ENERGY EFFICIENCY SOLUTIONS IN A SINGLE-FAMILY HOUSE

Case study in Canberra, Australia

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Degree Programme in Construction Engineering Abstract
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The constant increase in energy prices is not geographically bound and has an effect on everybody worldwide. The objective of this dissertation is to demonstrate that the implementation of photovoltaic panels and an evacuated tube collector in a residential building's system can improve energy efficiency and in turn provide financial savings.

In order to determine the different energy consumptions of the building before and after the implementation of the proposed energy system, simulations must be run. These simulations were performed using IDA ICE, a program that is designed to simulate the annual energy consumption and the indoor climate of a building. A comparison is then made of the energy consumption and production of the building and calculations are performed to determine the proposed solar system's financial exploits.

The calculations were performed based on the current energy prices at the time of writing and proved that the implementation of the proposed solar system does in fact save over $12,000 over the course of the life span of the proposed system. More studies are required to determine the exact environmental benefit of the implementation of the proposed solar system of the building in question.

Keywords Energy efficiency, residential sector, photovoltaic panels, solar collector, renewable energy.
Pages 31 pages and appendices 5 pages

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1 INTRODUCTION

1.1 Objective

With the ever-changing policy on climate change in Australia, the requirement to constantly review and analyse energy use in the residential sector increases in order to determine the maximum energy efficiency possible. In September of 2022, Australia pledged to decrease carbon emissions by at least 43% (from levels discovered in 1990) by 2030 and even to achieve a net zero status by 2050 (BBC, 2022). On top of these declarations, the ACT, or Australian Capital Territory, pledged back in 2019 to achieve this net zero status by 2045, ahead of the national schedule (ACT Government, 2019). In order to commit to these targets, an updated solution to the pursuit of energy efficiency must be found.

Due to the global interest in achieving net zero status, constant studies are being conducted and new methods of improving energy efficiency are frequently conceived. Previous studies have been conducted on residential buildings regarding the optimisation of renewable energy sources, however these studies generally take place in more populated parts of the world than Australia. On top of the lack of studies already conducted in Australia, the geography of the ACT provides several potential sources of renewable energy, which makes the ACT a fascinating place to perform a study on improving residential energy efficiency.

The purpose of this thesis is to model an existing building in Canberra, Australia, and simulate the energy consumption of this building, comparing the current energy system in place with the implementation of renewable sources. This will be performed by first analysing the geographical location of the building, followed by an analysis of the forms of renewable energy proposed and finally by an examination of results obtained from an energy consumption simulation program by the name of IDA ICE. The objective of these simulations is to determine the financial benefits, if any, of implementing renewable forms of energy in the residential sector.

2 METHODOLOGY

In order to analyse the energy consumption of the building with the addition of renewable energy sources a model of the building must be created. This was achieved using a program called IDA ICE (Equa, 2022), and simulations were undertaken analysing the energy consumption of the building both before and after the implementation of solar power. Calculations were then performed in order to determine the cost of the electricity and the price of the electricity produced by the solar system and resold.

2.1 Case study

The building upon which this study was based is located in Canberra, in the south-east of Australia. The population of Canberra is estimated to be nearing 470 000 at the end of 2022 (World population review, 2022). Canberra's climate is considered to be temperate, with no dry season and a warm summer as classified by the Köppen-Geiger climate classification system (Beck et al., 2018). Sunlight is plentiful in Canberra, with around 14.5 hours in peak summer and around 9.75 hours winter (Weatherspark, 2022).

2.1.1 Residential building

The building chosen for the study is a single-family detached house and was built in 1981. The building has a total floor area of around 180m^2, and contains 3 bedrooms, a bathroom, a master bedroom with ensuite, a laundry, a kitchen, a family room, a dining room, a living room, a study and a 2-car garage. The original floor plan of the building can be found in Appendix 1.

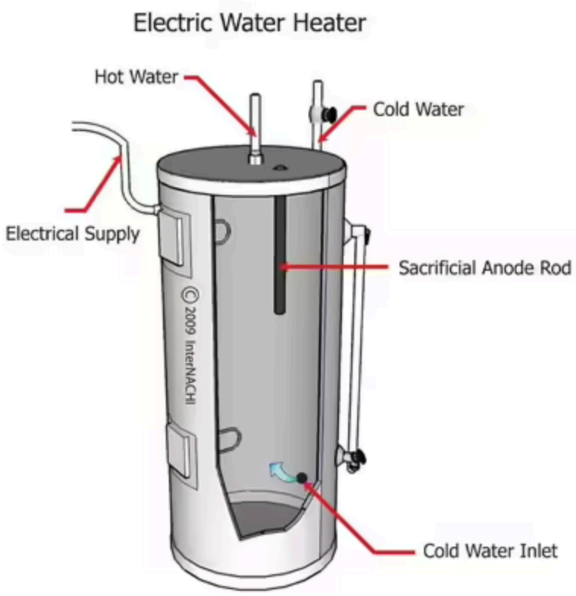
There are several reasons for which the building in question was chosen for an analysis of its energy efficiency. Firstly, Canberra's climate varies wildly; from over 40 degrees

Celsius in the peak of summer days to as low as -7 degrees Celsius during winter nights (Weatherspark, 2020). This is the cause for the second reason for which this building was chosen. Due to the hot summer months and cold winter months, the building was designed and conceived using passive design, a technique that aims to benefit from the building's capacity to utilise natural forms of energy in the simplest of methods (Le Page, 2019), such as maximising the amount of sunlight entering the building in the winter months and minimising the sunlight during the hot summer months. Due to the building's location in the southern hemisphere, in order to maximise sunlight during the day the living areas must be facing north, and by using a compass at the location of the building it was discovered that the building in question faces not directly geographically north, but -36 degrees. Facing towards north to benefit from natural sunlight is certainly the aim with this building's orientation, as its slender rectangular shape enables a maximum of living areas to have windows facing north. The vast majority of windows in the building, both facing north as well as south, stretch from the ground level and rise all the way to the ceiling, meaning these rooms benefit from a maximum amount of sunlight during the day. In addition to this exploitation, shading comes in the form of pergolas along the long sides of the building (see Appendix 3) which reduces the amount of sunlight entering the building in the hot summer months while still benefitting from the low sun in the winter. This is beneficial for the energy consumption of the building, as high sunlight during the summer days is overwhelming and not welcome, while low sunlight in winter is desired.

Due to the nature of the building, i.e. conceptualising passive design, the building's envelope was optimised to use a minimal amount of material. The façade of the building consists of concrete bricks, while the exterior walls consist only of a layer of insulation between 2 panels of gypsum. This meant that less money could be spent on the construction of the building, thus passing on the financial savings to the owner of the property. The interior walls consist of 2 gypsum panels separated by only an air gap, which provides financial benefits as this is cost effective however provides suboptimal acoustic insulation. The floor consists of a slab of concrete about 200mm thick underneath ceramic tiles in most of the building, other than in some bedrooms where the tiles are replaced by carpeting. The ceiling and roof form the same structure and consist of a timber panelling on the inside, followed by a layer of insulation with a sheet of corrugated iron on the exterior.

The building in question functions without the use of an air-handling unit, or AHU. The purpose of an AHU is to bring fresh air from outside into the building using ducts while regulating the temperature and humidity inside the building (Panasonic, 2022.) The building does however incorporate the use of a 250-litre capacity electric hot water tank, which can provide the building with water at a temperature of up to 75 degrees Celsius. The electric hot water tank works by pumping cold water into a large tank and using electricity to heat the water before expelling the hot water back into the building, ready for consumption. As its name suggests, the hot water tank is powered by electricity that comes from the grid, and the specific tank in question has a maximum power rating of 10kW according to the manufacturer. A diagram of an electric hot water tank can be found in Figure 1.

Figure 1: Inside a Water Heater (How Stuff Works, 2022)



The heating and cooling of the building in question is powered solely by electricity; the electric coil sub-floor heating provides the bedrooms with heated flooring and a Daikin air-conditioning unit in the walkway provides both heating and cooling in the family room, which is then distributed throughout the building. The electric floor heating was installed at the time that the building was constructed, and thus little is known about the specifics of the system.

It can be assumed however that the floor heating has a power of 40 W/m^2 as per the program's default values as there is little information regarding electric floor heating values from 40 years ago. It can also be assumed that the floor heating is located at a depth of 25mm below the top of the concrete slab in each of the rooms containing the system. In order to maximise the efficiency of the sub-floor heating it is only enabled during the coldest months of the year, i.e., from June until August. During all other months the system is disabled. The air-conditioning unit is a Daikin split system unit, model FTXV50UVMA, which is capable of providing a cooling power of 5kW and a heating power of 6kW (CF, 2022).

