ENERGY MODELLING ANALYSIS OF HEFFRON HALL

"Reducing the energy consumption of the Heffron Hall building and enabling its solar PV potential"

Internship Report

E.C.J. Karaliolios

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Author

E.C.J. Karaliolios s1197118

Sustainable Energy Technology MSc Student

University of Twente, CTW

Company

Blue Green Engineering

L5, 616 Harris St.,

Ultimo, Sydney, NSW, 2007

Supervision Blue Green Engineering Pty Ltd

Ir. V. Giotis

Director Blue Green Engineering Pty Ltd

Supervision University of Twente

Prof. dr. ir. T.H. van der Meer

Faculty of Engineering Technology

Thermal Engineering

PREFACE

As a part of the curriculum of the master track Sustainable Energy Technology, a master track of Mechanical Engineering at the University of Twente, it is mandatory to have work experience outside of the familiar domain of the university. In order to obtain such a work experience, in many cases an internship at a firm or another institute is an appropriate option. Many of these internships are being carried out abroad, as it is simultaneously a perfect opportunity to gain experience in another country and culture. Therefore, I have chosen to do an internship at a small firm, Blue Green Engineering, at a country on the opposite side of our globe, Australia.

Blue Green Engineering is a company that aims to create solutions in the fields of energy efficiency, energy reduction and implementation of sustainable energy technologies. To be able to create such solutions, models are needed to visualize the reality in a virtual way. During the internship, the focus was aimed at the creation of such models by Building Information Modelling (BIM), using these models to accurately model the energy consumption and creating solutions in a sustainable way to reduce the energy consumption and achieve higher efficiencies for the involved buildings. The main BIM software used during the internship was the interactive tool of Design Builder with the dynamic thermal simulations of EnergyPlus as underlying engine.

First, I would like to thank my internal supervisor and also director of Blue Green Engineering, Vasilios Giotis, for the opportunity to gain valuable working experience at the other side of the world. As the education at the university is mostly theoretical, it was refreshing to gain some better practical insights and see the differences between both approaches. I would also like to thank Vasilios for the many deep conversations we had during the internship and the insights he provided me in a wide range of subjects.

The result of a significant part of 13 weeks of internship is currently in front of you. The Heffron Hall project was the largest project I have undertaken during my internship and the most challenging. As the project management team had an initial intention of partly redoing the construction, it was very important to provide a sustainable solution in which such radical measures were not necessary. I am proud to say that we succeeded and that the implemented solution will provide many benefits for the Heffron Hall exploiters as well as for the environment.

Finally, I hope you find this report informative and a pleasure to read.

Evthimios Karaliolios

Sydney, March 2017

EXECUTIVE SUMMARY

The Heffron Hall building is aimed to fulfill an important role as a central meeting place within the community hub of East Sydney. Being a church in previous times, a radical refurbishment was needed to be able to house a multi-functional center providing children daycare, offices and multi-purpose halls. However, due to an installation error, the insulation for the ground floor was omitted. As an underfloor heating system is present in the ground floor, the consequences could be drastic and a large fear was present that the current construction was not compliant to the guidelines of the NSW government as stated in Section J of the BCA. This Section provides the energy efficiency requirements by the state government. Additionally, if the construction would be compliant, the presence of large energy losses is very probable and these needed to be compensated both financially and environmentally. This resulted in the following main research question:

"How does the most sustainable solution for Heffron Hall look like, being compliant to section J of the BCA, maximizing its renewable energy potential and minimizing the overall energy costs?"

Firstly, the compliance to Section J of the BCA needed to be checked. Subsequently the forecasted energy consumption of the Heffron Hall building and the forecasted occurring energy losses were modelled. This provided the necessary quantitative input to shape sustainable solutions and make full use of the solar potential of the Heffron Hall building with its 71.4 m^2 solar PV system installed on top of the roof.

In order to answer the first two sub-questions, four models were designed in an interactive tool called Design Builder. This enables the use of the dynamic thermal simulation engine EnergyPlus via Building Information Modelling (BIM). A virtual representation of the Heffron Hall building was constructed, with varying fabric and services details corresponding to the type of model. These details largely determine the energy consumption of the building, as it corresponds to insulation via R- and U-values and to the use of energy sources via schedules.

The compliance to Section J of the BCA was analyzed by running a model containing Deemed-To-Satisfy (DTS) guidelines from Section J for both fabric as services (DTS-model) and a model containing the actual construction with the proposed fabric and DTS-services (Proposed Fabric-model). In order to comply, the energy consumption of the actual construction may not exceed the annual energy consumption of the DTS-model (JV3 Analysis).

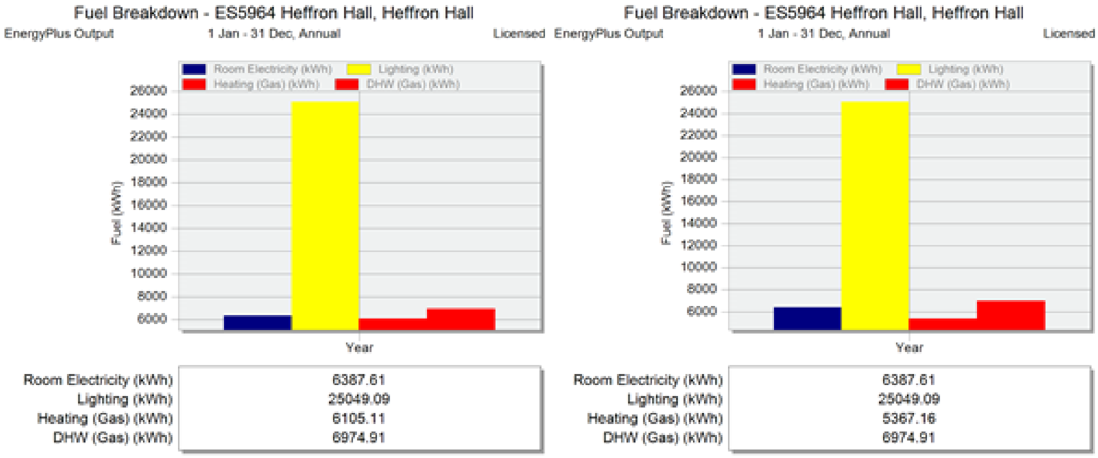

Figure 1: Results of the JV3 analysis, DTS-model (left) and Proposed Fabric-model (right)

As Figure 1 shows, the Proposed Fabric-model has a lower energy consumption in the heating area, while all other energy consumption values are equal. The latter is a strong indication that both models are compatible, while the former shows that the current construction of Heffron Hall **complies to Section J** of the BCA.

Using the actual opening hours for the Proposed Services-schedules, the future energy consumption of the building could be estimated. To determine the energy losses due to the lack of insulation, two models were constructed: one as 'base' model having insulation in the ground floor and one as 'actual' model having none.

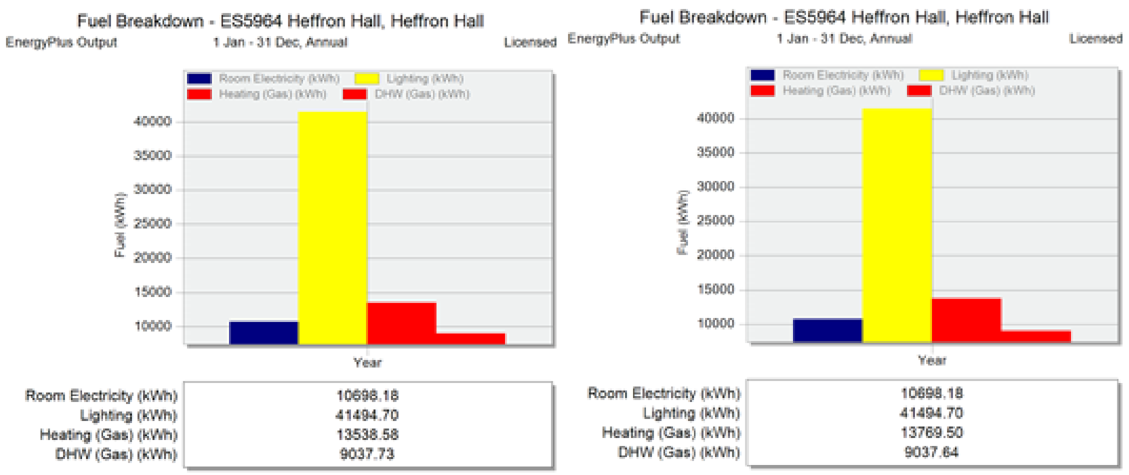

Figure 2: Results of the Energy Modelling analysis; 'base' model (left) and 'actual' model (right)

A small difference is present in the heating energy consumption, as the modelled energy loss due to the lack of insulation accounts for 231 kWh/year. However, Design Builder was not able to fully model the loss of energy as it does not fully simulate the principle of the underfloor heating. Assuming that a thermal equilibrium in the bottom layers would provide thermal insulation, a heat transfer model was created to determine when equilibrium was reached. A period of two weeks of preheating was obtained leading to an additional energy consumption of 2,592 kWh/year. This lead to a total additional energy consumption due to losses of **2,823 kWh/year**. Using natural gas for the heating, the energy losses also lead to additional costs of 295 $/year and environmental costs of 0.66 ton/year additional CO_2 emissions.

A three-part solution was proposed to eliminate the additional costs and improve the sustainability of Heffron Hall. As base of the solution it was suggested to make use of the solar potential and the present solar PV system. Using the full potential of the solar PV system during the shoulder tariff period and by generating and storing that electricity in a 13.5 kWh/day battery storage system (Tesla PowerWall or equivalent) enables Heffron Hall to use self-generated electricity during the more expensive peak tariff period. This leads to financial savings of 1,328 $/year. Additionally, two extra solar PV panels can be installed, eliminating the additional CO_2 emissions by saving 0.77 ton/year of emissions and saving 209 $/year in the process. Finally, a daylight sensor system can be installed for the perimeter lighting, saving about 500 kWh/year (170 $/year) and 0.54 ton/year in CO_2 emissions.

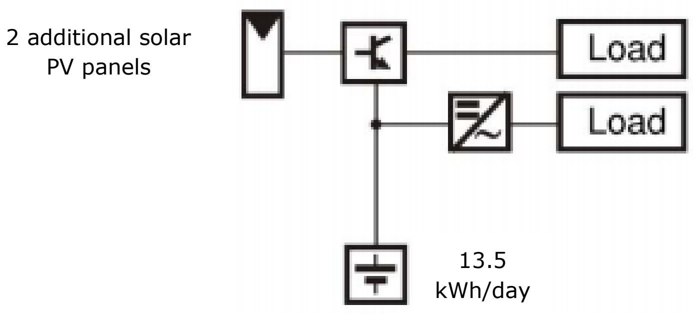

Figure 3: Suggested schematic solution with battery storage and additional solar PV panels

Concluding, a sustainable solution is created for Heffron Hall, consisting of a battery storage system, the addition of two solar PV panels and daylight sensors to deal with the additional energy consumption. The annual net savings account for **1,414 $/year** and **0.65 ton/year CO_2 emissions** although more energy in kWh will be consumed on annual basis.

It is recommended to install the suggested solution on short term to be able to complete the Heffron Hall refurbishment. Furthermore, it is advised to strictly monitor the performance of the battery storage system and if installed successfully, add a second battery storage system to be able to use all the generated electricity of the solar PV system and create even more financial benefits. Finally, the domestic and commercial use of solar PV systems combined with battery storage systems is an interesting topic, as it increases the use of renewable energy and decreases the peak demand in urban areas. It is recommended to pursue this topic for further research.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

BCA	Building Code Australia.
BIM	Building Information Modelling
Design Builder	BIM Interaction tool software used to enable the use of the dynamic thermal simulation engines of EnergyPlus. The virtual models are constructed and run in Design Builder.
DHW	Domestic Hot Water. Heated water used for tap water for bathing, washing and kitchen activities.
DTS	Deemed-To-Satisfy. DTS-models follow the requirements set in Section J of the BCA and represent the maximum amount of energy consumed by the building while still complying to Section J.
ESC	Energy Savings Certificates. Prove of being energy-efficient in the ESS.
ESS	Energy Savings Scheme. Scheme operated by the NSW government in order to stimulate the use of energy-efficient technologies by organizations.
HVAC	Heating, Ventilating and Air-Conditioning. Assembly name of all systems involving the transfer of heat and air within the construction.
JV3 Analysis	Analysis whether or not the construction complies to Section J of the BCA.
LRET	Large-scale Renewable Energy Target. Target providing the amount of GWh that need to be produced in 2020 by renewable energy.
NSW	New South Wales, Australian state in which Sydney is located.
PV	Photo-Voltaic. Part of solar energy that directly generates electricity by converting photon energy into electric energy.
Section J	Section within in the BCA that represents energy efficiency guidelines for new construction. In this Section schedules, activity details, requirements for fabric & glazing are specified.
SHGC	Solar Heat Gain Coefficient. Fraction of solar energy transmitted by glazing.

