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Low Energy Design of Existing Family Home

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Abstract

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The objective of this thesis was to produce a concept for a renovation of a house in Sydney, Australia to meet low energy requirements. New low energy houses have existed for many years, although the concept of renovations can create many challenges which will be looked at through this thesis.

Firstly, the concepts of passive house and low energy building were analysed to understand the requirements of these two concepts. Next, a real-life case study was reviewed to understand the possibilities for improvements, as well as what potential problems could arise.

An existing house in Sydney, Australia was utilized for the model and an evaluation of the existing building elements were reviewed to understand, where potential improvement could be achieved. Although there are many other methods that could help to achieve the low energy requirements, this thesis only considered feasible and practical solutions. Having calculated the existing U-values of the house, this allowed for the modification of the building elements to surpass the target values. The results show the final values of the building to indicate that it could reach the low energy status.

The methods in this thesis can be utilised to understand where different area of a house or building can be improved. Although every building is never the same the principles used throughout this thesis can be incorporated into any house or building, leading to improved indoor air quality and energy efficiency.

Keywords: low energy, passive house, energy, thermal, insulation, U-value

Contents

List of Abbreviations

NCC	National Construction Code is the requirement for the technical provisions of design, construction and performance of a building in Australia
ACH@50	Air Changes per Hour at 50 Pascals
$kWh/(m2a)$	Kilowatt hours per meter squared annum
PHPP	Passive House Panning Package is a design software that allows for designing low energy buildings
$CO2$	Carbon Dioxide is a chemical composed of one carbon atom and two oxygen atoms.
$kWh/m2$	Kilowatt hours per meter squared
N50	Number of times the volume of air within the building is changed in an hour @50 Pascals
$0.6h-1$	0.6 of the volume of the building changed in an hour
$W/(m2K)$	Watts per meter squared - Kelvin
$W/(m.K)$	Watts per meter - Kelvin
LED	Light-Emitting Diode is a semiconductor light source emitting light when a current pass through
Low – E	Low Emissivity glass minimizes the infrared and ultraviolet light that penetrates through glass

XPS	Extruded Polystyrene Insulation is a closed cell rigid insulation, which is extruded through a die and expands during cooling process
EPS	Expanded Polystyrene insulation is a closed cell rigid insulation where beads are molded or cut to various sizes
HER	House Energy Rating provided the rating of houses in Australia
ƛ	Lambda Value W/(m.K) is the heat conductivity of a material, used in thermal calculation of building and thermal components

1 Introduction

Throughout history people have looked to live in comfort and now it is at our fingertips, but we choose not to grab it. The development of renewable energy has become readily available; however, there remains doubts over the need to use it. Global warming and climate change have been discussed intensely over the last decade and been proven by many renowned scientists. However, some politicians have questioned that the threat of global warming or climate change exists. (1.)

As the development in renewable energy technologies continues to improve, responsible management for the energy produced and to optimise the efficiency is necessary. Although renewable energy sources are readily available in most countries, they are not cost effective in all climates.

Australian residential styles have evolved from imported corrugated iron to more sophisticated styles borrowed from other countries. These range from the Victorian style from the United Kingdom, Californian bungalow from the United States or even the Georgian style from North America and Europe. It seems that these homes were built with little consideration or understanding of the Australian climate, reliant on European styles that were unsympathetic to the Australian climate and landscape. (2.)

This thesis discusses an approach to improve the thermal characteristics for the building envelope of an existing house in Australia and how a building envelope plays an important role in providing a comfortable home. In chapter 2 the concept of energy efficient homes is explained from the requirements to the technologies and systems used within low energy homes and passive house. In addition, the different requirements of other countries to achieve the high standards set for energy efficient homes are discussed. Chapter 3 reviews a case study of homes in Victoria, Australia built in different decades, to discover how the renovations made to these homes have improved their energy ratings.

Chapter 4 analyses an existing house in Sydney, Australia using the Passive House Planning Package (PHPP) to calculate the primary energy of the house in its current condition. Following that, the thesis provides recommendations from a practical standpoint to lower the u-value of each element and the primary energy of the building.

2 Energy Efficient Houses

Energy efficient homes are becoming more and more common with the increase in discussions about global warming and energy prices. However, everyone is not always able to build or renovate to the standards set by different organisations, such as Passive house and low energy.

The terms low energy, passive house and sustainable buildings are used ever more frequently in the built environment. The whole concept of energy efficient houses was developed to curb the energy demand of buildings by using better insulation, reducing thermal bridges, air tightness and the use of mechanical ventilation with heat recovery to improve indoor climates. (3.)

2.1 Passive House

The first concept of a Passive house originated from a conversation between Bo Adamson of Lund University, Sweden and Wolfgang Feist of the Institut für Wohnen und Umwelt (Institute for Housing and the Environment, Germany) in May 1988. The definition given for a passive house is

> "A passive house is a building, for which thermal comfort (ISO 77320) can be achieved solely by post heating or post cooling of fresh air mass, which is required to fulfil sufficient indoor air quality conditions" and "The house heats and cools itself, hence "passive"". (3.)

The criteria to achieve Passive House certification requires that a residential building's total heating and cooling demand in climates that require cooling is 15 kWh/(m2a) or less or, alternatively, a heating and cooling load of 10 W/m2 or less. To achieve Passive House classic certification of renewable primary energy demand, the following requirements of heating, cooling, hot water, auxiliary electricity, domestic and common areas electricity must not exceed 60 kWh/(m2a). Air tightness pressure test result number n_{50} of $0.6h^{-1}$ or less provides the number of times the volume of air in the building changes in one hour as is shown in chapter 2.2. Also meeting the thermal comfort levels and not exceeding 25 degrees Celsius for 10% of the hours in a year. (4.)

The Passive House concept has become an accepted solution in European built environments to reduce the energy demand (6). In appendix 1 it describes the main design features of the building envelope along with the ventilation system that should be used as a starting point for the design and planning aspect of any new building or renovation (5).

2.2 Low Energy Houses

Low energy homes do not have a global definition, as the national standards of vary from one country to another. Energy consumption for low energy houses (Niedrigenergiehaus) in Germany have a limit of 50 kWh/(m2a) for space heating, and the Minergie standard in Switzerland has a limit of 42 kWh/(m2a). However, in most cases it is considered that in low energy houses, the amount of energy used for space heating is half of the energy stated above , typically between 20 kWh/(m2a) to 30 kWh/(m2a). (7.) The implementation of standardised low energy buildings in each country has developed in their own ways (2). Figure 1 below shows the comparison between the U-values that are required throughout a low energy home or a passive house (8).