2.2 Proposed renewable energies

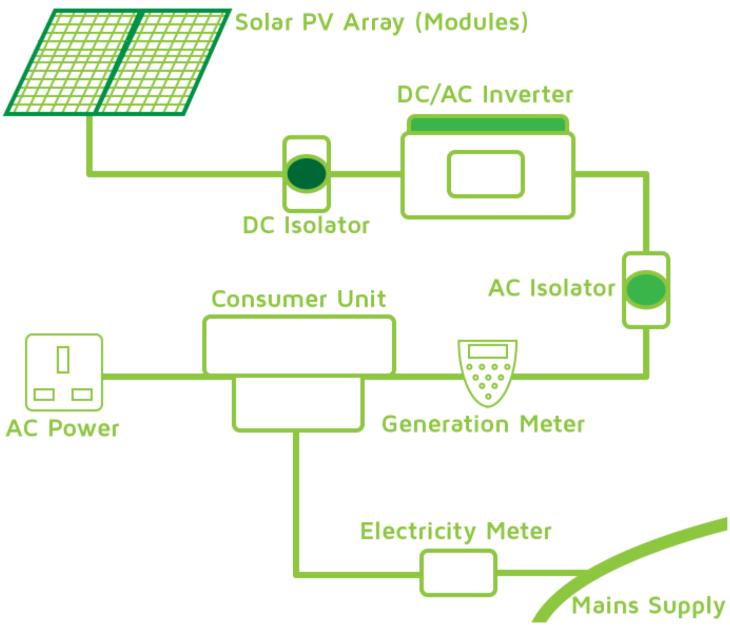
The sources of renewable energy proposed to improve the energy efficiency of the building in question are the implementation of both photovoltaic panels as well as solar collectors. The purpose of the photovoltaic panels is to provide electricity to the building while the purpose of the solar collectors is to heat water ready for consumption in the building.

2.2.1 Photovoltaic panels

Photovoltaic panels, or PV panels, consist of three principal components: the PV panel itself, an inverter and a monitoring meter. PV panels are arranged in modules which typically comprise of 2 rows of cells made up of thin layers of semi-conductor material, generally crystalline silicon. In a PV panel, light particles, or photons, hit the external layer of positively charged silicon, which causes a chain reaction and displaces electrons through an electric circuit towards the negatively charged layer of silicon, producing direct current, or DC. The electricity produced is however unexploitable at this stage, and requires the use of an inverter in order to benefit from this chain reaction. A solar inverter takes the DC produced by the PV panels and converts it into alternating current, or AC, which is the form of electricity used in everyday life. Before this ready-to-use electricity is fed to the building it passes through a monitoring meter, which as the name suggests monitors the output of the PV panels (Maxwell, 2004). A diagram of a typical PV system can be found in Figure 2.

The photovoltaic system proposed is a generic 6 kW PV system, with a total of 16 modules each measuring 1m by 1.8m and covering a total area of 28.8m^2 (Solar Quotes, 2022). The optimal angle at which photovoltaic panels should be installed in Canberra is at 30 degrees from the horizon (JFK Electrical, 2022).

Figure 2: How Solar PV Panels Generate Electricity (EWS Solar Power, 2015)

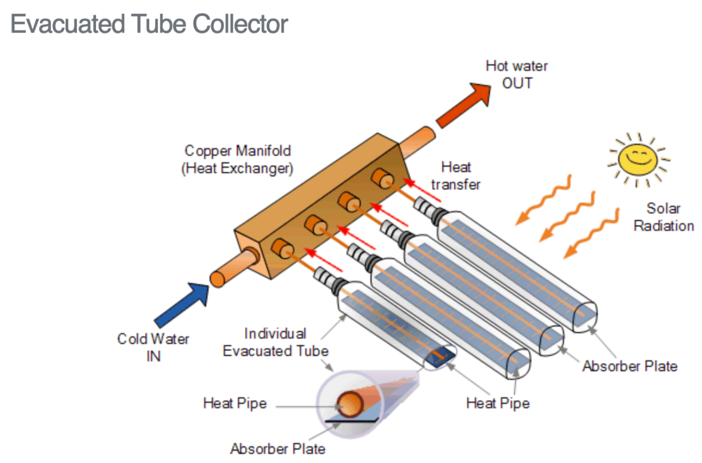


The implementation of this photovoltaic system in the building in question is certainly achievable, with few modifications to the building itself required, as only the installation of the panels on the roof and the connection between the panels and the main grid is required.

2.2.2 Solar collector

There are many different types of solar collectors, however the type of system chosen for this building is known as an evacuated tube collector system. This solar collector system consists of parallel rows of glass tubes generally made from borosilicate glass, more commonly known as soda lime glass, connected together at the top to a header which performs as a heat exchanger. Inside each transparent tube, sitting at an angle of 45 degrees (Sola Zone, 2022), sits a slightly smaller rod made from copper, sitting atop of a dark-coloured heat absorbing plate. This is optimal for absorbing solar energy, as providing the tubes are sitting at the optimal angle, the sun's rays will penetrate the tubes and hit the rod at a perpendicular angle all day-round, maximising heat transfer and warming the rod. Cold water is passed through the header, heated up by the rods before expelling hot water. This hot water is then run to the hot water tank where it is stored until used by the occupants of the building. There are multiple advantages of an evacuated tube collector; the systems are generally more modern and advanced than other types of collector systems, are able to retain their efficiency even on overcast days and according to the retailer happen to be maintenance free (Alternative Energy Solutions, 2022; Sola Zone, 2022). Evacuated tube systems do have a disadvantage as they are generally more expensive than other types of solar collectors like flat plate collectors (Alternative Energy Solutions, 2022), however this factor can be neglected due to the higher efficiency and better performance. A diagram of an evacuated tube collector system can be found in Figure 3.

Figure 3: Evacuated Tube Collector (Alternative Energy Tutorials, 2022)



The solar collector system proposed is a 20-tube evacuated tube collector, manufactured by Apricus. The frame of this collector system measures 1.98m by 1.496m, and as the name suggests contains 20 tubes (Energy Matters, 2022). The angle of the tubes is 45 degrees, as recommended by the supplier (Sola Zone, 2022).

The implementation of this water heating system is comfortably feasible, as all that needs to be installed is the tube system and the pump, and while the system must be connected to the main water supply, the hot water produced by this solar collector system can be expelled directly to the hot water tank already installed and connected to the building in question.

2.3 IDA ICE software

The program used to simulate the building's energy consumption is called IDA ICE and is produced by EQUA. The program is capable of simulating the year-round energy consumption of a building, both residential and commercial, as well as simulating and monitoring its indoor climate. IDA ICE is a highly customisable program that caters to specific designs, accommodating many different HVAC, and cooling and heating systems for basic and even complex buildings. The aim of using this program was to model the building in question as accurately as possible using as much attainable information on the building, and to use the provided default values found in the program's extensive database to make assumptions about unknown factors.

As with all simulations and experiments come limitations, and this simulation is no different. The limitations in regard to this endeavour are explained earlier in 1.2.

2.3.1 Modelling

There are inconsistencies between the original floor plan and the floor plan of the model (see Appendix 1 and Appendix 2). The first of these differences is the lack of interior walls between the foyer and living room, as well as in the master bedroom. This is due to the walls being deemed negligeable for the calculations of the program's simulation. The other difference is the lack of a wall as per the original floor plan on the exterior of the building on the northern side (see Appendix 1). This was also due to it being deemed negligeable for the simulation. For simplicity and due to the lack of separating walls, the family room and the kitchen were combined into the same zone, as were the dining room, living room and study.

The modelling of the building in question was performed in accordance with all of the information attainable, however as stated previously all information and values required to perform the simulation that were not found were assumed to be the same as the program's default values from the program's extensive database.

2.3.2 Parameters

As the building in question is situated in Canberra, the location chosen using the program's extensive database was that of the local airport, located only 10km away, for which IDA ICE provides a climate profile. The wind profile was left as the default profile, while no holiday dates were selected. The ground properties were assumed to be in accordance with those selected by the program's default values and were not modified. The air tightness value was assumed to be 4 (Vuolle, M., personal communication, November 2022). In the *pressure coefficients* section, the AIVC, or Air Infiltration and Ventilation Centre, was changed from semi-exposed to sheltered (Vuolle, M., personal communication, November 2022). The average hot water usage of the building over the year was estimated to be 3500 kWh (Energy Rating, 2012), which was modified in the *Extra Energy and Losses* section. The hot water usage reflects the hot water schedule of the tenants of the building in question, representing a total of 4 hours every day on average, for 1.5 hours in the morning at 06:30 then another 2.5 hours at 17:00. The values used for the *system parameters* section were untouched and thus remained as the program's default values.

The schedules for the building's equipment, occupants and lights were all modelled after the real occupants' schedules. The list of schedules for each input is extensive, however some examples include the living/dining room main lights, for which the inputs were 6 lights at 14W each, possessing a schedule of 1700-1900, a total of 2 hours every day of the week, and the TV in the kitchen/family room, for which the inputs were 1 unit of 183W and a schedule of 1700-2000, 3 hours for each day of the week.

2.3.3 Structure

The internal walls are all identical, containing two 8mm layers of gypsum separated by nothing but an 84mm-wide air gap (see Figure 4a). The layers in these elements use the program's default properties for the relevant materials.

