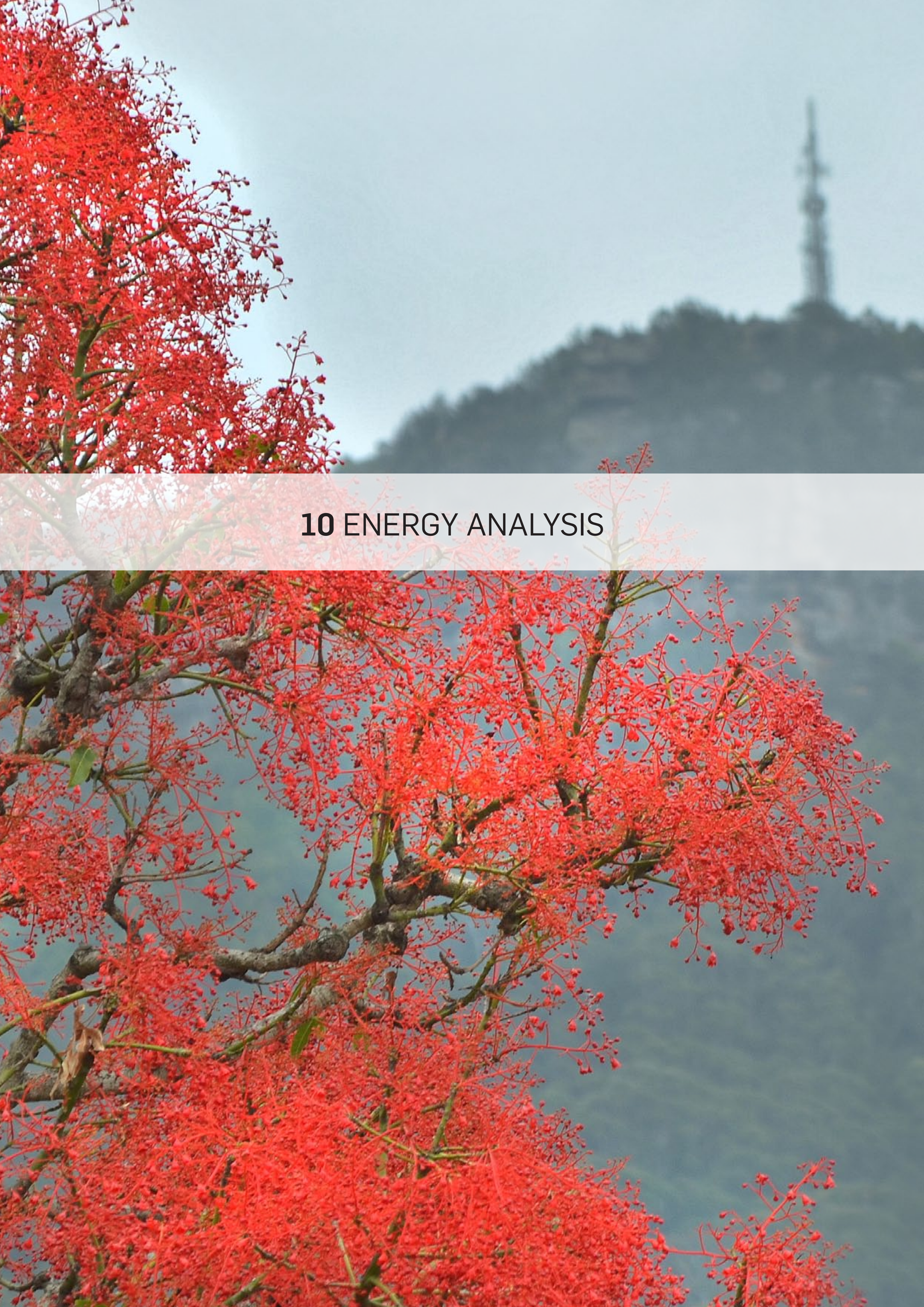
10 ENERGY ANALYSIS



10.8 Final House Thermal and Electrical Design Summary

This report has provided a comprehensive analysis and discussion on how to reduce the energy consumption of existing houses both passively and actively as well as demonstrating how Team UOW has developed a net-zero energy house.

The report has detailed a number of purpose-built analysis tools that have been built by Team to analyse the Illawarra Flame specifically and retrofitting options more generally. These tools include: i) a comprehensive thermodynamic model of a combine PVT, PCM and conventional air conditioning system built in MatLab; ii) a natural ventilation flow network model to determine wind-driven and buoyancy-driven air flows.

In addition a wide range of other modelling tools have been used to analyse the original pre-retrofitted building and the final Illawarra Flame prototype, including: a) building energy simulation tools (DesignBuilder, EnergyPlus, AccuRate); b) CFD and 2-dimensional conduction analysis tools (FLUENT and THERM); c) transient plant simulation tools (TRNSYS).

The report clearly shows the very significant potential for energy demand reduction in existing buildings through retrofit technologies. Moreover, the report demonstrates how to further reduce the energy consumption of HVAC systems by including advanced HVAC energy saving components such as PVT and PCM systems. Finally, it has been demonstrated how to correctly size a PV system to ensure net-zero energy based on the electricity consumption of the prototype Illawarra Flame.

obtained from NASA data for Datong would be reduced by 50%, the following range of estimated output is provided per day:

- Estimated best case = 11.83 kWh/day;
- Estimated worst case = 9.11 kWh/day.

10.7.1.2 SoloPower SP3S

Based on a solar array design with SoloPower SP3S panels 220 watt (SP3S) (4.40 kWp) mounted flat on the roof tilted at 18^{o}, half facing true South and half true North, (for the Datong installation) with the assumption that kWh/m^2/day obtained from NASA data for Datong would be reduced by 50%, the following range of estimated output is provided per day:

- Estimated best case = 10.24 kWh/day;
- Estimated best case = 6.8 kWh/day.

We have verified the expected yield data with the SMA commercially available software "Sunny Design" with a projected output for the system and applied historic irradiance data to depict the potential output variance based on the prevailing weather conditions.

10.7.1.3 Total Power Generation

Combining the two arrays the following total power generation was calculated:

- Estimated best case = 22.07 kWh/day;
- Estimated worst case = 15.91kWh/day.

As highlighted the PV system should cover the total calculated energy consumption even on a bad day.

10.7 PV Sizing and Electrical Energy Production Analysis

Net zero energy is achieved when electrical production is equal to or greater than that consumed by the house and its occupants over a period of time. This is a key feature of the house and the competition and it is necessary to achieve this for both design and competition conditions. As mentioned in the introduction the energy balance contest can have a significant effect on the final rank of a team, so it is important to understand how much energy is required during the competition and size the PV system appropriately to cover all electrical consumption.

10.7.1 System Design

The PV system was designed to deliver an output consistent with the calculated load of approximately 15kWh/day for the competition period whilst the system is located in Datong.

The performance of the solar system is dependent on the climate of the area, particularly the solar exposure and the temperature. The relevant climate statistics for the monthly average of August in Datong is 5.06 Peak Sun Hours (PSH), Temperature 18.55°C, wind speed 3.70 m/s, precipitation 97 mm, wet days 9.1.

Solar exposure of the system, which is measured by peak sun hours (PSH) is the dominating factor on the system yield, however on the other hand the peak power of the Trina and SoloPower panels has an inverse relationship with temperature. For instance the solar panels have higher efficiency during times of low temperature (25°C being the Standard Test Conditions at which rated output is determined). This was also taken into account in the system design as the open circuit voltage (V_{oc}) increases when temperature drops. The string configurations of the panels are designed such that at low temperature $V_{oc\,max}$ does not reach the maximum system voltage of the inverter to avoid inverter operation failure.

Energy yield estimates were calculated for the PV system based upon climate data with allowances made for dirt/contamination, air pollution, inverter efficiency and cable loss. As we have a limited time for the system to generate power (over the duration of the competition) as detailed in Solar Decathlon Rules appendix A-1 the expected yield calculations could vary widely based on the prevailing weather conditions. Also to be taken into account is the potential for air pollution that will reduce the level of irradiance on the arrays. Based on this a best case and worst case scenario were calculated for both panel types as shown below.

10.7.1.1 Trina TSM250 PC05A

Based on a solar array design with 20 x Trina panels 250 W (TSM250-PC05A) (5.0kWp) mounted flat on the roof tilted at 18° and facing true South (for the Datong installation) with the assumption that kWh/m^2/day

Item	QTY	Manufacturer/Model	Item Description	Average Daily usage (kWh/Day)
Outdoor Walkway	11		6W luminaire	0.099
Totals				1.136
Kitchen				
Dishwasher	1	Fisher & Paykel DD60SCX7	Dish Drawer	0.367
Kettle	1	N/A	N/A	0.024
Fridge	1	Electrolux/ETM4200SC	318kWh/year	0.871
Induction Cooker	1	Omega/OI64BB	4 Induction Zones	2.799
Microwave	1	Smeg/SA384X	5 Power Levels	0.005
Stick Blender	1	N/A	127W mixer	0.000
Oven	1	Smeg/SA304X8	60L Electric	0.459
Range Hood	1	Highland/CHH9013EP-W	600mm Canopy	0.159
Totals				4.829
HVAC/Water Heater				
HVAC Unit	1			4.700
Water Heater	1	Thermann	30 Evacuated Tubes	0.302
PVT/PCM fans	1			0.820
Control Standby	1	CBUS		1.320
Totals				5.002
Grand Total				16.40

Item	QTY	Manufacturer/Model	Item Description	Average Daily usage (kWh/Day)
Washing and Drying				
Washing Machine	1	Fisher & Paykel MW513	Top Loader	0.316
Dryer	1	Simpson/39P400M	Heat Dryer	3.682
Totals				3.998
Entertainment				
LED TV	1	Toshiba/46TL900	42 Inch screen	0.114
Laptop	1	Samsung NP3007A-S02AU	17 Inch screen	0.170
Stereo	1	Yamaha/YHT-299	5.1 Satellite HTIB	0.167
DVD/Recorder	1	Toshiba/BDX4300KY	3D Blu Ray	0.010
Totals				0.461
Lighting				
Downlights Recessed	10		In ceiling recessed	0.390
Downlights Kitchen	3		In ceiling recessed	0.164
Recessed Panel	2		300*300mm	0.102
Pendant Dining	1		Double Pendant	0.048
Pendant Raked Ceiling	1		8W luminaire	0.036
Wardrobe	1		In ceiling recessed	0.024
Pendant Master	1		Surface mounted	0.036
Strip Dining	1		Coffer light	0.130
Strip Bathroom	1		Coffer light	0.008
Vertica Garden	6		Uplights	0.027
Outdoor Balcony	4		8W luminaire	0.072

10.6 Demand-Side Electrical Energy Efficiency Analysis

To ensure the Illawarra Flame achieves net-zero energy, the energy consumption of all energy consuming equipment has been thoroughly analysed and tabulated throughout the design process. These results have been used progressively throughout the design process to choose appropriate appliances and to assist in sizing our PV array in order to achieve net-zero energy at the lowest cost.

10.6.1 Appliances and Lighting

Appliances

Highly efficient but affordable appliances have been used throughout the house and have been sized appropriately to maximise the energy efficiency of each item. For example, a small washing machine, dryer and dishwasher have been used in place of large machines as they are more efficient when washing small loads and are suitable for our target client.

Lighting

LED lighting has been used throughout the retrofitted prototype and has been used to replace all incandescent bulbs that would have been in the original pre-retrofitted house.

10.6.2 Total Power Consumption

For the competition period, all power consumption, except that of the HVAC system, has been determined using the competition schedule provided in the Solar Decathlon China 2013 Rule Manual V2 as well as mandatory energy ratings provided by manufacturers of large white goods appliances. Where possible, experiments have also been carried out to determine the actual power consumption of appliances such as dryers, lighting equipment and washing machines. These experiments, and a thorough analysis of available products on the market, have allowed Team UOW to source very energy efficient products.

A summary of the approximate average daily electrical power consumption of the home during the competition period is provided in Table 10-18.

<u>Total electrical consumption from heating and cooling and other electrical appliances was calculated to be 147.6kWh for the 9 day contest period, averaging out to 16.40kWh/day.</u>

Table 10-18: Daily Energy Consumption Estimate for Datong during the 9 day competition period. Results are based on the contest schedule found in SDC 2013 Rules Manual V2.

The average daily electrical energy consumption derived from the manual calculation for Sydney was equal to 1.29kWh/day which is in close agreement with the TRNSYS model. These calculations show that the hot water system should draw very little auxiliary energy during the competition period if the weather conditions are average, which will help our team achieve net-zero energy during the competition.

10.5.2 Manual Calculation

The following section describes the methodology for manually calculating the auxiliary energy needed to provide hot water in conjunction with the energy provided from the solar collector. The *f-Chart* method for liquid systems was employed to gain an approximate calculation of auxiliary energy. The following assumptions have been made:

- The heat energy delivered from pump to solar collector system is negligible and can be assumed to be zero;
- Heat energy loss from pipe work is negligible;
- Minimum acceptable water temperature in the tank is 60°C;
- Solar reflection from ground to solar collectors is negligible;
- Pump will be running 24 hours per day.

Direct beam and diffuse radiation data were extracted from EnergyPlus for both Sydney and Datong and then converted to daily monthly averages. The calculated consumption of hot water is 180 L per day based on the Solar Decathlon China 2013 Competition Schedule and additional water draws from cooking and cleaning during dinner contests were not considered. The results are provided in Figure 10-54 for the amount of electrical energy needed to sustain a minimum of 60°C in the 300 L tank including the pump for both Sydney and Datong.

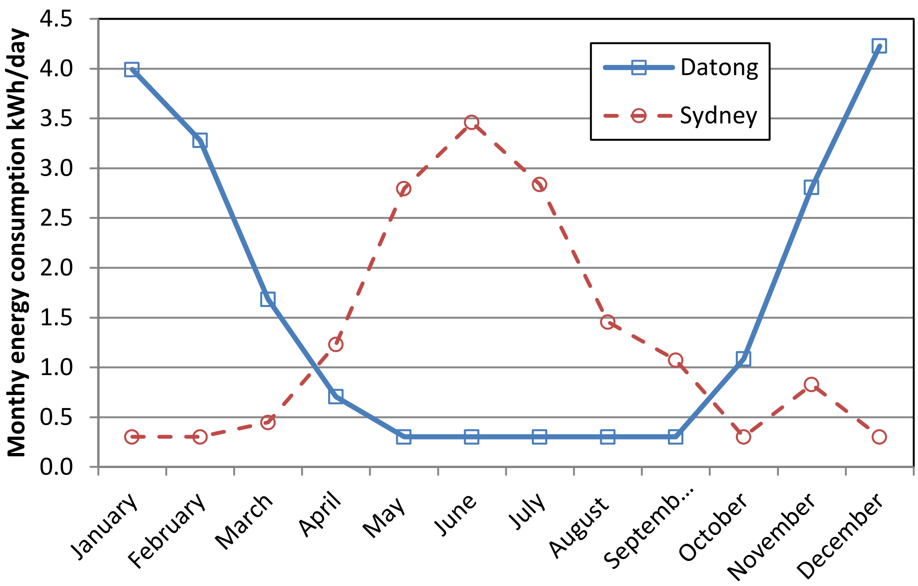


Figure 10-54: Monthly solar hot water system auxiliary energy consumption for Datong and Sydney

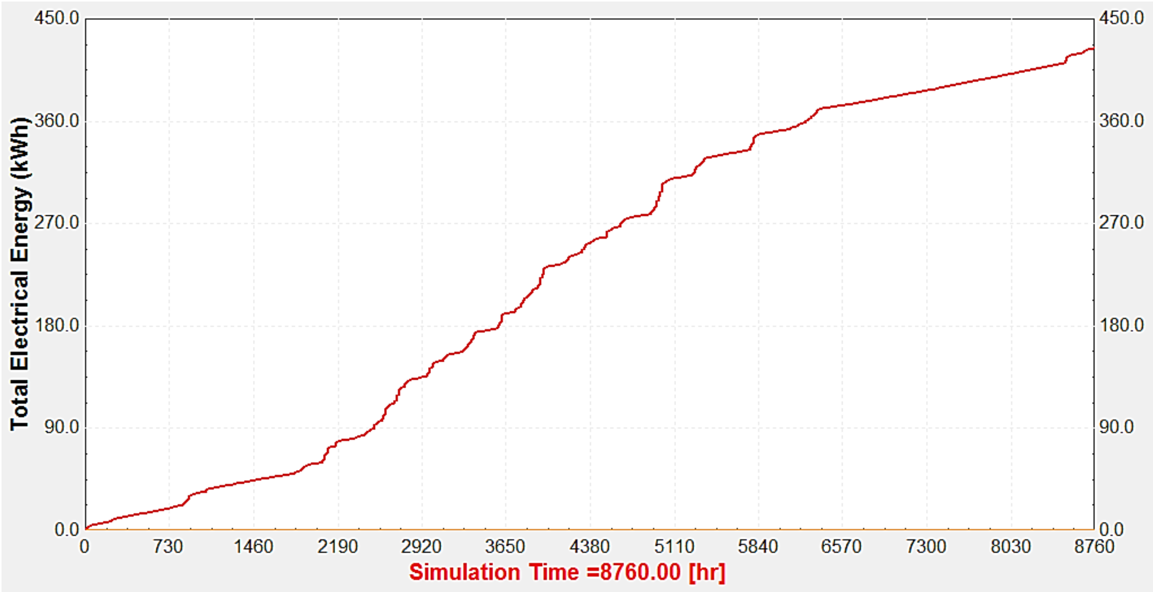


Figure 10-52: Annual cumulative auxiliary electrical energy consumption of the solar hot water system.

A traditional electrical hot water system was also simulated to compare the two systems. As shown in Figure 10-53, the annual energy consumption of a standard domestic hot water (DHW) system was predicted to be 3038 kWh which is equal to 8.32 kWh/day. Therefore, by installing a SHW system the annual domestic hot water energy demand can be dramatically reduced by 86%, or 2614 kWh/year under the simulation conditions. This result indicates that upgrading an existing hot water system to a solar powered system is a simple but effective way to reduce energy consumption.

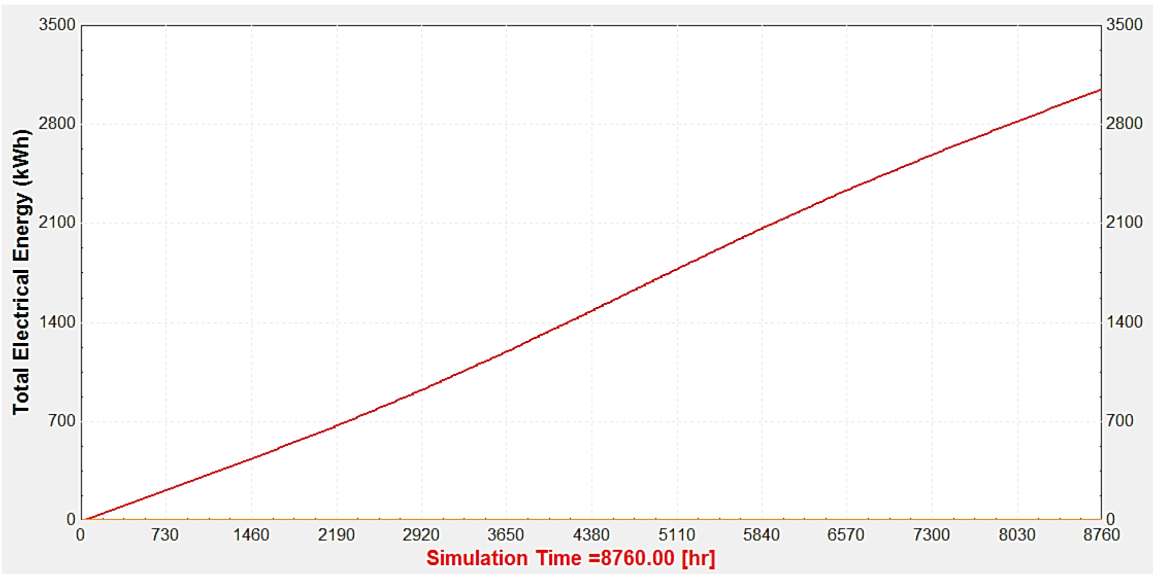


Figure 10-53: Annual cumulative auxiliary electrical energy consumption of a traditional domestic hot water system.

10.5 Solar Hot Water System Analysis

Domestic hot water systems (DHW) are the second largest energy consuming systems in Australian residential homes and normally contribute up to 25% of a house's annual energy usage. It is well known that the energy usage of domestic hot water systems can be significantly reduced by utilising a solar hot water (SHW) system. Quantitatively understanding the energy usage of a specific solar hot water system is vital for this project in order to select an appropriate system and to ensure the team achieves a net-zero energy balance.

10.5.1 TRNSYS Analysis

In this study TRNSYS which is a transient system simulation tool was used to predict the SHW system auxiliary energy usage together with manual calculations for validation. The key parameters of the SHW model were based on a Thermann SHW system. Figure 10-51 provides a schematic diagram of the system modelled in TRNSYS. The water draw schedule was defined as three 60L draws at 17:00, 19:00 and 21:00 which is similar to the most frequent single day scheduled in the Solar Decathlon China competition rules.

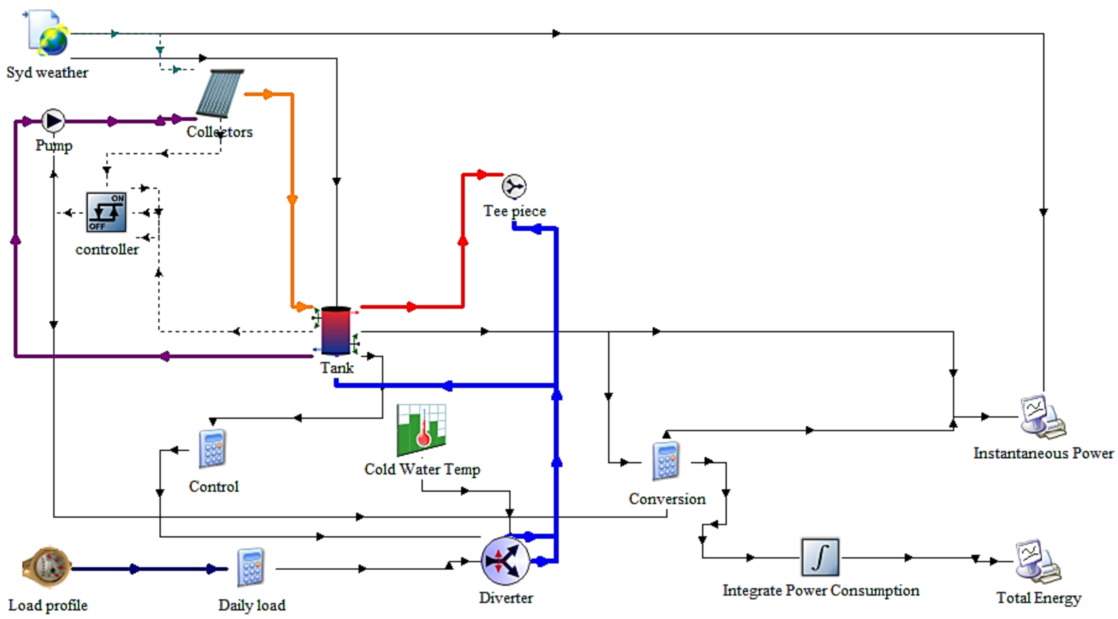


Figure 10-51: Schematic Diagram of the solar hot water system simulation in TRNSYS.