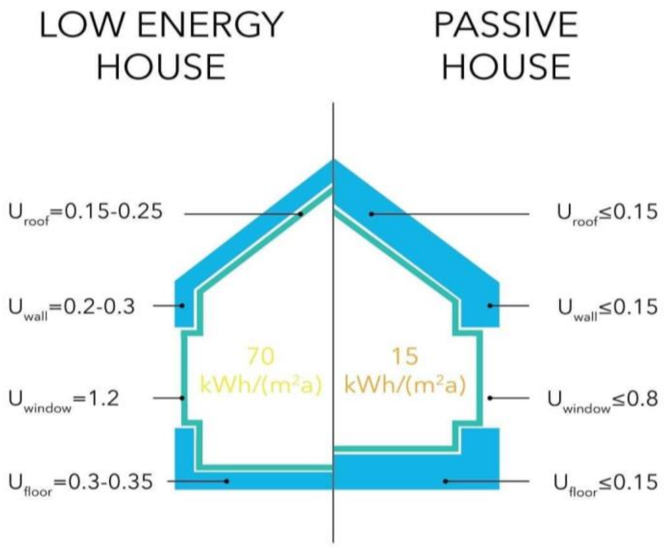

Figure 1. Comparison of the building elements U values of low energy house (left side) to passive house (right side) for central European houses (8).

Low energy buildings are designed to reduce the need for fossil fuels such as coal, gas and oil, while utilising sustainable energy sources to provide comfort in the buildings (3). In Denmark, the United States of America, Sweden, Canada and Germany, the concept of low energy building had some experimental initiatives in the 1970's. (6.)

Low energy houses may also implicate other measures to help reduce the energy consumption by using low energy equipment, home appliances, such as LED light bulbs and white goods (fridges, washing machines and ovens) with ecolabel certification that operate with less energy compared to older appliances which could require two or more time the energy to operate. (6.)

Thermal insulation is one of the key parts of a low energy home, keeping the heat outside in the summer and inside during the winter. Common insulation materials used throughout a house are soft insulation, such as mineral wool, and rigid insulation, such as Extruded Polystyrene Insulation (XPS) or Expanded Polystyrene insulation (EPS). Additionally, windows act as thermal insulation, whether they be double, triple glazed or have argon gas or just air between each pane of glass. (9.)

Each material has a thermal resistance or R-value W/(m.K), which is calculated by multiplying the thermal conductivity, or lambda value (ƛ), by the thickness of the material. Higher R-values provide greater thermal resistance performance. Knowing the R-value of a material, it is possible to calculate the overall heat transfer coefficient or U-value W/(m2.K) of the building element using formula 1 below. A lower U-value will represent higher levels of insulation and better performance of the building envelope. (6.)

$$u = \frac{1}{\mathrm{R}si + R1 + R2 + \cdots . + Rn + Rse} \qquad (1)$$

Where
R_{si} is the thermal resistance at interior surface
R_{se} is the thermal resistance at exterior surface
R_1 – R_n are the thermal resistances of individual construction layers in series, 1 - n. (6.)

The air tightness of the building envelope is another major key factor in the low energy design, as it prevents the building from leaking warm air outside in the winter and cool air during the summer. Any gaps for example between floorboards, or around doors or windows, holes, cracks or any other openings in the building envelope as shown below in figure 2 allow the air to escape. In most cases, a vapor or air barrier is installed during the construction phase behind the finished surfaces, with all joints sealed with approved tape. (9.)

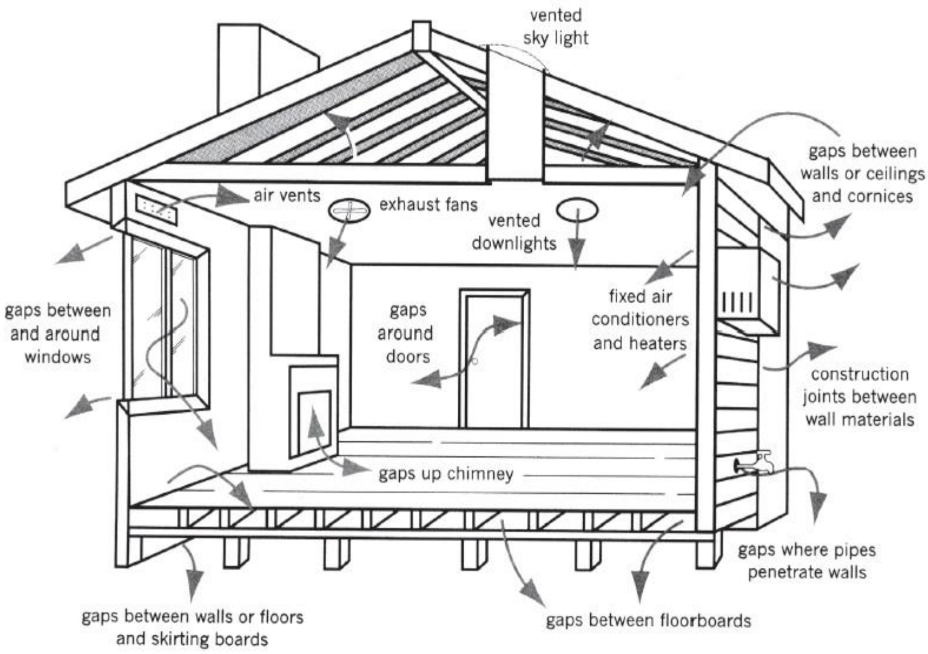

Figure 2. Common leakage points found in a building's envelop (9).

A pressure test or blower door test can be conducted to see if the building envelope meets the specific requirements. A pressure difference of 50 pascals (Pa) between the interior and exterior is used to measure the air tightness of a building, known as ACH50 (Air Change per Hour @ 50 Pascals). The test also provides the n_{50} number as shown below in formula 2, which indicates the air changes per hour (1/h) of the building. (9.)

$$n_{50} = \frac{V50}{\mathrm{Vn50}} \qquad (2)$$

Where

n_{50} is the number of air changes per hour at a pressure difference of 50 Pa (h^{-1})
v_{50} is the mean volumetric air flow at a pressure differential of +/- 50 Pa (m^3/h)
V_{n50} is the net air volume within the building (m^3). (9.)