LIST OF SYMBOLS

Latin symbols

A	Surface area [m^2]
C_p or c_p	Specific heat at constant pressure [J/kg-K]
E	Solar energy [W/m^2]
G	Irradiance [W/m^2]
h	Heat transfer coefficient [W/m^2-K]
k	Thermal conductivity [W/m-K]
m	Mass [kg]
Q or q	Heat flux [W/m^2]
R	Thermal resistance [K-m^2/W]
T	Temperature [K]
t	Time [s]
U	Thermal transmittance [W/m^2-K]
x	Spatial distance [m]

Greek symbols

α	Thermal diffusivity [m^2/s]
η	Efficiency [-] or Dimensionless variable [-]
ρ	Density [kg/m^3]

1. INTRODUCTION

In this Chapter a short introduction to the content of the Heffron Hall project, conducted during an internship at Blue Green Engineering in the city of Sydney, NSW, Australia will be presented. In the first Section the current status of sustainable energy in the specific region is addressed. Subsequently in Section 1.2 the company of Blue Green Engineering is discussed. In Section 1.3 more attention is given to the characteristics of the specific project regarding the internship, the Heffron Hall project in Darlinghurst, Sydney. This leads to the problem definition, the objectives and the research questions regarding this project in Section 1.4. Finally, the further outline of the report is stated in Section 1.5.

1.1. Sustainable Energy in Sydney, NSW, Australia

As many other countries worldwide, Australia faces challenges in the intended energy transition from fossil fuels towards more sustainable forms of energy. Especially considering the country's location, isolated and far from other continents, an urgency is felt to accelerate this energy transition in order to become not only fully sustainable, but self-sufficient as well [1] [2]. The country's characteristics provide Australia with large opportunities to be a renewable energy powerhouse in the far future, if it is able to make good use of its potential [2]. In order to achieve this goal, the federal and state governments are focusing on two kinds of projects: large, government driven projects resulting in high power output and smaller, bottoms-up driven projects resulting in many small power outputs [3] [4].

Currently, the situation as presented by the "Clean Energy Australia Report 2015" is the following [3]:

- The federal government reduced the large-scale Renewable Energy Target (LRET) from 41,000 to 33,000 GWh by 2020 in order to provide more incentive to achieve this goal and make it a realistic target. The new target is expected to create more than $ 10 billion in investments. Currently, Australia ranks 5th in terms of investments in small-scale renewable energy.
- In 2015, the contribution of sustainable produced electricity in the electricity mix went up from 13.3% to 14.6%, mainly due to large increases (~20%) in wind and solar energy. Still, the total production of 15,200 GWh is less than half of the intended amount in 2020. Hydro and wind attribute for the largest parts in the sustainable energy production with 40.1% and 33.7%. However, a large role is assigned to domestic use of solar energy (< 100 kW) with a percentage of 16.2%.
- At the moment, about 8 GW of wind farm projects and 2.5 GW of solar power projects are under construction, making it probable that the reduced target will be met in 2020.
- A large difference is present within the percentage of sustainable energy in the electricity mix across the different states. Tasmania is by far the country's leader being almost sustainable at 99.9%, largely due to old hydropower installations. Nevertheless, most other states are performing less well with NSW and Queensland being in the bottom regions with 7.7% and 4.4%.

As the numbers present, the state of New South Wales (NSW) is underperforming in comparison to the national performance in the area of sustainable energy production. In order to achieve the Renewable Energy Target, the state has installed a Renewable Energy Advocate and a system of precincts in order to encourage the use of renewable energy in private and building community projects [3] [4]. The underperformance is widely attributed to the delay in wind power guidelines and the resulting lack in large projects in that specific area. In New South Wales, the wind power capacity only is estimated at 668 MW, while the domestic solar power capacity outnumbers this greatly with 968 MW [3]. This underlines the influence of domestic solar energy in this region and the current success in of the state government in this specific area of sustainable energy production.

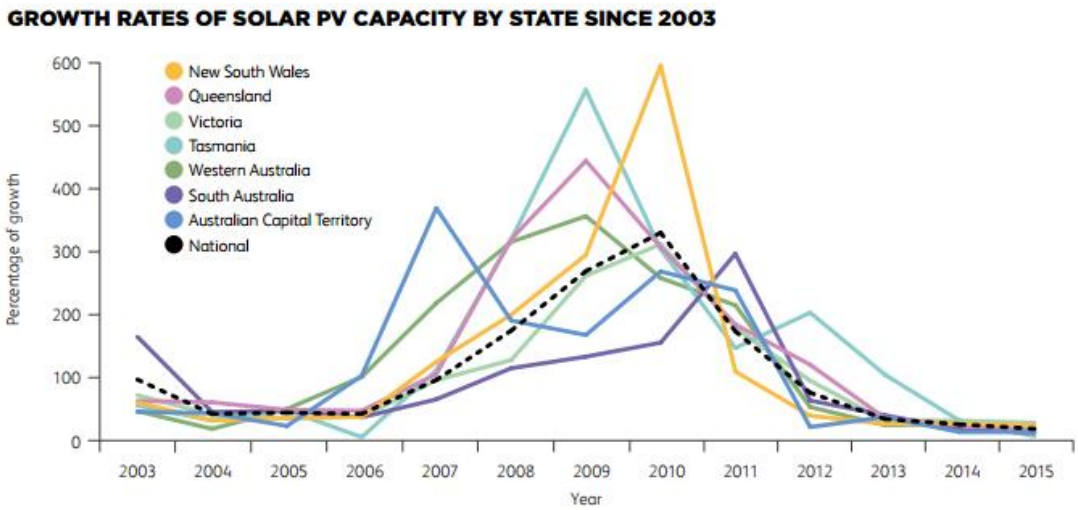

Figure 4: Growth rates over recent years for solar PV in Australia [3]

Although domestic solar power has a large share in the sustainable energy production, its growth rate has declined over the recent years due to the economic crisis and the lack of incentives from the government. This is also illustrated by the figure above. The average capacity of a solar PV system increases, but the amount of systems installed has declined in recent years [3].

With the focus on the LRET, the state government of New South Wales and the city of Sydney are aiming to increase the amount of renewable energy in the energy mix, as well as reducing the growth of the energy use by considering energy efficiency and energy reduction guidelines [4]. Two important examples of these energy reduction guidelines are the Section J of the Building Code Australia (BCA) and the Energy Savings Scheme (ESS) in NSW. The Section J of the BCA ensures the use of insulating, energy-reducing, materials in the construction of buildings resulting in less energy consumption overall and more energy efficient constructions [5]. Meanwhile, the ESS ensures that organizations are investing in new energy-reducing technologies for their equipment by providing financial incentives and handing out Energy Savings Certificates (ESC's). These ESC's can be traded to different liable parties, such as electricity retailers. With this revenue, more investments can be done in the field of energy-reduction, resulting in a continuous cycle of energy reduction and more sustainability [6].

Domestic solar energy, as one of the current strengths, will be an important part in the possible success of reaching this goal. Furthermore, research in the field of solar energy is of world class level within the Sydney and NSW universities and improvements are used in order to obtain higher output from the solar energy potential [4].

1.2. Blue Green Engineering

Aiming on the Renewable Energy Target in 2020, the government of NSW uses different measures to achieve this goal and accelerate the transition towards less energy consumption and higher share of renewable energy in the energy mix. These measures provide incentive for projects in the building environment to choose for more sustainable ways of constructing their buildings and projects [4]. In order to meet the requirements, set by the government, and find new ways of being sustainable, specialists are hired to provide the necessary knowledge. This is where Blue Green Engineering comes in play.

Blue Green Engineering is an engineering company that specializes in finding ways to be more energy efficient and providing sustainable solutions for replacing fossil fuel energy by renewable energy. It mostly focuses on the domestic use of solar PV solutions. The approach used by Blue Green Engineering consists of three stages [7]:

- First, the unnecessary energy use is eliminated by getting rid of redundant cooling, heating and ventilations service.
- Second, the now necessary energy use is optimized, using several energy efficiency measure to achieve the highest energy efficiency. These measures can consist of the use of specific fabric for the construction of the building or measures to adjust the schedules of occupancy or energy use in the building.
- Finally, the needed energy will be provided by renewable energy sources, in which domestic solar PV takes a central place.

With this approach, Blue Green Engineering focuses on projects within the residential, commercial and the industrial building environment [7]:

- In residential projects the approach focuses on low energy home solutions for existing buildings, while for new buildings possibilities arise to design a zero energy home. By the combination of energy reduction, energy efficiency and domestic solar PV solutions a home can be created which barely needs electricity input from the grid. Possible sustainable solutions include solar power systems, hot water systems such as solar hot water, innovative HVAC (Heating, Ventilation, Air-Conditioning) systems and energy monitoring systems. Examples of these solutions are a ventilation system design for a residential building in Marrickville and an off-peak cooling and heating system in Hurlsone Park.
- In industrial and commercial projects, five steps are included in the process. For existing buildings, an energy audit conducted in order to monitor energy use patterns. This leads to energy efficiency options to provide solutions for the needs identified in the first two steps. Blue Green Engineering subsequently implements the chosen solutions and monitors them along the process in order to verify that the intended energy savings are met. Examples of these projects are the energy audit for the Goodman Property Services at Macquarie Park and the Section J verification for GE Hunt Architects.

1.3. The Heffron Hall Project

One of the more complex projects in the last period was the Heffron Hall project. Subject of this project is the already being executed refurbishment of Heffron Hall, located at 225-245 Palmer Street, Darlinghurst, Sydney NSW. The building has multiple functions, which can be executed at the same time or alternately. Two multi-functional halls are present in the building, which can be used for childcare (out of school hours care service), sports lessons and various other activities. Furthermore, a study area and several offices are present within the building [8].

Figure 5: Sketch impression of Heffron Hall in daily use [8]

The construction of the refurbishment has been ongoing since 2014 and the building is designed to be an outstanding and unique construction. This includes the installation of 42 solar PV panels on the roof, unique shading patterns for the windows and an underfloor heating system to heat the building during winter months [9]. The refurbished Heffron Hall is aimed to have a central place in the community hub of East Sydney, connecting the various groups within the neighborhood and providing a community gathering function with the combination of the refurbished building and the renovated park [8].

However, in the last months of 2016, when the construction activities ended, a problem arose with the insulation of the building. The underfloor heating, which is present in a large part of the ground floor of the building, needs insulation layers in order to prevent the heat from flowing away through the bottom layers and causing large energy losses [9]. Unfortunately, the contractor omitted to install the insulation layers in the concrete slabs of the ground floor, resulting in an uninsulated underfloor heating system and causing the probability for large energy losses [10].

This created a very urgent problem for the management of the refurbishment as the building was intended to open its doors in the beginning of 2017, while suspicions were present that the building in its current construction would not meet the requirements set by the government. The initial suggested solution was to replace the current underfloor heating construction with an insulated one, resulting in a delay of the delivery of the project and more importantly a large exceedance of the budget. Other solutions suggested were for example extra insulation in the exterior walls in order to compensate the occurring heat loss [10]. At that moment, Blue Green Engineering was invited to help to construct a solution with minimal losses of time and money, but still meeting the requirements of the local government and the expectations of the client and the owner.