The simulation result shown in Figure 10-52 indicates that under Sydney weather conditions, the annual solar hot water system consumed 424 kWh which equals to 1.16 kWh per day. The graph also indicates that the energy consumption in a warm period is steady, which means the solar collector can cover most of the water heating energy requirement in a warm period.

A similar analysis has been performed for the cooling case in summer, with Sydney conditions in January having been used. The resulting profile is shown in Figure 10-50. In this case the charge is negative, since cold is stored, and the demand is positive.

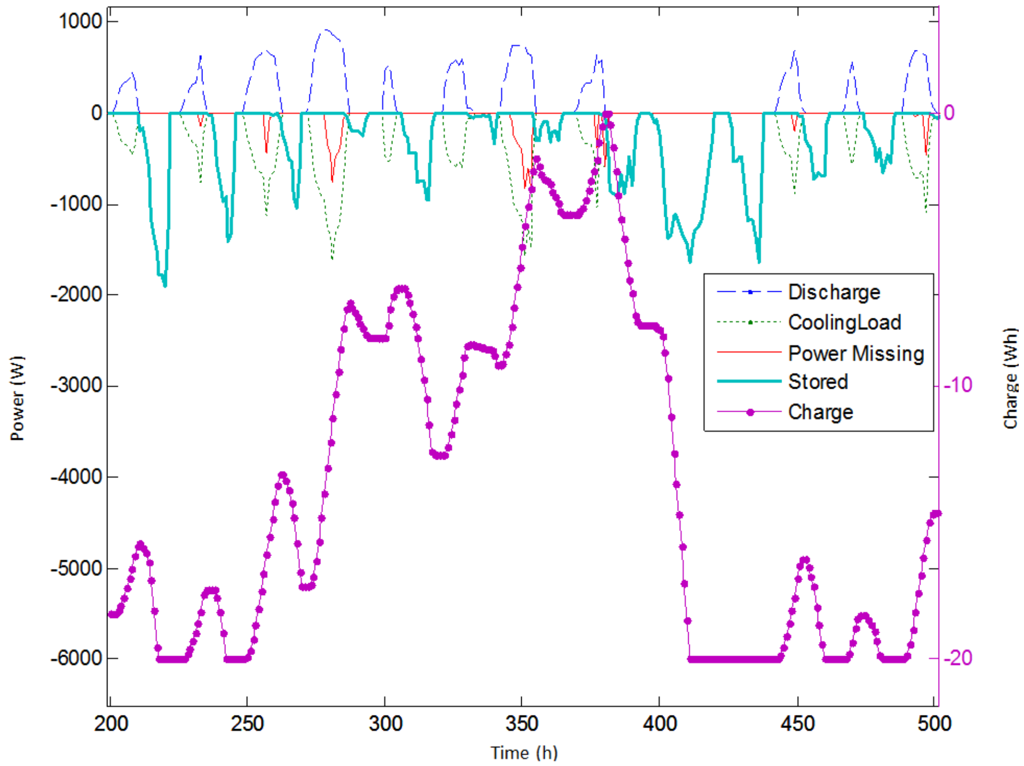


Figure 10-50: PCM storage and discharge profile for January in Sydney.

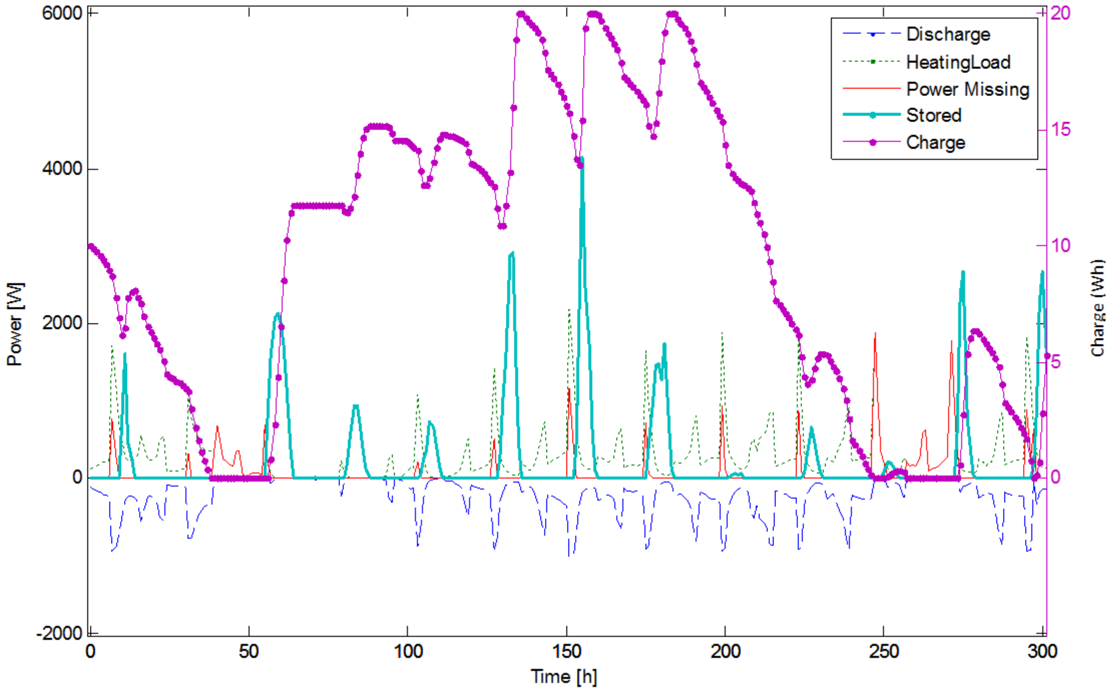


Figure 10-48: PCM storage and discharge profile for July in Sydney.

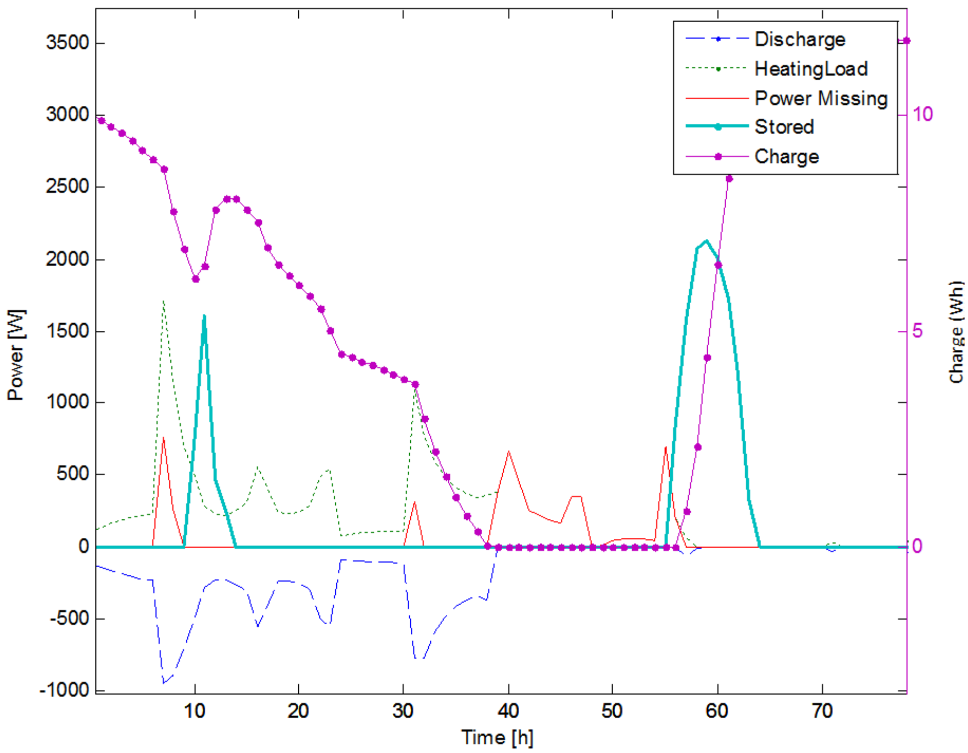


Figure 10-49: PCM storage and discharge profile for July in Sydney.

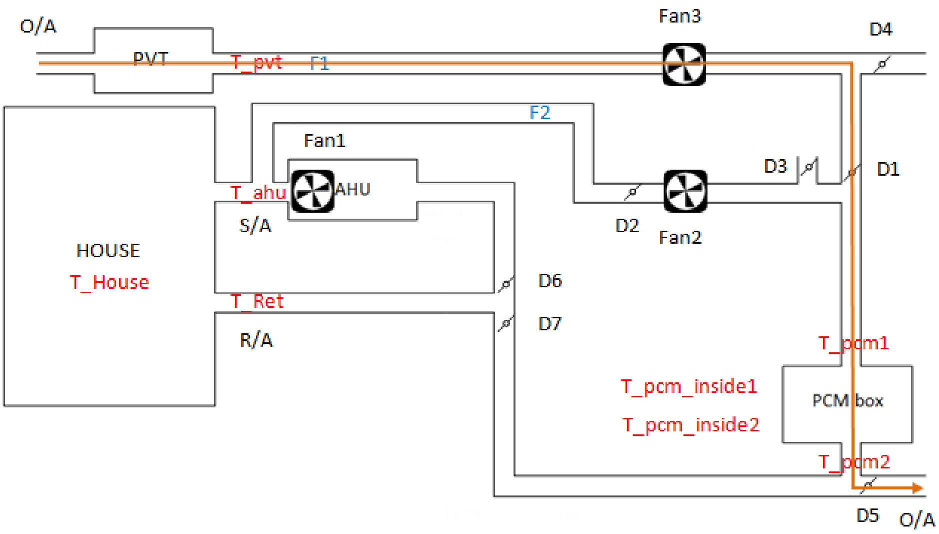


Figure 10-47: PVT – 'PCM Charging' mode.

10.4.7 Modelling and Simulation Results – Charging and Discharging Profiles

Prediction of the HVAC system behaviour has been developed through analytical and numerical modelling of the components included in the system. Three areas have been modelled for the PVT system including, PVT heat transfer; electrical generation and mechanical pressure loss (plant curve). Various aspects of the PCM system were also modelled including heat transfer and pressure loss.

With all the components modelled, optimisation of the system has been performed using Sydney hourly weather conditions, to maximise the energy output (both thermal and electrical) compared to the energy usage (fans). Using this model and the energy demand of the house predicted by Design Builder, it was possible to determine the charging and discharging profiles. Constraints on the system modelled include:

- The PCM store has a limited energy capacity, fixed at 20kWh;
- The fans have a maximum capacity, which consequently limits the maximum airflow achievable;
- If the PCM store is discharged it will be bypassed and only the air conditioning unit will be used.

An example of the PCM store charge profile is shown in Figure 10-48 which shows heating in Sydney in winter (July). In this plot "Charge" represents energy available in the PCM store (Watt-hours), "HeatingLoad" is the house heating demand (Watts), "Stored" is the rate of thermal charging (Watts), "Discharge" is the discharge rate (Watts) and "PowerMissing" is the energy that the PCM store cannot supply because either the demand is too high at that moment or because the store is discharged. Addition of heat to the PCM is considered positive, for this reason the charge is positive and the discharge profile is negative. These profiles can be seen also more in detail in Figure 10-49.

Supply Air Preconditioned Through Phase Change Material:

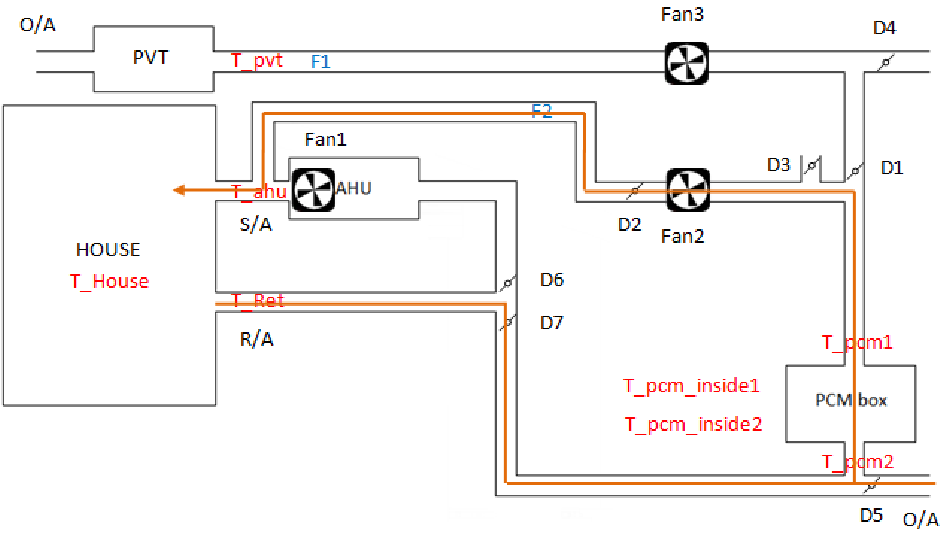


Figure 10-45: Preconditioned supply air mode.

10.4.6 PVT Operating modes

The PVT system has 2 operating modes as displayed below.

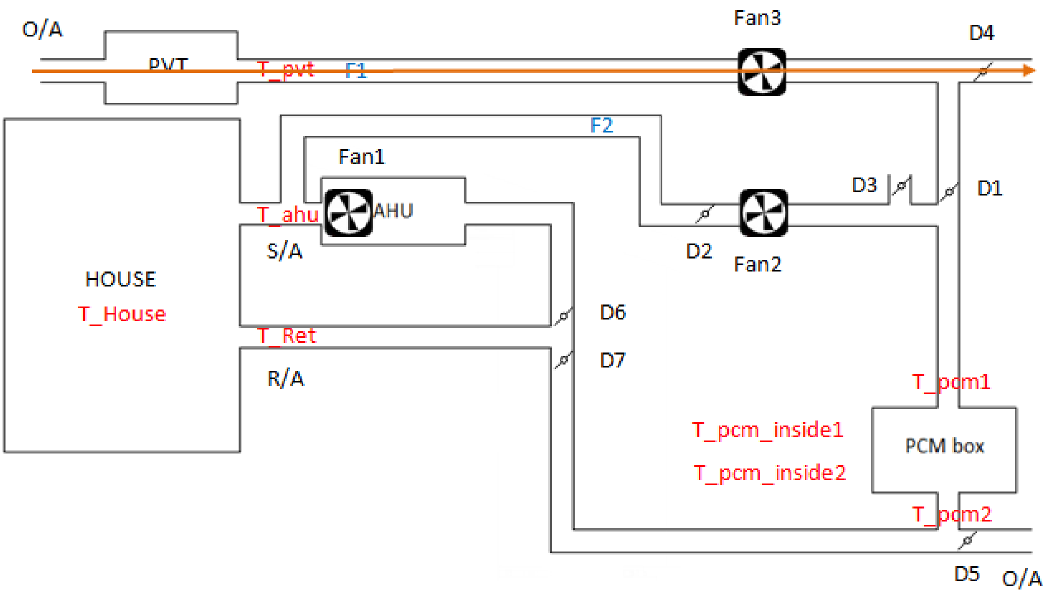


Figure 10-46: PVT – 'Direct Exhaust' mode.

Normal Conditioning Mode:

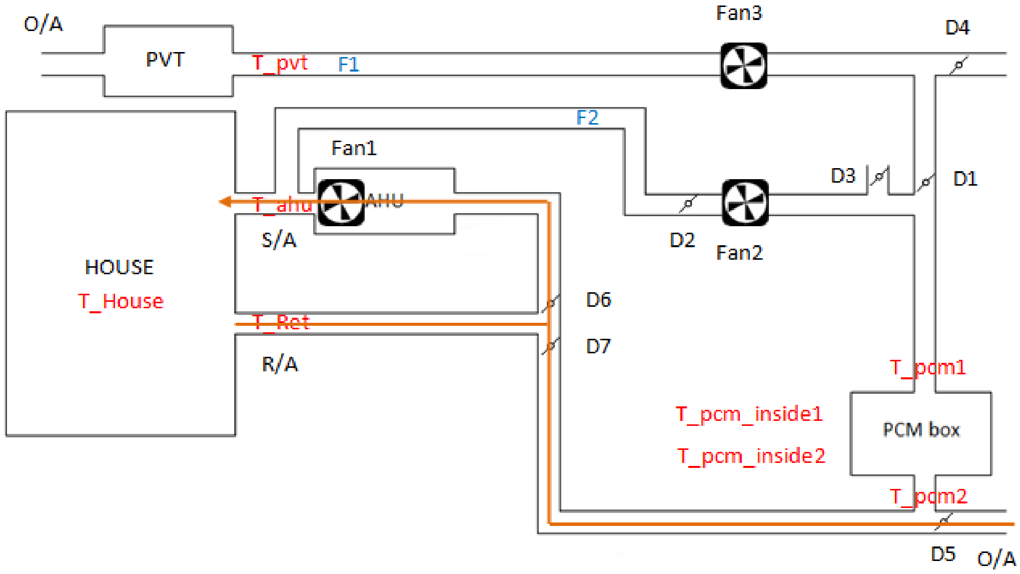


Figure 10-43: HVAC system in 'Normal' mode.

Direct Photovoltaic-Thermal Supply:

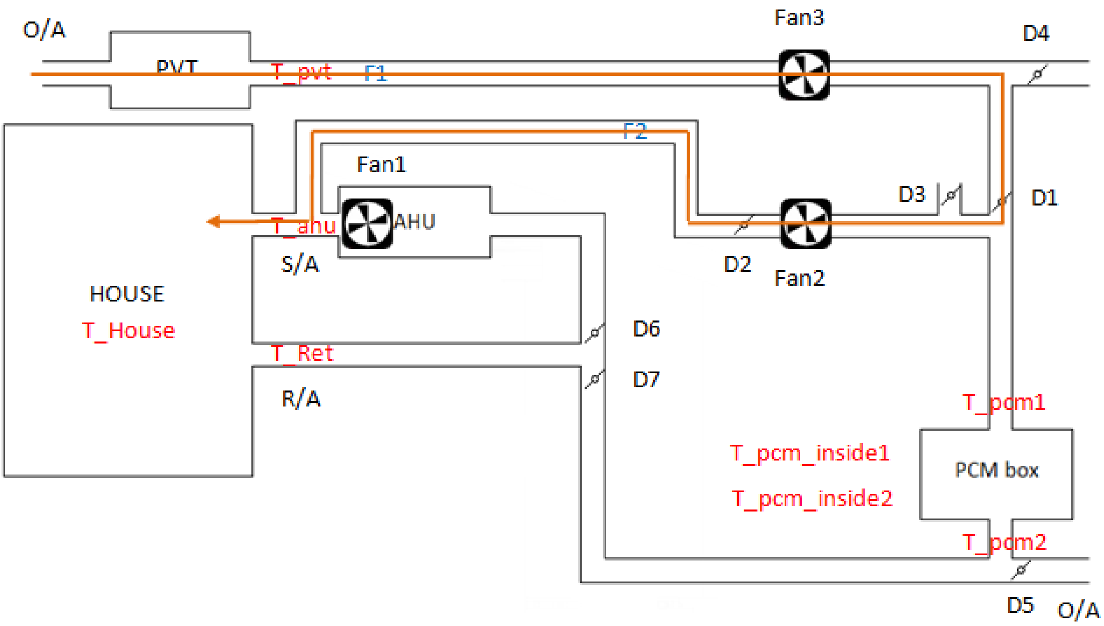


Figure 10-44: HVAC in 'Direct PVT Supply' mode.

- Normal Cooling Mode If there is no thermal generation and the PCM store is discharged, the AHU will supply the cooling required.

10.4.5 HVAC Operating Modes

The Illawarra Flame control system will manage the HVAC system by choosing different operating modes depending on the conditions at that particular moment. The following section outlines each of these modes (note that relief air is assumed to flow through exhaust fan outlets and is not shown on the diagrams below).

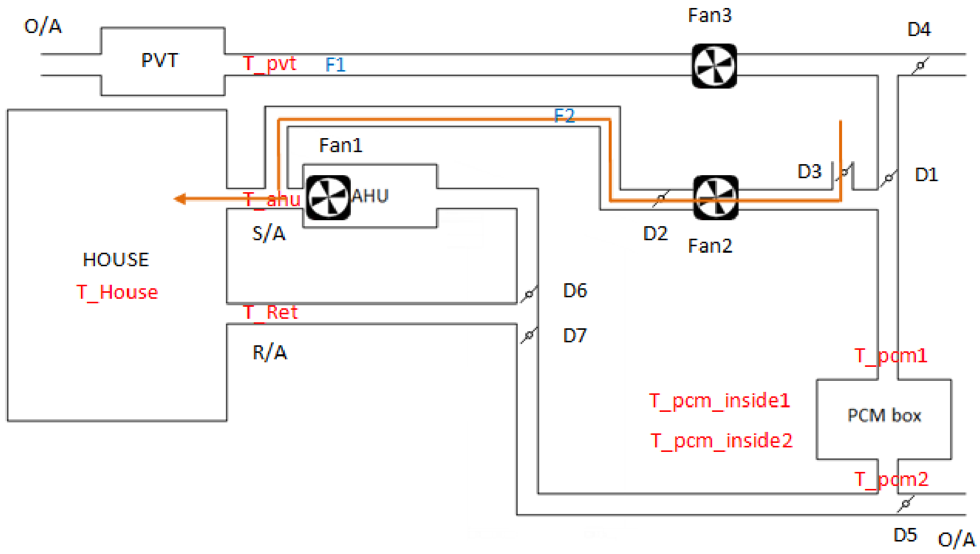


Figure 10-42: HVAC system in 'Off' mode.

10.4.4.2 HVAC Control Strategy

When active the BMS system will choose the most convenient operating mode based on both indoor and outdoor measured conditions.

Natural Ventilation Mode: The natural ventilation mode is mainly used during cooling periods (summer) because internal loads work against achieving comfort conditions and it is more likely that outside air conditions are favourable to assist. If the average of temperatures inside the house is between 20°C and 25°C and the outside air temperature is lower than the inside air temperature, the Natural Ventilation mode will be activated. If the inside temperature is outside this range, mechanical heating or cooling will be activated.

Heating Mode: The heating mode is activated when the temperature of the house goes below 21°C. It can also be activated if the temperature set-point is higher than the temperature inside the house. There are three sub – heating systems.

- Direct Photovoltaic-Thermal Supply: If the generation of heat and demand occur at the same time, the heated air flow is discharged directly into the house until the demand is matched.
- Supply Air Preconditioned Through Phase Change Material: If the PCM store is charged, the mixture of return air and fresh air will be preconditioned by the PCM store, increasing the supply temperature to 21 - 22°C. If the demand is higher than the energy extracted by this airflow, the AHU will cover the remaining heating requirement. The airflow will be varied using a proportional controller in order to match the demand.
- Normal Heating Mode: If there is no PVT thermal generation and the PCM store is discharged, the AHU will supply the heating required.