Increased insulation improves thermal comfort and energy efficiency within the building. However, air tightness in homes can have adverse consequences. The water vapour generated by the household activities, for example showering, cooking, washing or drying clothes, can lead to an increase in condensation. This condensation occurs because the water vapour is unable to exit the building through the air leaks. Instead, it needs to exit through the building elements, creating a risk of mould, mildew and decay. Vapour barriers are required to be placed in different areas of the walls and ceilings, depending on the climate. As can be seen in figure 3 below, the dew point in the wall influences where the vapour barrier is to be installed to prevent moisture penetrating the internal elements. (9.)

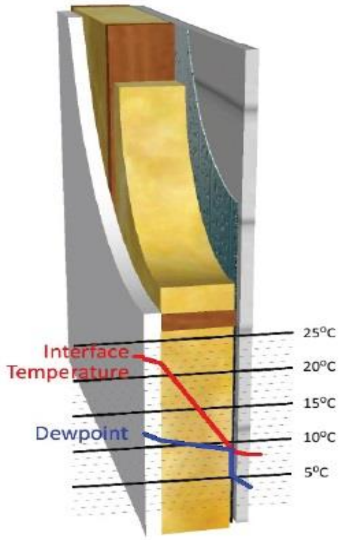

Figure 3. Vapor barrier placed inside the external cladding, preventing any condensation inside the wall space (9).

The problems of condensation can be eradicated with the installation of mechanical ventilation e.g. heat recovery systems, heat pumps or a permeable vapour barrier that will allow the water vapour to escape the building element before any condensation occurs. Heat recovery systems in a well-sealed home can provide all the necessary ventilation when designed correctly. Fresh external air is drawn in, while heat is extracted from the outgoing warm, humid air with heat exchangers or heat pumps to heat the fresh incoming air to the living spaces that require the supply air to start the circulation process. (9.)

Another major component of the building envelope, which can be an interesting design feature and a complex element, is the windows. They connect the indoor living space to the outdoors, allowing light and fresh air into the building. When a low energy home window is designed correctly, the internal surface temperature of the glass should be close to the desired room temperature. The U-value (U_w) of the window, as seen in formula 3 below, measures how much heat the window assembly of the frame, glass, seals and spacers will conduct.

$$U_w * T * A = W \quad (3)$$

Where
U_w the amount of heat conducted through a glazed unit (W)
T is the temperature difference on each side (degree)
A is the area of the glazing unit (m^2)
W the total watts. (4.)

The amount of solar radiation transmitted through glazing provides the visible transmittance of the window and can be reduced. However, it will reduce the amount of daylight entering the home. In other words, low visible transmittance of the window means one must turn the lights on, leading to higher energy usage.

3 Case Study of Homes in Victoria, Australia

A great number of Australian homes were built before the energy regulations for residential buildings were introduced in 2005. The potential losses of energy in the existing houses built before 2005 will continue to pose a problem of health, emission issues and energy cost to these homes. Even with the new increases of the minimum standards set by the National Construction Code (NCC) unless renovations can be made to meet the standards. (10.)

Existing homes in Australia possess large opportunities for saving energy in the residential sector. A study in 2015 done by Sustainable Victoria of 60 existing class 1 homes selected during a period between 2009 - 2012 that were built before the year 2005, found that houses built prior to 1990 had a House Energy Rating (HER) average of 1.5 stars out of a maximum 7 stars. Houses built during the period of 1990-2005 had an average of 3 stars, which is considerably less than the 5-star minimum efficiency standard that was introduced in 2005 for new homes. The minimum star rating was increased to 6 stars in 2011. (10.)

The HER provides a measurement of the building shells energy efficiency and expected energy costs which will provide the buildings star rating. A building with higher HERs require lower heating and cooling allowing for more comfortable internal environment and better energy efficiency. (11.)

The sample of houses as can be seen in figure 4 below shows the flooring area plotted against the decade of construction of the house (11).

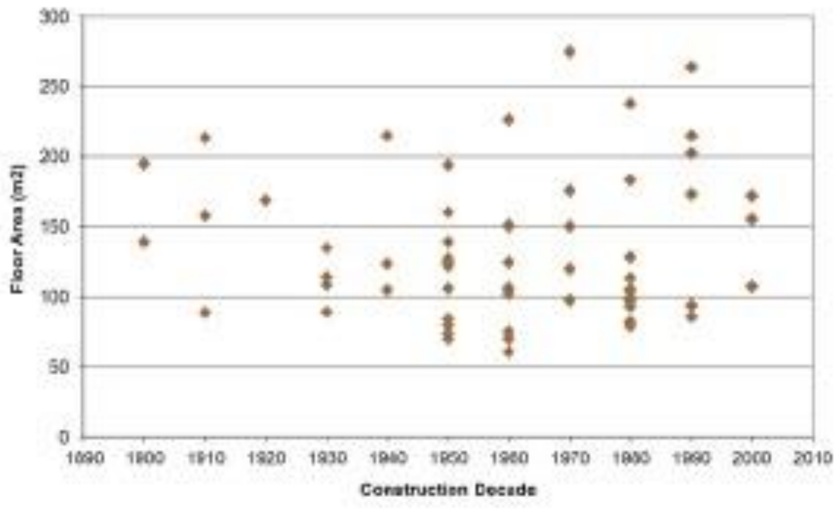

Figure 4. Floor area vs construction decade (10).

A blower door test was performed on all 60 homes in the Sustainable Victoria study to calculate their ACH@50. The average air leakage measured in the houses built pre-1990 had an average of 2.02 ACH and for the post-1990 homes the value was considerably less at 1.20 ACH. As can be seen in figure 5 below, most of the homes ranged between 1 and below 2.5 ACH. (10.)

