the following year.

The winter of 2016 was 1.3°C warmer than the previous year (Figure 3) so the duct heater was not needed and the house kept warm for 98.5% of the time.

Figure 12 shows the 2015 and 2016 dataset on a psychrometric chart overlaid with what the PHPP manual (2016b) defines as comfortable. Indoor winter humidity never exceeded comfort limits but did reach low levels, about 30%. This was likely the result of the MVHR bringing in dry winter air and warming it in the heat exchanger, decreasing the relative humidity.

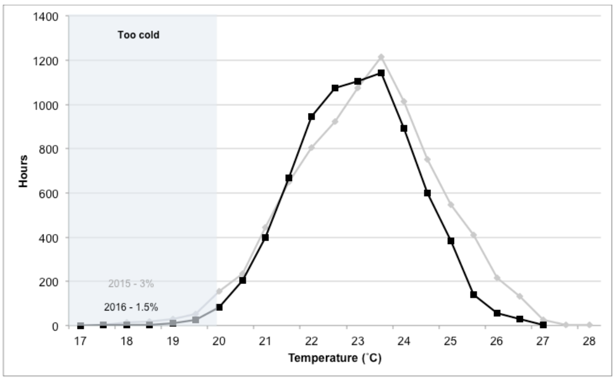


Figure 11: Two-year temperature distribution

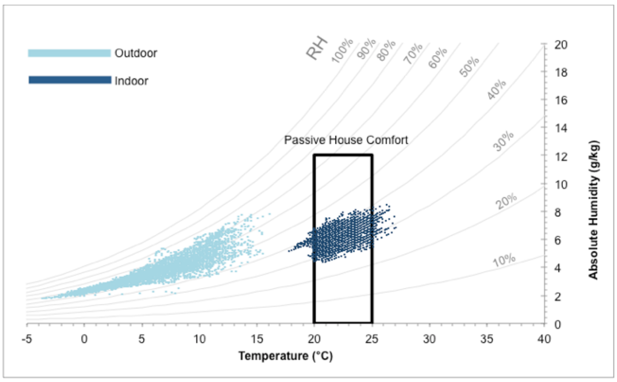


Figure 12: Psychrometric chart - winter

3.3 Summer performance

Summer days in Canberra are typically dry and warm but with cool evenings where the temperature drops rapidly after sunset. Figure 13 shows one such week in 2016 with hot days reaching up to 34°C and with overnight minimums down to 10°C. Under such conditions, the temperatures in the house stayed comfortable and kept below 24.4°C without the need for cooling devices and ceiling fans. The ventilation system was operated at normal speed on heat recovery mode during the day and it automatically switched to bypass mode when the outside temperature was cool enough at night.

The occupants observed that the ventilation system alone did not adequately cool the house at night. Consequently, they opened the windows and doors to purge the house of hot air. Sometimes the indoor temperature was allowed to drop below the 20°C comfort level in order to cool the slab and create a buffer for the next day. Despite the eaves shading the windows, the external blinds were kept closed throughout summer to minimise diffuse radiation gain. This was possible as the 71% block-out blinds were transparent enough to allow daylight to enter without significant amounts of heat. In Canberra, the diffuse radiation accounts for 36% of the global summer radiation (Meteonorm, 2016).

The summer strategy of using thermal mass, window blinds and night purging worked most of the time. Occasionally, however, there were days when overnight temperatures remained above 20°C. Without the cool air to purge the house at night, the indoor temperatures started at 24°C the following morning and without the benefits of a cool slab, the house overheated later that day. Figure 14 shows this effect starting with a warm night on the 12th January 2016.