1.4. Research Questions

As stated above, a solution needed to be found for a large construction error in the refurbishment of Heffron Hall, as it is presumed that the current building fabric is not compliant to NSW state demands. First, the problem needs to be defined a little clearer:

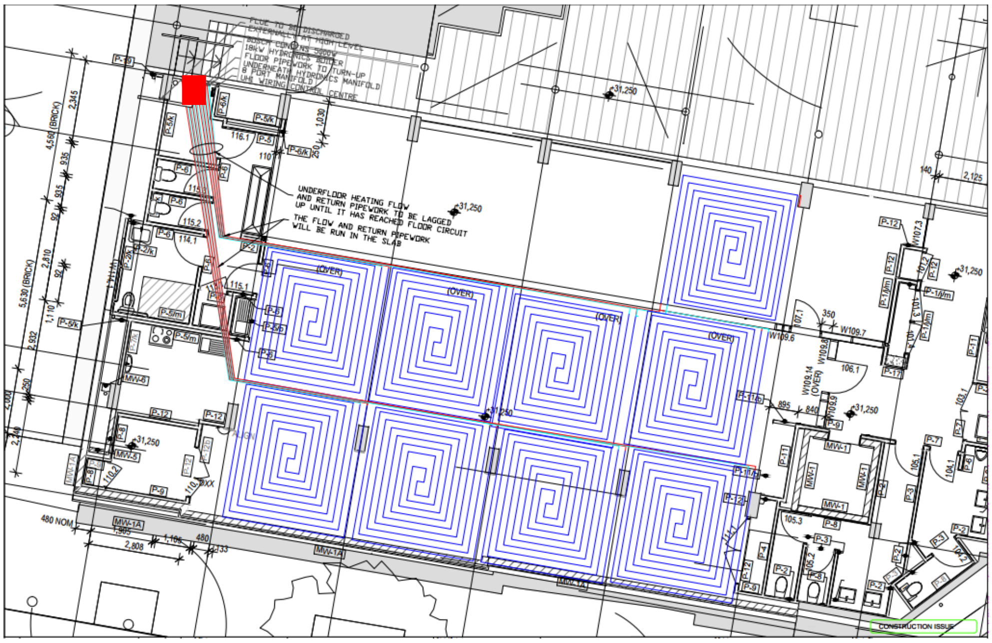

Figure 6: Underfloor heating (blue) and boiler (red) in the ground floor of the lower floor level [9]

The figure above shows the parts of the building where underfloor heating is installed. In terms of functions, this is the fact in the Multi-Purpose Hall #2 and the Study Area. An 18 kW boiler is installed at the northeast corner of the building, providing 100 W/m^2 amount of heat with a temperature of 40 °C. This underfloor heating is the main source of heating in the Heffron Hall building, with additional heating systems for both office areas [9]. As already, without insulation the ground floor concrete slab, it is assumed that a significant part of the provided 100 W/m^2 will be lost in the bottom layers of the ground area.

Following NSW guidelines, a certain building object is only allowed to have a certain annual consumption. This is further specified by Section J of the BCA. The code contains specifications for walls, roofs, floors, windows, glazing, occupancy, lighting, heating, cooling, etc., and these are described dependent on the type of building [5]. The constructed building has to comply to the specifics mentioned in Section J in a so-called Deemed To Satisfy (DTS) model. If it is not compliant, measures to reduce the energy consumption are obliged [5].

This lead to the following problem definition:

"Due to the absence of insulation in the ground floor concrete slab surrounding the underfloor heating system, the refurbished Heffron Hall building energy consumption will drastically be increased, leading to an insufficient energy use performance and non-compliance to Section J of the BCA."

As the consequences of a non-compliant building were severe, it was of urgent matter to find a solution for the posed insulation issue. Blue Green Engineering not only saw the consequences of the problem at the time, but as well the opportunities which were present. This lead to the project goal definition:

"Using the current configuration of the refurbished Heffron Hall building in order to comply to section J of the BCA and subsequently maximize the energy efficiency and minimize the energy costs by making use of its renewable energy potential."

This leads directly to the main research question:

"How does the most sustainable solution for Heffron Hall look like, being compliant to section J of the BCA, maximizing its renewable energy potential and minimizing the overall energy costs?"

In order to achieve these goals and answer the main research question, several steps had to be taken. First, the current energy consumption needed to be modelled in order to have comparison material to section J. This leads to a comparison between the DTS-model and the actual building fabric model with DTS-services. Furthermore, due to a different use of the building compared to the DTS-services, the actual energy consumption of Heffron Hall needed to be calculated, with the off-set caused by the lack of insulation considered. This additional consumption needs to be compensated in other aspects of the energy use of the building, making a call for the use of sustainable energy. The final solution will be presented to the project organization of Heffron Hall, preventing them from reinstalling the ground floor and saving them a large amount of money.

The steps above lead to the following sub-questions:

1. "Does the current construction of Heffron Hall building comply to section J of the BCA?"

2. "What is the actual energy consumption of the constructed Heffron Hall building and what amount of energy needs to be compensated due to the lack of insulation in the ground floor slab?"

3. "What solution is proposed to make maximal use of the renewable energy potential of Heffron Hall?"

These questions will be answered by the construction of several models in specially equipped Design Builder software using Energy+ calculations schemes. Furthermore, the heat transfer, the solar potential and the solar PV system design calculations will be done using own calculations. Further insights in the relevant background information is given in Chapter 2.

1.5. Report Outline

In this report the project of Heffron Hall will be discussed, using the several Design Builder models constructed in order to fully represent the reality. In Chapter 1, a short introduction to the Heffron Hall project is given, as well as sustainable development within the geographic region of Australia and NSW and within the company of Blue Green Engineering. This leads to the research objectives and questions that will be leading throughout this report. In Chapter 2, more background information will be given about certain aspects of the project, such as the detailed construction of Heffron Hall, the used software of Design Builder and the dynamic thermal simulation engine EnergyPlus. Subsequently in Chapter 3, the characteristics of the different models are explained in order to make the models transparent and enable outsiders to construct the models as well. Not only Design Builder models are included in this chapter, but also attention is given to models used for the solar PV potential as the heat transfer due to the underfloor heating system. Running the constructed models leads to the results and analyses of the results in Chapter 4. In this chapter, the sub-questions of the research will be answered. Finally, in Chapter 5, the conclusions and recommendations of the project will be drawn. Also, a Section is dedicated to a discussion of the results and the involved assumptions.

2. BACKGROUND INFORMATION

Several sides of this project, as stated in the previous chapter, need further explanation in order to fully be able to understand the matter. In this Chapter more background information regarding several aspects of the project are presented. First, in Section 2.1 more details regarding the Heffron Hall building are presented, as it is critical to understand the construction to be able to model it accurately. Subsequently, the used software tools will be discussed, regarding the Design Builder interface and the EnergyPlus thermal dynamic energy simulation engine (§ 2.2). Lastly, in Section 2.3 a little more information will be given about the use of solar PV systems as it is an important part of the possible sustainable design of Heffron Hall.

2.1. Heffron Hall construction details

The Heffron Hall building is situated at 225-245 Palmer Street in Darlinghurst in the city of Sydney, NSW. After having functioned as a church in recent decades, a new purpose was found as a part of the community hub in the area of East Sydney. To be able to host the several new functions within the building, a radical refurbishment needed to be executed. This resulted in a two-level building with multiple functions and a synergy of the refurbished building with the renovated park surrounding it, leading to a green oasis within this urban community.

Further understanding of the functions and the design of the building is achieved by analyzing several construction drawings, which give us also insight in conditioning characteristics. First, attention is given to <u>the lower floor</u> of the building:

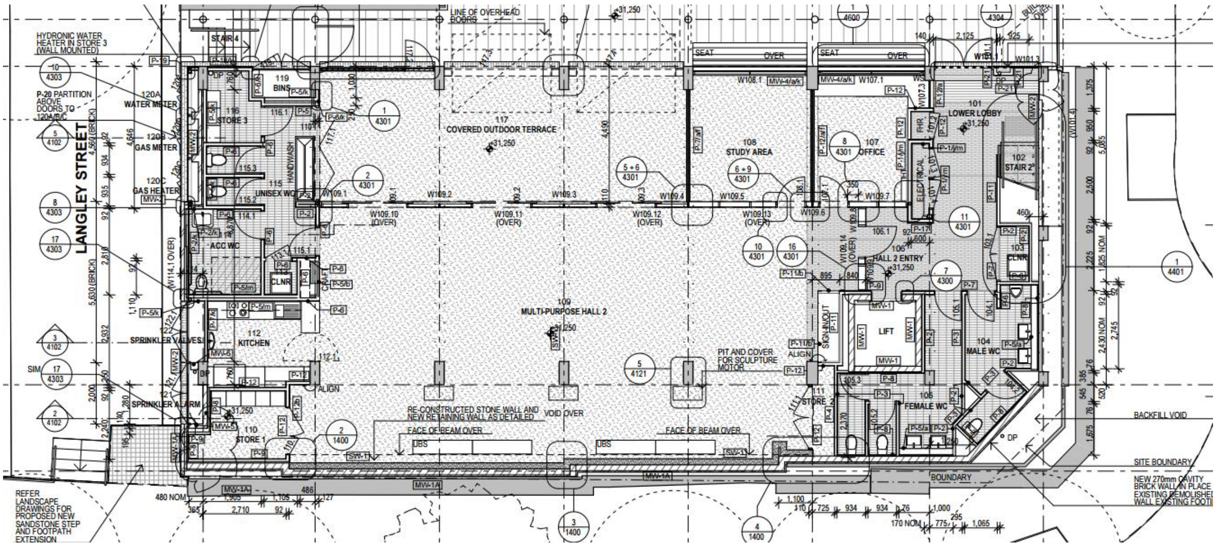

Figure 7: Construction drawings for the lower floor [9]

Visible on the construction drawing above is the central position of Multi-Purpose Hall #2. This hall will mainly be used for out-of-hours childcare, but other activities are also allowed to take place such as sports events and cultural activities. Together with the adjacent Study Area, the room is heated by the use of underfloor heating. Both areas are therefore conditioned. The Multi-Purpose Hall #2 has three pairs of doors opening towards the northern, covered terrace. This terrace is covered by the upper level of the building.

To the eastern side of the building are the lower level toilets, the kitchen and some storage area situated, all of which are non-conditioned. To the western side of the building, an office area is present which will be heated in winter months. Next to that, the entrance of the building is located. It has to be noted that the entrance of the building is positioned in between the lower level and the upper level as there is a North to South slope present. This is also presented in the East and West elevations on the next page. Besides the Lower Entry & Lobby, also an accessible toilet and an elevator is present for the disabled.