Cooling Mode:

The cooling mode will be activated when the temperature of the house goes above 25°C. It can also be activated if the temperature set-point is lower than the temperature inside the house. There are three sub – cooling systems.

- Direct Photovoltaic-Thermal Supply: If the generation of cool air and demand occur at the same time, the cooler air is discharged directly into the house until the demand is matched.
- Supply Air Preconditioned through PCM Store: if the PCM store is charged, the mixture of return air and fresh air will be preconditioned by the PCM store, decreasing the supply temperature to 23-22°C. If demand is higher than the energy extracted by this airflow, the AHU will cover the remaining cooling.

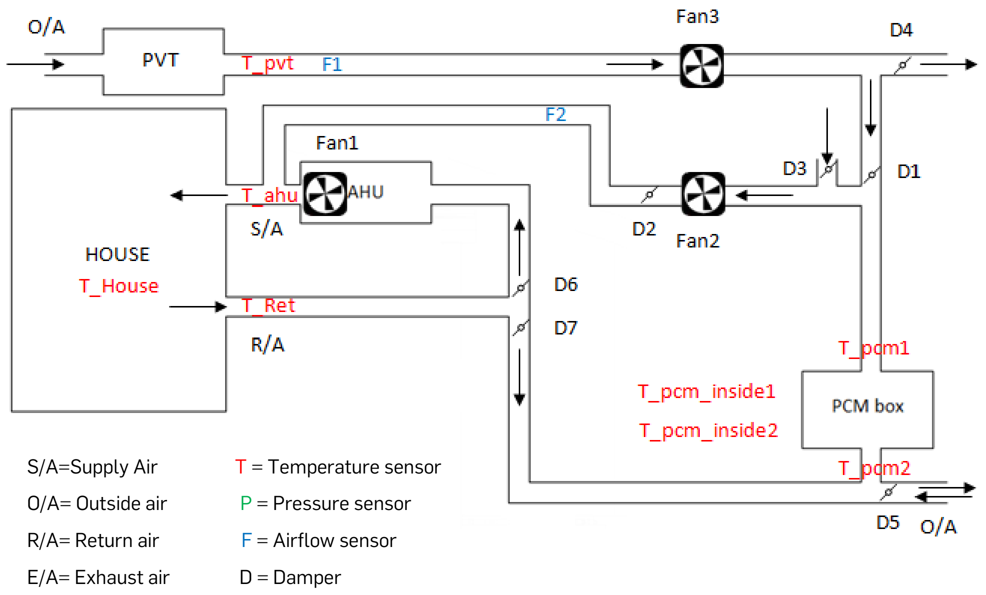


Figure 10-41: Schematic of the HVAC system including PVT, PCM and Air Handling Unit (AHU).

Figure 10-41 shows the layout of the HVAC system. Please note all dampers are electronically activated and that D3 and D5 are modulating while all other dampers are On – Off flow control. External sensors on the weather station relevant to HVAC system include: T_{amb} = Ambient Temperature and I_{rr} = Solar Irradiation.

10.4.4 Operating Modes

10.4.4.1 Mode selection

Individual modes may be selected automatically or manually from the C-bus control interface or key inputs on the walls. There are two main modes, 'occupied' and 'unoccupied' and a third mode 'sleeping' which is a sub-mode of the 'occupied' mode. The occupied and sleeping modes can also be selected using a fixed schedule.

Mode 1 – Occupied: all electrical equipment will be active, with the non-priority line connected to the grid. The AHU will run with comfort temperature set points, with conditioning of the living area a priority.

Mode 2 – Unoccupied: the electrical non-priority line will be disconnected from the grid. The AHU will be deactivated, keeping the inside temperature to an acceptable minimum/maximum value.

Mode 3 – Sleeping: the electrical non-priority line will be disconnected from the grid. The HVAC will be set on night-time set points.

An electrical non-priority line has been added through the house which allows all standby items to be switched off at one point when the occupant is not home, or when they are not required.

This will allow the house to use a much greater fraction of the thermal energy generated by the PVT, not just the energy that can be used when the generation and the demand are coincident.

10.4.2.1 Choice of PCM

Phase Change Materials (PCMs) are a group of materials that can be used to efficiently store thermal energy at a wide variety of temperatures. The best PCM's have a high latent heat of fusion, a narrow range of temperature over which the phase change is completed and have little degradation with repeated cycling.

A salt hydrate product was selected over other alternatives due to the advantages it offered for this application. Salt hydrate product could be purchased at a lower cost than organic and micro-encapsulated products when the thermal requirements of the present application are considered. The target melting temperature of 22^0C could be achieved by selecting a particular salt for use in the mixture. Trying to achieving the same with an organic compound would have required the mixing of many organic compounds, causing a wider melting range, or a significant increase in price. When changing from a solid to a liquid salt hydrates typically expand 10%, a manageable variation in volume. Salt hydrates represented a good balance between thermal efficiency and cost while meeting building regulations requirements (e.g. non-flammability). Further information on the PCM can be found in Division 23 – HVAC.

10.4.3 System Integration, Modelling and Control

In this section the integration of the PVT and PCM thermal energy store into the HVAC system will be discussed. An appropriate modelling system and control strategy have been developed in order to determine the optimal operating conditions of the system and the requirements for the HVAC and automation system in order to let the system operate correctly.

10.4.3.1 System Integration

The system has been modelled in blocks, for example, when charging the PCM store with the PVT, the PVT block is an input to the PCM block. When discharging the store, the mixture of return air from the house and fresh air is used as an input to the PCM store. The design facilitates independent charging and discharging of the PCM store, though of course this cannot occur simultaneously. In parallel to the PVT-PCM system, the normal air conditioning unit can supply any unmet heating and cooling demands to the prototype house.

10.4.1.2 PVT – Thermal and Electrical Energy Generation Optimisation

The PVT system has a key controllable variable, the airflow through the system, and two other measured non-controllable inputs, ambient temperature and solar radiation. The overall objective is to maximise both the electrical and thermal output of the PVT system. Optimisation of the thermo-electrical generation has to take into account a number of factors including: i) the PV modules operate more effectively if they are cooled by passing air through the ducts; ii) to achieve the latter electrical fan energy must be consumed; iii) heating or cooling generated by the PVT has to be stored in the PCM thermal store, at close to the PCM melting temperature. The maximum potential rate of heat storage in the PCM system is given by:

$$Q_{therm} = \dot{m}c_p(T_{PVT} - T_{PCM}) \text{ ,}$$

where $\dot{m}$ is the mass flow rate, c_p the specific heat capacity, T_{PVT} is the air temperature at the outlet of the PVT system and T_{PCM} is the melting temperature of phase change material of the PCM store. T_{PVT} is of course a complex function of the solar irradiation, the mass flow rate, the ambient temperature, etc.

A comprehensive transient thermodynamic model has been built from scratch by Team UOW to predict the thermal energy stored in the PCM store as a function of time, weather conditions and house occupancy and use. After extensive modelling of a range of configurations Team UOW have chosen to use a PCM melting temperature of 22°C so that a single PCM store can store energy for both heating and cooling seasons. This store was sized to provide approximately 20kWh of thermal storage.

A practical control system then needed to be developed and implemented in the Illawarra Flame house. This was built around a simplified model of the overall PVT/PCM system using parameters that have been statistically evaluated, using regression methods, from the results of the comprehensive theoretical analysis described above. The control system will dynamically provide an optimal airflow through the PVT/PCM system according to weather and demand-side conditions so as to balance enhanced PV panel efficiency and thermal storage against fan energy consumption. Overall the aim is that the system will maximise the total energy harvested from the natural environment (solar radiation and ambient air).

10.4.2 Phase Change Material (PCM) Thermal Energy Store

The performance of the Illawarra Flame PVT system is enhanced by coupling it with a thermal energy storage system. By using this thermal storage system it is possible to phase-shift the thermal generation so that thermal energy may be used at times when the generation is not possible (e.g. at night, on cloudy days, etc).

In order to select an appropriate PV module different aspects have been considered:

- Arrangement for maximum coverage on available roof area;
- Ability to properly and safely fasten the flashing to the roof;
- Air-tightness;
- Aesthetics;
- Wiring routing and access;
- Security against wind forces;
- Electrical efficiency and total electrical production.

After consideration of these issues, the flexible, thin-film large-format SoloPower SP3S PV module was chosen. The length of the module allows for two modules to be installed end-to-end between the ridge caps and gutter of the pre-retrofitted house. The layout utilises 5 flashings on each side of the roof, with 2 PV modules installed on each flashing. Further details of this installation can be found in Division 48 – Electrical Power Generation.

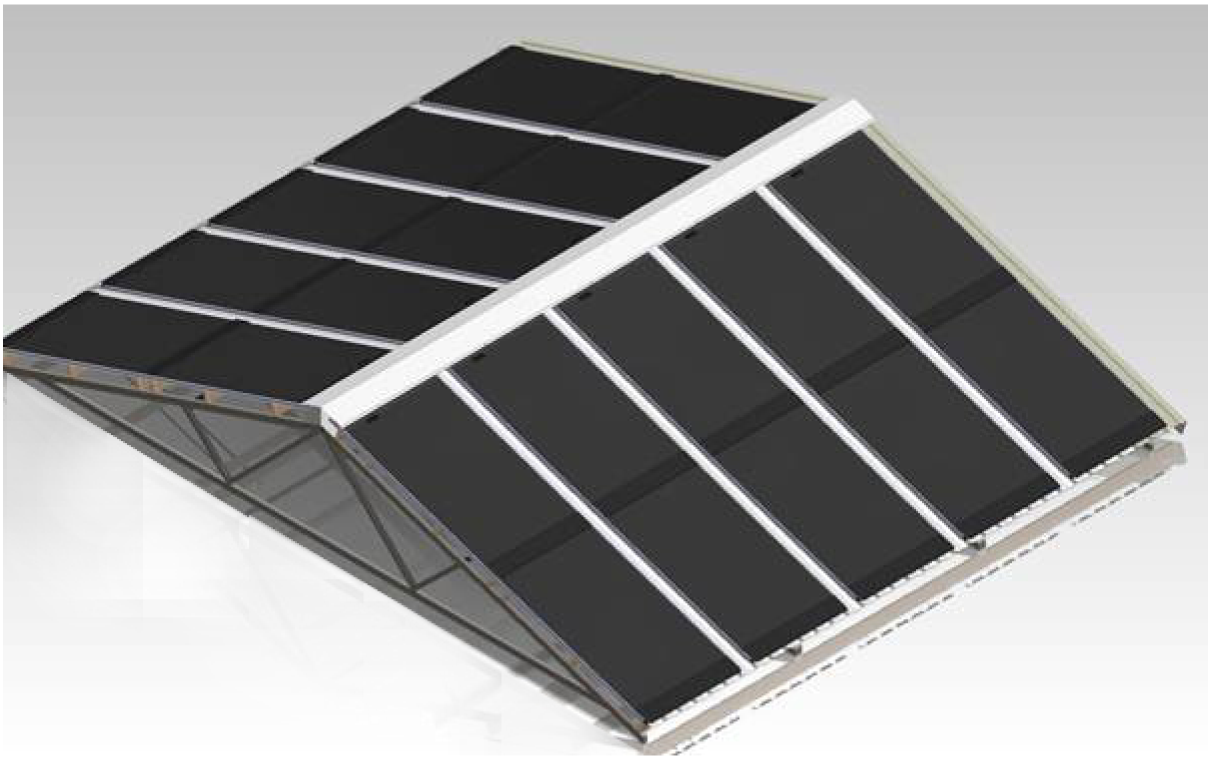


Figure 10-40: PVT layout showing location of the thin-film CIGS panels.

Figure 10-38: PVT installation on north- and south-facing roof surfaces.

To optimise the PVT generation the air flow is calculated and adjusted to suit each weather condition (i.e. insolation, wind and ambient temperature). A simulation of the PVT outlet temperature during daytime heat extraction is presented in Figure 10-39. This simulation has been calculated using Sydney weather data for July.

Team UOW have developed a purpose-built simulation tool (programmed in MatLab) to model the operation of the PVT system and the associated Phase Change Material (PCM) thermal store.

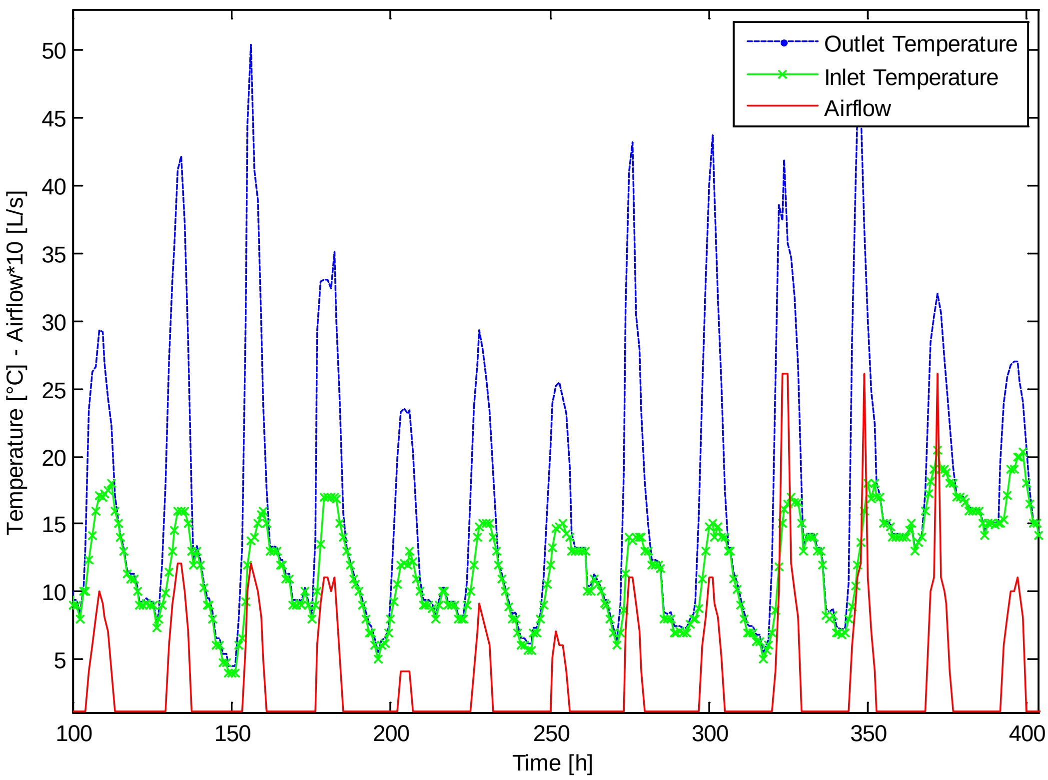


Figure 10-39: Simulated air temperatures and airflow rates through the Illawarra Flame PVT system using the purpose-built MatLab thermodynamic model of the system (using Sydney IWEC weather data for July).

10.4.1.1 Roof Design and Collector System

To create the void underneath the solar panels, a flashing system was designed to allow for installation of a PV system on top of an existing or retrofitted metal roof on the existing building. This particular configuration was chosen as the Trimdek™ sheet metal roof profile offered the best compromise between channel height and cost-effectiveness for a residential application.

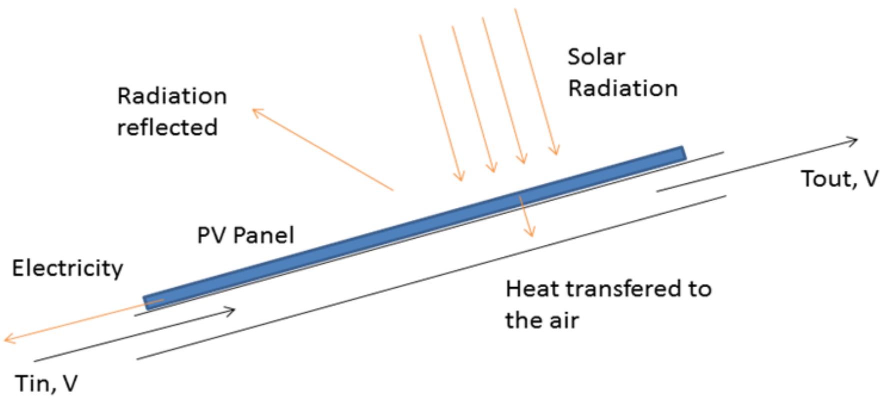


Figure 10-36: PVT schematic for daytime generation.

During the daytime, incoming solar radiation generates electricity through the PV modules. Some of the radiation is reflected and the remainder of the heat is transferred to the fluid. The air mass flow rate is the key parameter that allows the building automation system to control the temperature at the outlet of the PVT system and consequently the quantity of heat extracted. During summer the house will mainly require cooling. In this case the PVT will generate cooling during the night time, whereby the solar panel emits radiation to the sky if the sky is at a lower temperature than the panel. This process, as shown in Figure 10-37, will extract heat from the air flow.

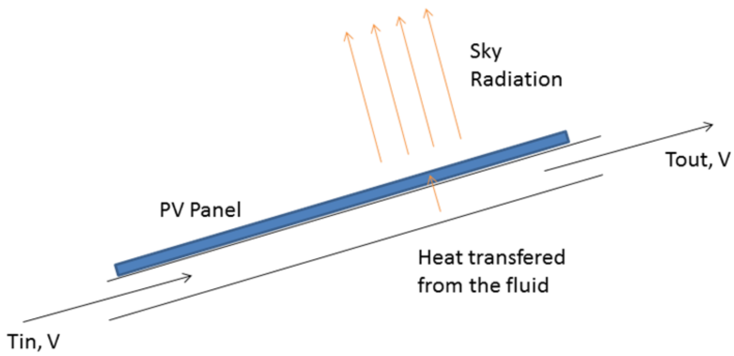
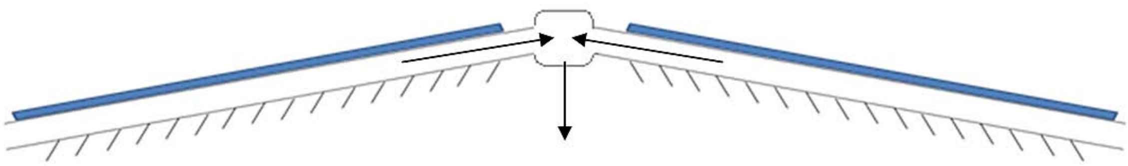


Figure 10-37: PVT schematic for night sky radiative cooling.

The PVT system is designed to draw air from both sides of the roof and both of the airflows come together in a plenum at the apex of the roof as shown in Figure 10-38.



10.4 HVAC System Design

10.4.1 Retrofitted Photovoltaic Thermal (PVT) system

Team UOW have developed a unique system to enhance the electrical harvesting efficiency of their PV system while also harvesting the thermal energy of the sun. The Illawarra Flame's Photovoltaic-Thermal (PVT) system consists of a number of thin-film PV panels mounted on a steel sheet flashing that is fixed to the top of an existing sheet metal roof profile. This system creates a cavity underneath the steel flashing through which the working fluid, air, can flow and exchange heat with the PV panel, as shown schematically in Figure 10-35.

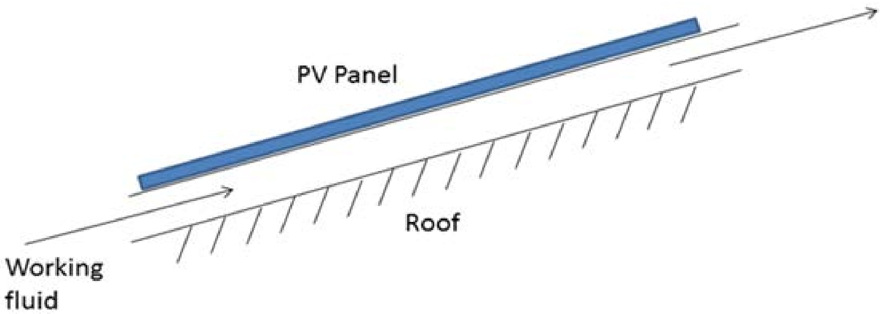
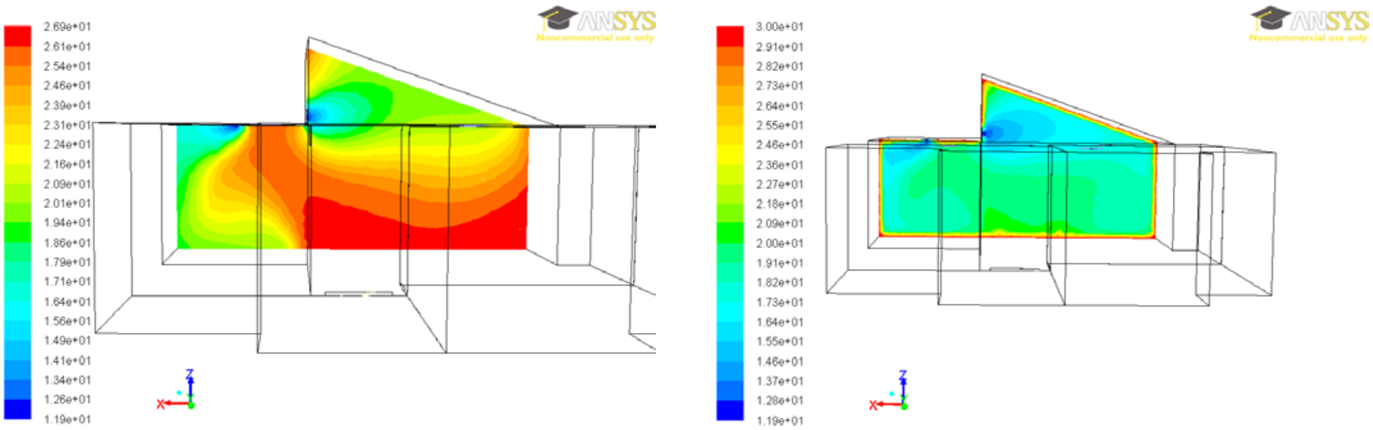


Figure 10-35: Schematic diagram of PVT System.

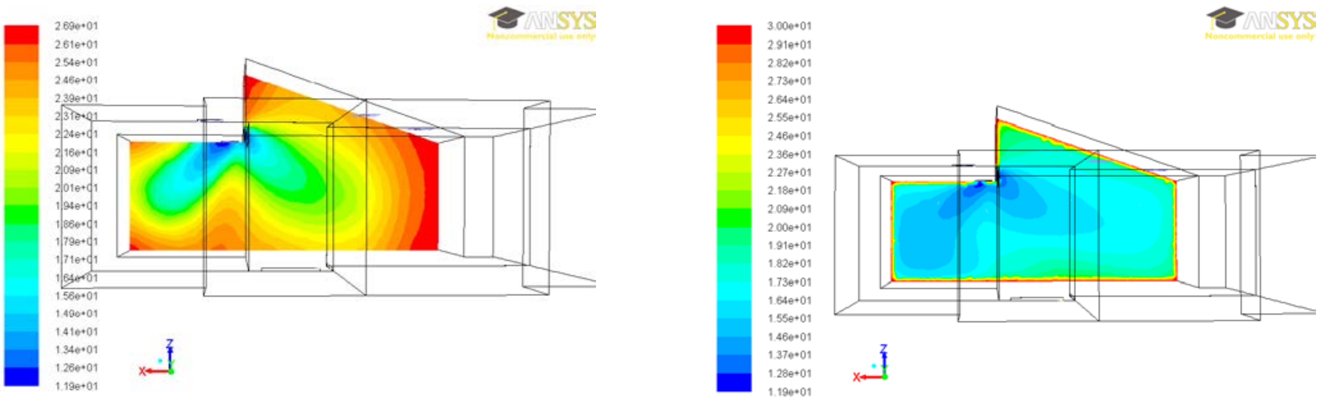
The advantages of a PVT system rather than a PV system include an increase in the efficiency of the PV panels by reducing and regulating their temperature and the possibility to extract or release heat for heating or cooling purposes which increases the total energy extracted from the solar system, therefore increasing the overall efficiency of the system.