The standard external walls contain, from the interior layer to the exterior, an 8mm layer of gypsum, 233mm of exterior wall insulation, a vapour barrier of 0.2mm, another 8mm layer of gypsum, followed by an air gap of 30mm then finally a 200mm layer of brick (see Figure 4b). All of the layers use the program's default properties except for the exterior wall insulation, which has a thermal conductivity of 0.045 W/(m.K), a density of 20 kg/m^3 and the default value of 750 J/(kg.K) for the specific heat (Ewen, M., personal communication, September 2022), and the vapour barrier, which has a thermal conductivity of 0.34 W/(m.K), a density of 947 kg/m^3 and a value of 2300 J/(kg.K) for the specific heat (Qenos, 2022). The only exterior walls that are different are the exterior walls of the garage; the northern wall of the garage is where the garage doors are located, and, as this is not a conventional wall, it consists solely of wood, therefore the default wood material of the program was selected with a width of 100mm, using the program's default properties. The other external garage walls are the same as the interior walls, covered above.

Figure 4a: Interior Wall Layers

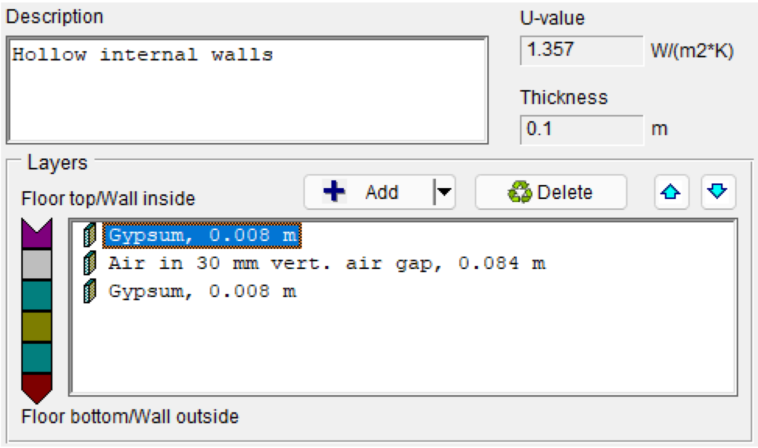
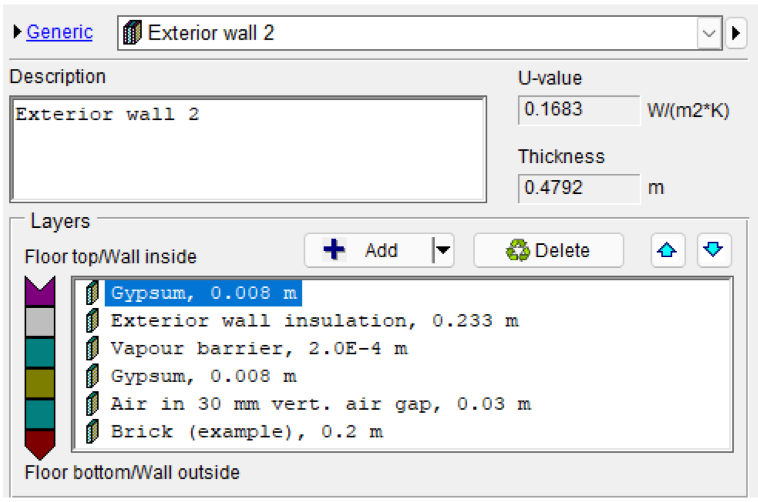


Figure 4b: Exterior Wall Layers



There are three different types of flooring used throughout the building. The first type is plain concrete, found only in the garage. This flooring consists solely of a 250mm thick layer of concrete (see Figure 5a), using the default properties of the program. The second type of flooring is tiled flooring, the most common type throughout the building in question. This flooring consists of a 200mm thick layer of concrete on the bottom, followed by a layer of cement tile adhesive of 10mm and then a 7mm layer of ceramic tiles, (see Figure 5b). The cement adhesive is considered to possess the same properties as those of the program's default lightweight concrete. The floor tiles in the building in question are approximately 300x300mm wide, and possess a density of approximately 1953 kg/m^3 (Larson Tiles, 2022), a thermal conductivity of 0.555 W/(m.K) (Slimanou et al., 2022) and a specific heat value of 1 W/(kg.K) (Effting et al., 2007). This type of flooring can be found in every room excluding the 3 bedrooms in the eastern section of the building. It should be noted that the floor of the master bedroom uses this type of flooring with the only difference being electric heating coils installed in the layer of concrete. The final type of flooring found in the building is carpeted flooring. This flooring consists of a 200mm base of concrete using the program's default properties, followed by a 10mm layer of carpet (see Figure 5c), with the following estimated properties: a thermal conductivity of 0.18 W/(m.K), a density of 175 kg/m^3 (CIAL, 2021) and a specific heat value of 1800 J/(kg.K) (McKinnon et al., 2015).

Figure 5a: Garage Flooring Layers

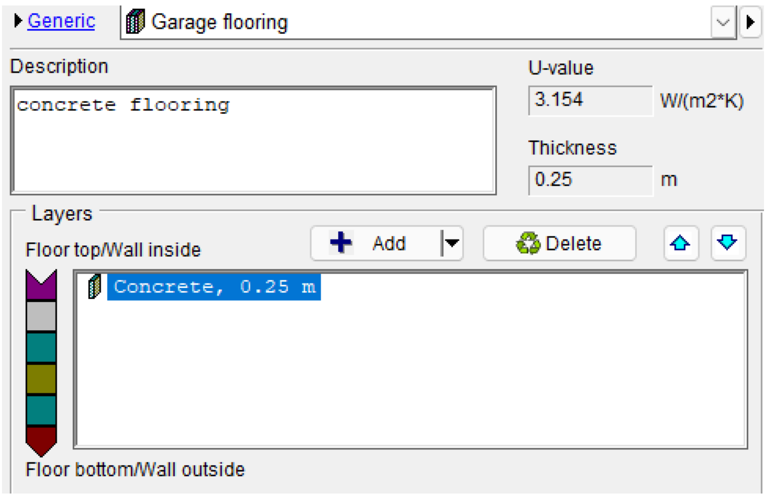


Figure 5b: Tiled Flooring Layers

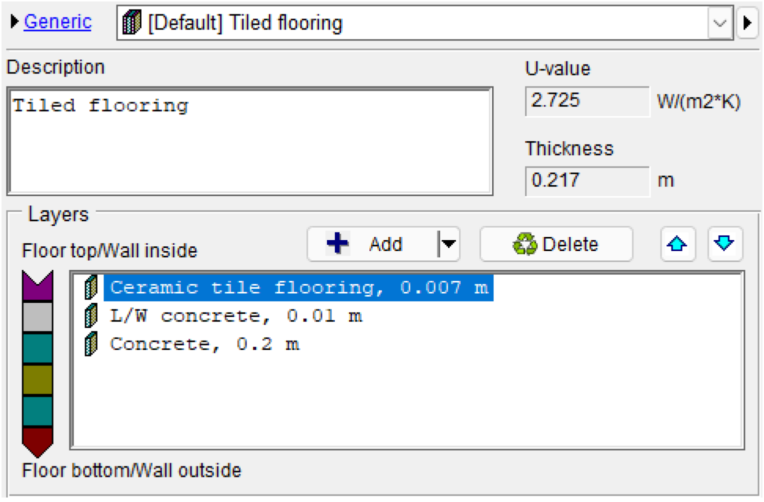
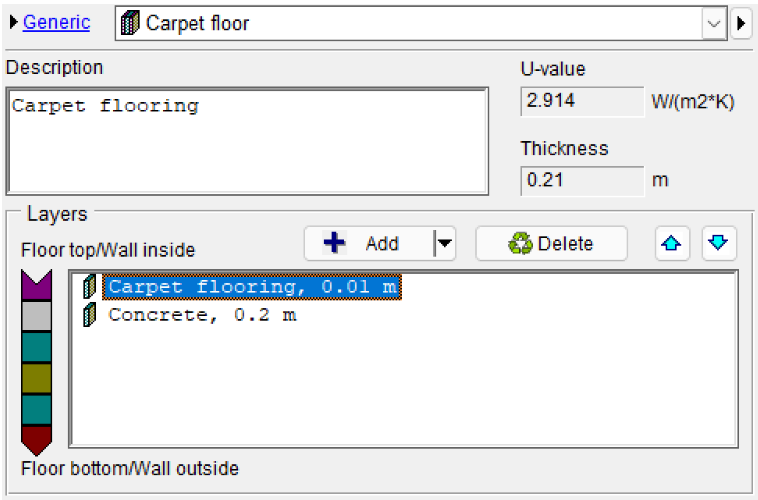


Figure 5c: Carpet Flooring Layers



The roof and the ceiling form the same structure in the building in question. From the exterior, the first layer is a sheet of corrugated iron 0.5mm thick, followed by the aforementioned vapour barrier. Then comes 50mm of insulation followed by the interior layer, 10mm planks of wood. The corrugated iron layer possesses the same properties as the default properties in the program for steel. The insulation in the roof has a thermal conductivity of 0.01 W/(m.K) (Ewen, M., personal communication, September 2022), a density of 20 kg/m^3 and a specific heat value of 750 J/(kg.K). The wooden panels possess the same properties as the default properties for wood according to the program.