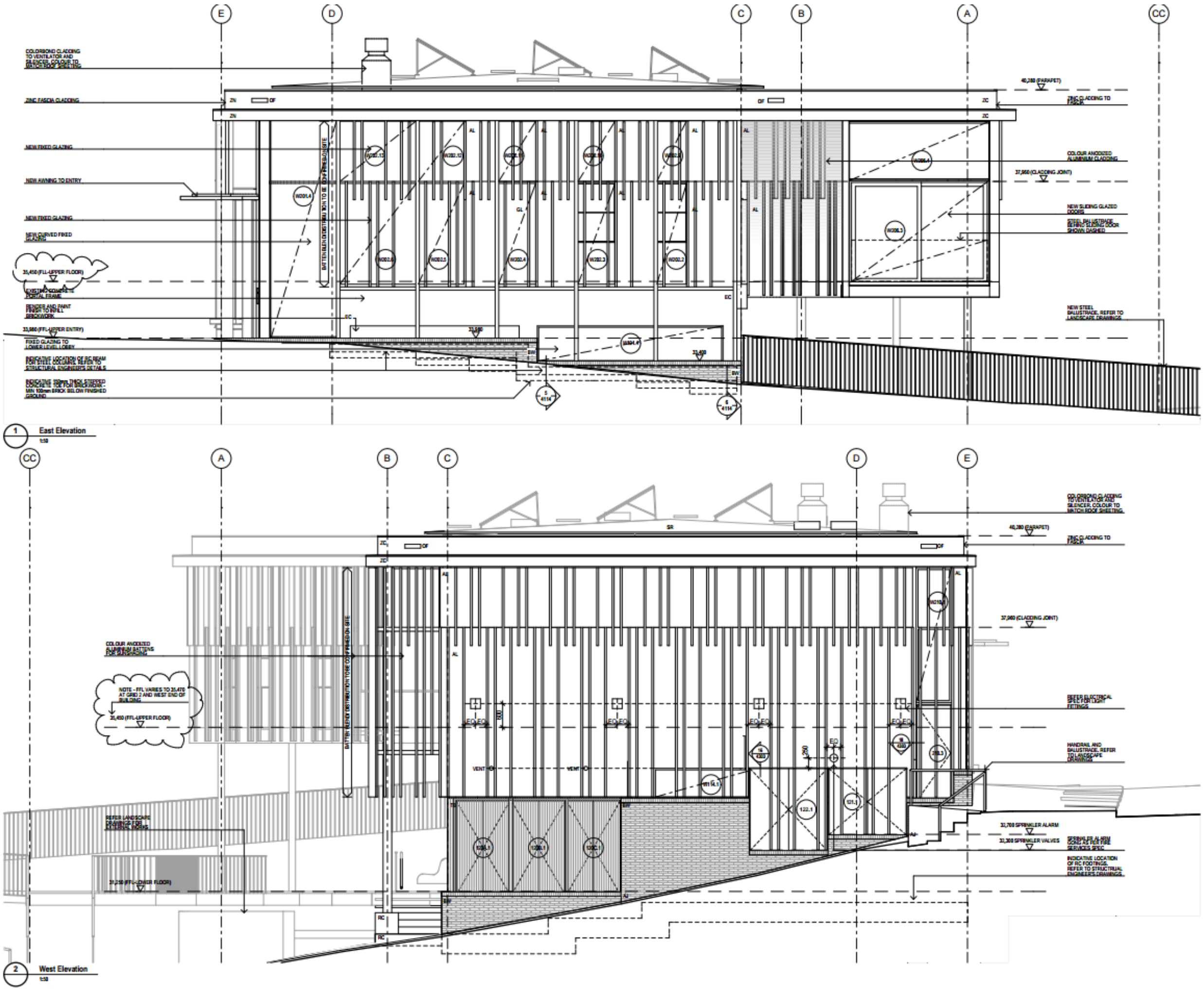

Figure 8: East & West elevations of Heffron Hall building [9]

In the elevations it is clearly visible that the building (and adjacent park) is located on a slope, going downhill to the North. The entrance of the building is situated at street level, in between lower floor and upper floor level. From the entrance level there is the possibility to either enter the lower floor or the upper floor.

<u>The upper floor</u> consists of the second multi-purpose hall called Multi-Purpose Hall #1 due to its larger size. This area has some natural ventilation but is not heated, which means it is not conditioned. To the Eastern side of the building, storage areas are situated, while near the Southern wall a large void is present, connecting the lower and upper floor and taking care of natural ventilation.

When the building is entered and the upstairs route is taken, the Upper Entry & Lobby area is reached. This area provides entrance to toilets, the elevator and a kitchenette, all of which are non-conditioned. However, it also gives access to a special part of the building, called the Breakout Area. This area rests on pillars and has no lower floor level, but overseas the adjacent park. In this part of the building several offices are located and therefore this part is heated in the winter times.

At the upper floor, above the entrance, an awning is installed to prevent sunlight from hindering the visitors when they enter of leave the building. An exact construction drawing of the upper floor is presented in Figure 9:

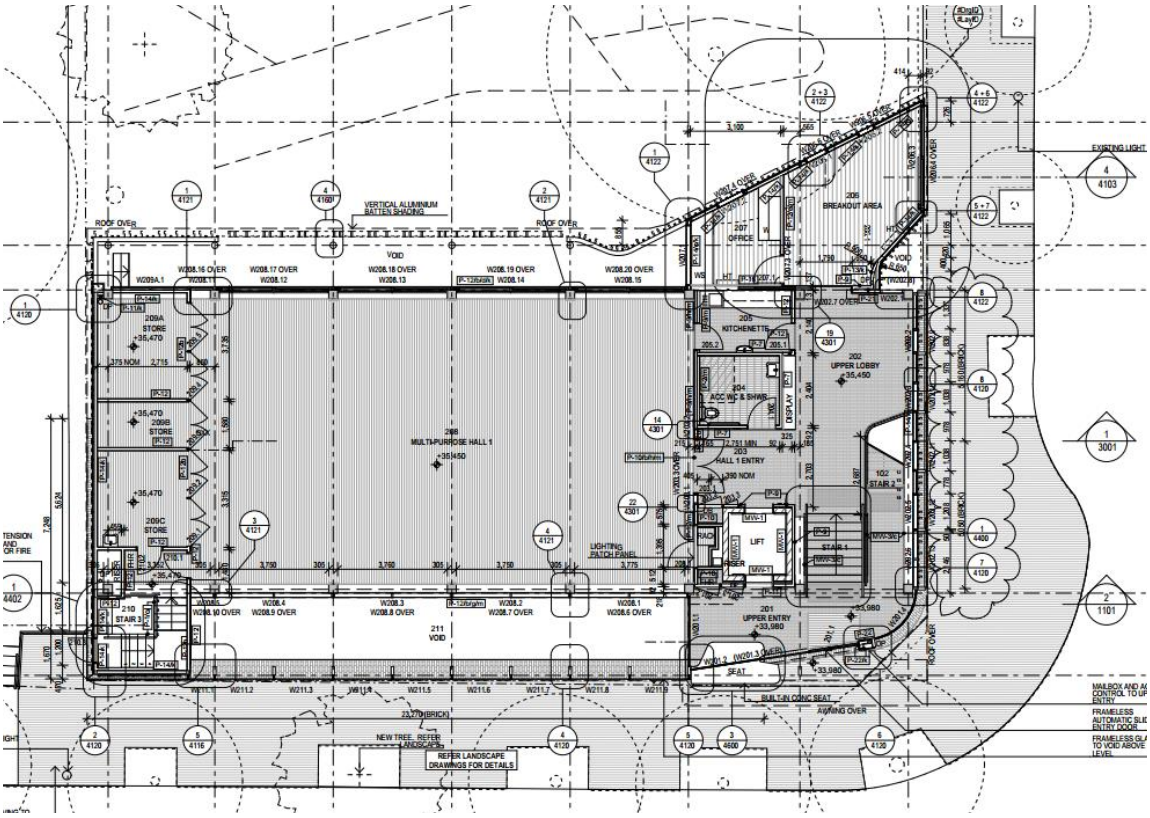

Figure 9: Upper floor construction drawings [9]

Already vaguely visible in the elevations drawings, the roof exists of lightly pitched roof (3° angle) on the main structure and an even lighter angled roof on the breakout area (1° angle). On the main structure 42 solar PV panels are present to reduce the energy impact of the building. The total covered area by the PV panels accounts for 71.4 m^2.

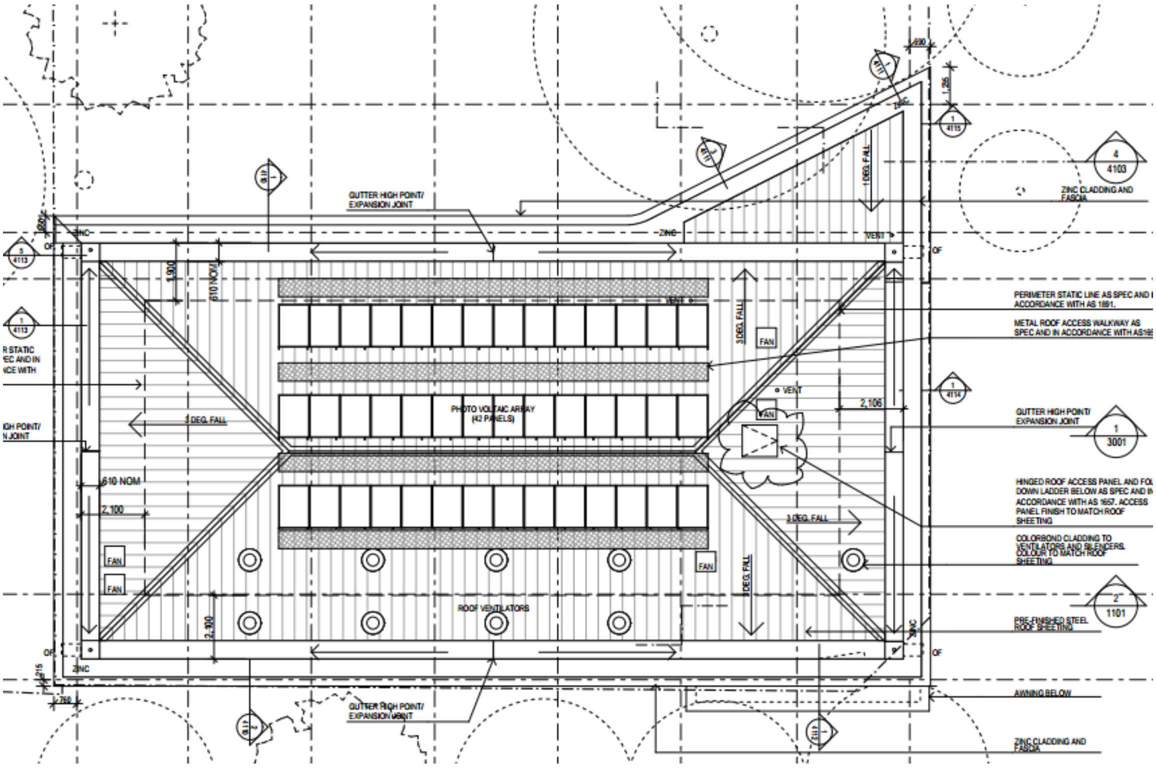

Figure 10: Roof drawings for Heffron Hall [9]

The PV panels have an assumed angle with the horizontal surface of 34° in order to have the highest year through performance. Further visible on the roof drawings in the previous figure are the ventilation shafts in the Southern part of the roof, use for natural and mechanical ventilation.

For further details, larger construction drawings, elevations and sections can be found in Appendix I: Construction Drawings Heffron Hall.

2.2. Design Builder & EnergyPlus

To be able to calculate the energy use performance of the built construction and simulate the Deemed-To-Satisfy building, a virtual model has to be built. Within Blue Green Engineering different software programs are used for this purpose, such as 4M and Design Builder [10]. In this case, Design Builder is the chosen software program.

Design Builder software is one of the first comprehensive user interfaces which gives access to the EnergyPlus simulation engine. Via the construction of virtual models, it gives the user the possibility to use the dynamic thermal simulation engine of EnergyPlus to calculate time dynamic performance outputs [11]. In Design Builder, EnergyPlus is the preferred simulation engine, but other simulation engines are as well applicable. However, in the simulations for Heffron Hall, EnergyPlus is used as the dynamic thermal simulation engine as prescribed by the NSW government guidelines [5].

<u>Design Builder</u>

Using Design Builder, several steps need to be taken in order to construct a working and accurate virtual model of the specific building:

- Assign the correct location and direction of the to-be-built model.
- Construct the specific building per level. Building blocks are used to form levels within a building, as well as roofs or adjacent structures.
- Construct openings such as doors and windows by selecting the appropriate exterior wall. Openings which continue along different floor levels need to be arranged per floor level separately.
- Construct the accurate inner structure of the building by constructing partition walls. These partition walls give the possibility to assign different zones within the building. This is important for simulation purposes.