The utilisation mode of the PVT system generally depends on the demand of the building at a particular period of time. For example in winter heating will be necessary and no cooling will be required. In this case the heat can be extracted as shown in Figure 10-36.



(a) Transient (b) Steady

Figure 10-33: Design 1 – example air temperature distribution from CFD analysis showing cross-section through living room and kitchen and the interaction between kitchen and living room supply air diffuser jets.



(a) Transient (b) Steady

Figure 10-34: Design 2 – example air temperature distribution from CFD analysis (diffusers closer together).

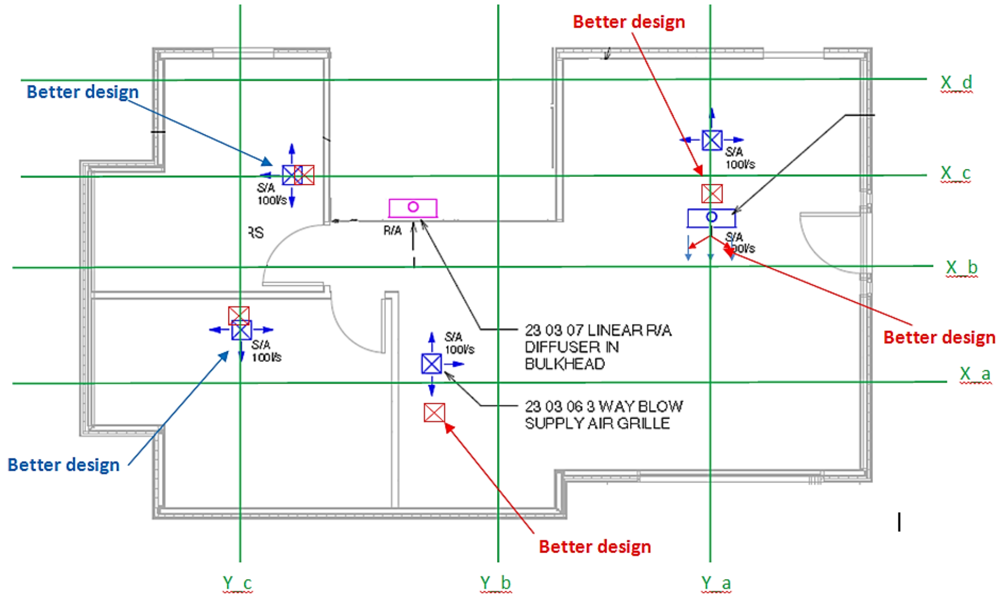


Figure 10-32: Example of CFD analysis outcome for improving diffuser locations.

In the transient calculations the walls were set as insulated walls, all inlets were set as velocity inlets with the air temperature set at 12°C, all zones had an initial temperature of 30°C and the outlet was set as a pressure boundary condition.

In the steady state calculation the temperature of all walls was set to 30°C, all inlets were set as velocity inlets with the air temperature set to 12°C and the outlet was set as a pressure boundary condition.

Temperature contour plots for each cross section obtained from the simulations are shown in Figure 10-33 and Figure 10-34. It is seen that both the steady state and transient analysis have the same qualitative distribution and also highlights the influence of diffuser placement in the kitchen and living rooms. For instance the second design will provide cooling more affectively to occupied areas rather than cooling the upper portion of the living room. Similarly the location of the kitchen diffuser in Design 2 (Figure 10-34) more effectively cools the room rather than simply cooling the wall as shown in Design 1 (Figure 10-33).

The results from this series of simulations were used in conjunction with the physical constraints of the built home to optimise the position of the diffusers within the home for the most effective air distribution system.

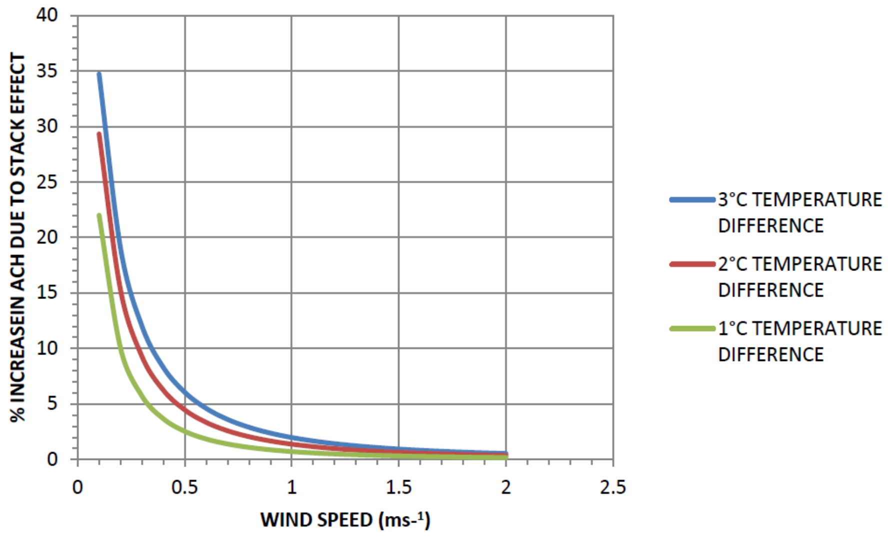


Figure 10-31: Percentage increase in air change rate in the Living Room due to the 'stack effect' as a function of wind speed.

The Team UOW ventilation flow network analysis tool and CFD simulations described above have been used to provide in-depth understanding and to optimise the location and size of openings in rooms for ventilation purposes. It has also been used to ensure that the external features, such as awnings, green walls, etc, quantitatively enhance the cross-flow and buoyancy-driven flows through the house.

10.3.2 Air Distribution Analysis

An analysis of the air distribution from the HVAC supply air diffusers within the house was conducted in order to improve the temperature distribution (hot and cold spots) and thermal comfort in each room. The analysis was conducted by Team UOW using 3D CFD simulations of the internal air field of the Illawarra Flame using the CFD software FLUENT.

Considering the fact that heat and mass transfer is a dynamic and transient process, both transient and steady state simulations were conducted to ensure a reliable result. In both of these types of simulations a number of different diffuser locations and air discharge types were tested. After each simulation the temperature field and discharge type were compared across 7 different cross sections in order to obtain a good understanding of the influence of the diffuser locations in 3D space. A comparison of 2 of the tests is shown in Figure 10-32.

Table 10-17: Flow through Laundry Openings for various wind directions (V_w = 4m/s)

Laundry								
Wind Direction (°)	0	45	90	135	180	225	270	315
Flow Element	Flow Change (%)							
Laundry Internal	100.00	69.49	100.00	100.00	100.00	100.00	74.80	89.16
Laundry External	76.80	100.00	77.10	82.62	90.08	88.05	100.00	100.00
Bath Door	23.20	30.51	22.90	17.39	9.92	11.95	25.20	10.84

Figure 10-30 shows the air change rate in different rooms of the house based purely on thermally driven ventilation. An interesting point to note is that the retrofitted clerestory located in the living room does not significantly improve wind-driven natural ventilation when the house is fully open as shown in Table 10-14. However, as Figure 10-30 shows, it plays a significant role in improving natural ventilation during calm days through the stack effect. The ACH in the living area is significantly higher than other rooms in the house. Figure 10-31 further highlights this point showing the relationship between the stack effect, temperature difference and wind speed.

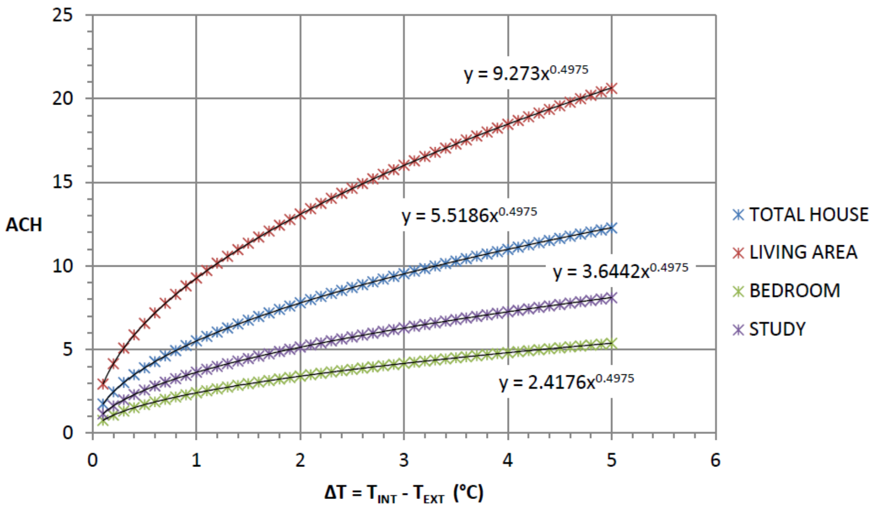


Figure 10-30: Influence from indoor and outdoor temperature difference on air change rate.

Table 10-14: Flow through Living Area openings for various wind directions (V_w = 4m/s).

Living Area								
Wind Direction (°)	0	45	90	135	180	225	270	315
Flow Element	Flow Change (%)							
Entry Door	18.63	15.20	34.14	2.19	18.02	13.64	21.67	13.85
Living Room Bifold Door	48.38	43.20	60.32	70.14	61.71	60.96	52.19	50.74
Living Window	10.24	10.27	6.61	16.12	13.30	6.40	5.73	10.78
Dining Window	10.98	13.55	17.47	10.03	18.13	17.73	31.74	15.96
Bed 1 Door	11.76	11.08	15.87	1.53	6.86	14.90	12.91	8.66
Bed 2 Internal Door	6.19	12.07	17.36	15.67	15.90	9.64	7.64	20.18
Laundry Internal	11.42	9.83	15.17	13.68	13.14	16.45	8.38	19.67
Kitchen Door	26.65	29.11	10.97	21.38	16.09	14.07	14.24	16.18
Kitchen Window	43.96	43.94	13.44	32.63	24.11	28.42	35.38	32.92
Clerestory 1	3.27	2.79	2.23	5.49	4.17	7.90	1.43	5.98
Clerestory 2	4.42	4.89	2.85	5.57	4.28	5.56	3.93	3.73
Clerestory 3	4.09	4.08	3.57	5.57	4.28	4.33	4.76	1.34

Table 10-15: Flow through Bedroom openings for various wind directions (V_w = 4m/s).

Bedroom								
Wind Direction (°)	0	45	90	135	180	225	270	315
Flow Element	Flow Change (%)							
Bed 1 Door	100.00	100.00	100.00	18.07	42.73	100.00	30.54	57.18
Bed 1 Window 1	63.06	64.15	67.56	100.00	100.00	79.38	100.00	100.00
Bed 1 Window 2	36.94	35.85	32.44	81.93	57.27	20.62	69.46	42.82

Table 10-16: Flow through Bedroom 2 openings for various wind directions (V_w = 4m/s).

Study								
Wind Direction (°)	0	45	90	135	180	225	270	315
Flow Element	Flow Change (%)							
Study Internal	25.78	100.00	100.00	100.00	100.00	48.38	13.26	98.39
Study External	100.00	33.38	42.05	45.53	47.83	100.00	86.74	99.18
Study Window 1	37.84	32.93	28.68	27.73	27.05	26.88	50.16	0.82
Study Window 2	36.38	33.69	29.27	26.75	25.12	24.74	49.84	1.61

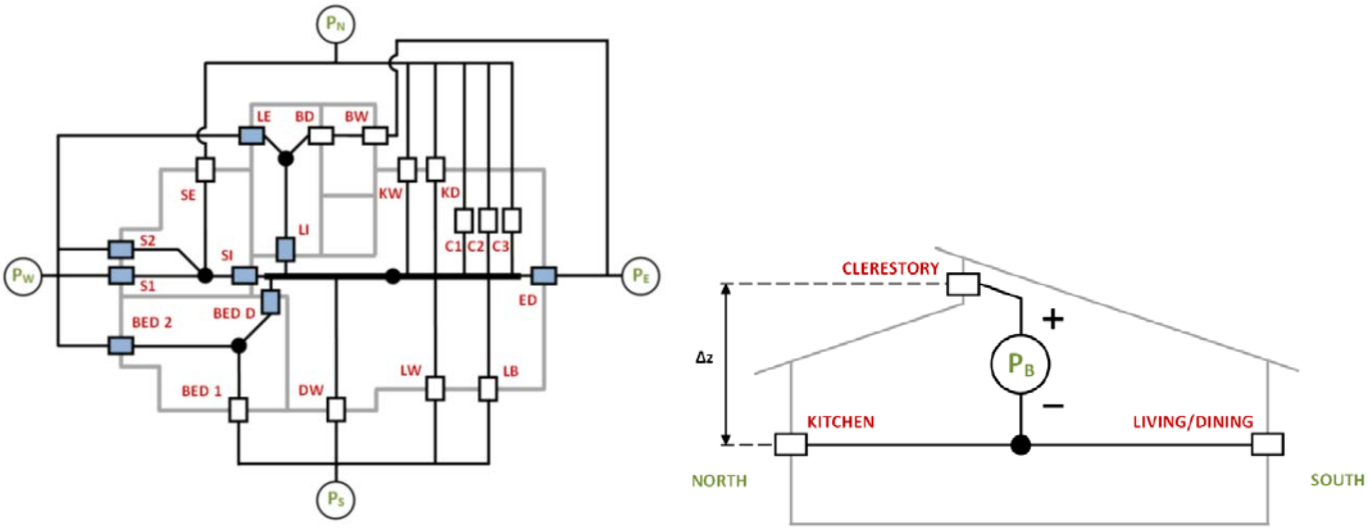


Figure 10-28: Schematic of the Team UOW natural ventilation flow analysis network for the Illawarra Flame.

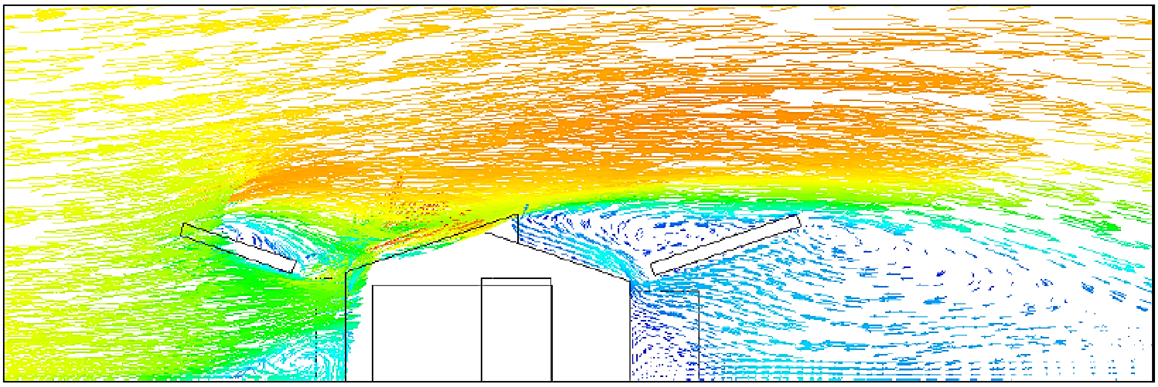


Figure 10-29: One of many examples CFD analyses carried out to determine pressure coefficients acting of surfaces of the building and window/door openings as a function of wind direction. Here the wind is blowing from the south. The influence of a range of different awning geometries on natural ventilation was also carried out.

Table 10-14 to Table 10-17 summarise the percentage contribution of each individual flow element to the air change rate of the identified room under different wind directions. These values are colour coded so that figures in blue represent the percentage of flow into an area, whilst values in orange indicate the percentage of flow out.

10.3 Ventilation and Air Distribution Analysis

This section outlines the techniques and analyses that Team UOW has completed to quantitatively determine and improve natural and mechanical ventilation processes for improved thermal comfort, energy efficiency indoor air quality of the Illawarra Flame.

10.3.1 Natural Ventilation

Natural ventilation is one of the most efficient passive cooling and heating methods and is also the most important method in maintaining indoor air quality. However, without proper design and control it is often hard to maximise its benefit without the side effects of over-heating, over-cooling or uncomfortable drafts. Team UOW has completed an analysis of wind driven and buoyancy driven ventilation using an analytical model and FLUENT CFD software.

Compared to single zone houses, which were quite common in previous Solar Decathlon competitions, the natural ventilation situation in the Illawarra Flame is more complicated due to multiple zones within the house. In addition, natural ventilation was not properly considered in the design of the original pre-retrofitted house making the improvement of natural ventilation in the Illawarra Flame both critical but somewhat difficult.

The natural ventilation study conducted by Team UOW was based on a purpose-built flow resistance network model of the Illawarra Flame as shown in Figure 10-28. Here all the openings in the building envelope (windows, doors, etc) have been modelled as sharp edged orifices with appropriate loss coefficients. The flow network for the retrofitted house is presented in the left hand diagram. Flow resistances through openings are shown as red or blue rectangles and pressures on the exterior of the building are given in circles. DW for example represents the flow resistance through the Dining Room window. The right hand schematic of Figure 10-28 shows how the buoyancy pressure difference drives flow through the clerestory windows above the lounge. Pressure coefficients on the exterior of the building were determined through numerous CFD analyses of the external flow over the Illawarra flame with wind impinging on the building from 8 azimuthal directions. An example of one such CFD analysis is shown in Figure 10-29. A solution to the flow network for a given wind direction and set of window sizes/openings was then found using the Hardy-Cross Method for either isothermal conditions or buoyancy-driven flow arising from a difference in outside and inside air temperature.

The 2-D temperature distribution for this situation is shown in Figure 10-26. It is clear that that internal surface temperature of the wall and floor increases by only ~2°C in the very corner of the wall-floor as compared to the one-dimensional heat flow that is occurring only 100mm or so from the corner. This indicates that the presence of the rigid foam insulation outside the steel frames has successfully reduced the effect of that potential cold bridge significantly. A heat flux calculation was also conducted using THERM and the results can be seen in Figure 10-27. The left hand figure shows heat flux using vectors and the right hand figure indicates heat flux magnitude by colour. The steel section do facilitate higher local heat flux rates but overall have little effect on heat flow into the room because of the exterior rigid foam insulation.

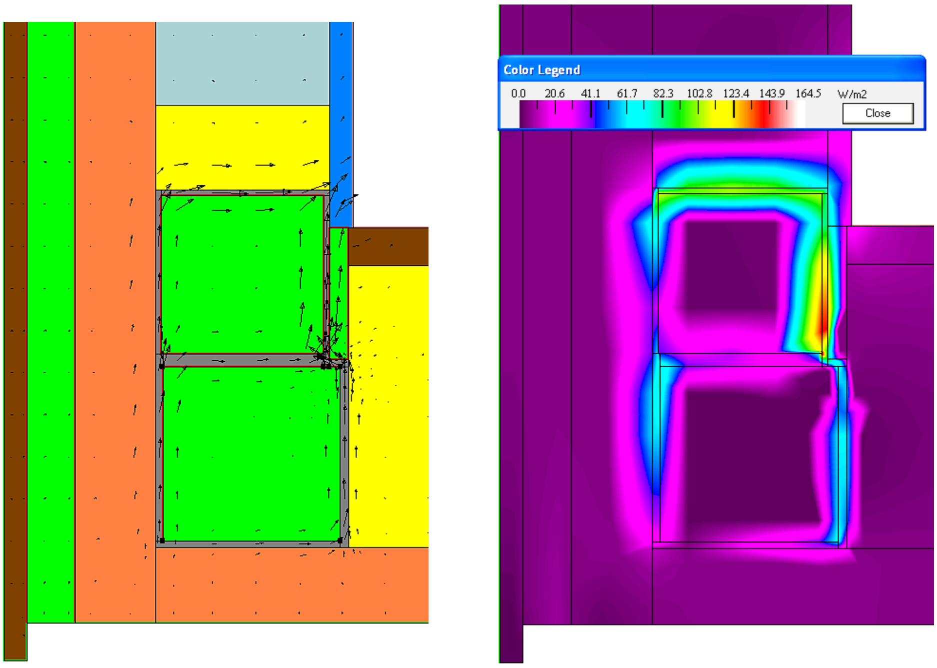


Figure 10-27: Heat flux simulation results for the wall-floor joint section. The left hand diagram shows heat flux magnitudes and directions using vectors and the right diagram shows the absolute heat flux magnitude by colour.

The key conclusion that can be made from the results displayed in Figure 10-27 is that although there is some intensification of the heat flux through the inside surface of the wall in the corner between wall and floor – however, its magnitude and extent is very limited.

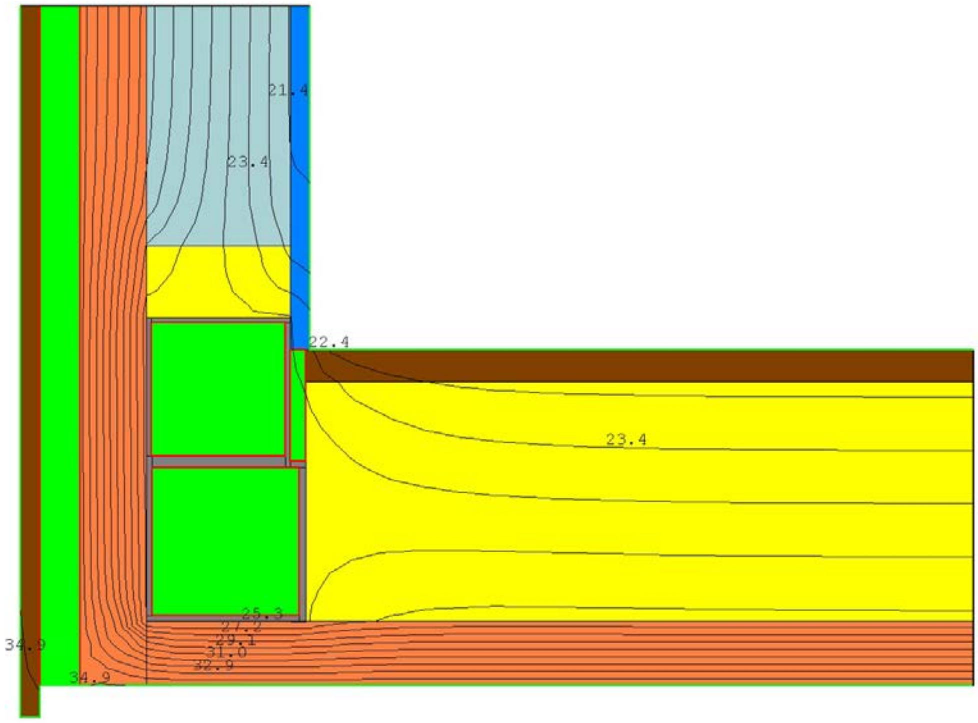


Figure 10-26: Two-dimensional conduction thermal model of a typical wall-floor joint of the Illawarra Flame using the software THERM (developed by Lawrence Berkeley National Laboratories). Colours correspond to those in Table 10-13 and contours are isotherms labelled in degrees Centigrade.