All the windows on the north side of the building in question are single pane, using the program's default properties for 1 *pane glazing, clear, 4 (example)*. All the windows on the south side of the building in question are double glazed and use the program's default properties for *2 pane glazing, clear, 4-12-4 (example)*, with the exception of the bathroom and ensuite windows which are single pane and use the program's default properties for 1 *pane glazing, clear, 4 (example)*. The total area of north facing windows is 25.98m^2, while the total areas of south facing single pane and double pane windows are 1.59m^2 and 21.27m^2, respectively.

The doors of the building have all been modelled using the program's default settings and properties for the specified function of the door. All the doors on the exterior of the building are modelled at 800mm wide and 2000mm tall using the *entrance door* properties. All the internal doors are the same size, 800x2000mm, and consist of a 40mm thick layer of wood and have thus been modelled using the program's default properties for this type of material. The garage doors on the north wall of the garage have a combined area or 11.02m^2 and are fabricated using steel, possessing the properties of the program's default steel properties with a thickness of 10mm. Though not technically a door, the building in question contains a large opening between the hallway and the kitchen/family room which is reflected in the model by a large vertical opening measuring 5.85m^2 on the specified wall. In total there are 9 internal doors, 3 external doors, 2 garage doors and the large vertical opening, all of which can be located on the model's floor plan (see Appendix 2).

Due to the nature of the building, i.e., conceptualising passive design, the main living areas face north to benefit from the sun's direction, therefore the orientation of the building has been orientated to reflect that at 146 degrees. The building possesses two shadings, one on the north side of the building and one on the south side of the building, as seen in the 3D model of the building (see Appendix 3). The shading on the north side of the building extends 19.2m along the building as specified in the floor plans (see Appendix 1) and extends 1.8m deep, giving a vertical rise of 0.36m. The shading on the south side of the building extends only over 11m as per the floor plans (see Appendix 1) and also extends 1.8m deep, providing a vertical rise of 0.36m.

The values for the thermal bridges could not be calculated accurately due to insufficient information regarding the structures in order to perform the calculations. The values for the thermal bridges were then estimated to be considered good, providing the relevant values in the figure below (see Figure 6).

Figure 6: Thermal Bridges Model Values

As stated previously, the building in question supplies hot water using an electric hot water tank. The hot water tank in question has a capacity of 250L, or 0.25m^3, and all other properties are assumed to be coherent with the program's default properties for a generic hot water tank (see Figure 7a). The top-up heating values were unmodified, and therefore remain the as the program's default values (see Figure 7b). Both the hot water supply system and the cold water supply system properties also remained unaltered, and therefore also remain as the program's default values (see Figure 8a and Figure 8b).

Figure 7a: Hot Water Tank Properties

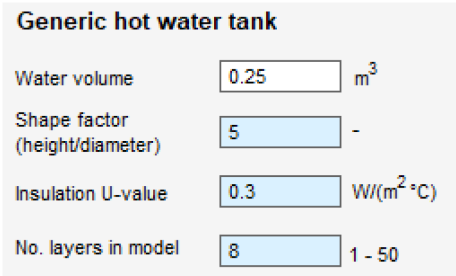


Figure 7b: Top-up Heating Properties

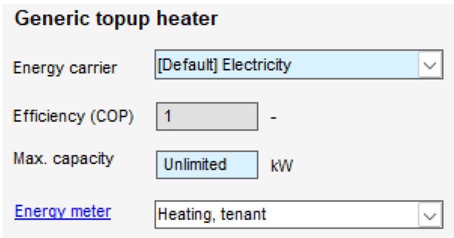


Figure 8a: Hot Water Supply System Properties

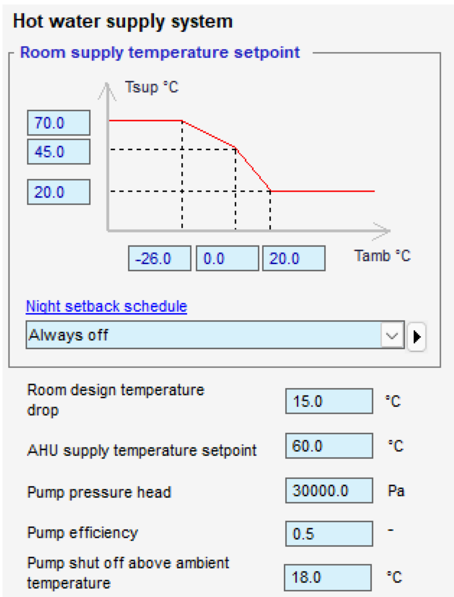
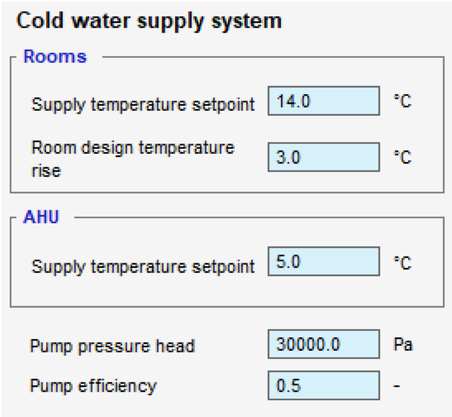


Figure 8b: Cold Water Supply System Properties

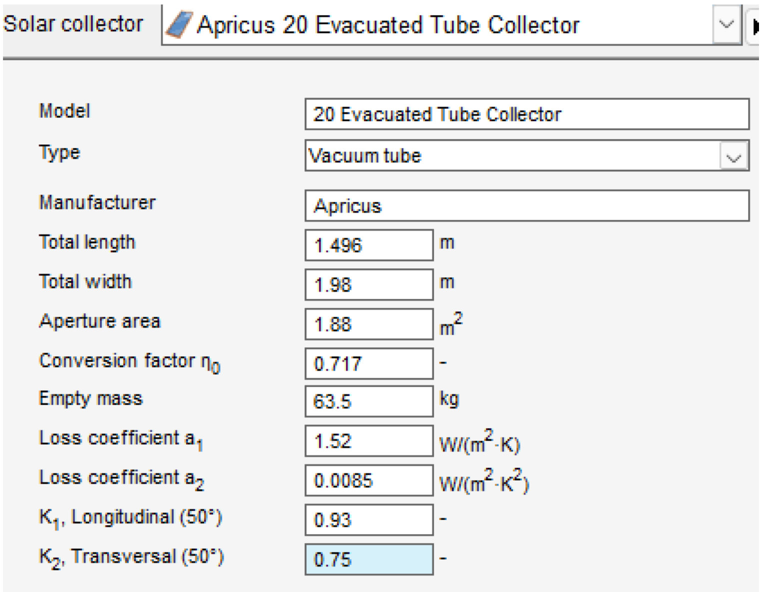


2.3.4 Proposed additions

The PV panels modelled for the purpose of the simulation are generic photovoltaics which do not possess customisable properties. All that can be modified is the size of the panels, their orientation and their overall efficiency. For the purpose of the model, a 6 kW PV system was chosen. As stated earlier, this system contains a total of 16 modules, each measuring 1m wide by 1.8m long, covering a total area of 28.8m^2. The panels face north at 146 degrees orientation to maximise their potential, and have a tilt of 30 degrees, the optimal angle for the building's latitude (JFK Electrical, 2022). The value for overall efficiency was selected to be 0.15 (Vuolle, M., personal communication, November 2022). The PV system modelled does not incorporate the use of a battery to store any surplus of energy.

The solar collector modelled for the purpose of this simulation is the Apricus 20-tube evacuated tube collector system, as stated earlier. In the model, the type of collector system was changed to vacuum tube, and all the values in white boxes in the figure below (see Figure 9) were inputted based on the system's properties (Energy Matters, 2022) except for the final value K_2, which was left unchanged. The collector is north facing in line with the roof at 146 degrees orientation and is angled at 45 degrees from horizontal as recommended by the supplier (Sola Zone, 2022).

Figure 9: Solar Collector Properties



3 RESULTS

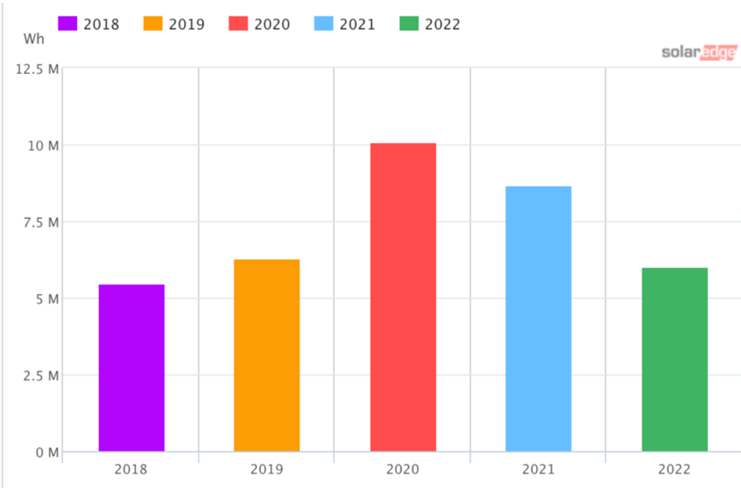
The results of the simulation are based purely on the consumption of electricity of the building in question, using the program's default settings for the simulation, other than the climate profile which was chosen as Canberra airport, as stated previously.