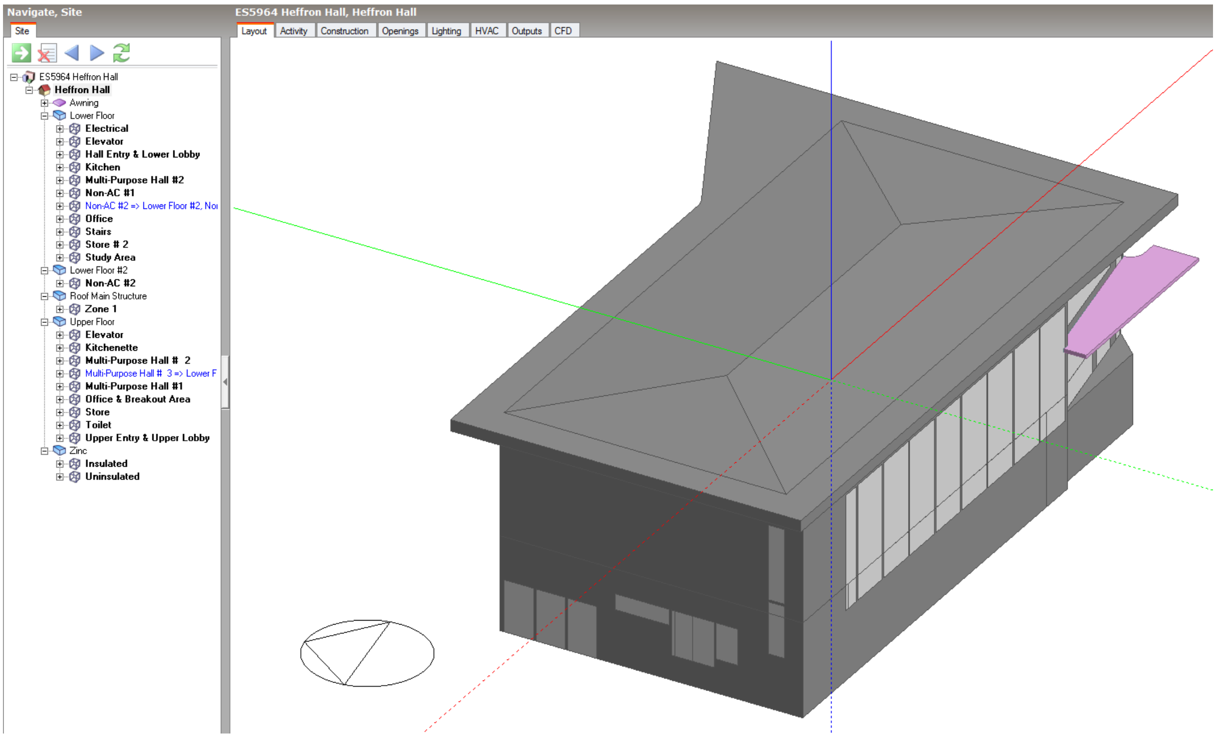

Figure 11: Lay-out tab of the Heffron Hall model in Design Builder

If the steps earlier mentioned are executed properly, the lay-out of the virtual model corresponds to the construction drawings and the elevations. Minor differences can occur due to wall constructions or difficulties with using imported bitmap files.

In Figure 11 the lay-out tab of the Heffron Hall building is projected. As visible on the left part of the figure, different floors are distinguishable such as Lower Floor, Upper Floor and Roof Main Structure. Within these blocks, the zones are present, which are usually assigned as the purposes of these specific areas. For example, both the Multi-Purpose Halls are present within the list of the zones.

As the lay-out of the model is finished, attention shifts towards the building fabric and conditioning of the different parts and areas of the building. As visible in Figure 11, different tabs (upper section of the main screen) are present for the construction of the model. In these different tabs, first the building fabric such as brick walls, insulated roofs and double-glazed windows can be assigned to the correct parts of the building (Construction & Openings tabs). Also it gives the possibility to assign accurate thermal conductivity values (U- or R-values [12]) and solar heat gains values (SGHC-values [13]). In the other tabs the occupancy and equipment details can be configured (Activity tab) as well as the details for lighting, heating, cooling, domestic hot water (DHW) and ventilation (Lighting & HVAC tabs).

EnergyPlus

EnergyPlus is dynamic thermal simulation engine released in 2001 by a US federal agency and is based on two older simulation tools named DOE-2 and BLAST. As these programs were written in the late 1960's, consisted of many 'spaghetti code', an urge for a new simulation engine emerged. Although both previous tools were based on different calculation methods, DOE-2 using a room weighting factor approach and BLAST using a heat balance approach, it was decided to bundle the experiences and create a new engine [14].

Since 2001 many versions are released, but they are all based on the same principles [14] [15]:

- Integrated and simultaneous solution of the thermal zone conditions, plus the assumption that the HVAC system cannot always cope with the zone loads and is as well able to simulate unconditioned and under-conditioned zones.
- The provided outcome of the simulation is based on heat balances of radiant and convective effects. This results in accurate surface temperatures and condensation calculations
- Sub-hourly, hourly, daily and monthly fixed time steps as well as user definable time steps to enhance the interaction between the thermal zones, the HVAC systems and the environment.
- Combined heat and mass transfer calculations to enable air movement calculations between the different zones.
- Standard summary and detailed output reports with enabled time-resolution selection options and added energy source multipliers.

As mentioned in the first bullet point, EnergyPlus performs as an integrated simulation. All the major parts of the model therefore need to be solved simultaneously, in contrast to other thermal simulation engines which used sequential ways of simulating. This integrated way of simulating results in a more complex yet more accurate solution, as constant feedback loops are in place. An example for the physical loops of air and water is given in the figure below [14] [15] [16]:

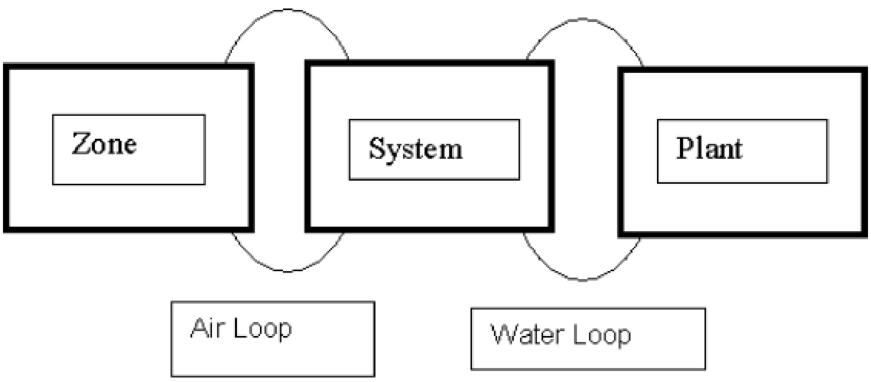

Figure 12: Schematization of a simultaneous solution scheme [16]

The loops visualized in Figure 12 are divided in supply and demand sides, from where on the simulation engine tries to provide a solution by successive substitution iteration for the supply side and the Gauss-Seidell philosophy of continuous updating for the demand side [16].

The integration of the different loops within the major parts of the model is based on the ability to formulate energy and moisture balances and solving the derived ordinary differential equations using a predictor-corrector approach. As differential equations are usually solved by numerical integration, attention has to be given to the potential build-up of truncation errors, which may occur if a misbalance is present between the time step size and the spatial step sizer or if the time step size is taken too small [16]. Although the cyclic nature of building energy simulations should lead to the erasing of truncation errors over the period of one day, the errors can be of large consequence if the hourly and sub-hourly performances are discussed.

To be able to deal with the different forms and time periods within the simulation engine, three solution algorithms are employed [16]. The basis is formed by the algorithm based on the Euler-method, in which unknown terms are lagged by one time-step. For example, this leads to the following formula in which the zone mean air temperature is calculated for time step t:

$$T_z^t = \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i^t + \dot{m}_{sys} C_p T_{\text{supply}}^t + \left(C_z \frac{T_z}{\delta t} + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\text{inf}} C_p T_\infty \right)^{t-\delta t}}{\frac{C_z}{\delta t} + \left(\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\text{inf}} C_p + \dot{m}_{sys} C_p \right)}$$

Equation 1: Euler method formulation to derive zone mean air temperature [16]

This basis method is a simple and robust solution to provide a solution for the simulation. However, it is sensitive for truncation errors and therefore the time step size can be limited. To prevent these limitations from occurring, higher order expressions are needed. These have higher order truncation errors, which are by definition (if $\Delta t < 1$) smaller than using the Euler method and can provide larger stability domains. It has been concluded in previous research by Taylor that the third order finite difference approximation provides the best and most stabile solutions [16]. This results in the following solution for the zone mean air temperature:

$$T_z^t = \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\text{inf}} C_p T_\infty + \dot{m}_{sys} C_p T_{\text{supply}} - \left(\frac{C_z}{\delta t}\right)\left(-3T_z^{t-\delta t} + \frac{3}{2} T_z^{t-2\delta t} - \frac{1}{3} T_z^{t-3\delta t}\right)}{\left(\frac{11}{6}\right)\frac{C_z}{\delta t} + \sum_{i=1}^{N_{surfaces}} h_i A + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\text{inf}} C_p + \dot{m}_{sys} C}$$

Equation 2: Third order Backward Difference method formulation [16]

By using the zone air temperatures in the previous three time steps, the stability of the method is larger but leads as well to more required data. To be able to provide an accurate solution, it is assumed that the time step lengths remain the same over those three time steps [15] [16]. This method is used as the default method in the EnergyPlus calculations [16].

To provide the largest range of flexibility within the simulation calculations, a possibility to use different time steps sizes is given by providing an algorithm containing the analytical solution. This eliminates the still present truncation errors in the third order BD method. Also, the analytical solution only needs the zone air temperature for the previous time step [16]. On the downside, more computational power is needed as the equation gets more complex:

$$T_z^t = \left(T_z^{t-\delta t} - \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\inf} C_p T_\infty + \dot{m}_{sys} C_p T_{\sup}}{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\inf} C_p + \dot{m}_{sys} C_p} \right)$$
$$* \exp\left(- \frac{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\inf} C_p + \dot{m}_{sys} C_p}{C_z} \delta t \right)$$
$$+ \frac{\sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\inf} C_p T_\infty + \dot{m}_{sys} C_p T_{\sup}}{\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\inf} C_p + \dot{m}_{sys} C_p}$$

Equation 3: Analytical solution for the zone mean air temperature T_z [16]

As in this example, the formulations are used for the zone mean air temperature T_z. However, the three algorithms presented form the base for the building energy calculations in the EnergyPlus simulation engine.

Another important aspect of the calculations in EnergyPlus is the way it handles the heat conduction through building elements. For these calculations, EnergyPlus uses state space method as a base for temperature differences along building elements, making use of the following set of equations and the following schematization of the conductivity problem:

$$C\frac{dT_1}{dt} = hA\left(T_o - T_1\right) + \frac{T_2 - T_1}{R}$$

$$C\frac{dT_2}{dt} = hA\left(T_i - T_2\right) + \frac{T_1 - T_2}{R}$$

$$q''_i = h\left(T_i - T_2\right)$$

$$q''_o = h\left(T_1 - T_o\right)$$

Equation 4: Set of equations for heat conductivity along building elements [16]

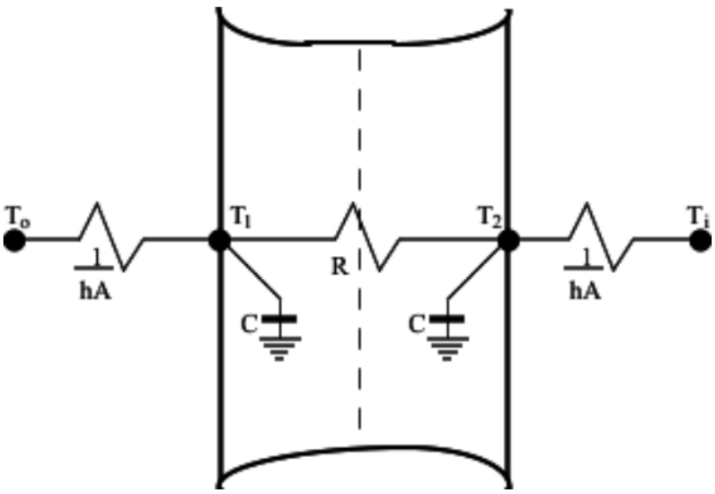

Figure 13: Schematization of the heat transfer along a building element and the resistive forces in it [16]

The use of conduction transfer functions are efficient to compute heat fluxes along and through building elements. However, the functions become more and more unstable as the time step size decreases, leading to divergent behavior. As the time step size is fixed, it is hardly possible to find values for intermediary time step sizes, reducing the flexibility of the simulation engine. In order to still be able to calculate values at small time differences, a solution is found in the use of multiple histories for the conduction transfer functions. Several ways of using multiple histories are possible, with EnergyPlus employing a hybrid solution between multiple, staggered time history scheme and a sequential interpolation of histories [16]. The final solution is visualized in the figure below:

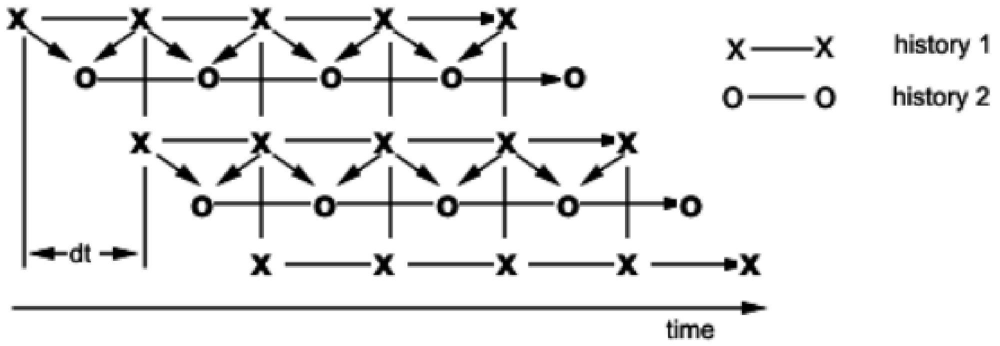

Figure 14: Master history scheme with interpolation [16]

The method shown in Figure 14 was found to provide the best solutions as it eliminates the propagation of information backwards in time and has a limited need for memory storage as it uses only one master history and two sets of temperature and flux histories [16].