Table 10-13 Thermal conductivity assumed for materials and corresponding colour for the 2-D thermal bridging conduction model.

Material	Thermal Conductivity(W/mK)	Colour
Timber cladding and floor boards	0.14	
Timber stud frame and floor joist	0.16	
Rigid foam insulation	0.022	
Glasswool insulation	0.038	
Steel frame	43	
Plasterboard	0.48	
Air (heat transfer coefficients $W/m^2 {}^oC$)	10.0 inside 20.0 outside	

number of steel frames. This design change has resulted in potentially serious thermal bridging problems as the thermal conductivity of steel is much higher than wood. Team UOW methodically checked all potential thermal bridge points throughout the envelope and structure of the building and ensured that a continuous layer of insulation was everywhere in place to prevent serious thermal bridging.

Nevertheless, it was thought important to quantitatively determine the effect that potential thermal bridge points might have on the performance of the Illawarra Flame. An example analysis of a key junction of two steel frames (floor to wall) as shown in Figure 10-25 was completed using the THERM software.

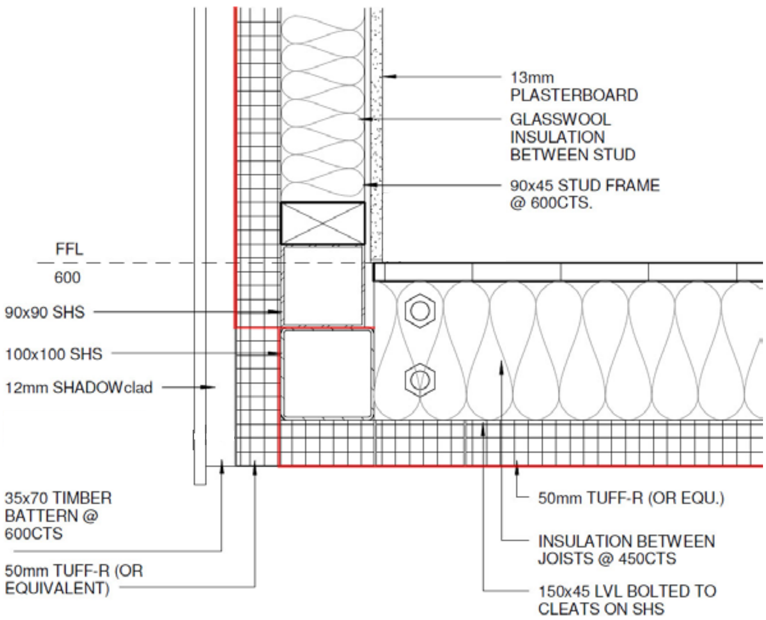


Figure 10-25: Construction detail of a wall-floor joint section illustrating continuous layer of rigid insulation (Thermax) over potential thermal bridge through 90 x 90 mm SHS steel frame. (Red line shows detail of location of the air-tight layer on the wall and floor modular sections and where this membrane is joined at the split point during assembly).

Figure 10-26 shows the modelled wall-floor joint cross section in THERM. Table 10-13 shows the thermal conductivities assumed for the various materials found in the drawing and their corresponding colour in the THERM simulation. So as to mimic hot summer conditions the indoor and outdoor temperatures were set at 21°C and 35°C with internal and external convection heat transfer coefficients 10 and 20 W/m^2°C, respectively.

The total expected heating and cooling energy consumption for the competition period was calculated by multiplying the average daily energy consumption of the house under each simulation by the number of days that each schedule would be employed over the competition. Subsequently the total heating and cooling electrical energy required during the 9-day competition period was calculated to be 42.3kWh (or 4.70kWh/day). This figure is used in section 10.6.2 to calculate the total energy consumption of the house.

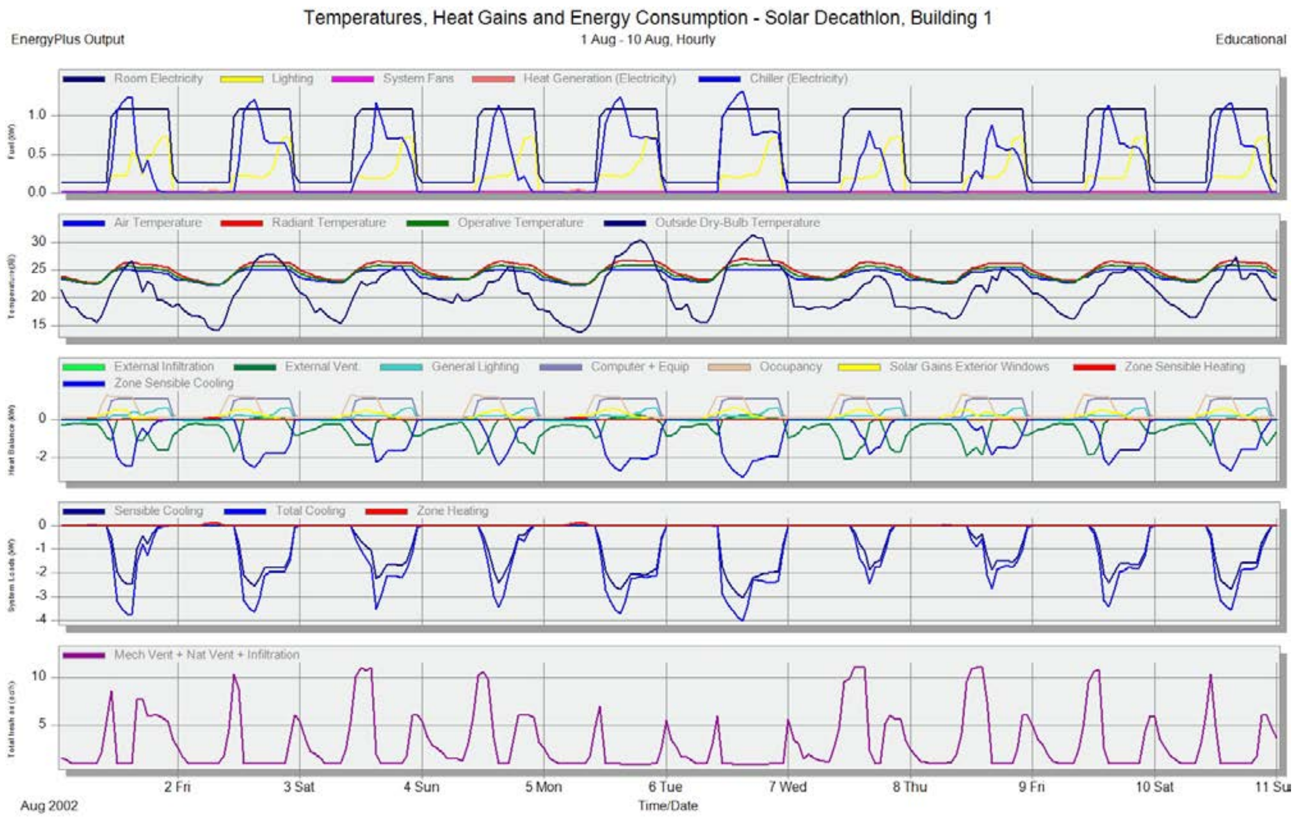


Figure 10-24: Temperatures, Heat Gain and Energy Consumption assuming the house is mechanically conditioned from 4:30pm to 7:00am using Datong weather data from the 1st - 10th August.

10.2.8 Thermal Bridging Analysis

Due to the limitations of energy simulation software such as DesignBuilder, which only deals with one dimensional heat flow through building elements, 'thermal bridging' through walls, floors and roofs, cannot be modelled. However, the presence of significant thermal bridging in a potentially Net-Zero Energy Building may significantly reduce the building envelope thermal performance and has been analysed here to determine its potential effect on the performance of the Illawarra Flame.

Due to the need to transport and reconstruct the Illawarra Flame a number of times, the wooden frames found throughout the original design of the pre-retrofitted house have been modularised and surrounded by a

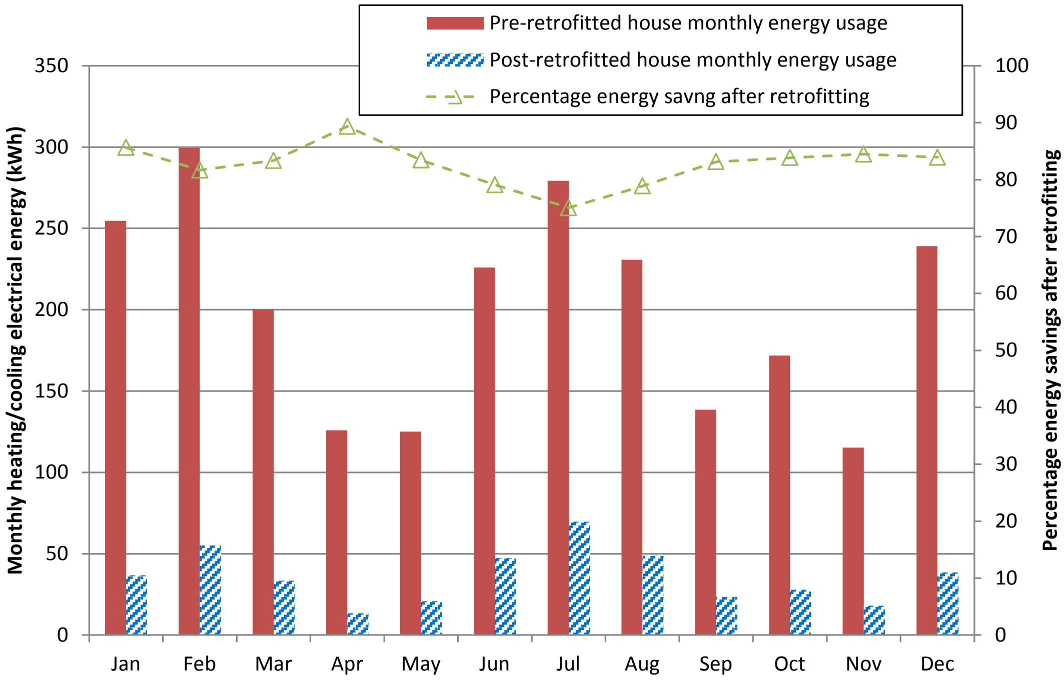


Figure 10-23: Comparison of monthly heating and cooling electrical energy consumption for pre- and post-retrofitted house.

10.2.7.3 Predicted House Performance under Competition Conditions

Early August weather conditions in Datong are similar to those of Sydney during the corresponding summer period but less humid. Simulations were conducted for the competition period to account for the two different running schedules reflected in the competition rules. The first simulation was run with the house conditioned from 4:30pm to 7:00am and open to the public for the remaining hours. The results from this simulation are displayed in Figure 10-24 where it can be seen that leaving the house unconditioned during public visiting periods during daytime hours results in high internal gains and high indoor temperatures. This makes the cooling load required to pull the house down to temperature at the beginning of the thermal comfort contest period very high. The graph also indicates that natural ventilation may provide effective cooling of the house if the outside air temperature/enthalpy is sufficiently low. The average heating/cooling energy consumption over the first 10 days of August was calculated to be 3.64kWh/day for this schedule.

A second simulation was conducted assuming that the house would be conditioned for 24 hours per day as in the second schedule provided in the competition rules. It was found that the average heating and cooling energy consumption for the first ten days of August for this schedule was 5.40kWh/day.

Overall the percentage of hours in a year that the indoor operative temperature of the house was between 18°C and 28°C was dramatically reduced, by approximately half, following the retrofits to the fabric of the building as shown in Table 10-12.

Table 10-12 Number of hours annually that simulated internal operative temperatures fall between 18°C and 28°C before and after retrofitting of the existing building for Sydney weather conditions .

Room	Pre-retrofit	Post-retrofit
Living Room	47.8	20.7
Bedroom 1	43.3	23.7
Bedroom 2	45.0	32.4

10.2.7.2 Pre- and Post-Retrofit Energy Consumption Analysis

The previous section highlighted how the retrofits to the building envelope and passive design improved the performance of the house in a free-running mode. However, the prototype has been designed to operate with mechanical ventilation and advanced active heating and cooling systems to maintain tight thermal comfort control. This section focuses on the dramatic reduction in electrical energy consumption achieved through the retrofitting the house.

The following comparison assumes that both the pre- and post-retrofitted house has the same type of HVAC installed with a COP of 3.0 and with a capacity to meet any required heating and cooling load. The schedules and other parameters are the same as the schedule defined in Table 10-2.

The graph shown in Figure 10-23 clearly demonstrates that the retrofitting results in a saving of 80% of the heating and cooling energy. The percentage energy saving if relatively consistent over the whole year.

Overall our DesignBuilder simulations show that the pre-retrofitted house requires 2406 kWh of electricity per year for heating and cooling while the post-retrofitted house requires only 432 kWh per year, for heating and cooling which is equal to an 82% reduction in energy consumption.

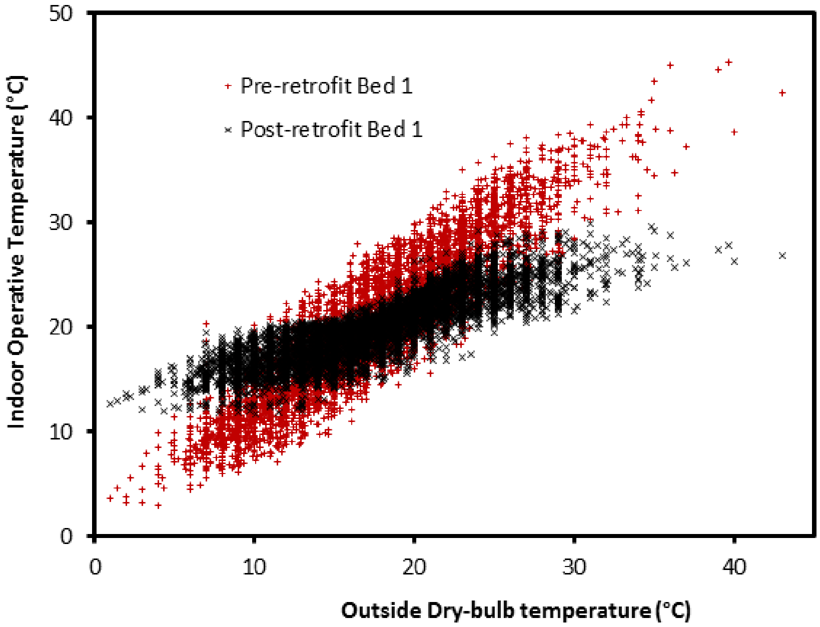


Figure 10-21: Relationship the between indoor operative temperature and the outside dry-bulb temperature for the main bedroom of the pre-retrofitted and post-retrofitted house using hourly Sydney data from the DesignBuilder simulation.

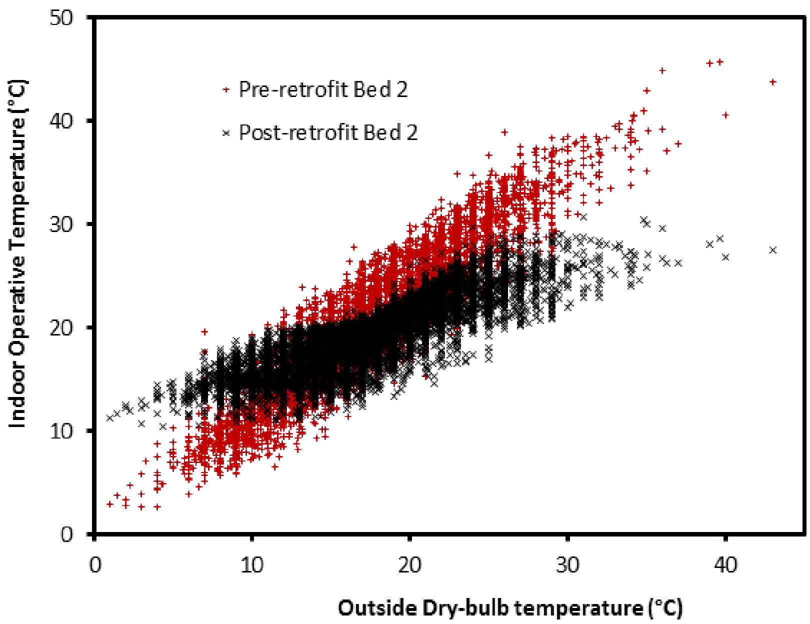


Figure 10-22: Relationship the between indoor operative temperature and the outside dry-bulb temperature for the Bedroom 2 of the pre-retrofitted and post-retrofitted house using hourly Sydney data from the DesignBuilder simulation.

retrofitted prototype operates significantly more hours per year in the range internal temperatures from 20 to 25°C. Th.

Secondly the simulated indoor operative temperature was plotted against the hourly outdoor dry-bulb temperature for each of the three areas as shown in Figure 10-20 to Figure 10-22. These graphs once again show that the extreme hot and cold indoor temperatures are eliminated and the reduction in the gradient of a linear best fit to the data demonstrates how the thermal performance of the building fabric has been greatly improved. Future inclusion of the thermal mass retrofitted to the Illawarra Flame (i.e. the recycled terracotta tile wall implemented in the dining room) in our simulations would demonstrate that further improvements in thermal comfort conditions are achievable in practice.

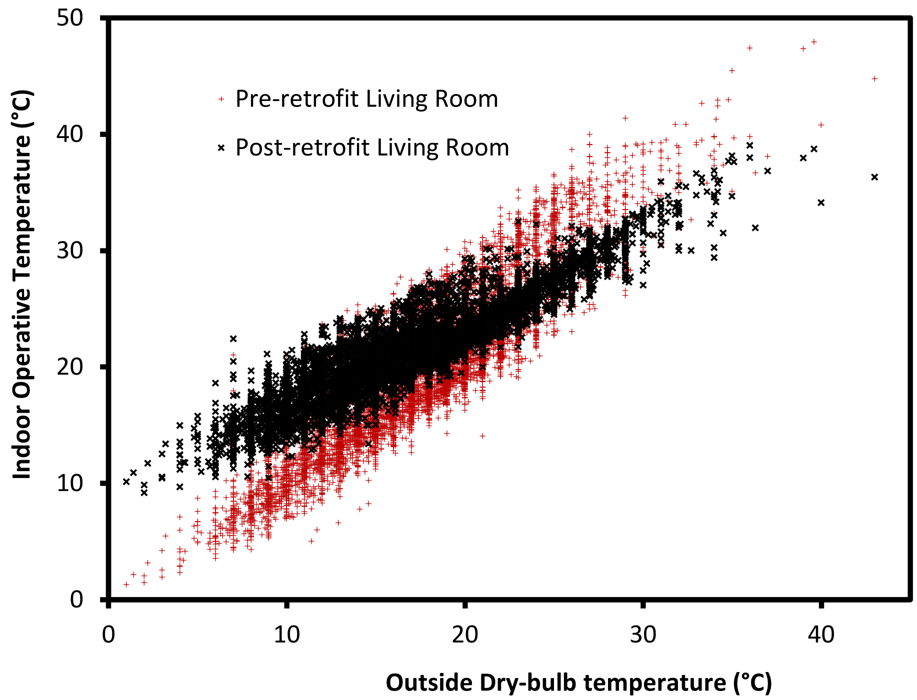


Figure 10-20: Relationship the between indoor operative temperature and the outside dry-bulb temperature for the living room of the pre-retrofitted and post-retrofitted house using hourly Sydney data from the DesignBuilder simulation.

Firstly the annual internal temperature frequency distributions were graphed for three zones in the house (living room and the two bedrooms) to demonstrate the improvement between the pre- and post-retrofitted house's thermal comfort conditions as shown in Figure 10-18 to Figure 10-19.

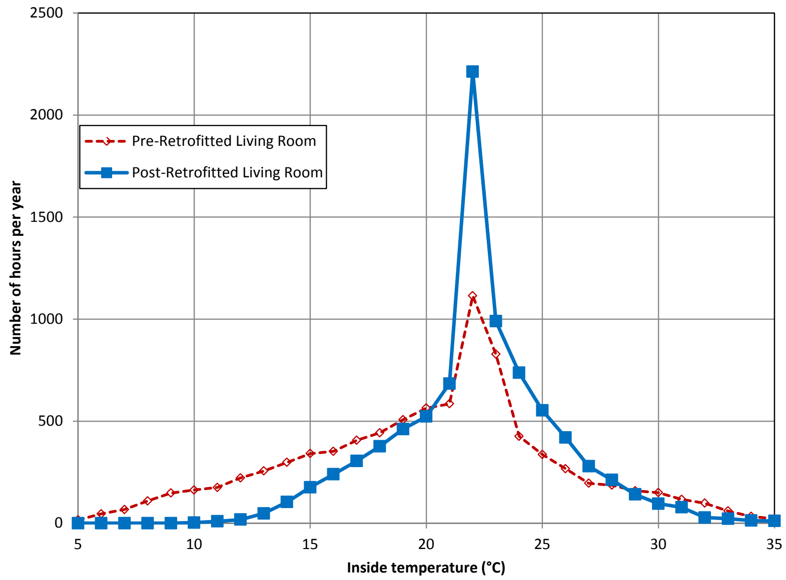


Figure 10-18: Annual temperature frequency distribution comparison between pre- and post-retrofitted house Living Rooms (Sydney weather conditions).

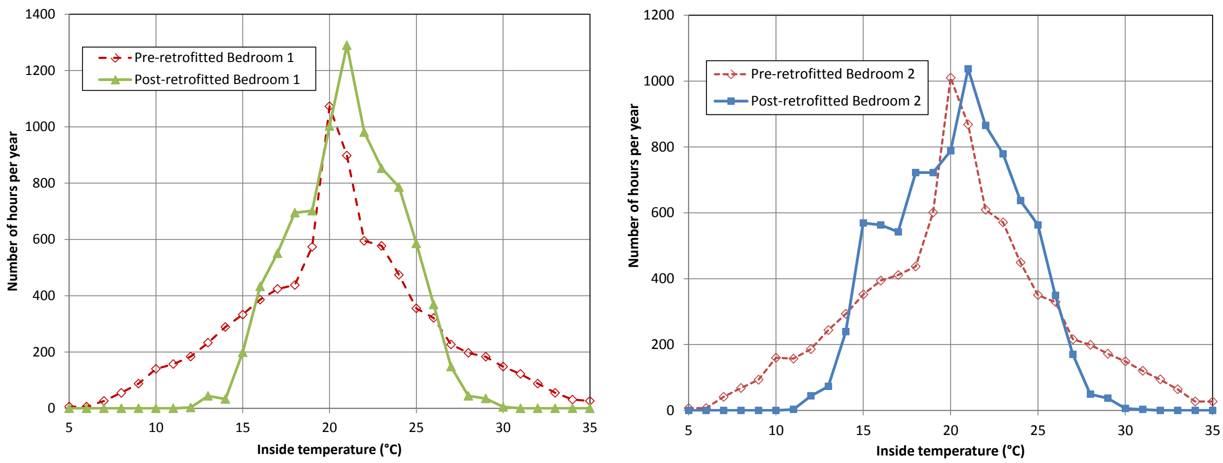


Figure 10-19: Annual temperature frequency distribution comparison between pre- and post-retrofitted house Bedrooms 1 and 2 (Sydney weather conditions).