3.1 Energy provider data

According to the energy consumption values provided by the energy provider of the building, SolarEdge (see Figure 10), the average annual energy usage of the building totals to 7.29 MWh, however upon further investigation it was discovered that during 2018 and 2019 the energy supplied to the building was not provided by the same company that provided these results.

Further calculations proved the actual average annual energy consumption of the building to be around 9.32 MWh.

Figure 10: Annual Energy Consumption (SolarEdge, 2022)



3.2 Standard Model

The following results were taken from the report of the energy consumption of the building in question over the space of an entire year. The results represent the energy consumption of the building the way it currently is, without the addition of the proposed solar system.

The building in the simulated model consumed a total of 11.14 MWh (see Figure 11) over the space of 12 months, all purchased from the main grid. This consists of around 5.16 MWh of consumption for the lighting, electric cooling and electric heating, and around 5.98 MWh for appliances, equipment and the hot water system.

Figure 11: Delivered Energy Overview of Standard Model

Delivered Energy Overview

	Used energy		Purchased energy		Peak demand
	kWh	kWh/m²	kWh	kWh/m²	kW
Lighting, facility	977	5.4	977	5.4	0.56
Electric cooling	532	2.9	532	2.9	1.39
HVAC aux	0	0.0	0	0.0	0.0
Electric heating	3649	20.0	3649	20.0	2.86
Total, Facility electric	5158	28.3	5158	28.3	
Total	5158	28.3	5158	28.3	
Equipment, tenant	2511	13.8	2511	13.8	1.79
Heating, tenant	3470	19.1	3470	19.1	3.22
Total, Tenant electric	5981	32.9	5981	32.9	
	Generated energy		Sold energy		Peak generated
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	0	0.0	0	0.0	
Grand total	11139	61.2	11139	61.2	

A further in-depth analysis of the building's monthly energy consumption can be found in Appendix 4.

3.3 Solar Panels & Collectors

The addition of the PV system and the solar collectors proposed earlier produced outstanding results. As can be seen below (see Figure 12a), the building consumed a total of just over 12 MWh, however only 5.1 MWh of this was supplied by the grid over the 12-month period, the rest being the result of the energy generated by the photovoltaic panels, while the solar system installed generated a total of 5116 kWh over the same period. A monthly breakdown of the energy consumption of the building in question when incorporating this new system can be found in Appendix 4. As shown in the table below, the building consumed a total of around 0.927 MWh for the lighting and electric heating and cooling and a total of around 2.51 MWh for the hot water tank and building's appliances.

Figure 12a: Delivered Energy Overview of Proposed System

Delivered Energy Overview

	Used energy		Purchased energy		Peak demand
	kWh	kWh/m²	kWh	kWh/m²	kW
Lighting, facility	977	5.4	815	4.5	0.56
Electric cooling	477	2.6	120	0.7	1.39
HVAC aux	45	0.2	40	0.2	8.62
Electric heating	3827	21.0	3293	18.1	2.89
Total, Facility electric	5326	29.3	4268	23.4	
Total	5326	29.3	4268	23.4	
Equipment, tenant	2510	13.8	1801	9.9	1.79
Heating, tenant	765	4.2	694	3.8	2.69
Total, Tenant electric	3275	18.0	2495	13.7	
	Generated energy		Sold energy		Peak generated
PV production	-6954	-38.2	-5116	-28.1	-5.35
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	-6954	-38.2	-5116	-28.1	
Grand total	1647	9.0	1647	9.0	

The figure above insinuates that the total consumption of energy of the building with the implementation of the solar system proposed is 1647 MWh, however this is net total of energy consumed. This value cannot be used for the financial analysis calculations as it does not reflect the difference in value of the energy consumed and produced by the building and its solar panels. In order to determine the total amount of energy purchased from the main grid the monthly energy consumption breakdown must be analysed (see Figure 12b). Using this table, it can be deduced that the total amount of energy purchased from the grid amounts to 6763 MWh, while the total amount of energy supplied back to the grid totals 5116 MWh.

Figure 12b: Monthly Energy Consumption Breakdown of Proposed System

Month	Facility electric				Tenant electric		Produced electric	
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Electric heating (kWh)	Equipment, tenant (kWh)	Heating, tenant (kWh)	PV production (kWh)	CHP electricity (kWh)
1	60.9	37.2	26.5	0.9	140.7	0.3	-616.7	0.0
2	59.0	40.8	0.0	0.5	136.4	15.2	-467.4	0.0
3	68.9	14.1	0.0	6.1	155.2	19.0	-554.1	0.0
4	67.5	1.0	0.0	74.0	141.5	52.1	-442.5	0.0
5	76.0	0.6	0.0	222.2	163.6	106.0	-332.9	0.0
6	75.9	0.5	0.0	865.3	169.8	139.9	-159.7	0.0
7	77.3	0.5	0.0	991.2	171.6	126.3	-191.6	0.0
8	72.0	0.5	0.0	860.3	151.5	85.2	-272.4	0.0
9	67.6	0.4	0.0	185.7	141.3	60.4	-436.9	0.0
10	63.6	2.6	0.0	70.0	135.7	39.4	-551.9	0.0
11	63.0	7.6	0.0	13.7	147.2	25.1	-536.3	0.0
12	62.9	13.8	13.7	2.9	146.5	24.5	-554.0	0.0
Total	814.6	119.7	40.3	3292.7	1801.1	693.6	-5116.4	0.0

The entire energy report of the proposed system's simulation can be found in Appendix 4.

4 ANALYSIS

The financial analysis of the proposed solar system is based on the building's entire energy supply coming from the main grid, while all the energy produced by the solar system is sold back to the grid. All the prices provided for the financial analysis are neglecting inflation in the future years, as well as any changes in energy prices.

4.1 Benefits of proposed solar system

The financial value of the photovoltaic system simulated, a 6 kW system at an angle from the horizon of 30 degrees, is estimated to be around $6000 (Solar Quotes, 2022). The rest of the values inputted into the online calculator in order to perform the calculation are neglectable as they only serve to propose a payback plan, which does not incorporate the solar collector modelled as well and is therefore neglectable. The only value taken from this calculation is therefore the cost of the system itself. An extra fee of 15% can be assumed for the transport and handling of the system, bringing the total cost of the photovoltaic system proposed to $6,900.

The cost of the whole evacuated tube collector system includes the cost of installation of the system, the collector's tubes and frames as well as a pump and a controller system, totalling $1,990 (Sola Zone, 2022). It does not however include the cost of freight shipping and delivery of the system, which when assumed to amount to 15% of the total cost of the system brings the total cost of the evacuated tube collector system to $2,289. There is also an option to include a hot water tank as part of the aforementioned system bundle. The cheapest of these options includes the addition of a 200L stainless steel hot water tank, bringing the total cost of the solar collector system to $3,270 (Sola Zone, 2022), meaning the new hot water tank of 200L is valued at $2,280. This is not financially optimal, as there are other electric hot water tanks available such as the Rheem 250L electric hot water tank, Model – 491250G7, which is valued at $1,448 (Australian Hot Water, 2022). This would not only have the same capacity as the original hot water tank rather than shrinking by 20%, but would also cost $832 dollars fewer. The optimal solar collector system to install would therefore only include the collector system itself, without the tank, which as mentioned above would require an initial investment of $2,289.

The life expectancy of a photovoltaic system is estimated to be between 20 and 30 years (PLICO, 2022), while the life span of an evacuated tube collector is between 10 and 15 years (AHW, 2022) and that of an electric hot water tank also between 10 and 15 years (AHW, 2022). This insinuates that if the photovoltaic system and the solar collector system are installed at the same time, the solar collector and the hot water tank can be expected to be replaced at least once during the life span of the photovoltaic panels. An investigation into the age of the current hot water tank connected to the building in question revealed that its current age is nearing 17 years. Although this is above the national average in Australia, it can be assumed that the tank will likely need replacing within the coming years. It would therefore be opportunistic to replace the electric hot water tank at the same time as the installation of the solar system in its total. As stated earlier, the Rheem 250L electric hot water tank, Model – 491250G7 is an ideal hot water tank, as it is of the same size as the original one, maintaining the same capacity thus not interfering with the current building's occupants' lifestyle.

The current energy plan functions based on a constant price of electricity throughout the day, where all energy purchased comes directly from the grid. This plan is valued at 27.6815c per kWh used plus an additional surcharge of 103.1250c per day, GST included (ActewAGL, 2022). The proposed energy plan would see the price of electricity purchased from the grid drop to 22.65c per kWh, while the daily surcharge rises to 123.75c per day, however all energy produced by the solar system and sold back to the grid would be sold at a rate of 7.6c per kWh (Energy Australia, 2022).

The life span of the photovoltaic panels is used as the time period over which to compare the financial savings of the proposed system. As mentioned previously, the life span of both a solar collector as well as an electric hot water tank is 10 to 15 years, therefore 13 years was chosen as the time for new installations of the collector system and new hot water tank for the purpose of these calculations. Using the energy system currently in place, the proprietors of the building in question can expect to pay around $86,496 in electricity bills after 25 years, almost $3,500 per year (see Figure 13). Using the proposed solar system, which includes the purchase of a new hot water tank at the time of the installation of the solar system, the proprietors can expect to pay around $74,000 at the end of 25 years (see Figure 13). This includes the initial investment cost of $10,854 for the photovoltaic system, the tube collector system and a new hot water tank, in this case the Rheem 250L mentioned previously, then another $3,954 when the tube collector and the hot water tank need replacing. As can be seen in the figure below, the solar system proposed turns profitable after the 10th year post-initial investment, however as a new collector system and a new hot water tank are required after the 13th year, most of this profit is reinvested into maintaining the system. After the 14th year however the solar system becomes profitable again. After 25 years, at the theoretical end of life of the photovoltaic panels, the total savings due to the proposed solar system amount to over $12,000, or $492 per year.