For the heat transfer and balance equations, the conduction transfer functions are further used in the finite difference schemes for the simulation engine. Since the beginning of EnergyPlus, the semi-infinite Crank-Nicholson scheme was used, but since version 7 the fully implicit discretization scheme shown is operational [16].

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \frac{1}{2}\left(k_W \frac{T_{i+1}^{j+1} - T_i^{j+1}}{\Delta x} + k_E \frac{T_{i-1}^{j+1} - T_i^{j+1}}{\Delta x} + k_W \frac{T_{i+1}^{j} - T_i^{j}}{\Delta x} + k_E \frac{T_{i-1}^{j} - T_i^{j}}{\Delta x} \right)$$

Equation 5: Heat transfer fully implicit discretization scheme [16]

Since the spatial step size is important in het heat transfer discretization schemes, usually a Fourier number of 0.5 or smaller is used. However, the exact critical spatial step size is calculated by the following formula:

$$\Delta \mathrm{x} = \sqrt{\mathrm{C}\alpha\Delta\mathrm{t}}$$

Equation 6: Defining the smallest acceptable spatial step size [16]

The number of nodes used for the calculations in the state space method is then calculated by using the width of the building element and the minimum spatial step size.

Due to the implicit character of this scheme, a Gauss-Seidell iteration scheme is used to update the node temperatures and the under-relaxation is implemented for extra stability. The amount of loops of the Gauss-Seidell iteration is limited to 30 runs, except if the difference in temperature is already negligible in which the runs are cut short [16].

Many more examples of physical phenomena are present in the EnergyPlus software. It has been chosen to show two of the most important aspects of the simulation engine in order to be able to understand the background of the tool. The current versions of EnergyPlus are very complex and contain various aspects of building energy simulation from basic heat transfer, air transfer and heat conduction functions to complicated formulations for shading, HVAC and internal gains. These aspects are considered to be out of scope for the purpose of this report and for more information one is referred to the Engineering Reference report from the U.S. Department of Energy (2016) [16].

2.3. Photo-Voltaic Systems

Another aspect of the Heffron Hall building that needed attention was the solar PV installation installed on the roof of the main structure. It gives the building the opportunity to use sustainable energy in order to reduce its impact on the environment. In this Section more insight will be given in PV systems for stand-alone use and for connections to the grid.

First, the solar irradiation present in the region of Sydney, NSW, Australia, should be discussed as it is providing the energy potential for generating sustainable electricity. As the interest lies in the total irradiance received by the solar PV panels on the roof of the Heffron Hall building, the irradiance levels throughout the year per surface area are taken to provide the solar PV potential in kW/m^2-day [17]. With a total surface area of 71.2 m^2 [9], the points of time of sunrise and sunset and the knowledge that the integral of the curve results in the daily potential, the solar potential curves during the day can be derived [17]. This leads to the following graph for the location of the Heffron Hall building for the four different seasons:

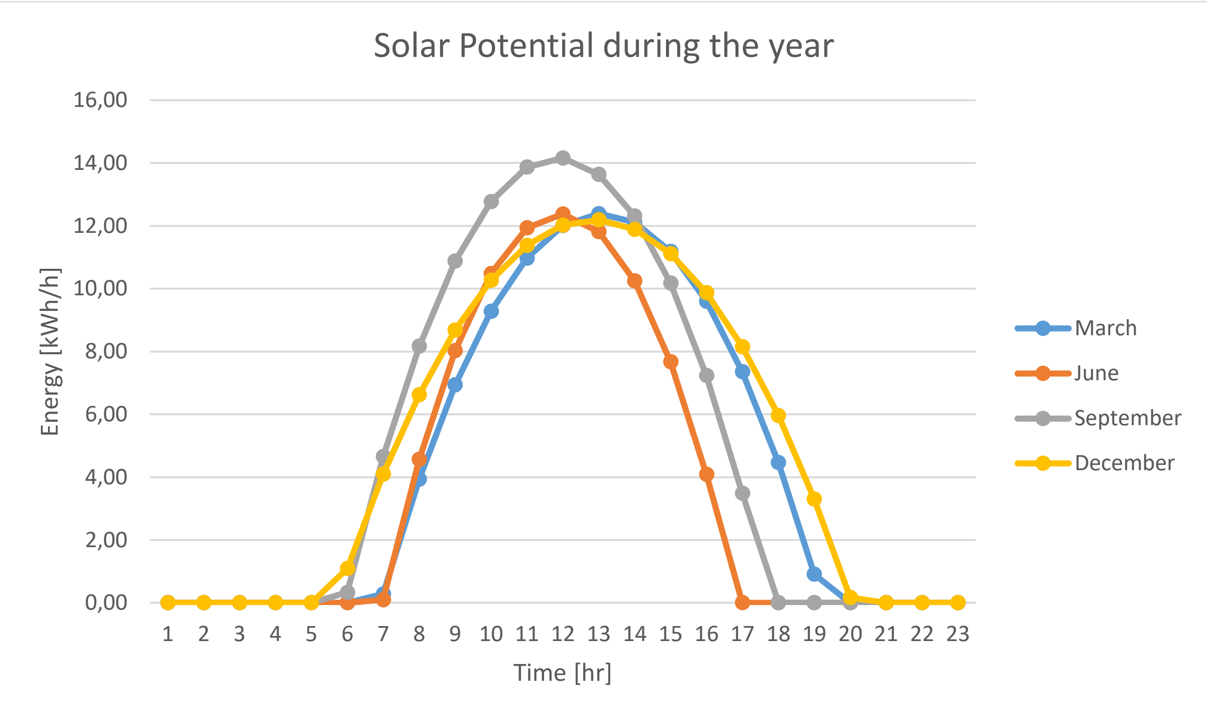

Figure 15: Solar potential of the Heffron Hall building during the year, shown per hour

As shown in Figure 15, the peak power during the day does not vary a lot across the different seasons. However, due to the longer daytime periods in summer, the possible highest electricity generation per day is likely to be achieved in this season. Detailed calculations for the irradiance can be found in Appendix II: Detailed Calculations Solar Irradiance.

The solar PV panels on the roof of the Heffron Hall building are currently connected to the grid, providing sustainable electricity to a feed-in tariff. Before the electricity is fed to the grid however, the possibility is present to link it directly to equipment in the building, providing sustainable DC electricity and eliminating the need for an inverter. This leads to the schematization of the current setup:

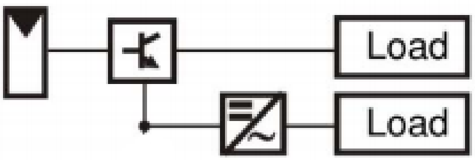

Figure 16: Electrical setup of the solar PV installation; DC load as top load, AC load as bottom load [18]

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In the figure, the solar PV panel is presented on the left, with a charger connected to it. The photovoltaic panel can be installed in different ways on the rooftop. There are differences in directions and in angles with the rooftop surface itself, resulting in different performances throughout the year. In the case of the Heffron Hall building, the PV panels have a year optimal performance angle of 56° while facing directly to the North.

Naturally, the PV panel has an efficiency transforming the photon energy into electricity. A large variety of solar PV modules are present currently, varying from thin film solar cells (like multi-junction and amorphous silicon) to mono crystalline silicon solar cells. The last type is mainly used in commercial use, having module efficiencies between 15% and 20%. Furthermore, the solar PV panels usually have a mismatch when no MPP tracker is installed, resulting in the system not able to find the Maximum Power Point (MPP) as a balance between the voltage and the current in the solar PV cells. This reduces the potential by an estimating 90% [18].

The remaining parts of the electrical installation have efficiencies of around 95%, such as 95% for the charger, 97% for the cables and 94% for the inverter transforming DC to AC [18]. The product of these efficiencies can be used to calculate the total electricity output to the grid of to a storage system:

$$\boldsymbol{E_{PV} = G\eta_{PV} \sum \eta_{electrical}}$$

Equation 7: Electricity output of the solar PV system [18]

3. MODEL CONSTRUCTION

In this Chapter more attention will be given to the construction of the used energy models in the Design Builder software with the use of the EnergyPlus engine. In Section 3.1 attention will be given to the Deemed-to-Satisfy model, using the guidelines of the NSW government. Subsequently, in Section 3.2, the Proposed Fabric-model will be presented, representing the construction as it is in reality. The last Design Builder model is the Proposed Services-model, which shows the actual proposed occupancy of the building (§ 3.3). In Section 3.4, the heat transfer of the underfloor heating is calculated in order to better understand the consequences of the lack of insulation in the ground floor of the building. Finally, the potential of the solar PV system on top of the roof of Heffron Hall building is modelled, using the irradiance of the location and the daily energy consumption patterns (§ 3.5).

3.1. DTS-model

The first model that needed to be constructed had as objective to be able to assess whether or not the already constructed Heffron Hall building complies to the guidelines of Section J of the BCA. In the Building Code of Australia, the specific characteristics of a compliant building are specified for conditioned areas. In this Section the details of this Deemed-To-Satisfy model are discussed.

As already presented in Section 2.1, the lay-out of the building is designed according to the provided construction drawings. Using the Design Builder software, several layers are constructed, presenting the lower floor layer, the upper floor layer and the roof layer. In the following figures the exterior lay-out of the model of the Heffron Hall building is presented, from two different angles:

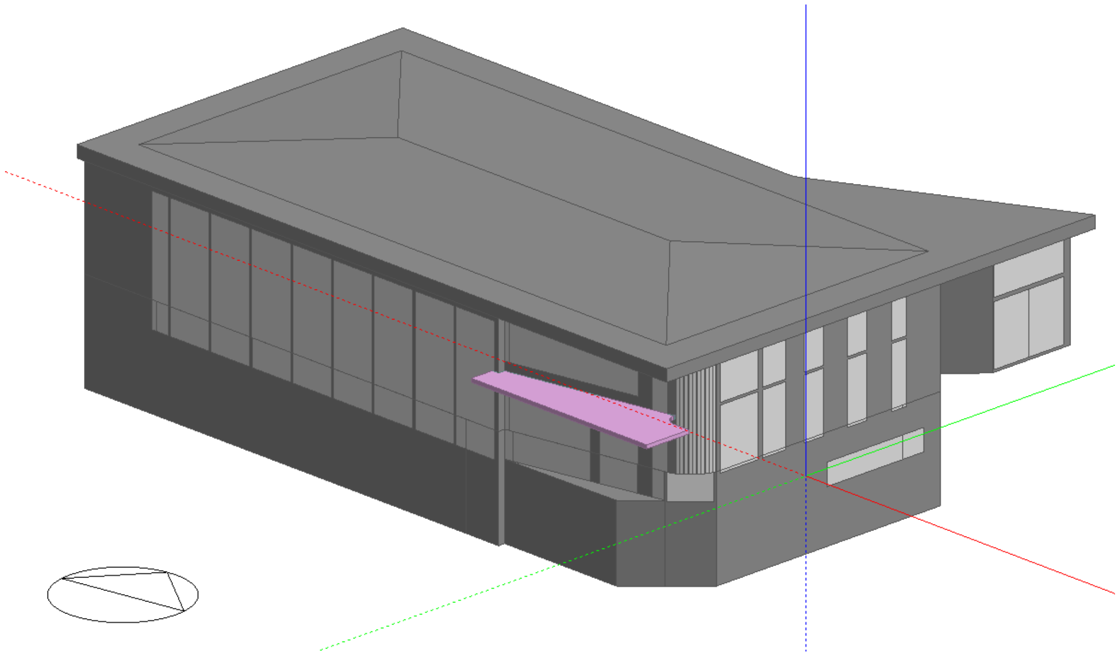


Figure 17: Exterior lay-out of the model in Design Builder, observed from a South-East angle