The improvement in thermal comfort conditions for all three rooms can be seen clearly in these graphs as the frequency of temperatures within the thermal comfort band increases significantly and the free-running post-

Cooling design capacity was also determined for competition conditions, which represent an entirely different challenge for the system. During the completion quite different occupancy and use will occur than for the house located in Sydney. At the competition the house will be open to the public with high sensible and latent internal heat gains during which times the house is likely to be purely naturally ventilated. However, during the Thermal Comfort Competition the building will be mechanically heated and cooled as required.

The results from the competition design capacity simulation indicate that the cooling capacity should be as high as 11.1kW. However, one reason for this high cooling capacity is that at the start of mechanical cooling for the Thermal Comfort Competition due to the configuration of the software the DesignBuilder simulation by necessity brings the room temperature to the required room set point within half an hour after the unconditioned public visiting hours are complete. However, during the actual competition it is likely that a period of one hour is scheduled for the house cool-down period. Therefore the cooling design capacity has been reduced accordingly. After consideration of a range of factors, including the above, the final required heating and cooling design capacity of the prototype HVAC system was determined to be:

- Cooling design capacity = 7.1kW;
- Heating design capacity = 2.0kW.

10.2.7 Comparison of Pre- and Post-Retrofitted House

A comparison study between the pre and post-retrofitted house was conducted in order to quantitatively understand the improvement in energy consumption from the original building. The study was divided into two parts, with the first part comparing thermal comfort conditions in the pre- and post-retrofitted houses under natural ventilation, which allowed us to test the proposed improvements to the building envelope. The second part of this study focused on the energy reduction achieved in the annual heating and cooling energy consumption for Sydney weather, and the total energy consumption of the retrofitted prototype during the 9-day competition period.

10.2.7.1 Natural Ventilation Thermal Comfort Simulation

DesignBuilder simulations were conducted to determine the improvement in thermal comfort conditions between the pre and post-retrofitted house. This simulation was conducted by operating the house under natural ventilation conditions with no mechanical ventilation (i.e. 'free-running' operation). Occupancy and other gains are as detailed in Table 10-1 to Table 10-3. Please note that no additional thermal mass was modelled as retrofitted to the building.

10.2.6 HVAC Design Load Analysis

Following extensive analysis of the weather data available for Datong and the Sydney/Illawarra region the following internal and external design conditions were adopted for the heating/cooling system, where the Prototype Design Conditions were those that determined the size of the plant installed.

Table 10-11: Prototype HVAC plant sizing design conditions.

Design Condition	Indoor Conditions	Ambient Design Conditions
Datong Cooling	23°C ± 2°C	35°C DB 21°C WB
Datong Heating	23°C ± 2°C	12°C DB
Wollongong Cooling	23°C ± 2°C	30°C DB 23°C WB
Wollongong Heating	23°C ± 2°C	8°C DB
Prototype Cooling	23°C ± 2°C	35°C DB 23°C WB
Prototype Heating	23°C ± 2°C	8°C DB

The other heating and cooling input parameters for the sizing were as follows.

- Humidity to be kept below 60%.
- Occupation density of 4 people total under normal conditions.
- Lighting Loads of 8 W/m^2.
- Power/plug loads of 20 W/m^2. (Appliances, IT, etc.)
- Outside air of 10 L/s/person in accordance with AS1668
- Infiltration – Allow for 0.2 air changes per hour.
- Allow for 24hr operation.
- Design margins: heating 25%, cooling 15%.

A system sizing simulation using DesignBuilder for normal occupancy of the prototype in the Sydney/Illawarra region was carried out and the required heating and cooling capacities of the plant under operational design conditions were determined to be as follows:

- Sydney cooling design capacity = 3.3kW;
- Sydney heating design capacity = 2.1kW.

Table 10-10: Comparison of embodied energy and U-value of various window frame materials.

Materials	U-Value	Embodied Energy(MJ/window)
Timber	2.8	230-490
Aluminium	10	5470
Thermally broken aluminium	3.8	5470
Fibre glass	2	unknown
PVC	unknown	2150-2470

Insulation and Airtightness

A lot of effort was placed in designing a thermally efficient and robust building envelope for the Illawarra Flame and much emphasis was placed on choosing environmentally sound products that provided the required insulation values for the home. In order to achieve R-Values greater than 5 the team has utilised a combination of glasswool bulk insulation and PIR foam to insulate the home. The bulk insulation is Knauf Earthwool and is used to insulate the cavity formed between the timber studs in the floors, walls and ceiling of the home. The PIR foam board is used to further insulate the home and provides and airtight barrier. Further information on the insulation and airtightness of the Illawarra Flame can be found in Division 07 – thermal and Moisture Protection.

Thermal Mass

A small amount of thermal mass has been retrofitted and demonstrated in the Illawarra Flame and can be found in the wall between the living room and the main bedroom. A significant amount of thermal mass was difficult to add to building as outlined in section 10.2.5.4. More information on the composition of the thermal mass can be found in Division 03 – Concrete.

Shading

Shading in the form of fixed slatted timber screens have been fitted to the east and west faces of the home as both an aesthetic and functional feature. These screens protect the house from the morning and afternoon sun and prevent unwanted solar heat gain.

Table 10-9: AccuRate NatHERS energy analysis of the pre-retrofitted house and with a range of different retrofit options applied to the house.

	Existing House	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Actual
Improve envelope insulation level	—	√	√	√	√	√	√	√
Reduce window U-value	—		√				√	√
Reduce door U-value	—			√			√	√
Change external wall colour (light shade)	—				√			
Increase living room eave projection	—					√	√	√
Introduce 100mm concrete thermal mass to floors	—						√	
Star Rating Result (stars)	**2.2**	**5.4**	**6.2**	**6.3**	**5.4**	**5.6**	**8.7**	**7.4**
Total energy consumption (MJ/m^2/year)	**134.3**	**45.6**	**37.2**	**36.6**	**45.1**	**43.1**	**15.0**	**26.3**

10.2.5.6 Conclusions from Thermal Modelling and Practical Application of Results

The results from the thermal modelling analysis have played a crucial role in the design and construction of the Illawarra Flame. Outlined below are the various features of the home that have been designed based on these results.

Windows

The Illawarra Flame has been fitted with high performance double glazed unit with a U–value of 1.09 and an SGHC of 0.29. Timber was the preferred option for our frames based on the embodied energy and the thermal conductivity of the material as outlined in Table 10-10. Accoya timber was chosen as the preferred timber as it is a highly sustainable product made from FSC certified soft woods which have been converted to a class one timber using an acetylation process. This process results in a product with improved thermal conductivity, improved stiffness and dimensional stability, lower equilibrium moisture content and a 50 year above ground warranty. This is a fantastic environmentally sound product that is far superior to many other types of timbers and does not have the negative environmental effects of using unsustainably harvested hardwoods. For more details on the windows used in the Illawarra Flame please see Division 08 – Openings.

10.2.5.5 Australian NatHERS Analysis & Star Rating

An analysis of the house was conducted using the AccuRate™ software, firstly to provide a comparison with the results from the more complex DesignBuilder simulation tool, and then to determine the energy efficiency 'star rating' of the retrofitted house. The analysis was conducted by varying a series of parameters as listed in Table 10-9 below.

From November 2011, the Building Code of Australia (BCA) has required all newly constructed houses to achieve 6 stars under the Nationwide House Energy Rating Scheme (NatHERs) which in Australia is considered to be a high level of thermal energy performance. A high star rating has been shown to increase the marketability of a home in Australia and as such it is important both from an energy consumption and marketability perspective that the Illawarra Flame has a high star rating.

The key benchmarks NatHERS rating scheme is shown below.

- 0 star means the house has almost no insulation or passive design features.
- 5 stars is acceptable but is not an outstanding performance.
- Most states in Australia now require new homes to meet a 6 star rating.
- 10 stars is the highest available rating which indicates the house would require almost no active heating or cooling throughout the year, which is clearly very difficult to achieve.

The results of the AccuRate analysis of the pre-retrofitted and retrofitted homes carried out by Team UOW are shown in Table 10-9. The results show the improvement in the star rating of the pre-retrofitted house as a range of improvements are made to individual elements of the house.

The original existing fibro house model was found to have a 2.2 stars rating using the AccuRate software. After the house shape and insulation upgrade, the star rating improved to 5.4 stars. The table also demonstrates the benefit from improving the thermal properties of windows and external doors. The fully retrofitted house without retrofitted thermal mass is rated to be 7.4 stars.

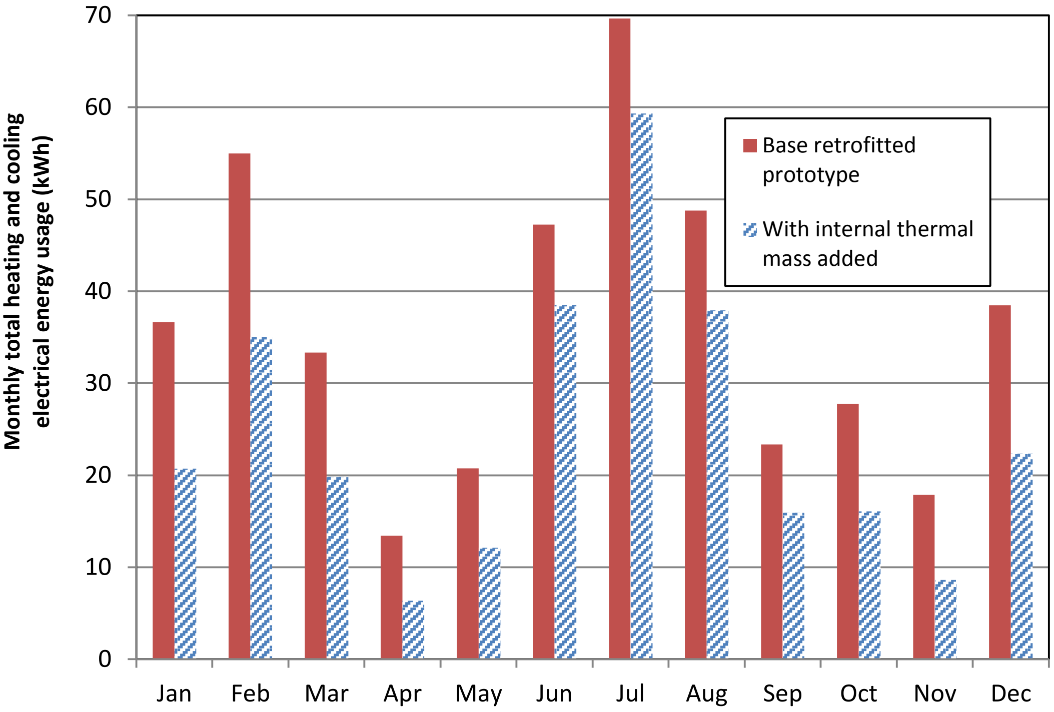


Figure 10-17 Conceptual comparison of the monthly total heating and cooling electrical energy consumption in Sydney for the retrofitted house with and without thermal mass (100mm of concrete added to all floors).

While this test shows that there can be a significant reduction in heating and cooling energy consumption if thermal mass is included into the house, it does not take into account the practical implications of retrofitting significant thermal mass to an existing timber structure. For the purposes of the Solar Decathlon China competition Team UOW have included a practical demonstration of how thermal mass can be implemented in the Illawarra Flame by developing a novel and attractive thermal mass wall in the dining room, which is constructed of recycled roof tiles and a low emissions cement mix.

A further design consideration was that the team was concerned that having too much thermal mass in the house could cause difficulties in controlling comfort conditions during the competition period. This is because conditions are expected to be warm to hot in the house during the periods when the house is open to the public throughout the day. During this time thermal mass will absorb heat and this could increase the transient cooling load particularly at the start of the thermal comfort competition, due to the release of heat from the thermal mass. It was therefore decided, for the purposes of the competition, to demonstrate the principle of retrofitting thermal mass rather than retrofitting the entire house with thermal mass.

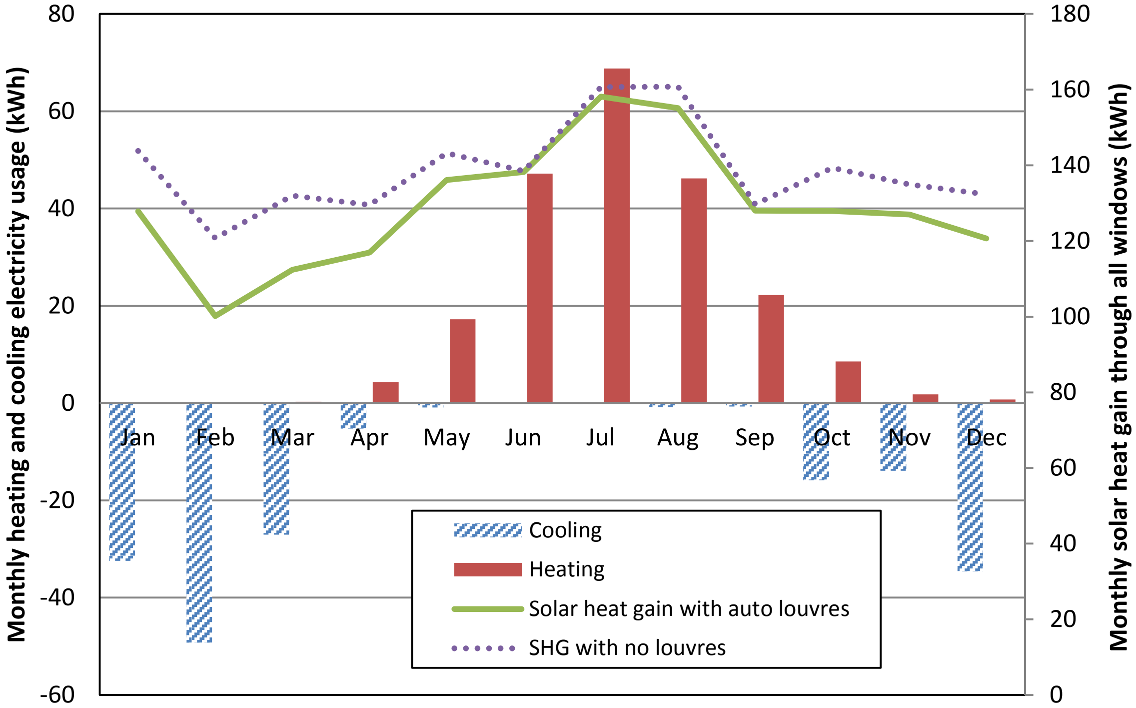


Figure 10-16: Monthly heating and cooling electrical energy consumption for Sydney with use of automatic external louvres, and monthly solar heat gain through all windows with and without external automatic louvres.

10.2.5.4 Retrofitted Internal Thermal Mass

The original pre-retrofitted house was assumed to be a lightweight timber-framed house with very little thermal mass. It is known that internal mass in the interior of a well-insulated building can improve both the energy efficiency and thermal comfort in the building. Thus, the addition of thermal mass to the building was simulated to determine its influence on energy consumption. To test this conceptually, a layer of concrete 100mm thick was added to all internal floors to act as thermal mass on the inside of the floor insulation. The addition of the layer of concrete had only a very small influence on the thermal resistance of the floor since the retrofitted insulation already resulted in an R-value of 6.0 $m^{2o}C/W$. DesignBuilder simulations showed that this option significantly reduced the annual energy consumption of the building. The annual heating consumption was predicted to be reduced by 19% to 175 kWh while annual cooling energy consumption was significantly reduced by 45% to 117 kWh. The monthly breakdown and comparison with the base retrofitted prototype is illustrated in Figure 10-17.

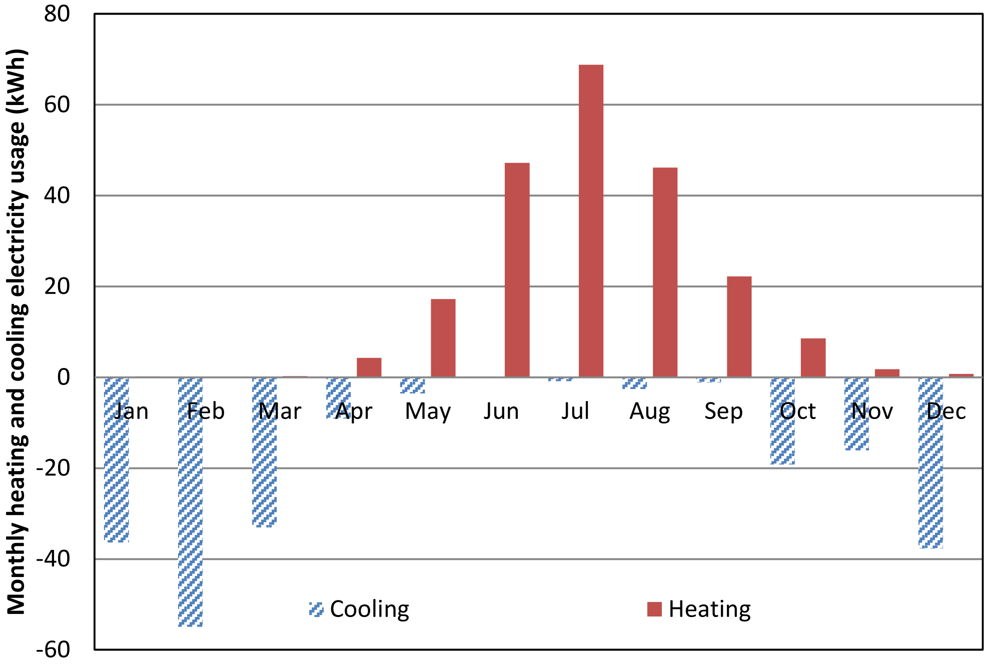


Figure 10-15: Monthly heating and cooling electrical energy consumption for Sydney of the base case retrofitted house.

Other factors such as window sizes were also tested as part of the preliminary energy analysis study, however these factors were largely determined by constraints such as architecture and the limitations of the original structure that the team was retrofitting.

10.2.5.3 External Louvres

The option of retrofitting external automatic louvres to all external windows and doors was tested. The louvres were simulated as being activated so as to prevent direct radiation reaching all windows during periods when cooling is required and were assumed not to obstruct incident radiation at all other times. The simulation results show that, as expected, 217kWh of electrical energy was still required by the heating system, however cooling energy consumption was reduced by 16% to 180kWh. While this reduction was reasonably significant the cost of installing external louvres on all windows was found to be excessive and the negative aesthetic impacts deemed unacceptable, thus, Team UOW have chosen not to install this retrofit option.

etc). It should be noted that the air-tightness appears to have a much greater influence on heating energy requirements for the current modelling and the Sydney climate. (Please note that these results align with previous research by Emmerich *et al.* (2005)[1] that showed that infiltration accounted for about 33% of office building heating energy, but only 3% of cooling requirements).

Conclusions from Preliminary Study

The results from the preliminary thermal analysis are summarised in Table 10-8 below and define the values that Team UOW sought to achieve in the construction of the Illawarra Flame house. These values are also used to form the default building envelope parameters of a new base model that has been used for additional thermal modelling outlined below.

Table 10-8: Summary of the key building envelope parameter targets developed from preliminary thermal modelling.

Key Building Envelope Parameter Targets for the Base Case Illawarra Flame Prototype	
House envelope R-value	6 m^2K/W
Windows U-value	1.5 W/m^2K
Windows SHGC	0.3
Infiltration rate	0.2 ACH

For Sydney weather conditions the annual heating and cooling energy consumption of the base retrofitted prototype was found to be 217kWh and 214kWh per annum, respectively. The monthly heating and cooling energy consumption is shown in Figure 10-15: Monthly heating and cooling electrical energy consumption for Sydney of the base case retrofitted house.

[1] *Impact of Infiltration on Heating and Cooling Loads in U.S. Office Buildings.* Building and Fire Research Laboratory, National Institute of Standards and Technology Gaithersburg, MD USA. TESS, Inc. Madison, WI USA. 9 p. December 2005

Figure 10-13: Annual heating and cooling electrical energy consumption as a function of the U-value of windows for Sydney weather conditions.

Based on these results and a cost and environmental analysis of various window types Team UOW therefore targeted timber-framed windows, with a U-Value of less than 1.5 and a SGHC of 0.3.

10.2.5.2 Airtightness and Infiltration

The air tightness and infiltration rate are important properties of the building envelope. In practice airtightness is measured using a blower door test or using tracer gas measurement apparatus as it is difficult to analytically determine air leakage paths in a real building. To quantitatively determine the influence of air tightness on annual energy consumption simulations with air change rates of between 0.1ACH and 1ACH were carried out and plotted in Figure 10-14. The graph shows that total heating and cooling energy consumption is linearly related to the infiltration rate.

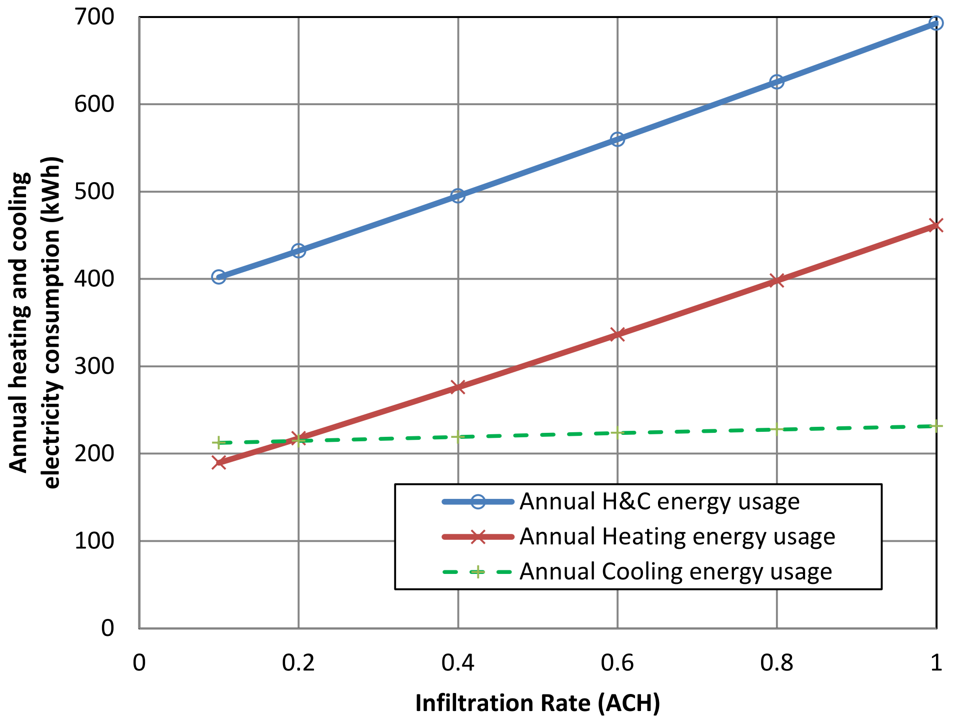


Figure 10-14: Predicted annual heating and cooling electrical energy consumption as a function of infiltration rate for Sydney weather conditions.