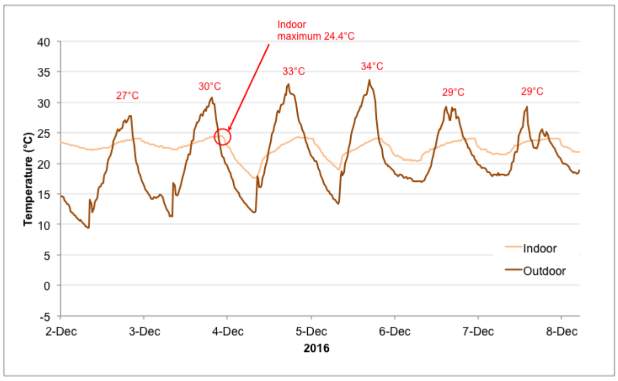


Figure 13: Temperature during a hot week in summer with cool evenings

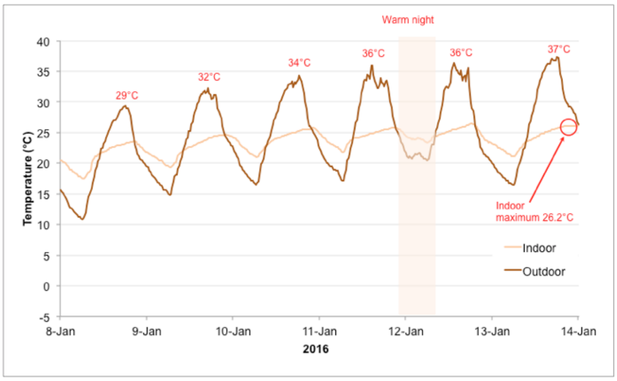


Figure 14: Temperature during a hot week in summer with warm evenings

Figure 15 again shows the temperature distribution for 2015 and 2016. Temperatures were comfortable most of the time with overheating above 25°C occurring 9% of the time in 2015 and 3% of the time in 2016. This compares to the PHPP prediction of 7.1% overheating. Despite both summers being 1.2°C and 1.8°C warmer than average (Figure 3), respectively, the living room temperature reached a maximum of only 27.6°C in 2015 and 26.5°C in 2016. The performance was significantly better in 2016 than the previous summer, partly because the occupants installed security screens on the doors that allowed better night ventilation. Passive night ventilation is an important design feature for passive houses but only effective if fully implemented with insect or security screens.

Figure 16 shows that for the vast majority of the time, the absolute humidity was below the Passive House Institute recommended limit of 12g/kg of dry air.

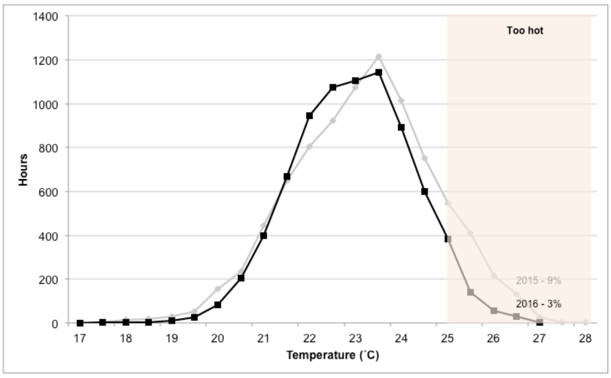


Figure 15: Two-year temperature distribution

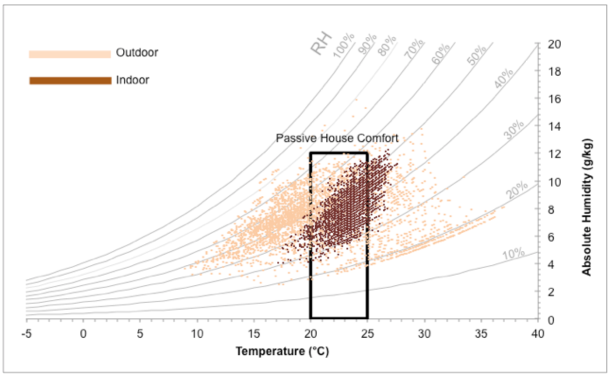


Figure 16: Psychrometric chart - summer

3.4 Temperatures in different rooms

One of the promised benefits of a Passive House is thermal comfort in the form of even temperatures throughout different rooms. Figure 17 shows the measured temperatures over the period of a week in three rooms (living room, bedroom, bathroom), the living room slab surface, and the southern exterior. No heating or cooling devices were used during the measurement week.

All four indoor temperatures were within the comfort ranges and were within 2°C of each other. The slab temperature was the most stable and varied less than +/-0.5°C, consistent with the floor playing an important role in stabilising the indoor air temperature. The living room was the warmest room, since it had the largest glazing ratio and the bathroom was the coolest since it only had a small south facing window.