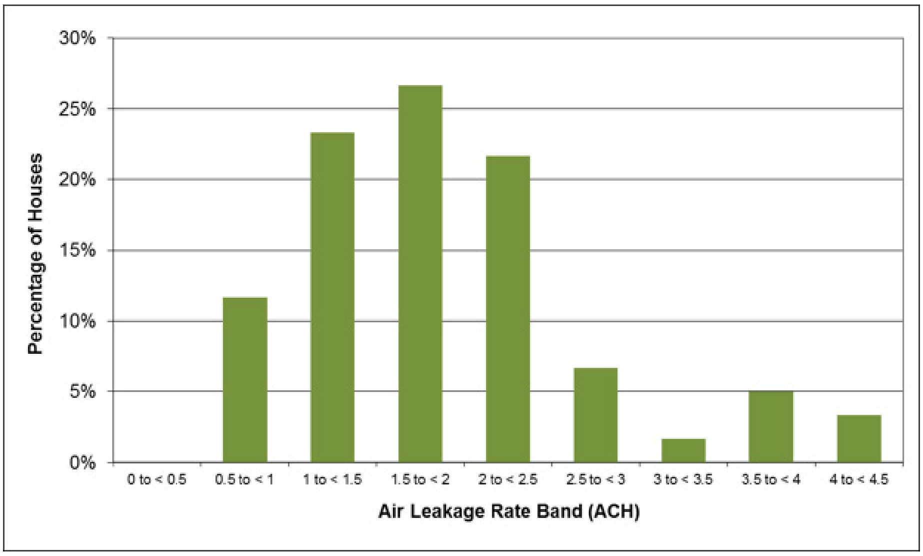

Figure 5. Distribution of measured air leakage rates for the studied homes (10).

Higher ACH@50 demands additional heating in winter months as the warm air will leak out of the building and be replaced by the cold outside air. This is also the case in the summer months when the home will be more difficult to cool. Summer or winter, all these draughts can reduce the thermal comfort levels for the occupants. (10.)

There were three different construction method of the walls for the 60 different houses that were selected for the case study done by sustainable Victoria. The first is brick veneer consisting of plaster board with timber frame and external brick wall. Second is the brick cavity which is built from a double brick wall with a cavity in between skins. The weatherboard houses are constructed with internal plaster board on timber frame with a fibro cement sheet externally. (11.)

Houses constructed with brick veneer walls have a higher HER rating than houses constructed from brick cavity or weather board as seen in table 2 below. From the 1960’s onwards, brick veneer was the dominant type of wall construction for new houses and continues to be. The newer brick veneer houses in the study had a slab ground floor, as well as wall and ceiling insulation, which helped to increase their HER ratings. (11.)

Table 1. Different wall constructions and their average HER and ACH in a study by Sustainable Victoria (10).

Main wall construction type	**Percentage of construction type**	**Number of houses**	**Av. HER**	**Av. ACH**
Weather board	28.30%	17	1.45	1.78
Brick cavity	8.30%	5	1.56	1.99
Brick Veneer	63.30%	38	2	1.94
Total	**100%**	**60**		

Cavity brick, in theory, should have efficiency advantages due to their higher level of internal thermal mass. However, they had a lower average HER than brick veneer, which could be due to the older age of the houses. Nonetheless, the average ACH for all three types of wall construction were rather similar. (11.)

The floor construction in the houses studied by sustainable Victoria consisted of either suspended timber frame above ground with crawl space, concrete slab on ground or mixed construction consisting of both concrete and timber. The suspended timber floors as well as the mixed construction floors achieved a much lower HER average and higher air leakage rates than the slab on ground. Presumably, the lower wintertime heat losses and summertime heat gains through the concrete slab, due to its higher thermal mass and lower air leakage, contributes to the figures in table 3 below. (11.)

Table 2. Different floor construction and average HER and ACH in the study by Sustainable Victoria (10).

Floor construction type	**Sample**	**Number of houses**	**Av. HER**	**Av. ACH**
Suspended timber	68.30%	41	1.63	2
Concrete slab on ground	20%	12	2.62	1.43
Mixed construction	11.70%	7	1.44	2.08
Total	**100%**	**60**		

Older houses more frequently have higher air leakage rates, occurring from degradation to the building shell over time e.g., movement of foundations to develop cracks and gaps. Furthermore, the use of fixed wall ventilation was more common prior to the 1990s and these houses were also more likely to have natural gas heaters or open fireplaces, needing a source of fresh air. (10.)

The Sustainable Victoria study concluded in their final report that the average HER of houses constructed prior to 1990 was 1.57 stars and the average HER of houses constructed between 1990 and 2005 was 3.14 stars. The requirement for mandatory insulation introduced in 1991 certainly contributed to the increase in energy efficiency. These requirements lead to an increase in concrete slab on ground construction as it removed the need for floor insulation and also the removal of the wall ventilation to reduce air leakage. (11.)

High levels of air leakage are one of the critical elements to the low level of energy efficiency of existing Australian houses. The Sustainable Victoria study found that houses constructed prior to 1990s had an air leakage rate of 2.02 ACH and houses constructed between 1990 and 2005 achieved a considerably lower rate of 1.20 ACH. However, the average for all 60 houses in the study was 1.90 ACH, more than three times the rate required to meet the Passive House standards. (11.)

The results of the Sustainable Victoria study indicated that the upgrades to the wall insulation was the main source of energy efficiency. Ceiling insulation also had a large impact when implemented to the houses that did not have any insulation. These upgrades improved the average HER for the 60 houses studied from 1.81 stars to 5.05 stars. The average HER of the pre-1990s houses was increased from 1.57 stars to 5.00 stars and the post 1990s house from 3.14 stars to 5.37 stars. (11.)

4 Simulation of House

4.1 Description of Case Building

The house selected as the case building for this report is a single-family house located in Sydney, Australia and built during the 1930’s in the Californian bungalow style that was popular during that period. The front facade is facing south-east, with the living area in the back facing north-west, which is almost the optimal orientation for houses in the southern hemisphere. The bedrooms are located on the south and east side of the building, which prevents overheating in the summer months during the day. This helps to reduce uncomfortable temperature levels in the evening.

Sydney has a temperate, humid climate with abundant sunshine, resulting in warm to hot summers and mild to cool winters. As a coastal city, sea breezes in the afternoon are common, which are very refreshing on humid summer days. The average temperature of Sydney ranges from 18.6 to 25.8 degrees Celsius in the summer, and in the winter, between 8.8 to 17 degrees Celsius. (12)

The house consists of a suspended timber floor on brick piers and a ventilated crawl space as can be seen in figure 6 below. The timber floor construction was a cheap and efficient way of building a floor as the walls could continue to be constructed at the same time. However, the perimeter of the floor along the external walls requires a gap between the walls to the floor to prevent moisture transfer on one hand and movement of the timber flooring on the other. The air gaps would provide fresh air to the building and allow the warm heated air to move through the building, as discussed later in the report.

Figure 6. Crawl space under house with no floor insulation.