Team UOW has chosen to target an ACH of less than 0.2, which equates to approximately 4ACH at 50Pa (as would be measured empirically with a blower door), as this is thought to be achievable in practice using good retrofitting techniques (e.g. using draught strips, sealing gaps/holes, using special covers on exhaust fan vents, which is likely to increase artificial lighting loads due to a decrease in the transmission of visible light. The results from the SHGC study are shown in Figure 10-12 and they indicate that reductions in SHGC below ~0.3 provide only very minor reductions in annual heating and cooling energy consumption.

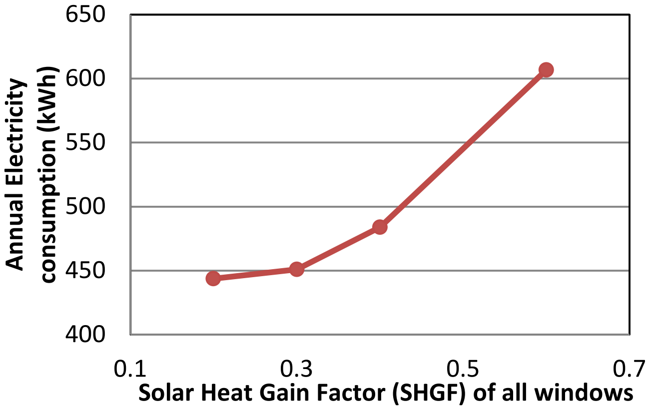
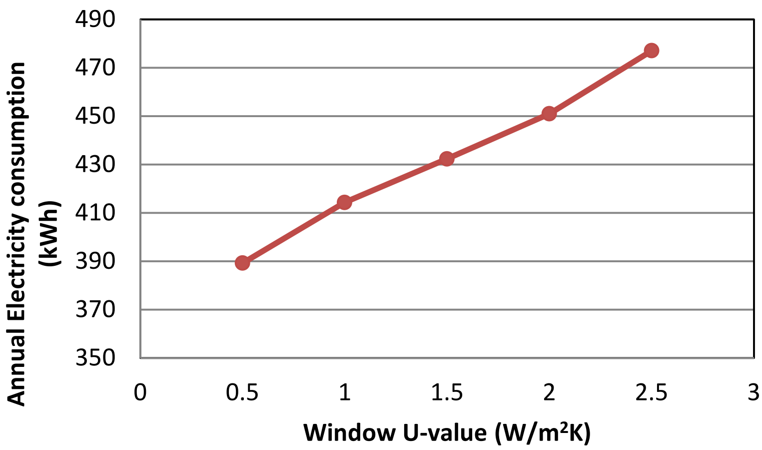


Figure 10-12: Annual total heating and cooling electrical energy consumption as a function of Solar Heat Gain Factor (SHGC) for Sydney weather conditions (SHGF assumed the same for all windows).

Heat transfer through external glazing represents a major portion of the heat gain to the house in summer but also a major cause of heat loss in winter. The choice of the performance level of the retrofitted glazing system in a house is a major determinant of the economic viability of a retrofit package of works. For example, in Australia, triple-glazed windows are prohibitively expensive and if double-glazing systems are able to be used the cost-effectiveness of the building retrofit will be improved. Figure 10-13 illustrates the relationship between the U-value of the windows and the simulated annual heating and cooling electrical energy consumption of the retrofitted house. This figure shows that between U = 0.5 W/m^{2} °C (highest value available) and U=2.5 W/m^{2} °C (standard double glazing), the relationship between the U-value and energy consumption is approximately linear.



Glazing System U-value	5.0 W/m^{2}K
Solar Heat Gain Coefficient (SHGF) for all windows	0.8
Infiltration Rate	2 ACH

Insulation Analysis

An analysis was conducted to determine the effect that various levels of insulation would have on the energy consumption of the home and to determine an optimum level of insulation for the retrofitted prototype. The study was based on changing the wall, roof, ceiling and floor insulation levels (R-values). The results plotted in Figure 10-11 and show that installing insulation greater than R6 (i.e. R = 6.0 m^{2o}C/W) has a small additional benefit in terms of reducing heating and cooling energy consumption of the home. As a result Team UOW decided to target an overall thermal resistance of approx. R6 for the walls, floors and ceiling of the Illawarra Flame.

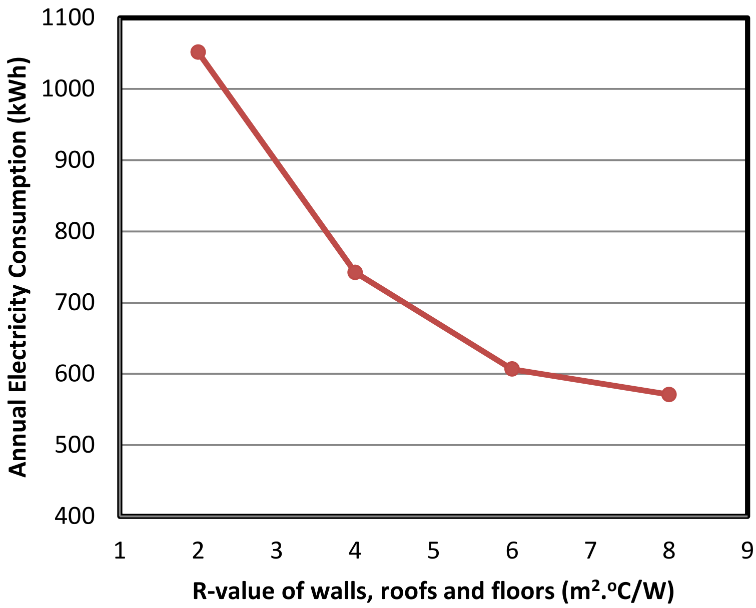


Figure 10-11: Annual heating and cooling electrical energy consumption as a function of R-value (all walls, roofs and floors taken to have the same R-value) for Sydney weather conditions.

Windows

The Solar Heat Gain Coefficient (SHGC) of a window determines both direct solar radiation and diffuse solar radiation gains through windows. A lower SHGC value can help reduce cooling loads in summer but can also result in higher heating loads in winter. A lower SHGC is often associated with a lower Shading Coefficient (SC) *assuming a standard vapour-compression HVAC system with a COP of 3.0. Thus, the results presented below will be an underestimate of the energy savings available from the full retrofits implemented in the Illawarra Flame. In sections 10.4.1, 10.4.2 and 10.4.3 results from the modelling of the PVT-PCM system using a custom-built simulation tool are presented as a separate system.*

10.2.5 Retrofit Options Analysis

A series of simulations were run to determine the influence that a variety of retrofitted energy saving options would have on the energy performance of the house. The results provided quantitative guidance on how to optimise design of the final retrofitted prototype. A preliminary analysis was initially completed to determine suitable characteristics for the building envelope by examining four primary building envelope parameters:

- Insulation;
- Solar heat gain coefficient (SHGC) for glazing;
- U-Value for glazing elements; and
- Airtightness and associated infiltration rates.

Once this preliminary analysis was completed a further study was conducted to determine the effect a series of additional parameters would have on the performance of the building. The additional parameters examined included:

- External Shading; and
- Retrofitted Thermal Mass.

A further analysis using Accurate software was completed to determine the 'star rating' of the house under the Australian Nationwide House Energy Rating Scheme (NatHERS) so as to provide a measure of the effectiveness of the energy efficiency retrofits that would be readily understood by the general community.

10.2.5.1 Preliminary Building Envelope Study

The model used in the preliminary building envelope study has default parameters as outlined in Table 10-7.

Table 10-7: Default thermo-physical characteristics of the pre-retrofitted house used for the Preliminary Building Envelope Study.

Parameter	Value
Building Envelope Insulation	R = 0.5 m^2K/W

Revit to DesignBuilder, and after discussion with industry experts, the 3D geometric/thermal model of the house was developed by members of Team UOW directly within DesignBuilder. Note: as is customary in energy simulation software programs, all the key building elements influencing energy flows within and to/from the building were modelled within DesignBuilder (e.g. windows, doors, shading elements, insulation, etc). However, the detailed geometry of many the building elements held in the Revit model were not replicated as they were not relevant, or could not be incorporated in the thermal model.

Figure 10-10 provides a 3D-view of the geometry used for thermal modelling of the base design of the prototype. A summary of the floor area for each zone can be found on drawing G-102 in the drawing package.

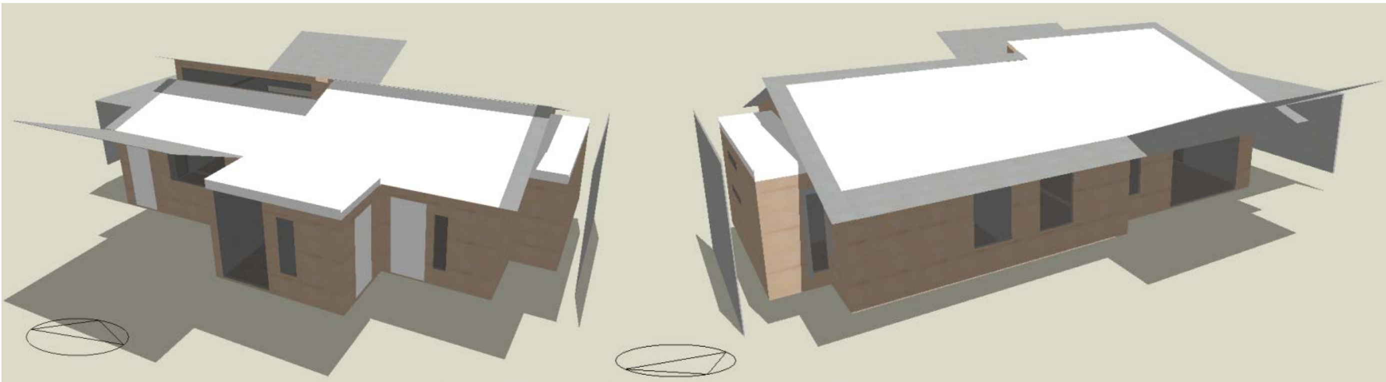


Figure 10-10: 3D model developed in DesignBuilder simulation software and used for thermal modelling of the performance of the retrofitted house prototype.

10.2.4.3 Assumptions and Default Values for Thermal Modelling

For all thermal modelling conducted using the DesignBuilder simulation software the following key assumptions and parameters were used:

- Whenever the system calls for heating and cooling it is assumed that mechanical ventilation is also activated;
- The outside air rate of air change is at a fixed value of 10ACH when natural ventilation occurs;
- The overall COP of HVAC system (including parasitic fan energy, etc) was taken to be 3.0; and
- The heating and cooling plant capacities were sufficiently large so as to meet all simulated heating and cooling loads.

PLEASE NOTE: that due to the limitations of DesignBuilder a model of the full innovative HVAC system of the Illawarra Flame (including the Photovoltaic Thermal system and the Phase Change Material (PCM) thermal store was not possible. The results presented in the following sections therefore have been generated

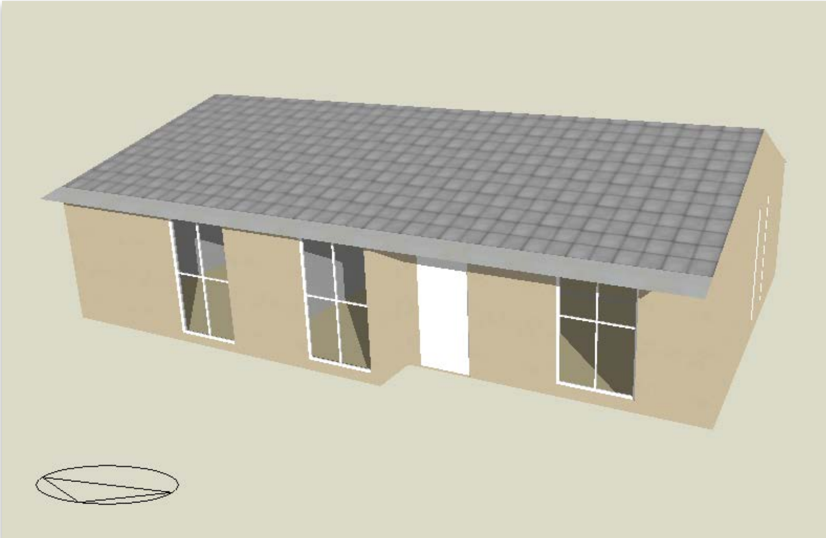


Figure 10-9: Geometry of the 3D DesignBuilder model of the original pre-retrofitted fibro house used for thermal analysis.

Table 10-6: Floor area and volume – original pre-retrofitted house.

Zones	Floor Area (m^2)
Living Room	17.2
Dining Room + Kitchen	11.8
Bedroom 1	8.6
Bedroom 2	11.8
Bedroom 3	9.2
Laundry	4.6
Bathroom	4.63
Corridor	4.14
Total	**71.9**
Conditioned Space Simulated	**49.4**

10.2.4.2 Model of the Retrofitted Prototype

During the early stages of the project the geometry of the house was imported directly into DesignBuilder through a gbXML file from the Revit model. However, due to problems in exporting geometry information from

10.2.4 Geometry for Thermal Analyses

This section summarises the geometry of the original pre-retrofitted building and the retrofitted prototype that has been used for the thermal modelling simulations.

10.2.4.1 Original Building Prior to Retrofitting

The original house was chosen from the Housing NSW municipal dwellings register and is very common throughout the Illawarra region (NSW, Australia). The original house was taken to be a 3-bedroom timber-framed fibro house with a floor plan as shown in Figure 10-8. For the purpose of thermal modelling, the existing house was divided into 8 thermal zones as shown in Figure 10-8 and a 3D view of the original pre-retrofitted house is shown in Figure 10-9. A summary of the floor area for each zone can be found in Table 10-6.

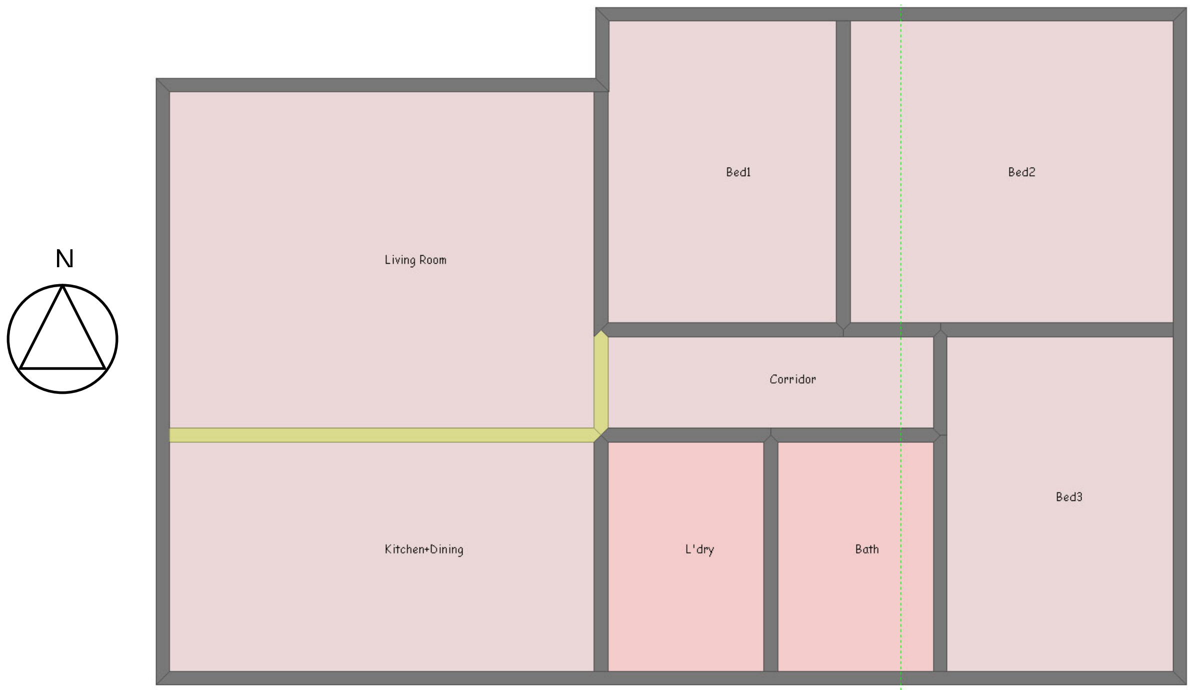


Figure 10-8: Schematic of floor plan of the original pre-retrofitted fibro house as modelled in DesignBuilder shown oriented as in Sydney. Each space is a simulated “zone”, dark lines and light (yellow) lines represent physical walls and virtual zone boundaries, respectively.

Table 10-4: Competition conditions – air conditioned zones schedule

Competition Condition	Weekdays Time (Weekdends Time)	Fraction
HVAC System		
Mechanical Ventilation system operating with 0.5L/s/m^2 outside air, Set Points: Heating = 22^{o}C; Cooling = 25^{o}C (option 2 is for 24 hour monitoring)	00:00am – 7:00am	1
	7:30am – 04:00pm	0(1 for option 2)
	04.30pm – 00:00am	1
Natural Ventilation		
The DesignBuilder "Scheduled" Natural Ventilation option was used with a ventilation cooling set point temperature = 22^{o}C; natural ventilation rate = 10ACH. (option 2 is for 24 hours monitoring)	00:00am – 7:00am	0.5
	7:30am – 04:00pm	0(0.5 for option 2)
	7:30am – 04:00pm	0.5
Occupancy		
0.25 person/m^2	00:00am-10:00am (00:00am-10:00am)	0.1
	10:00am-01:30pm (10:00am-05:00pm)	1
	01.30pm-00:00am (05:00pm-00:00am)	0.1
Office Equipment		
20W/m^2	10:00am-10.30pm	1
	10:30pm-10:00am	0.1 (0.2 for Living & Kitchen)
Lighting		
4W/m^2 (with daylighting control)	10:00am-10:00pm	1
	10.00pm-10.00am	0

Table 10-5: Competition conditions – laundry & bathroom schedule.

Design Condition	Time	Fraction
Natural Ventilation		
The DesignBuilder "Scheduled" Natural Ventilation option was used with a ventilation cooling set point temperature = 15^{o}C; natural ventilation rate = 6ACH.	24hrs	1

Table 10-2: Sydney design conditions – bedroom schedule.

Design Condition	Time	Fraction
HVAC System		
Mechanical Ventilation system operating with 0.5L/s/m^2 outside air and Heating Set Point = 20°C; Cooling Set Point = 25.5°C	00:00am – 09:00am	1
	09:00am – 04:00pm	0
	04:00pm – 00:00am	1
Natural Ventilation		
The DesignBuilder "Scheduled" Natural Ventilation option was used with a ventilation cooling set point temperature = 22°C; natural ventilation rate = 10ACH.	24hrs	1
Occupancy		
0.05 person/m^2	00:00am – 07:00am	1
	07:00am – 10:00pm	0
	10:00pm – 00:00am	1
Lighting		
2W/m^2 (with daylighting control)	00:00am – 08:00pm	0
	08:00pm – 11:00pm	1
	11:00pm – 00:00am	0

Table 10-3: Sydney design conditions – laundry and bathroom schedule.

Design Condition	Time	Fraction
Natural Ventilation		
The DesignBuilder "Scheduled" Natural Ventilation option was used with a ventilation cooling set point temperature = 15°C; natural ventilation rate = 6ACH.	24hrs	1

10.2.3.2 Competition Schedules and Internal Gains

The competition schedules have been defined using the Solar Decathlon China 2013 detailed event schedules found in the SD China Rules Manual V2. Detailed information can be found in Table 10-4 and Table 10-5.

10.2.3 Schedules, Internal Gains and Assumptions

Schedules, internal gains and assumptions for the Sydney design conditions and Competition (Datong) conditions are outlined below.

10.2.3.1 Sydney Design Conditions

The schedules and internal gains used for the Sydney design conditions were based on the Australian Nationwide House Energy Rating Scheme (NatHERS) with minor modifications. Detailed information can be found in Table 10-1 to Table 1-3. For more details about NatHERS, please refer to http://www.nathers.gov.au/about/settings.html#building.

Table 10-1: Sydney design conditions – kitchen, living and dining room schedules.

Design Condition	Time	Fraction of the design condition
HVAC System		
Mechanical Ventilation system operating with 0.5L/s/m^2 outside air, Set Points: Heating = 20°C; Cooling = 25.5°C	00:00am – 07:00am	0
	07:00am – 00:00am	1
Natural Ventilation		
The DesignBuilder "Scheduled" Natural Ventilation option was used with a ventilation cooling set point temperature = 22°C; natural ventilation rate = 10ACH.	24hrs	1
Occupancy		
0.05 person/m^2	00:00am – 07:00am	0
	07:00am – 09:00am	1
	09:00am – 05:00pm	0.5
	05:00pm – 10:00pm	0.75
	10:00pm – 00:00am	0
Equipment Gains		
13 W/m^2 (no internal gains for dining room)	00:00am – 07:00am	0.1
	07:00am – 08:00am	0.4
	08:00am – 06:00pm	0.1
	06:00pm – 07:00pm	1
	07:00pm – 10:00pm	0.25
	10:00pm – 00:00am	0.1
Lighting		
4W/m^2 (with daylighting control)	00:00am – 07:00am	0
	07:00am – 09:00am	0.6
	09:00am – 05:00pm	0
	05:00pm – 10:00pm	1
	10:00pm – 00:00am	0

simulation accuracy requirements by the standard verification software BESTEST. EnergyPlus Version 7.0 (released in November 2011) has been used for the analysis of the Illawarra Flame.

DesignBuilder

DesignBuilder is a user-friendly EnergyPlus interface. DesignBuilder has its own database of construction materials, properties and control schedules which can be easily accessed by selecting and dragging the data into the model. The features of DesignBuilder provide a thermal modelling interface that is relatively easy to use where the task of defining building geometry is similar to most CAD software tools. Once the geometrical and other data has be input to the tool, DesignBuilder automatically exports an input file to EnergyPlus and automatically runs the simulation. The output from EnergyPlus is then handled within the DesignBuilder software for post-processing evaluation.

AccuRate

AccuRate is an energy modelling tool which is used for assessing the sustainability of Australian residential homes. It was developed by the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) over many years of research and validation. It is accredited for use in the Nationwide House Energy Rating Scheme (NatHERS). The software assesses the energy efficiency of the house on a scale of zero to 10 stars. The more stars, the less likely the occupants require heating or cooling to stay comfortable and a 10 star building is one that requires no active/artificial heating or cooling systems.