Figure 13: Delivered Energy Overview of Standard Model

	TIME OF INITIAL INVESTMENT										
after xx year(s)	0	1	2	5	6	7	10	13	14	20	25
CURRENT SYSTEM	- AUD	3 460 AUD	6 920 AUD	17 299 AUD	20 759 AUD	24 219 AUD	34 598 AUD	44 978 AUD	48 438 AUD	69 197 AUD	86 496 AUD
SOLAR SYSTEM	10 854 AUD	13 226 AUD	15 598 AUD	22 715 AUD	25 087 AUD	27 460 AUD	34 576 AUD	45 647 AUD	48 019 AUD	62 253 AUD	74 114 AUD
							New collector system and tank required				New PV required
SAVINGS											
SOLAR SYSTEM	- 10 854 AUD	- 9 766 AUD	- 8 679 AUD	- 5 416 AUD	- 4 328 AUD	- 3 241 AUD	22 AUD	- 669 AUD	419 AUD	6 944 AUD	12 382 AUD
	0	1	2	5	6	7	10	13	14	20	25
	TIME OF INITIAL INVESTMENT										

4.2 Validity of results

Limitations in information required influence the accuracy of any results obtained. Firstly, it should be noted that the plans upon which the model is based date back to 1981, and that the plans lacked certain information about the building's envelope. Contact was therefore made with the designer who described the structures to the best of his memory. The details missing were minor, and appropriate assumptions were made with the help of the program's database and are therefore unlikely to drastically affect the final results. There are multiple reasons why the results from the simulation may not equate exactly to the real-life data of the annual energy bill collected from the energy provider. The two factors influencing inaccuracies are the imprecise modelling of the building and imprecise real-life data from SolarEdge, the energy provider of the building in question.

The first of these reasons is the lack of accurate information regarding the specifications of the structure of the building in question. As stated previously, information regarding the plans of the building in question could only be acquired from state records and not the developers due to the age of the building. Only a small minority of the missing information was acquired through communication with the developers, however this was all provided according to the memory of the few people remaining who were involved when the building was under construction. Parts of the missing information that have the potential to cause inaccuracies include but are not limited to: the air tightness of the building, its thermal bridges, the exact thermal properties of the components in the building's structure and exact specifications of the building's electric floor heating system. The potential for inaccuracies to arise from these uncertain values is significant, however due to IDA ICE's advanced modelling capabilities and recommended default values as well as research regarding the building's components and specifications it can be assumed that the values chosen were as accurate as possible, given the circumstances.

The second potential source of inaccuracies is the source of real-life data regarding the energy consumption of the building in question. Records of the annual energy consumption of the building showed that the energy provider in question, SolarEdge, was not the provider for the building for more than a few months over the time period of the records, from 2018 until 2022. 6 months from January to June in 2018 and 6 months from February to July in 2019 worth of data and energy consumption records is missing in total. This has a tremendous impact, as further analysis of data provided by SolarEdge proved the actual average annual energy consumption of the building over the past 5 years is 9.32 MWh, higher than the perceived average calculated from the graph in Figure 14a. This, coupled with the lack of information regarding periods of time during which the occupants are absent for extended periods of time such as holidays, leads to inaccuracies between the results provided by the program and the results provided by the energy provider SolarEdge. Another factor arising from the real-life data is a lack of submetering, which would provide data regarding the amount of energy consumed and where it was consumed, such as lighting or electric cooling. This prevents a more precise analysis of the energy consumption of the building, such as the figure below, a graph from the energy consumption report of the simulation performed with IDA ICE. A breakdown of the energy consumption such as the one provided by IDA ICE below (see Figure 14b) could provide more details about where the inaccuracies in the modelling of the building lie, ameliorating the model and improving results.

Figure 14a: Annual Energy Consumption (SolarEdge, 2022)

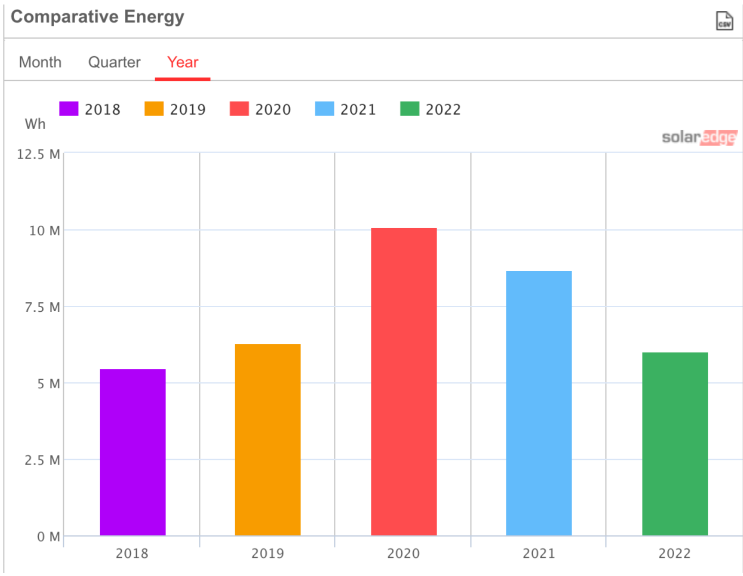
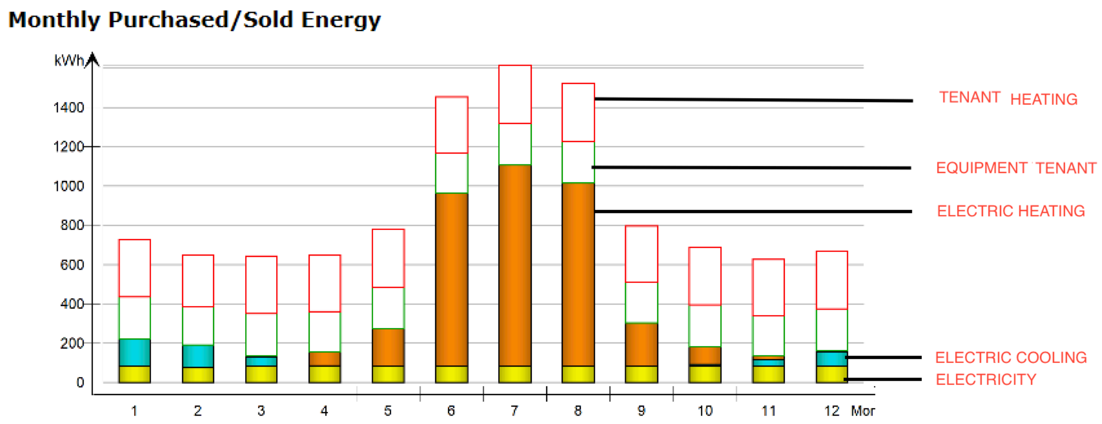


Figure 14b: Example of Monthly Breakdown of Energy Consumption



As stated previously, the adjusted total annual energy consumption of the building according to data provided by SolarEdge comes to a total of around 9.32 MWh, while the simulation of the annual energy consumption of the current building without the proposed additions comes to a total of around 11.14 MWh. The difference between these two results equates to 1.82 MWh, or about 20%. The magnitude of inaccuracy is debatable, however a total difference of 20% over the course of a year with the aforementioned modelling inaccuracies can be assumed to be reasonable and acceptable.

5 DISCUSSION

As stated previously, the purpose of this thesis was to improve the energy efficiency of a residential building, and in doing so prove that this amelioration has the potential to provide financial savings in the future. It was therefore concluded that the addition of photovoltaic panels and a solar collector to an already existing residential building proved to be financially beneficial. With an initial investment of under $11,000 and another investment of just under $4,000 between 10 and 15 years later, the solar system proposed produces total savings amounting to over $12,000 after 25 years when compared with the predicted cost of energy if the building retains its current energy system and plan.

Although the proposed system is financially advantageous, further savings can be created when implementing other types of energy plans. For instance, an energy plan that regulates the exportation of solar energy produced and the consumption of electricity from the main grid could prove to improve the energy efficiency of the proposed system even further, however this would require for more methodical and comprehensive analyses of the building's energy consumption to be performed. Further improvements in a residential building's energy efficiency can occur if renewable sources of energy are taken into consideration in the planning and designing phase of the building. For example, the implementation of a ground source heat pump, exploiting geothermal energy, has the potential to improve the energy efficiency of a building, however as stated before this improvement is only feasible if the building is still yet to be constructed. The use of double or even triple glazed windows would also have a positive effect on the energy consumption of the building, however this is easier to be included from the beginning rather than acquiring through renovations.