Sandstone had been used for the foundation walls around the perimeter and beneath the load bearing walls, which can be seen above in figure 6 and below in figure 7. Locally produced red bricks were used to construct the double brick wall separated by a cavity that prevents moisture from being transferred from the external wall to the internal wall of the house, also reducing thermal transmission. The internal walls are lined with plaster to provide a smooth clean finish. The benefit of the double brick wall is its thermal mass properties of absorbing the sun's heat and gradually releasing the heat internally during the night, which can boost comfort levels in wintertime.

Air vents are located within the external walls at the bottom and top to allow the air in the cavity to circulate to remove moisture between the internal and external walls. The bottom vent in figure 7 below on the left would also provide air into the crawl space under the timber floor. The air vent located at the top of the wall, as seen in figure 7 below on the right, penetrates through the internal and external walls. The purpose of this vent is to regulate environmental factors, keeping the house operational and, unfortunately, allowing the warm internal air another opportunity to escape the building envelope. The ventilation was designed to allow the cool air to enter the building throw air gaps in floor or under the doors to move the heated air from the gas heater of fireplace inside the building around the house and out through these vents positioned at the top of the wall in each room. This process is also known as the chimney effect.

Figure 7. Natural air vents to allow the cavity air to circulate. Bottom of the wall to let air into the cavity (left), top of the internal wall (Right).

The roof structure of the case building is a pitched roof built from timber frame, with gable ends, as seen below in figure 8. Having explored the Sydney suburbs it seems like this roof type is the most common practice of building. Terracotta roof tiles were used throughout the entire roof structure, which are locally produced. The high thermal mass of the tiles ensures that they can withstand the harsh Australian climate. Internally, the ceiling has a plaster board. Since it is the same existing ceiling that was originally installed, apart from a few repairs of painting and cracks, it would be safe to assume that it was built with asbestos. This would have to be professionally tested and removed if any modifications were to occur.

Figure 8. South side of the house with new installed aluminum windows on left and the original timber frame window on right.

All the windows in the house are made from single glazed glass with either a timber frame or aluminium sliding frames in places where the windows have been replaced to provide better air flow for the natural cross ventilation of the house. As can be seen in figure 8 above, the bedroom window on the left has been replaced, whereas the large windows on the right side are the original timber window frames. All the windows have gaps around the edges of the windows, sealed with either timber or plaster once the frames were installed.

Throughout the house, the only place where insulation has been installed is in the ceiling space. However, the insulation has not been positioned properly between the joists and it has not been installed all the way to the edges of the wall. This leaves air gaps for the heat to escape and can also lead to condensation in the colder nights.

Table 3. Area of wall compared to the area of windows of the house.

Elevation	Walls (m2)	Window (m2)	Number of windows	Total (m2)	Window % of wall
North	24.9	3.4	2	28.3	12.1
East	47.3	11.5	4	58.8	19.6
South	26.4	5.2	4	31.6	16.4
West	55.5	4.4	4	59.9	7.3
TOTAL	**154.1**	**24.5**	**14**	**178.6**	**13.7**

The external surface area of the buildings wall is 178.6 m^2 as seen in table 4 above about the ratio of walls to windows. A passive house is recommended to have the total area of window to be less than 15 % of the total area of the wall. In the case building, this is achieved with the house having only 13.7 % of the total walls being windows. Although the aim of the final year project was not to get the case building to meet the Passive House standards, it is good to achieve the goals to help reduce energy usage.

4.2 Simulation Targets

Firstly, the U-value of the current building elements must be conducted using PHPP to work out to gather a solid reference number to base the calculation off as can be seen in appendix 2. The results show that the floor has a U-value of 0.772 W/(m^2K) which is poor, especially as there is no insulation underneath. Thus, there is great and feasible potential for improvement with good access to the crawl space. Furthermore, the double brick walls are an important area for improvement, with the highest U-value of 2.94 W/(m^2K). However, although this is where the most improvements could be made, it is also the most difficult building element in the house to improve. The ceiling, with a U-value of 1.05

W/(m^{2}K), is the area where most of the heat will be lost. It would also be a great place to improve in order to reduce the loss of heat in the winter.

Using the results of the Sustainable Victoria study discussed in chapter 3, an average was taken (as can be seen in appendix 3) to provide an ACH@50 figure for houses built in the same period as the case house in this thesis. The average was calculated to be 1.6 ACH@50. However, looking at the building elements and only using the houses in the Sustainable Victoria study that had the same construction elements as the case house in this thesis, the average was 2.3 ACH@50. Therefore, a figure of 2.0 ACH@50 is used for this simulation to create a base model for the case house.

Table 4. Energy consumption of electricity and gas.

Electricity		
Date		**Total usage (kWh)**
8.12.2018	11.3.2019	1664
12.3.2019	12.6.2019	1455
13.6.2019	12.9.2019	1287
13.9.2019	11.12.2019	1858
	Total (kWh)	**6264**
	Average (kWh)	**1566**
	Floor area (m2)	**143**
	Energy kWh/(m2a)	**43.8**

Gas		
Date		**Total usage (MJ)**
21.12.2018	19.3.2019	3156
21.3.2019	20.6.2019	5332
21.6.2019	20.9.2019	13910
21.9.2019	19.12.2019	4123
	Total (MJ)	**23365**
	Average (MJ)	**7788**
	Floor area (m2)	**143**
	***Energy (kWh/m2a)**	**45.4**

* Conversion on 1 MJ/(m2a) equals 0.2778 kWh/(m2a)

The energy usage in the house, as seen in table 5 above, shows that the gas consumption of the house is higher than its electricity consumption. Gas is not only the main source of heating in winter, but also the main source for cooking and the hot water system all year round. Electricity is used for all the other equipment in the house such as washing machine, dishwasher, tv, lighting, and air conditioner.

Table 5 above also shows an increase in the electricity consumption during the summer months compared to the winter. However, the gas consumption dramatically raises during the winter months. This is the perfect indication that there is a need to improve the building envelope to prevent the escape of warm internal air.

4.3 Modification Model of House

A modification model was created for the case house. The modifications in the model were made to the building envelope, with improved thermal insulation and air tightness to meet the recommended U values of low energy houses as shown in chapter 2.2. The recommendations will be of practical approach and not of options that will be almost impossible to achieve or financially impractical.