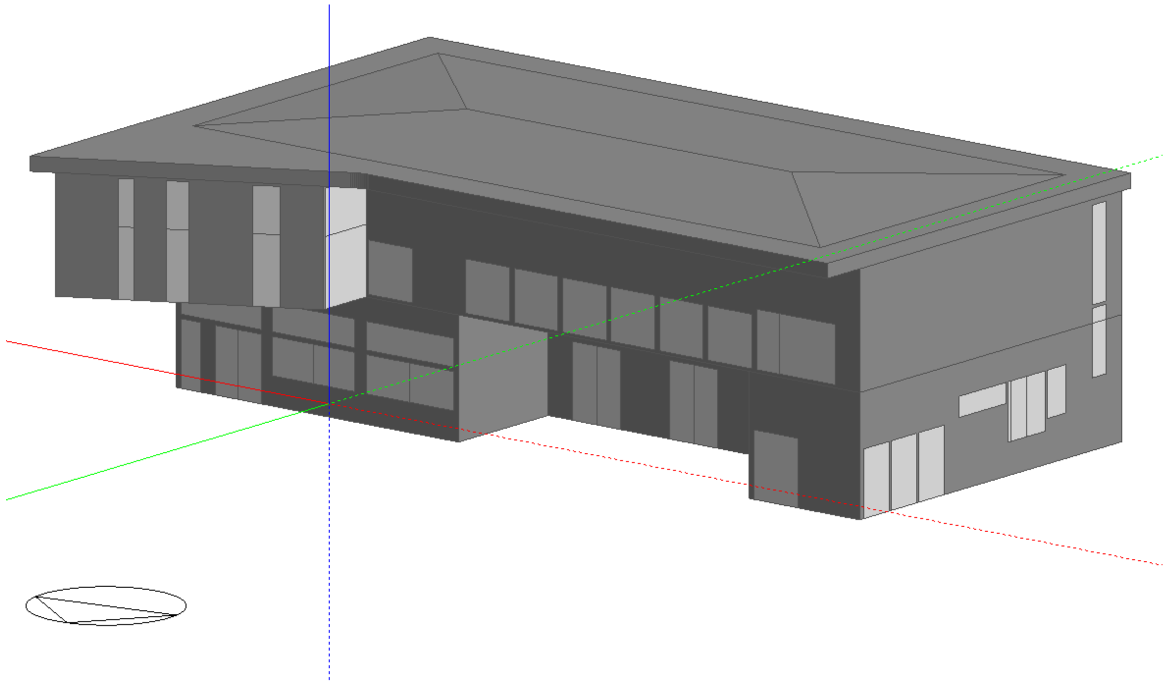


Figure 18: Exterior lay-out of the model in Design Builder, observed from a North-West angle

As shown in Figure 17, the entrance to the Heffron Hall building is situated at a higher level than the level of the lower floor. Furthermore, the awning has a pink color, due to the fact that it is defined as a component block and not a zonal part of the actual building. This has advantages in the zoning of the spaces in the different floors. In both figures, the windows and doors can be noticed, as well as the slightly pitched roof on top of the main structure. Also noticeable is the breakout area on the upper floor level, which is modelled without support structures, as the construction mechanics are no part of the simulation.

Zoning

In the construction drawing of the different floors, the separate rooms are visible. For the energy building simulations in EnergyPlus, it is of the highest importance to clearly specify the characteristics per room. This is valid for all models. In the DTS-model, only conditioned areas, meaning where heating or cooling takes place, have to constructed following the guidelines of Section J in the BCA. The other, unconditioned, areas are constructed as non-insulated [5].

First, a distinction is made between the different type of activities in the building. A division is chosen between a Class 5 Offices type for the office areas and a Class 9b School/Assembly type for the other areas in the building [5]. These classes are defined by the BCA and account for the differences in the usage of space, lighting, equipment and HVAC-systems between areas with different purposes. Using the construction drawings, only the Multi-Purpose Hall #2, the Study Area and the Office are conditioned on the lower floor, while for the upper floor it is only valid for the Break-out Area. This is also shown in the following figures:

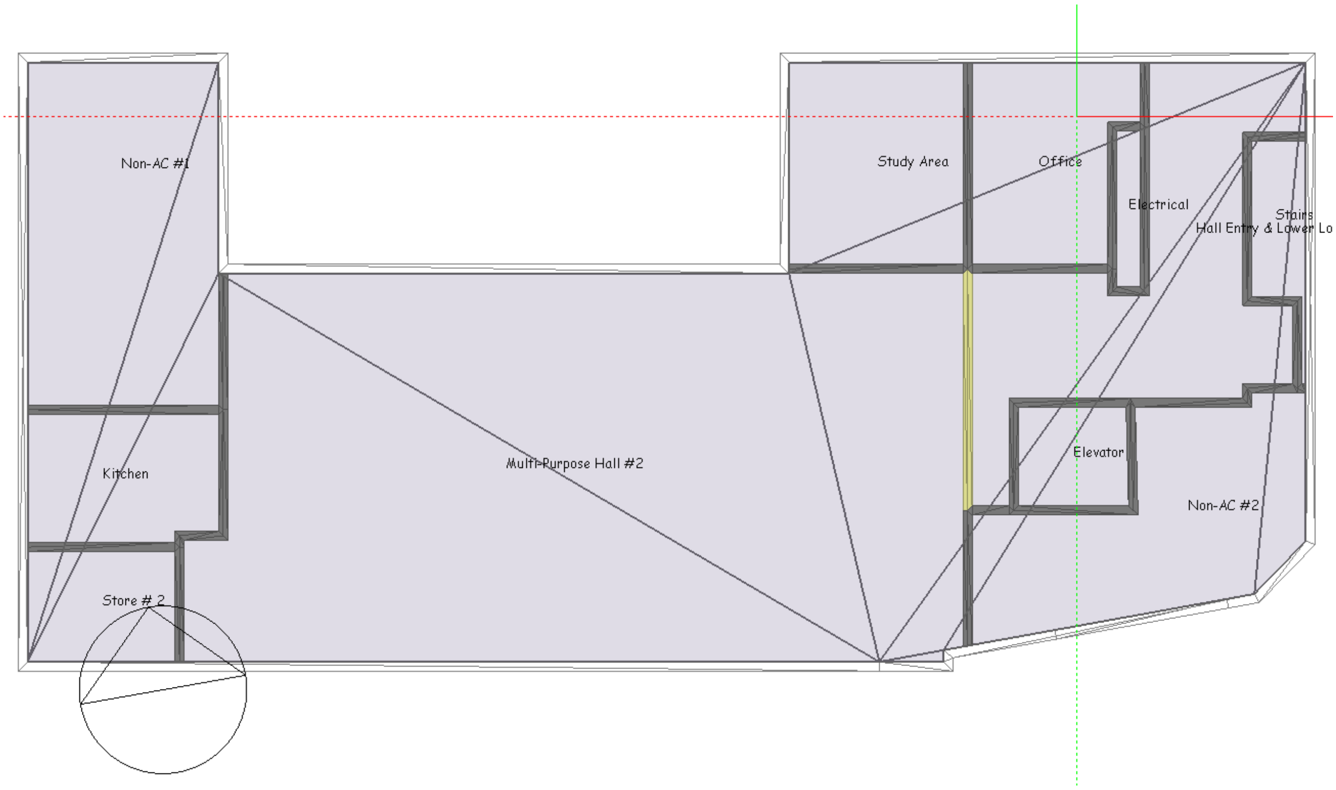


Figure 19: Zoning lower floor including virtual partitions (yellow)

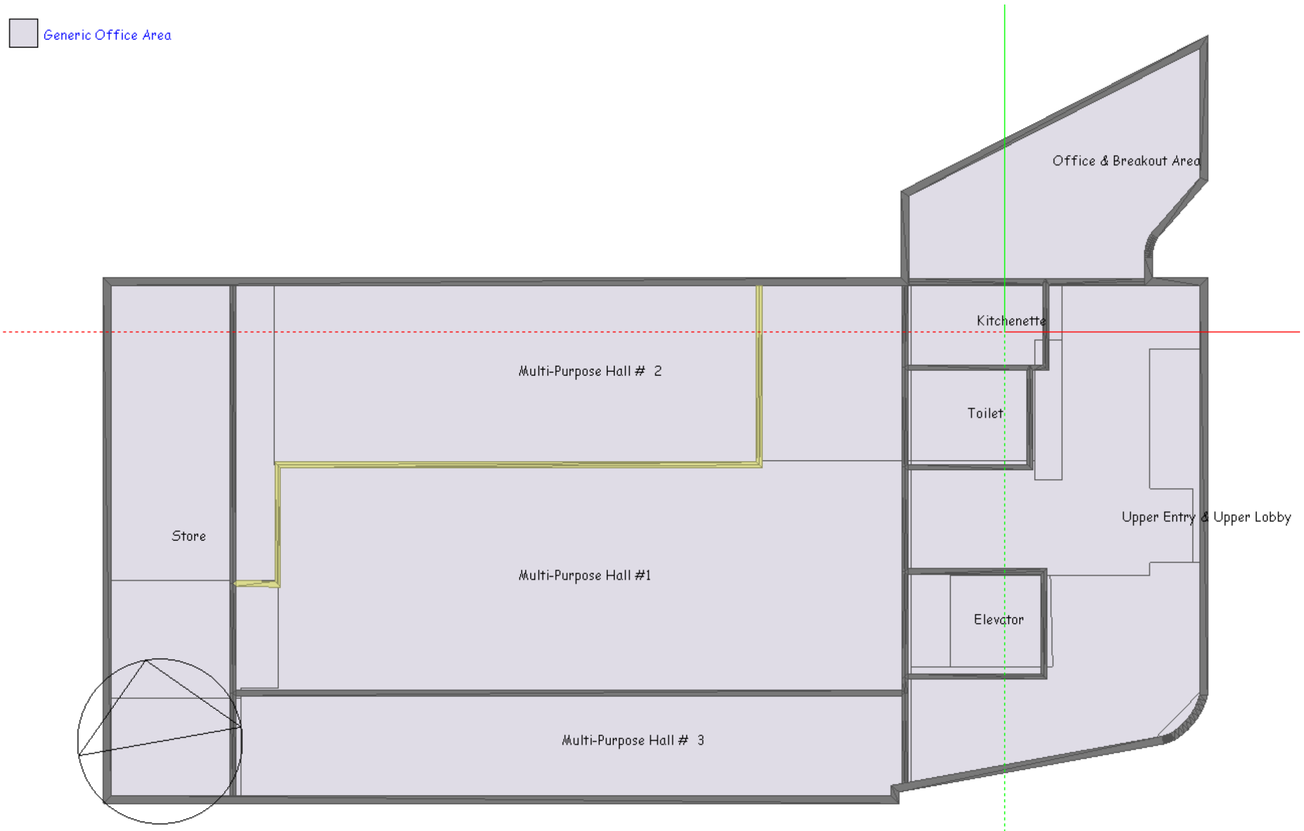


Figure 20: Zoning upper floor including virtual partitions (yellow)

Virtual partitions are used in the zoning do assign non-physical divisions, which are related to the conditioning specifics. In the lower floor the virtual partition determines the end of the underfloor heating, while in the upper floor it is important for the building fabric of the floor.

Building Fabric

In Section J of the BCA, the characteristics for the exterior walls, partition walls, floors and roofs are specified with a given R-value (resistance to heat conduction) [12], determining the rate of thermal conduction through the building element. The specific, needed, R-value is based on the climate zone of the location, which in this case is climate zone 5. This leads to the following specifications for the conditioned areas:

Table 1: R-values building fabric DTS-model conditioned areas

Building Element	R-value
Exterior Wall	2.8
Roof	3.2
Floor	1.25 (External) 1.0 (Internal)
Partition Wall	1.0

The values are set in the Design Builder software, which does not require a defined layer construction for the building elements. For the unconditioned areas the following non-insulated specifications are used:

Table 2: R-values building fabric DTS-model unconditioned areas (non-insulated)

Building Element	R-value
Exterior Wall	0.26
Roof	0.37
Floor	0.41
Partition Wall	1.0

For the unconditioned areas, non-insulated building elements are chosen. For example, this leads to a 200 mm concrete slab for the floors, which is resulting in an R-value of 0.41.