Further studies can also be conducted on the environmental benefit of the proposed solar system. By determining the quantity of carbon dioxide emitted due to the current energy system of the building and comparing this with the proposed solar system, the environmental benefits along with the financial benefits demonstrate further the advantages of the implementation of renewable energy sources in the residential sector in Australia and even the world.

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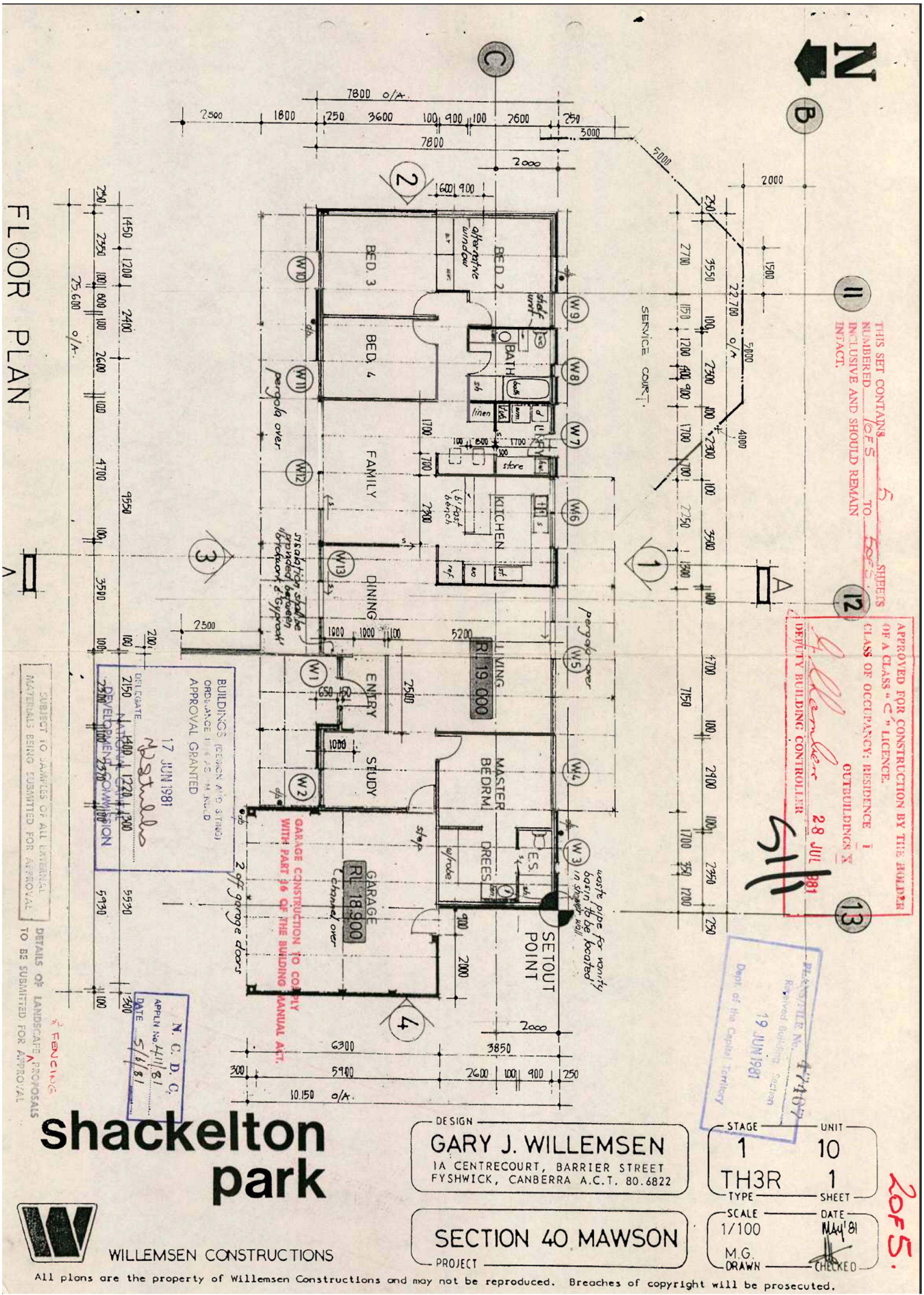
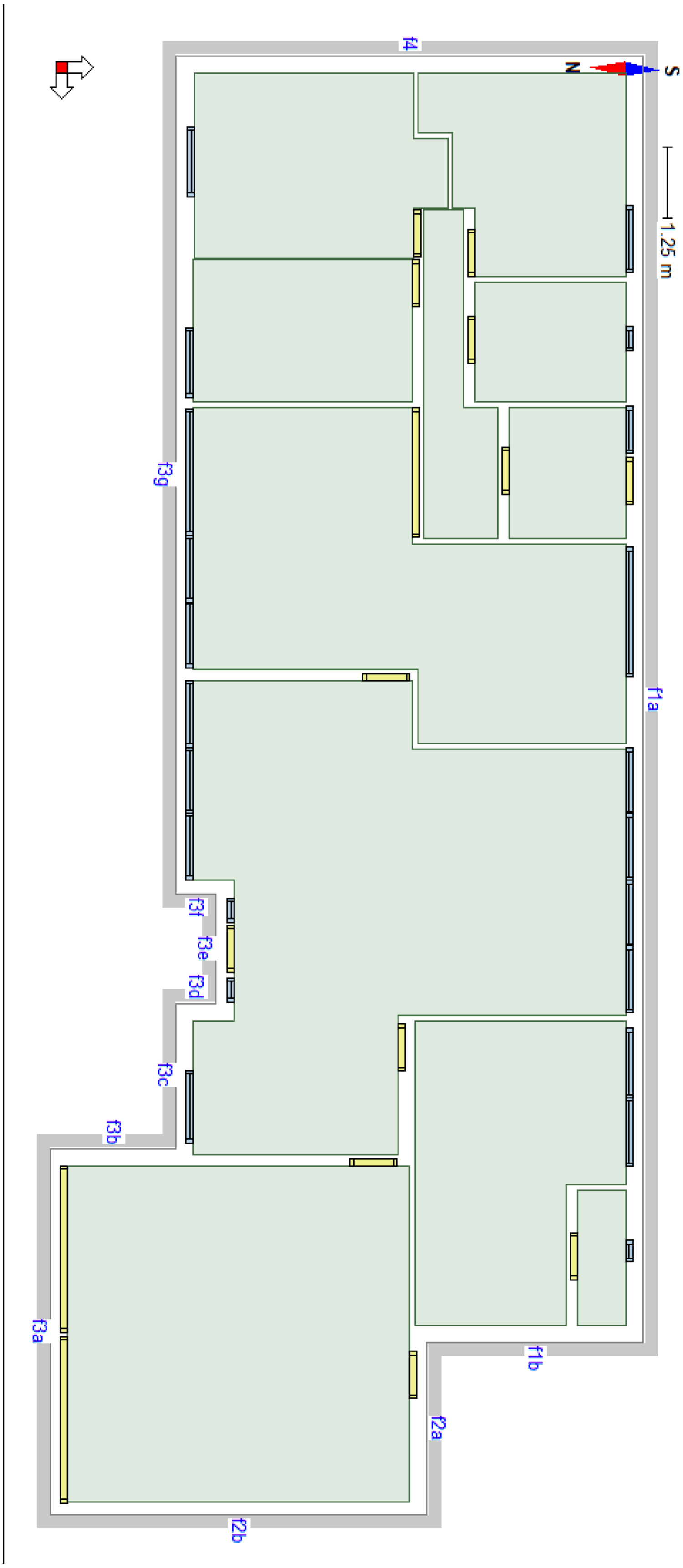
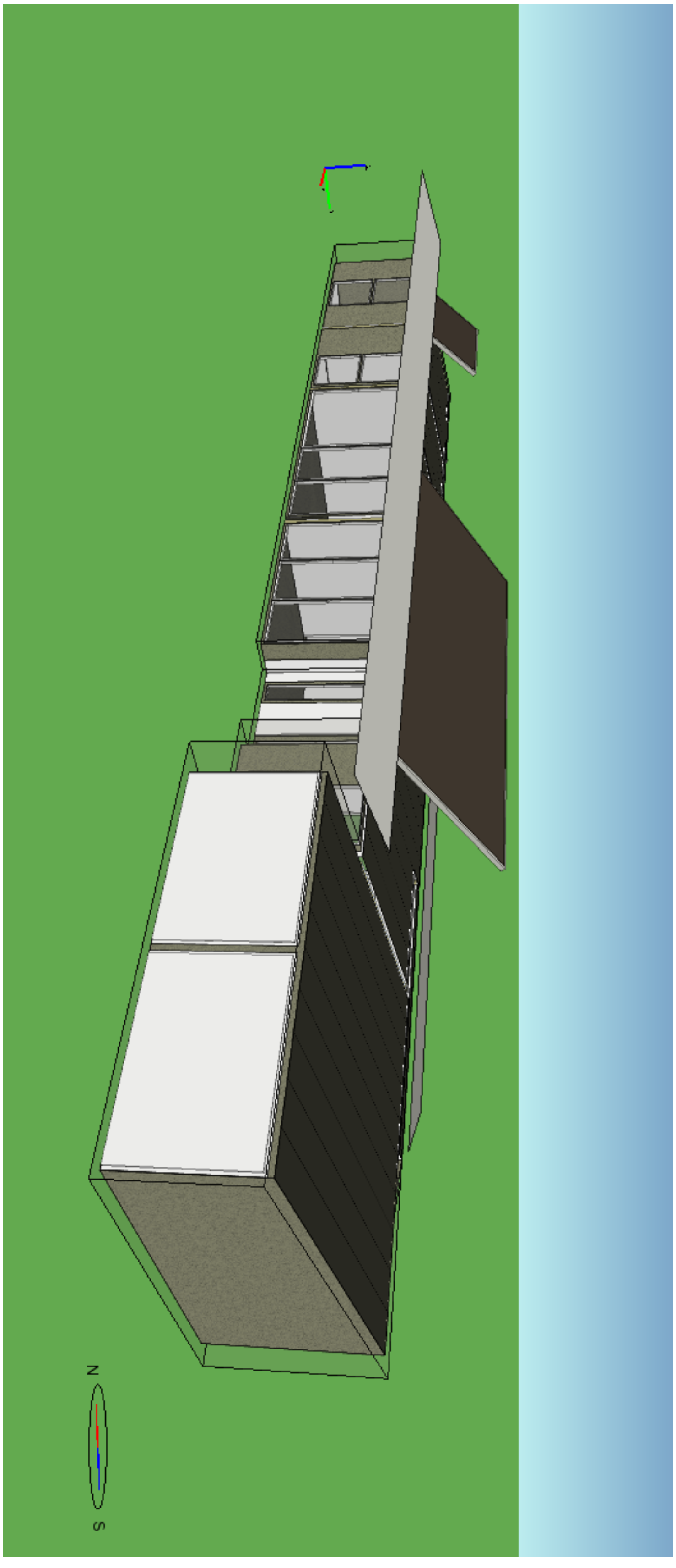
Appendix 1: Building Floor Plan