The most practical way to improve the building envelope would be to use the existing crawl space under the house and install mineral wool between all the floor joists. This is shown below in table 6 that compares the U-value of the floor with and without insulation. Insulating the floor would also be an economical solution. Installation of 100 mm insulation in between the 100mm floor joist almost meets the required U-values of 0.3 – 0.35W/(m^2K) of lower energy houses. The use of rigid insulation could be an option, but, in this situation, it would be difficult to manoeuvre the sheets under the house, so rigid insulation was not considered for the case house modelled in the thesis.

Table 5. Comparison of floor U-values with and without insulation.

Floor	**U-value (W/(m^{2}K))**
Existing	0.772
Modified	0.395

The brick cavity wall of the case house has limited options of how to implement insulation. The alternatives are blown mineral wool, EPS beads or expanding foam. Both were modelled in the modification model created in the thesis. The first step in the insulation process would be the sealing of all the natural ventilation holes in the walls by removing the old vents and sealing the holes with bricks to match the existing walls. This would reduce any heat loss through the vents and reduce the ACH@50 figures. Secondly, the electrical cables that run throughout the cavity walls would also have to be seen to if the walls are to be insulated as they pose a fire risk.

Table 6. Comparison of existing and modelled wall insulation.

Walls	**U-value (W/(m^{2}K))**
Existing	2.068
EPS	0.577
Mineral wool	0.615

Table 7 above shows the comparison of the U-values of the existing brick wall with a ventilated cavity and the modelled brick wall sprayed with EPS beads or mineral wool. The model shows that EPS insulation would reduce the U-value of the wall significantly, by almost three quarters compared to the existing U-value, and the mineral wool insulation would also result in an impressive reduction of two thirds. However, mineral wool is not permeable and, consequently, moisture could be absorbed from the external brick wall, leading to mould growth and other health risks. On the other hand, EPS beads are permeable and would allow the moisture to escape through the weep holes in the brick walls. As bricks are a porous material and the cavity originally designed to help prevent moisture being absorbed by the inner skin of the wall, the mineral wool would not be a viable option.

Expanding foam was also considered for the model, but further research showed that it might be problematic to make sure the foam has filled all the gaps inside the wall; even though it expands, it may not fill all parts of the wall leaving air gaps. As seen in figure 9 below, the EPS beads are pumped into the wall cavity under high pressure from below to make sure they fill all the voids in the walls as the beads are pushed up the cavity.

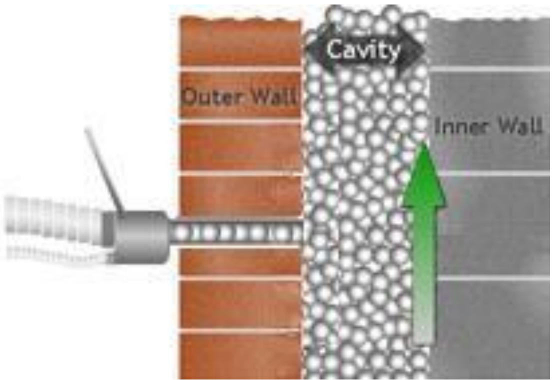

Figure 9. EPS beads pumped into the wall cavity through small holes drilled into bricks wall (13).

The ceiling of the case house studied in this thesis has also great potential to reduce the heat losses in the winter as it would be easy to access in order to install additional insulation. As can be seen in table 8 below, the existing ceiling is not up to standard that is required by low energy houses. However, modelled with mineral wool insulation installed between the ceiling joists, the U-value was halved. Considering the additional space in the ceiling crawl space, a 100mm layer of mineral wool was added in the modification model, causing the

U-value to reach an impressive 0.192 W/(m2K), which falls inside the 0.15 – 0.25 W/(m^2K) recommended values of low energy houses.

Table 7. Comparison of existing and modified modelled ceiling insulation and an additional 100mm of mineral wool.

Ceiling	**U value**
Existing	1.045
Modified	0.458
Additional mineral wool	0.192

The replacement of windows throughout the house would need to be considered, as all windows do not need to be of the same glass. The windows on the north and east sides of the case house receive the most sunlight during the day, whereas the windows of the south do not receive much sunlight. On the west, the shading caused by the neighbouring house and a tree does not allow much sunlight either.

Therefore, the north and east facing windows are modelled with double glazed low emissivity (Low - E) glass with argon gas. The low E glass minimises the amount of ultraviolet and infrared light without compromising the amount of sunlight entering the house. Windows on the south and west are modelled with double glazed glass with a 12mm air gap. All windows have the same frames of Kowa Therm with Thermix, which is certified to Passive House standards for cool temperate climates, as can be seen in appendix 4. The alternative with two different windows were chosen from a financial viewpoint, as many of the windows face south and west as shown in appendix 5.

Table 8. Existing and modelled window glazing comparison.

Window	U_g value
Existing single glazed	5.80
Double glazed air gap	2.90
Double glazed low E argon	1.30

The double-glazed window used in the modification model already halved the U value of the glass, and the low E argon glazing reduced the U value by over 75% compared to the single glazing as shown in table 9 above. When the new windows and frames are installed, the sealing of all the gaps around the frames must be insulated and sealed to prevent any air drafts of leakages that could have an effect of the ACH.

The final improvement to the building envelope would be to seal the gaps around the front and rear doors both where the door closes and underneath the door. This is modelled with the installation of rubber seals around the rebate of the frame to seal the door and frame together when the door is closed. Underneath the door, a rubber or brush draught extruder as seen in figure 10 below can be installed so the doors can be opened but the air flow is stopped when the door is closed.

Figure 10. On the left, rubber door draught extruder, installed inside the door (14), on the right, brush door draught extruder, screwed onto the door (15).

The modelled improvement over the building heat demand had different effects than expected, as each element was improved to the u values discussed below. The under-floor insulation did not change the heating demand for heating load for the building, they remained at 214 kWh/(m2a) and 56 W/m2, respectively, as can be seen in table 10 below. However, the ACH@50 was not considered in the improvements as it could be an unrealistic assumption and was ignored at this time without performing a blower door test.

Table 9. Improvements as the insulation is added to the house, ACH has not changed from the initial 2.0 ACH@50.

Element	**Heating demand kWh/(m2a)**	**Heating load W/m2**
Current house	214	56
Only under floor insulation	214	56
Under floor and ceiling insulation	161	44
Under floor and ceiling insulation with EPS bead in walls	69	23
Windows and door upgrades	38	15

The ceiling insulation added to the modified model made the first improvement to the heating demand by decreasing the demand to 161 kWh/(m2a), which does not seem to be a major improvement. However, as this is a rather standard practice nowadays, the model shows how helpful the ceiling insulation can be to reduce energy demand.