THERM

THERM is a two-dimensional finite element conduction heat flow analysis package that was developed at the Lawrence Berkeley National Laboratory (LBNL) and is widely used in the Building Physics research community and in industry to determine temperature distributions, thermal resistance and heat flow in building elements such as window frames, floor, wall and ceiling insulations, particularly at corners, etc. This was the software chosen in the present project to analyse situations where "thermal-bridging" might be an issue in the structure of the building envelope and for analysis of window framing.

FLUENT

Team UOW has carried out extensive analysis of the air flow outside and inside the building using one of the leading Computational Fluid Mechanics (CFD) tools, FLUENT. FLUENT been used by the academic and industrial research community for several decades and by the building services industry for many years as a tool to determine the details of air flow and heat transfer in buildings.

air temperature is low, however, upon an increase in dry-bulb air temperature the relative humidity decreases, and generally absolute humidity is relatively constant for this set of data.

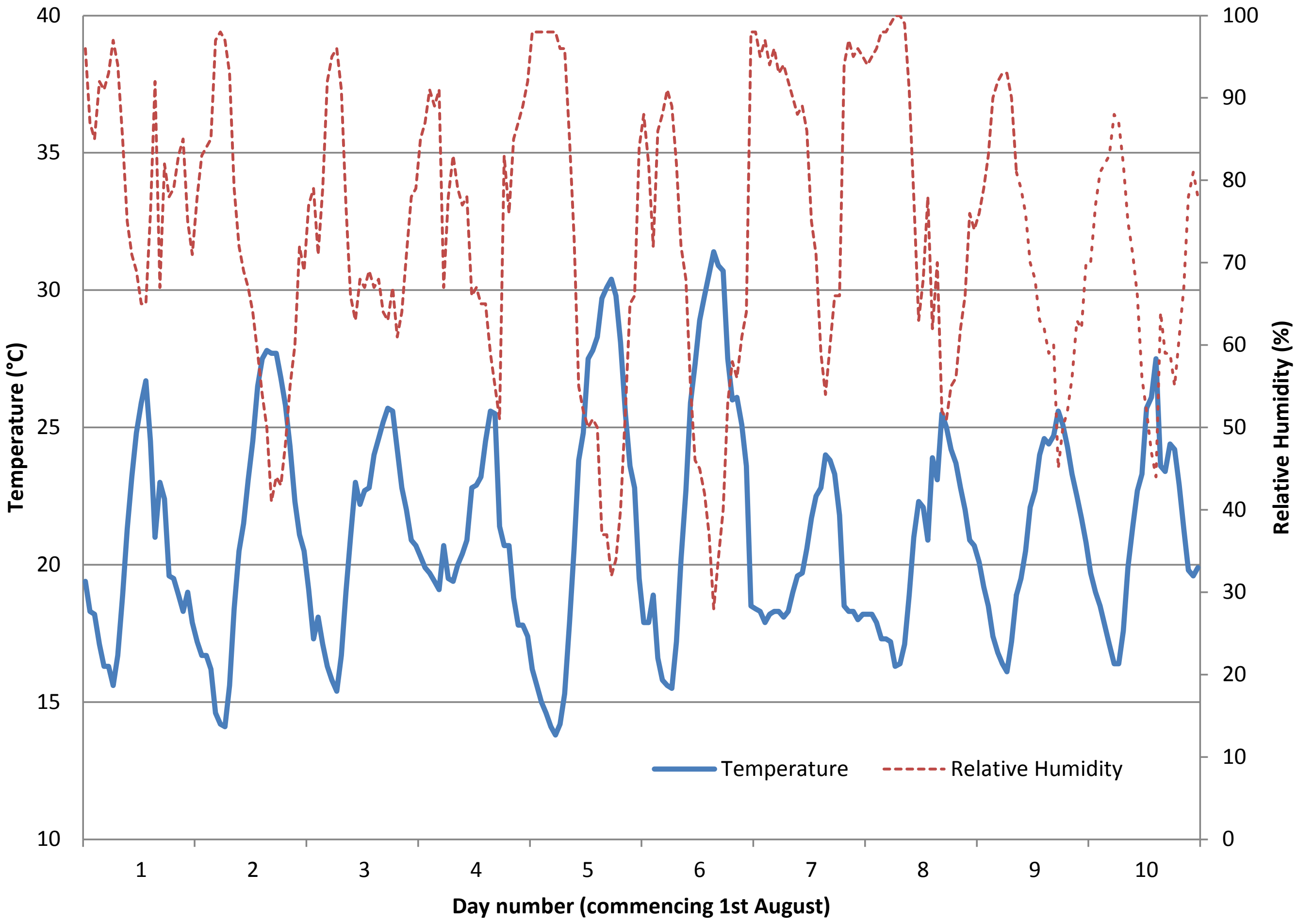


Figure 10-7: Hourly ambient temperature and relative humidity from CSWD weather data for Datong (1st to 10th August) representative of that expected for the competition period.

10.2.2 Building Energy Simulation Tools Used

A number of state-of-the-art simulation software tools have been used by students of Team UOW to complete the thermal modelling of the Illawarra Flame. A brief outline of these tools is provided below.

EnergyPlus

EnergyPlus was developed by the U.S Department of Energy and is a free whole-of-building energy simulation software designed for engineers, architects and researchers. EnergyPlus is now widely used in building design and research throughout the world, and it has weather data available for more than 2100 locations of, including many Australian cities and towns. EnergyPlus has been successfully tested and found to meet

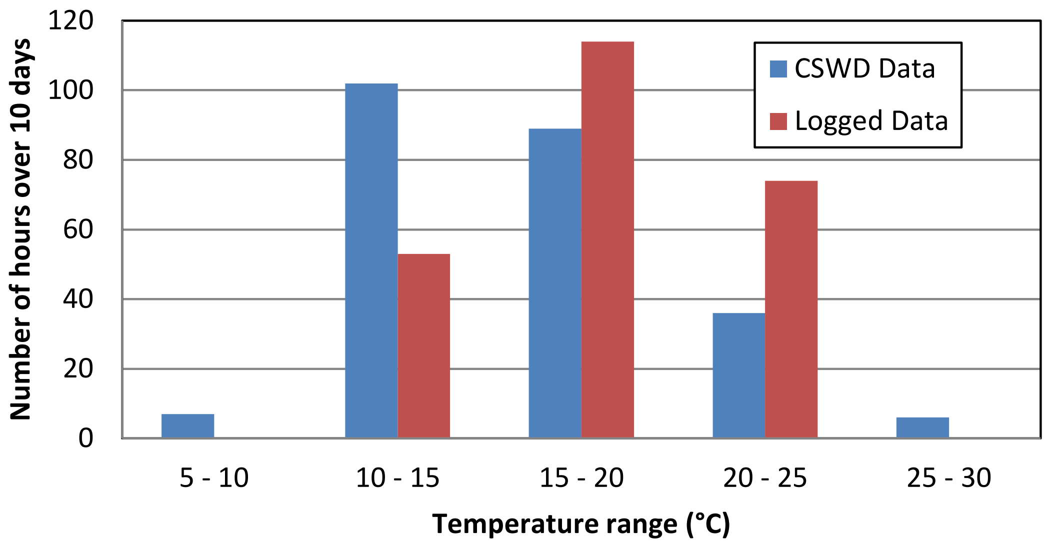


Figure 10-5: Temperature distribution comparison between CSWD weather data and 2012 logged data for Datong 1-10th August.

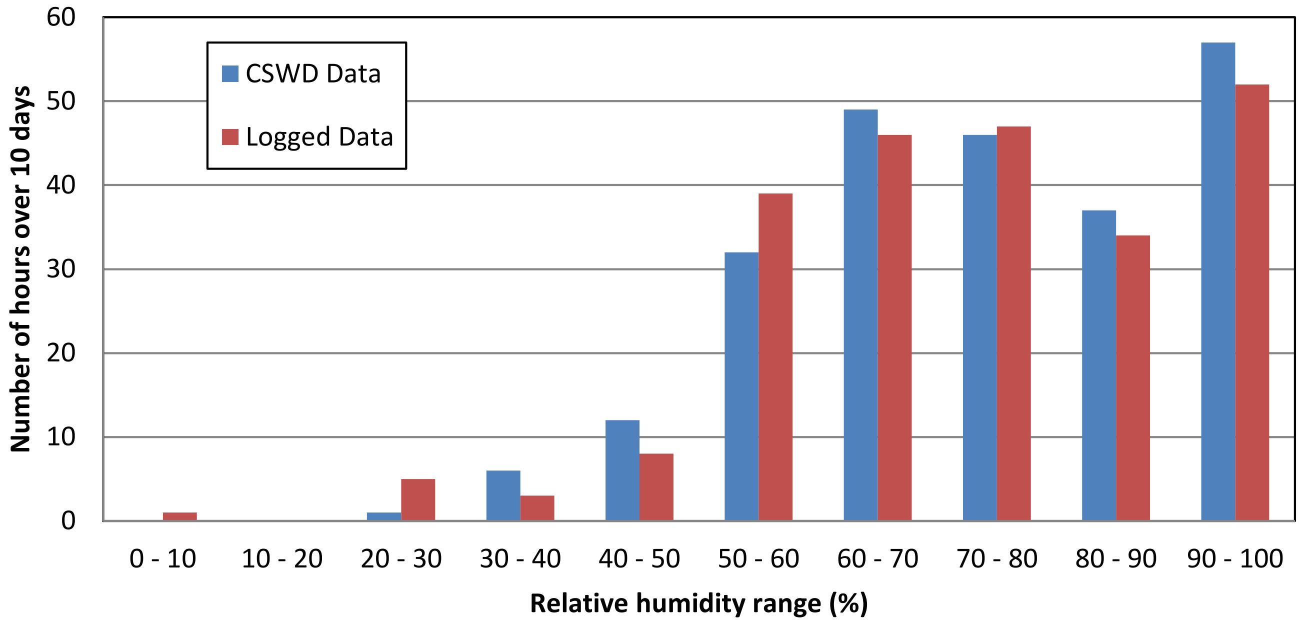


Figure 10-6: Relative humidity distribution comparison between CSWD weather data and 2012 logged data– Datong 1-10th August.

Figure 10-7 shows the CSWD temperature and relative humidity data versus time for a representative sample of 10 days in August. This graph provides a good illustration of the type of weather conditions that may eventuate during the competition period. The average dry-bulb temperature and relative humidity during this period are 21.1°C and 73.8%, respectively. The relative humidity is in general reasonably high when the outdoor

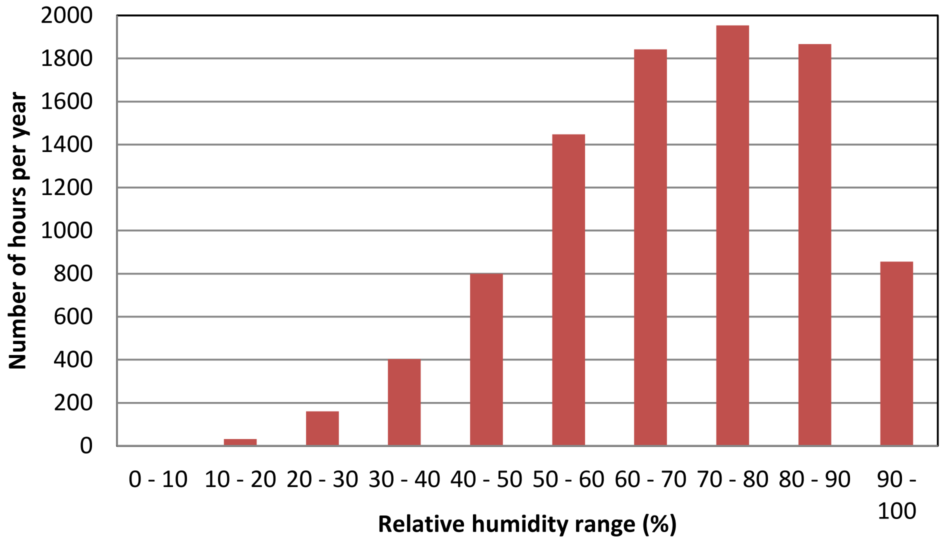


Figure 10-4: Sydney annual hourly relative humidity distribution from IWEC Data.

10.2.1.2 Competition Weather Conditions (Datong)

The Datong 534870 CSWD file was used in all simulations of the Datong competition conditions. CSWD is the abbreviation of Chinese Standard Weather Data which was developed by Dr Jiang Yi from Tsinghua University for determining heating and cooling loads, and energy consumption of buildings.

CSWD is a weather file of a typical year based on measured weather data from 1971 to 2003. In order to compare this weather data against current Datong weather conditions, hourly temperature and relative humidity data for Datong were logged by Team UOW throughout August 2012 through the Weather China website (http://www.weather.com.cn/english/).

As the competition will be held in August 2013 for 9 days from 2nd to 10th of August, a sample weather data set from the August 2012 CSWD data was used for the simulations and for a comparison with the logged 2012 data. A summary of the temperature and relative humidity data for both the CSWD data and the 2012 logged data are presented in Figure 10-5 and Figure 10-6.

The temperature distribution during the competition period was generally found to be within a moderate region of between 15°C and 30°C. Very hot conditions (>30°C) appear to be quite rare. The logged relative humidity data matched well with the CSWD data however there was a noticeable difference between the dry-bulb temperature data sets particularly with the distribution of temperature as highlighted in Figure 10-7, with a larger proportion of data sitting in the 25-30°C range. The CSWD weather file was still considered acceptable for the simulation with the caveat that hotter conditions may be experienced at the competition itself.

- The day/night temperature difference is low for areas near the coast;
- Spring and autumn are thermally comfortable;
- Winter is mild with low humidity; and
- During summer, the temperature can be very high but humidity is moderate.

NSW Sydney 947670 IWEC (International Weather for Energy Calculation) data has been used for all simulations of the Sydney conditions that follow in this report. IWEC data is prepared by ASHRAE based on up to 18 years of DAVSAV 3 hourly data originally archived at the U. S. National Climatic Data Centre. A brief overview of the data is as shown in Figure 10-2 to Figure 10-4.

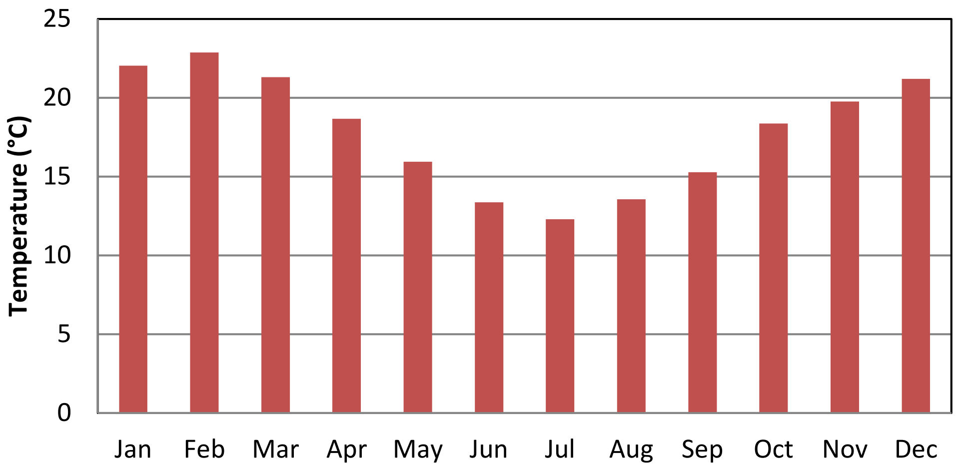


Figure 10-2: Sydney monthly average temperatures from IWEC data.

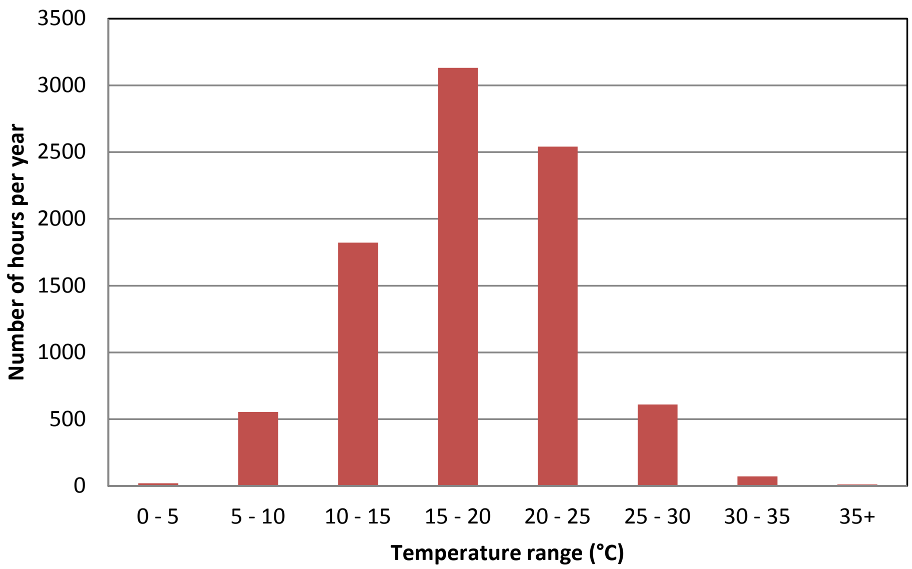


Figure 10-3: Sydney annual hourly temperature distribution from IWEC Data.

10.2 Thermal Modelling

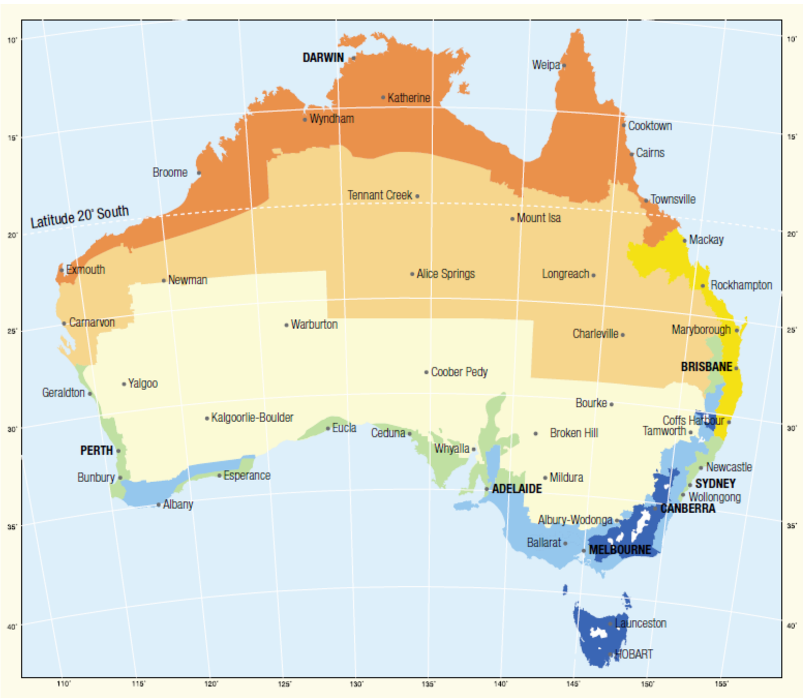
Thermal modelling has been used extensively to aid in the design of the Illawarra Flame. This section outlines: the data and assumptions used to model the house; the analysis of a series of retrofit options and recommendations on appropriate retrofit options; a comparison of the performance of the pre- and post-retrofitted home to communicate the improvements achieved; an analysis of retrofits to avoid thermal bridging in the home; the predicted performance of the house under competition conditions.

10.2.1 Weather Data

The energy analysis began with an investigation of the weather data that corresponds to the conditions under which our house is likely to operate. The weather data investigation was divided into two sections – the design conditions (Sydney) and competition conditions (Datong) and the data derived from this investigation was used for our thermal modelling analysis.

10.2.1.1 Design Conditions (Sydney)

The Building Code of Australia (BCA) defines 8 climate zones for thermal design as shown in Figure 10-1.



ZONE	DESCRIPTION
1	High humid summer, warm winter
2	Warm humid summer, mild winter
3	Hot dry summer, warm winter
4	Hot dry summer, cool winter
5	Warm temperate
6	Mild temperate
7	Cool temperate
8	Alpine

Figure 10-1: Australian climate zones for thermal design.

Sydney and the Illawarra regions are classified as Climate Zone 5 – warm temperate. This climate zone has the following characteristics:

- Carry out a design and optimisation analysis of a Phase Change Material (PCM) thermal store
- Develop and model effective control strategies for the integrated HVAC, PVT and PCM systems;
- Analyse and optimise natural and mechanical ventilation strategies for the home;
- Determine the energy consumption of all loads in the home including, HVAC, hot water, appliances and lighting, and determine the overall energy consumption of the home under Australian and competition conditions; and
- Develop and optimise a photovoltaic system to ensure the home is net-zero energy over the course of the competition.

10.1.3 Scope

This energy analysis and discussion chapter covers the following:

- Analysis of the climate for both the design location (Sydney) and competition location (Datong);
- Testing of energy saving strategies for the retrofitted house;
- Rating of both the existing house and the retrofitted house using NatHERS.
- Comparison of the pre- and post-retrofitted house for thermal comfort and energy efficiency;
- Natural ventilation analysis and diffuser location optimisation;
- Analysis and communication of the design of an advanced HVAC system;
- Auxiliary electrical energy consumption of an evacuated tube solar hot water system;
- Electrical energy budget analysis to ensure the house is net-zero energy; and
- Sizing and optimisation of the PV array.

10 Energy Analysis Results and Discussion

10.1 Introduction

10.1.1 Background

A comprehensive energy analysis has been completed by Team UOW and covers 3 major areas. The first is to understand the changes in household energy consumption that come from retrofitting energy saving products, systems and strategies designed to minimise energy consumption. The second is to ensure that the house can achieve net-zero-energy under both design conditions (Sydney) and competition conditions (Datong) by understanding all electrical loads of the house and designing an appropriate PV system to offset this demand. The third is to communicate the innovations and design that Team UOW has developed in order to meet these requirements.

After an analysis of the 2011 Solar Decathlon it became evident that a strong performance in the energy balance and thermal comfort contests are critical in ensuring a high ranking in the competition. In the Solar Decathlon 2011, seven teams achieved full marks in the energy balance contest while five teams received zero marks, which significantly affected their final rank. This highlights how crucial it is to conduct a thorough energy analysis of the house.

10.1.2 Aims and Objectives

The aim of this energy analysis was to provide information to support the work of other sub-groups within the team and to predict the performance of the house during both design (Sydney) and competition (Datong) conditions. The objectives of the analysis were to:

- Outline the key thermo-physical characteristics of the pre-retrofitted house and develop a baseline model that reflects the performance of this house;
- Conduct a number of simulations to test the influence of passive and active retrofit options on the heating and cooling loads and overall energy consumption of the home and to use this information to guide the design of the house;
- Conduct further analysis on the house to optimise retrofit strategies;
- Provide data for the services team to determine the size of the HVAC system and PV arrays;
- Create a pre- and post-retrofitted house thermal model using AccuRate software, and rate the house according to the Australian Nationwide House Energy Rating Scheme (NatHERS);
- Accurately model and optimise a Photovoltaic Thermal System (PVT);