Appendix 2: Model Floor Plan



Appendix 3: Model 3D View



Appendix 4: Default System Delivered Energy Report

EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
		Model floor area	182.1 m²
Customer		Model volume	449.7 m³
Created by	Benjamin Thomson	Model ground area	188.0 m²
Location	Canberra Airport_949260 (ASHRAE 2013)	Model envelope area	522.5 m²
Climate file	AUS_CANBERRA-AP_949260(IW2)	Window/Envelope	9.3 %
Case	Thesis_project_v4	Average U-value	0.7811 W/(m² K)
Simulated	12/1/2022 2:16:53 PM	Envelope area per Volume	1.162 m²/m³

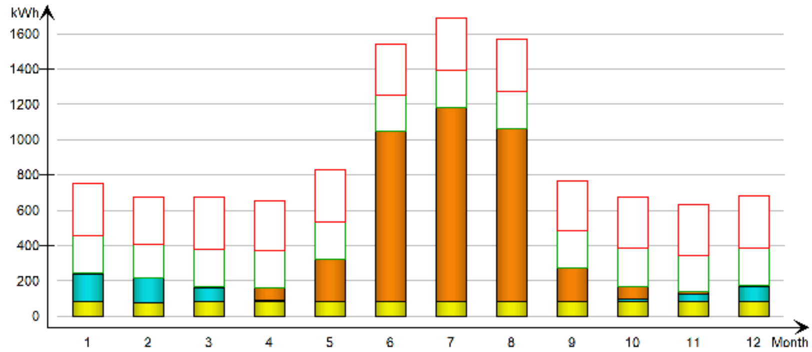
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	14 %

Delivered Energy Overview

	Used energy		Purchased energy		Peak demand
	kWh	kWh/m²	kWh	kWh/m²	kW
Lighting, facility	977	5.4	977	5.4	0.56
Electric cooling	532	2.9	532	2.9	1.39
HVAC aux	0	0.0	0	0.0	0.0
Electric heating	3649	20.0	3649	20.0	2.86
Total, Facility electric	5158	28.3	5158	28.3	
Total	5158	28.3	5158	28.3	
Equipment, tenant	2511	13.8	2511	13.8	1.79
Heating, tenant	3470	19.1	3470	19.1	3.22
Total, Tenant electric	5981	32.9	5981	32.9	
	Generated energy		Sold energy		Peak generated
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	0	0.0	0	0.0	
Grand total	11139	61.2	11139	61.2	

Monthly Purchased/Sold Energy



Month	Facility electric				Tenant electric		Produced electric
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Electric heating (kWh)	Equipment, tenant (kWh)	Heating, tenant (kWh)	CHP electricity (kWh)
1	83.0	157.0	0.0	1.3	213.4	293.7	0.0
2	74.9	139.9	0.0	0.8	192.6	265.6	0.0
3	82.9	76.8	0.0	5.7	213.0	294.6	0.0
4	80.3	7.6	0.0	76.3	206.3	285.4	0.0
5	83.0	1.8	0.0	235.4	213.4	295.0	0.0
6	80.3	0.7	0.0	968.1	206.4	286.1	0.0
7	83.0	0.7	0.0	1099.0	213.4	295.4	0.0
8	83.0	0.8	0.0	976.3	213.1	295.2	0.0
9	80.3	0.7	0.0	195.7	206.5	285.8	0.0
10	83.0	15.0	0.0	73.7	213.3	294.7	0.0
11	80.2	45.1	0.0	13.9	206.3	284.8	0.0
12	82.9	86.0	0.0	3.2	213.2	293.8	0.0
Total	976.7	532.1	0.3	3649.4	2510.8	3470.1	0.0

Appendix 5: Solar System Delivered Energy Report

EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
		Model floor area	182.1 m²
Customer		Model volume	449.7 m³
Created by	Benjamin Thomson	Model ground area	188.0 m²
Location	Canberra Airport_949260 (ASHRAE 2013)	Model envelope area	522.5 m²
Climate file	AUS_CANBERRA-AP_949260(IW2)	Window/Envelope	9.3 %
Case	Thesis_project_v4	Average U-value	0.7811 W/(m² K)
Simulated	12/1/2022 8:02:50 PM	Envelope area per Volume	1.162 m²/m³

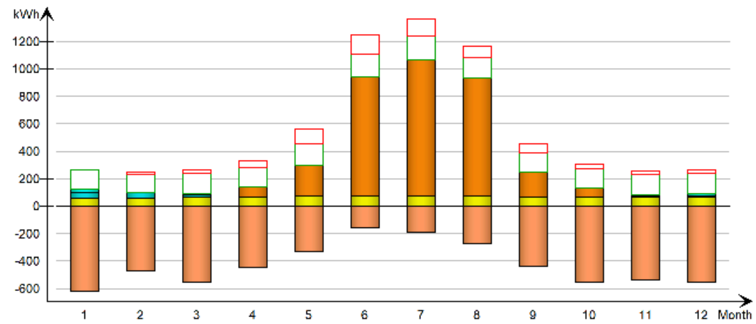
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	14 %

Delivered Energy Overview

	Used energy		**Purchased energy**		**Peak demand**
	kWh	**kWh/m²**	**kWh**	**kWh/m²**	**kW**
Lighting, facility	977	5.4	815	4.5	0.56
Electric cooling	477	2.6	120	0.7	1.39
HVAC aux	45	0.2	40	0.2	8.62
Electric heating	3827	21.0	3293	18.1	2.89
Total, Facility electric	5326	29.3	4268	23.4	
Total	5326	29.3	4268	23.4	
Equipment, tenant	2510	13.8	1801	9.9	1.79
Heating, tenant	765	4.2	694	3.8	2.69
Total, Tenant electric	3275	18.0	2495	13.7	
	Generated energy		Sold energy		Peak generated
PV production	-6954	-38.2	-5116	-28.1	-5.35
CHP electricity	0	0.0	0	0.0	0.0
Total, Produced electric	-6954	-38.2	-5116	-28.1	
Grand total	1647	9.0	1647	9.0	

Monthly Purchased/Sold Energy



Month	Facility electric				Tenant electric		Produced electric	
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Electric heating (kWh)	Equipment, tenant (kWh)	Heating, tenant (kWh)	PV production (kWh)	CHP electricity (kWh)
1	60.9	37.2	26.5	0.9	140.7	0.3	-616.7	0.0
2	59.0	40.8	0.0	0.5	136.4	15.2	-467.4	0.0
3	68.9	14.1	0.0	6.1	155.2	19.0	-554.1	0.0
4	67.5	1.0	0.0	74.0	141.5	52.1	-442.5	0.0
5	76.0	0.6	0.0	222.2	163.6	106.0	-332.9	0.0
6	75.9	0.5	0.0	865.3	169.8	139.9	-159.7	0.0
7	77.3	0.5	0.0	991.2	171.6	126.3	-191.6	0.0
8	72.0	0.5	0.0	860.3	151.5	85.2	-272.4	0.0
9	67.6	0.4	0.0	185.7	141.3	60.4	-436.9	0.0
10	63.6	2.6	0.0	70.0	135.7	39.4	-551.9	0.0
11	63.0	7.6	0.0	13.7	147.2	25.1	-536.3	0.0
12	62.9	13.8	13.7	2.9	146.5	24.5	-554.0	0.0
Total	814.6	119.7	40.3	3292.7	1801.1	693.6	-5116.4	0.0