Next, the insulation of the walls with EPS beads was modelled. This addition provided the biggest improvement of all. The heating demand dropped dramatically to 69 kWh/(m2a). Although this modification may be the most difficult one to implement, it should not be ignored due to the massive improvement it provided in energy consumption. This reduction in the U-value would also be helped by the fact that the air gap between would fill with the EPS beads, creating a greater thickness to the external walls.

At first glance, the window and door upgrades modelled to the building envelope seem to make rather small improvements, reducing the heating demand to 38 kWh/(m2a). However, in a larger scale when examined closer, they reduce the heating demand by almost 50% and might be considered at an earlier stage to see if the improvements would have the same effect. Therefore, the simulation was run again without the wall EPS insulation. In this modification model, the heating demand was left at an extremely high level at 128 kWh/(m2a), highlighting the importance of the walls as the most significant element of the building that need to be insulated to lower the energy demand.

5 Conclusion

The results of the simulation using PHPP to reach low energy standards for the building elements can be seen in table 11 below. Although the ceiling was the only building element to meet the high expectations, the vast improvements made in each of the elements, can be considered a success.

Table 10. Comparison of the current elements to the recommended target U-value of low energy houses element and the outcome of the element used in the model according to PHPP.

Element	**Current**	**Target**	**Final**
Floor	0.772	0.3 - 0.35	0.395
Wall	2.07	0.2 - 0.3	0.557
Window	3.95	1.2	*2.1
Ceiling	1.05	0.15 - 0.25	0.192
* Average of windows 1.3 and 2.9			

Although the PHPP has not been used for the correct building, as it is designed for new building not renovations, it has provided evidence that there is potential for improvement in the building envelope. Even so, the results of the space heating demand, space heating load, space cooling demand, space cooling load and primary energy of the current house compared to the final modified model can be seen in table 12 below. It indicates that although the final modified model would not quite meet the low energy target, the drastic improvements can, however, also be regarded as a success.

Table 11. Comparison of the current house to final modified model.

Description	**Current**	**Final**
Space heating demand (kWh/(m2a))	214	39
Space heating load (W/m2)	56	15
Space cooling demand (kWh/(m2a))	2	3
Space cooling load (W/m2)	13	7
Primary Energy (kWh/(m2a))	263	60

Achieving energy efficient homes can be very demanding even when beginning from the start of a new build, and to try and achieve energy efficiency during a renovation can be even more difficult. Although the target can be out of reach at times, it should be considered even if the target out ways the economic benefits. Improving the energy efficiency of a home will save money over the lifetime of the building, however the financial outlay on the renovations may never be recovered during the lifetime of the building.

The goal in the thesis was more to find environmental benefits in order to improve the living conditions rather than any financial goals. Although this report focused on the building envelope, photovoltaic power and batteries should be considered with the abundance of sunlight available all year round to reduce the electricity consumption. As technology improves over time, new products will be available to improve living conditions. However, every house is different and will require thinking from outside the box to achieve these goals.

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Design features of the Passive House in Darmstadt-Kranichstein

Building Component	Description	U-Value W/(m2K)
Roof	Grass roof: Humus, non-woven filter, root protective membrane, 50mm formaldehyde-free chip board; Wooden light-weight beam such as I-beam of wood, stud link of hardboard, counter lathing, sealing with polyethylene sheeting bonded without jointing, gypsum plasterboard 12.5 mm, woodchip wallpaper, emulsion paint coating, entire cavity (445 mm) filled with blown-in mineral wool insulation.	0.1
Exterior Wall	Fabric reinforced mineral render; 275 mm of expanded polystyrene insulation (EPS) (installed in two layers at that time, 150+125 mm); 175 mm sand-lime brick masonry; 15 mm continuous interior gypsum plastering; woodchip wallpaper, emulsion paint coating	0.14
Basement Ceiling	Surface finish on fiberglass fabric; 250 mm polystyrene insulation boards; 160 mm concrete; 40 mm polystyrene acoustic insulation; 50 mm cement floor finish; 8-15 mm of parquet, adhesive; sealing solvent-free	0.13
Windows	Triple-pane low-e glazing with Krypton filling: Ug-value 0.7W/(m²K). Wooden window with polyurethane foam insulated framework (CO2-foamed, HCFC free, handcrafted)	0.7
Heat recovery ventilation	Counter flow air-to-air heat exchanger; Located in the cellar (approx. 9°C in the winter), carefully sealed and thermally insulated, the first one to useelectronically commutated DC fans.	Heat recovery rate approx. 80%

U-value of elements

Assembly no.	Building assembly description					Interior insulation?
1	Timber frame floor					no
	Heat transfer resistance [m²K/W] interior Rsi :	0.17				
	exterior Rse :	0.04				

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Timber Joists	0.13	Rigid Insulation	0.00			100
2	Hardwood floorboard	0.18					20
3	Sound proofing	0.03					1
4	Laminate Flooring	0.07					12
5							
6							
7							
8							
		Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
		17%					13.3 cm
	U-value supplement		W/(m²K)	U-Value:	0.772	W/(m²K)	

Assembly no.	Building assembly description					Interior insulation?
2	Double Brick wall					no
	Heat transfer resistance [m²K/W] interior Rsi :	0.13				
	exterior Rse :	0.04				

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Brick	0.77					110
2	Insulation	0.035					30
3	Brick	0.77					110
4	Render/Plaster	0.18					5
5							
6							
7							
8							
		Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
		100%					25.5 cm
	U-value supplement		W/(m²K)	U-Value:	0.746	W/(m²K)	

Assembly no.	Building assembly description	Interior insulation?
3	Timber frame floor E:	no

Heat transfer resistance [m²K/W] interior Rsi : 0.17

exterior Rse : 0.04

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Timber Joists	0.13	Rigid Insulation	0.036			100
2	Hardwood floorboard	0.18					20
3	Sound proofing	0.03					1
4	Laminate Flooring	0.07					12
5							
6							
7							
8							

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
17%	83.00%		13.3 cm

U-value supplement: W/(m²K)

U-Value: 0.395 W/(m²K)

Assembly no.	Building assembly description	Interior insulation?
4	Double brick wall Existing	no