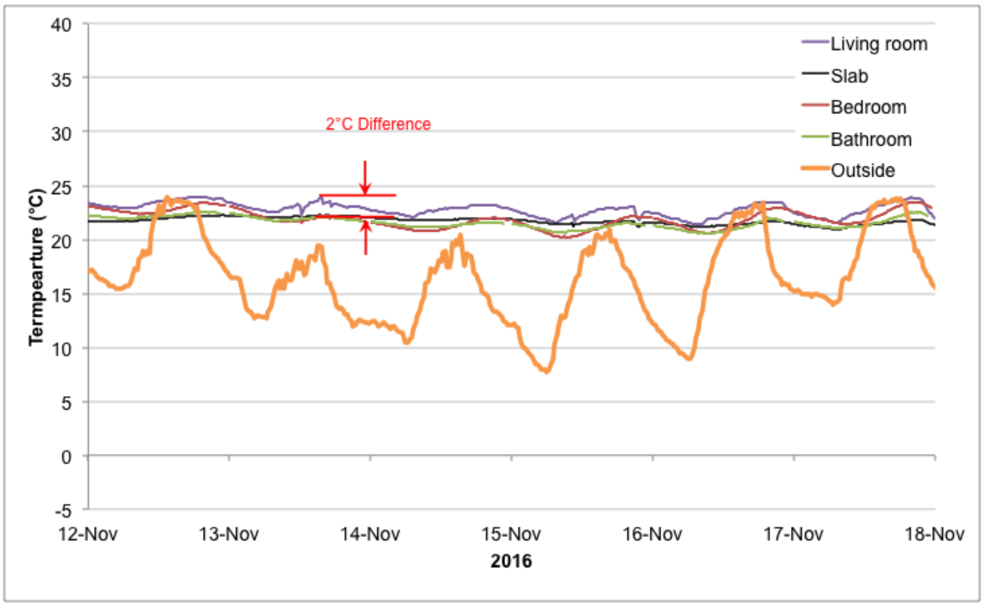


Figure 17: Temperature readings throughout the house during a week in spring.

3.5 Indoor Air Quality

Another promised benefit of a Passive House is excellent indoor air quality. The European standard EN 13779:2007 defines different indoor air quality classes based on CO_2 concentrations, from IDA1 (High quality) to IDA4 (Low quality). Figure 18 presents CO_2 readings in the living room over a week in spring 2016 and shows that the indoor air quality mostly fell into the ‘High quality’ range, occasionally fell into the ‘Good quality’ range and only briefly reached the ‘Moderate quality’ range during International Passive House day on the 13th November when there were 13 people in the house.

The CO_2 concentrations kept low even when the occupants kept the windows and doors shut for three days at a time. Carbon dioxide concentrations within the room increased when occupants were active and decreased when they were absent from the room.

During three of the evenings, the occupants opened the windows for night purging and this immediately reduced CO_2 concentrations to below 500 ppm. On other occasions, even with the windows closed, the concentrations still dropped below 600 ppm after four hours. This indicates the effectiveness of the MVHR system in removing CO_2 from the house.

In addition to bringing in fresh air, MVHR systems also remove moisture from bathrooms and kitchens. Figure 19 shows the relative humidity readings in the bathroom over a week in spring 2016. The readings increased rapidly when occupants showered, often rising from 50% to about 70%. However, after four hours the relative humidity would return to normal levels indicating the success of the MVHR in removing excess moisture without the need to open windows and without dedicated extraction fans.

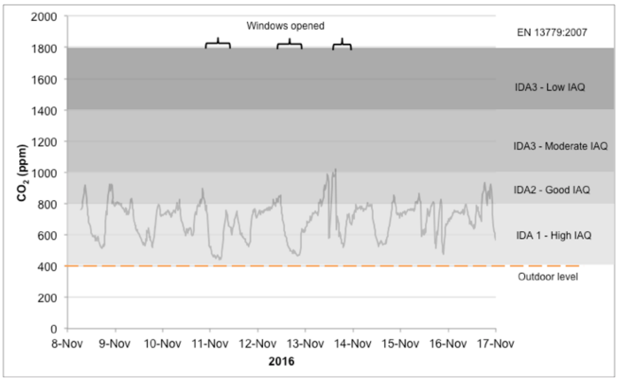


Figure 18: Carbon dioxide readings over a week in spring 2016

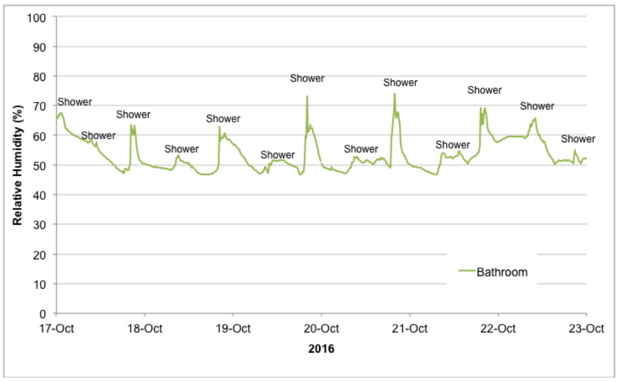


Figure 19: Relative humidity readings in the bathroom over a week in spring.

4. Conclusion

Fear of the unknown has led some to believe Passive House only works in cold European climates. This paper firmly counters the argument and convincingly answers three important questions: (i) How comfortable is it to live in an Australian passive house? (ii) How much energy can an Australian passive house save? (iii) Is the PHPP valid in the Australian context?

The Chifley Passive House was found to be comfortable in all seasons and in particular winter where temperatures stayed above 20°C for 98.5% of the time in 2016. In summer, the house overheated 3% of the time in 2016. Room to room temperatures only varied 2°C during one measurement week in spring and indoor air quality and moisture levels were well controlled using the MVHR.

Energy savings of 64% over similar households in Canberra proved that large amounts of energy are not required to maintain comfort. Also important was the predictability of the savings. The difference between the actual energy usage and the predicted usage was only 13%. This result adds to the growing body of evidence giving designers confidence to rely on the PHPP predictions.

5. References

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