Heat transfer resistance [m²K/W] interior Rsi : 0.13

exterior Rse : 0.04

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Brick	0.77					110
2	Insulation	0					0
3	Brick	0.77					110
4	Render / Plaster	0.18					5
5							
6							
7							
8							

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			22.5 cm

U-value supplement: W/(m²K)

U-Value: 2.068 W/(m²K)

Assembly no.	Building assembly description	Interior insulation?
5	Ceiling	no

Heat transfer resistance [m²K/W] interior Rsi : 0.10

exterior Rse : 0.04

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Plaster board	0.25					12
2	Ceiling joists	0.13	Insulation	0.035			100
3							
4							
5							
6							
7							
8							

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
17%	83.00%		11.2 cm

U-value supplement: W/(m²K)

U-Value: 0.458 W/(m²K)

Assembly no.	Building assembly description	Interior insulation?
6	Ceiling Existing	no

Heat transfer resistance [m²K/W] interior Rsi :	0.10
exterior Rse :	0.04

	Area section 1	l [W/(mK)]	Area section 2 (optional)	l [W/(mK)]	Area section 3 (optional)	l [W/(mK)]	Thickness [mm]
1	Plaster board	0.25					12
2	Ceiling Joist	0.13					100
3							
4							
5							
6							
7							
8							

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			11.2 cm

U-value supplement ___ W/(m²K)

U-Value: 1.045 W/(m²K)

Average ACH

House number	Year	Wall	Floor	Floor area	ACH @50	Ceiling	Walls	Floor
A7	1930	brick cavity	suspended timber / concrete slab on ground	114.3	1.43	R2.5	none	none
A12	1930	Weatherboard	suspended timber / concrete slab on ground	108	1.4	R2.5	none	none
A15	1930	Brick cavity/brick veneer	suspended timber / concrete slab on ground	134.4	0.98	R2.5 flat roof not in pitched roof	none	none
B13	1920	Brick cavity	suspended timber	169	2.49	R4.0	none	none
B22	1930	Weatherboard	Suspended timber	89	0.95	R1.5	RFL	none
B30	1900 with 1930 and 1990 extention	Brick cavity with some brick veneer	Concrete slab on ground / suspended timber	195	2.02	R2.5 in extention	none in main area. R1/5 in extention	none
C9	1940 with1980 extention	Brick cavity	suspended timber	105	2.12	R1.5 in main house, none in extention	none	none
			Total	914.7	11.39			
			Average	130.7	1.6			
			Average B13 and C9	137	2.305			

Kowa thermix window

CERTIFICATE

Certified Passive House Component

Component-ID 0059wi03 valid until 31st December 2016

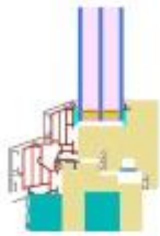
Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
Germany

Category: **Window frame**

Manufacturer: **KOWA Holzbearbeitung GmbH, Goldenstedt, Germany**

Product name: **KOWA Therm**

This certificate was awarded based on the following criteria for the cool, temperate climate zone



Comfort	$U_W = 0.80$	$\leq$	0.80 W/(m² K)
	$U_{W,\,installed}$	$\leq$	0.85 W/(m² K)
	mit U_g	=	0.70 W/(m² K)
Hygiene	$f_{Rsi=0.25}$	$\geq$	0.70

cool, temperate climate

phB

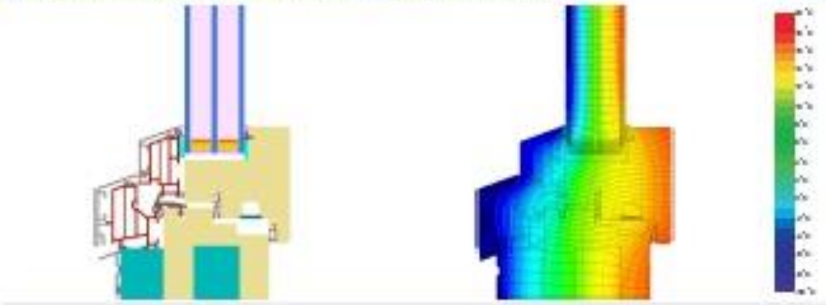
CERTIFIED COMPONENT

Passive House Institute

Passive House efficiency class | phE | phD | phC | phB | phA

www.passivehouse.com

KOWA Holzbearbeitung GmbH
Haselnussweg 1, 49424 Goldenstedt, Germany
+49 (0)4444/970-0 | info@kowa.de | http://www.kowa.de |



Calculation model   Isothermal

Description

Timber frame with insulation and external aluminium shell

Explanation

The window U-values were calculated for the test window size of 1.23 m × 1.48 m with U_g = 0.70 W/(m² K). If a higher quality glazing is used, the window U-values will improve as follows:

Glazing	U_g =	0.70	0.64	0.58	0.53	W/(m² K)
		↓	↓	↓	↓	
Window	U_W =	0.80	0.76	0.72	0.69	W/(m² K)

Transparent building components are classified into efficiency classes depending on the heat losses through the opaque part. The frame U-Values, frame widths, thermal bridges at the glazing edge, and the glazing edge lengths are included in these heat losses. A more detailed report of the calculations performed in the context of certification is available from the manufacturer.

The Passive House Institute has defined international component criteria for seven climate zones. In principle, components which have been certified for climate zones with higher requirements may also be used in climates with less stringent requirements. In a particular climate zone it may make sense to use a component of a higher thermal quality which has been certified for a climate zone with more stringent requirements.

Further information relating to certification
can be found on www.passivehouse.com and passipedia.org.

Frame values		Frame width b_f mm	*U*-value frame U_f W/(m K)	Ψ-glass edge Ψ_g W/(m² K)	Temp. Factor $f_{Rsi=0.25}$ [-]
Top		128	0.74	0.036	0.77
Left		128	0.74	0.036	0.77
Right		128	0.74	0.036	0.77
Bottom		128	0.76	0.036	0.77
		Spacer: Thermix		Secondary seal: Polysulfide	

Windows to wall comparison

Elevation	Walls (m2)	Window (m2)	Number of windows	Total (m2)	Window % of wall
North	24.9	3.4	2	28.3	12.1
East	47.3	11.5	4	58.8	19.6
South	26.4	5.2	4	31.6	16.4
West	55.5	4.4	4	59.9	7.3
TOTAL	**154.1**	**24.5**	**14**	**178.6**	**13.7**