Glazing

The glazing used for opening such as windows and doors is assessed in the Building Fabric Assessment. Not only the U-values (= 1/R [12]) are of importance here, but also the Solar Heat Gains Coefficients (SHGC) (solar energy transmittance value [13]) need to be assigned as specified in the BFA. For the conditioned areas the specified characteristics as stated in the BFA are used, leading to the following table of glazing specifics:

Table 3: U- & SHGC-values for the glazing of the conditioned areas in the DTS-model

Area	Direction	U-value	SHGC-value
Multi-Purpose Hall #2	North	3.3	0.63
	South	3.6	0.63
Study Area	North	3.2	0.29
Office	North	3.2	0.29
Break-out Area	North-West	4.3	0.63
	West	3.2	0.29
	East	3.2	0.29

For the unconditioned areas, a glazing type of single glass is used, leading to a U-value of 5.8 and a SHGC-value of 0.82. More information about the glazing can be found in Appendix III: Glazing Details.

Occupancy & Schedules

A very important aspect of the building energy modelling is the occupancy of the different areas and the thereby assigned schedules. As certain areas are not used during night hours or during the weekends, no heating, cooling and lighting may be needed there at that moments.

The occupancy density changes as the use of the areas is different. For example, in an office area the occupancy density is probably higher than in a lobby area. In the AS 1668.2 – 2012 by Standards Australia, the occupancy density details are specified for different functions in accordance with the use of ventilation and air-conditioning in buildings-ventilation design [19]. This leads to the following lists of occupancy densities throughout the Heffron Hall building:

Table 4: Occupancy details for the whole building according to Standards Australia [19]

Level	Area	Occupancy Density (people/m^2)
Lower Floor	Electrical, Elevator, Non-AC #1, Non-AC #2, Stairs, Store #2	0.00
	Office, Study Area	0.10
	Multi-Purpose Hall #2	0.20
	Hall Entry & Lower Lobby, Kitchen	0.29
Upper Floor	Elevator, Store #1, Toilet	0.00
	Office & Break-out Area	0.10
	Multi-Purpose Hall #1	0.20
	Kitchenette, Upper Entry & Upper Lobby	0.29

As shown in the table above, the occupancy density is assumed different for different areas in the building. For certain areas, an occupancy density of 0.00 is assumed as usually no persons are present in this area throughout the day. Although this is not totally accurate, it is general practice to assign the occupancy in this way [10].

This maximum occupancy density is not always met in accordance with the occupancy schedule provided by the BCA. For the DTS-model, typical occupancy schedules for different building classifications are specified in the BCA [5]. The schedule for weekdays for the Class 9b areas in the building is shown in Figure 21:

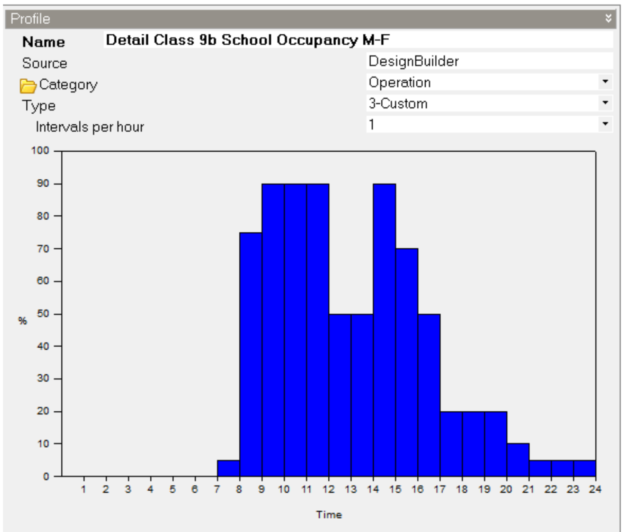


Figure 21: Occupancy schedule for Class 9b areas during weekdays (DTS-model)

These schedules are not only present for occupancy details, but as well for equipment, lighting, ventilation, heating, cooling and DHW. In a lot of cases (heating, cooling, DHW), schedules based on occupancy are used. More detailed schedules for Class 5 and Class 9b areas can be found in Appendix IV: Detailed schedules.

3.2. Proposed Fabric-model

In the DTS-model, both fabric and services are designed by using the guidelines of section J of the BCA. To investigate if the current, already built, building is compliant to the requirements of Section J, an energy modelling comparison needs to be made with the model that includes the proposed fabric with DTS services. Alterations need to be made to change the fabric of the DTS model to the proposed fabric of the already built construction. In this Section attention will be given to these changes.

In the Building Fabric Assessment of the Heffron Hall building the proposed fabric details are being presented. First, the changes to the exterior walls are extensively discussed for example purposes. For the exterior walls, two types are defined, corresponding to the two types of walls used in the building. The main type is called EW-05 and has an R-value of 3.10. The layers are assigned accordingly to the BFA as in the figure below:

Figure 22: Cross section of EW-05, main type exterior wall in proposed fabric model

For specific parts of the Heffron Hall building, another type of exterior wall (EW-03) is used. Instead of cast concrete, a brick layer is used to insulate the building with an R-value of 2.97. This can be illustrated by the following image:

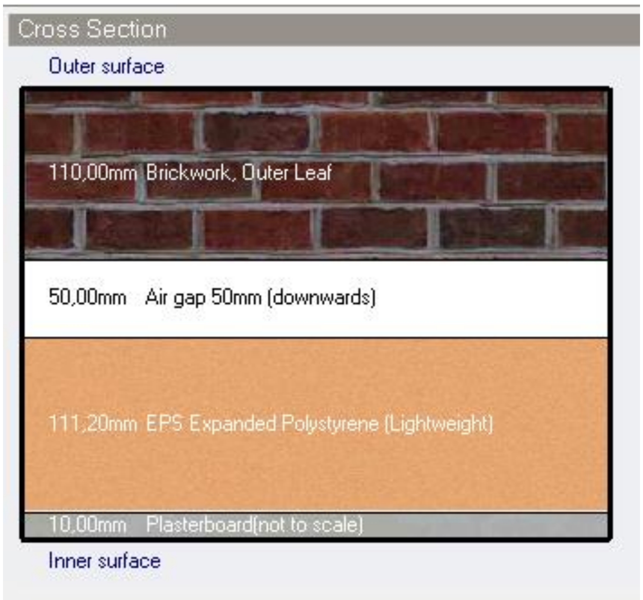


Figure 23: Cross section of EW-03

A second part of the building fabric that has been altered is the roof construction. Instead of a DTS roof with an R-value of 3.2, a roof is installed with an R-value of 4.79, ensuring less energy use through better insulation. This R-value is assigned to both flat as pitched roofs. Cross section of the roof layers can be found in Appendix V: Proposed Fabric Details.

Another building element that has different characteristics than the DTS specifications are the ground, internal and external floors. For the internal and external floors, a construction is used which has an R-value of 2.69. However, for the ground floor, the R-value is not in that order of magnitude. As the problem definition already states, the insulation in the ground floor with the underfloor heating was not installed, leading to possible problems with the Section J of the BCA. Therefore, just a concrete slab is currently present in the Heffron Hall building, having only an R-value of 0.4. Insulation losses are therefore very likely through the ground floor, leading to an enhance use of energy and particularly natural gas. Cross sections of the floor layers can be found in Appendix V: Proposed Fabric Details.

Finally, attention is shifted towards the glazing of the Heffron Hall building. In the DTS-model, already proposed glazing was used for the conditioned areas. In the proposed fabric model this is the case for all the glazing present in the building. Resulting, the values of Table 3 are valid throughout the whole building.

3.3. Proposed Services-model

The Heffron Hall building will have in reality different operational hours than the schedules assigned for Class 9b and Class 5 buildings. This directly results in other energy use patterns and energy use values than calculated in the DTS-model and in the Proposed Fabric model. Therefore, the intended occupancy hours of Heffron Hall are used for the Proposed Services-model.

The opening hours of the childcare in Heffron Hall during weekdays are mainly between 6 am to 9 am and between 3 pm to 6 pm. From 9 am to 3 pm and from 6 pm to 11 pm regularly the multifunctional hall #2 will be used for other activities. In the weekend activities are employed regularly between 6 am and 7 pm. This leads to the following occupancy schedules:

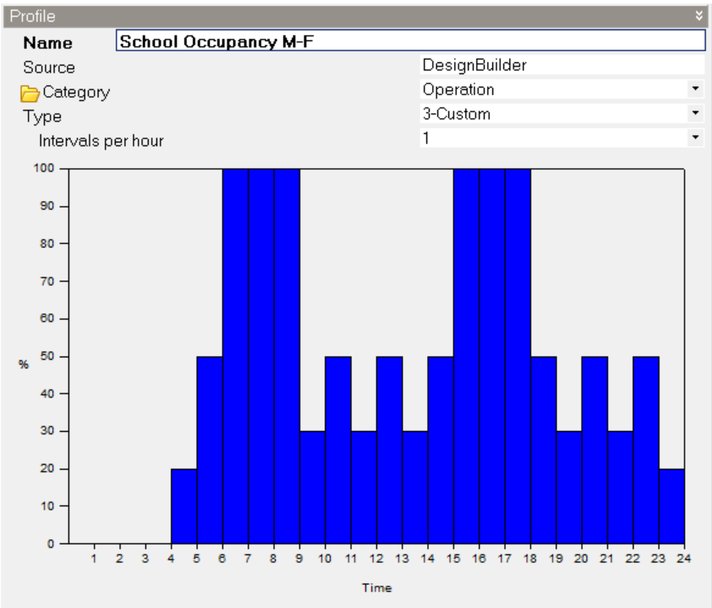


Figure 24: Occupancy of the school area during weekdays, according to intended opening hours of Heffron Hall

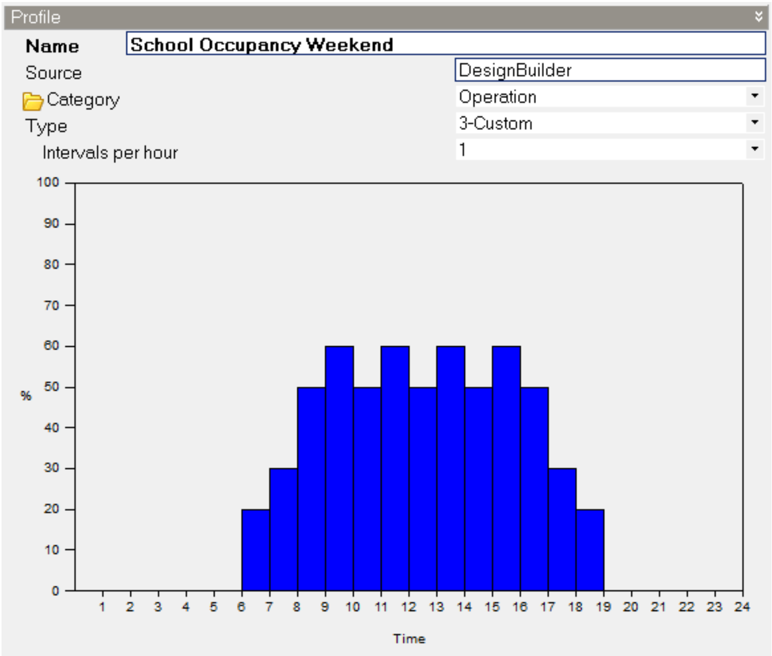


Figure 25: Occupancy of the school area during weekends

In the first figure, the peak hours are clearly visible between 6 am to 9 am and between 3 pm to 6 pm. Furthermore, the regularly use of the multipurpose hall #2 is visible with the alternating occupancy levels around 50% occupancy.

For the office areas as well as the upper floor areas, other occupancy details are assigned. The office areas schedules are mainly based on the occupancy schedules of the lower floor school areas. For the upper floor areas, a totally different occupancy schedule is present, as the opening hours are stated between 9 am and 11 pm. This results in the following occupancy schedule for both weekdays as weekends:

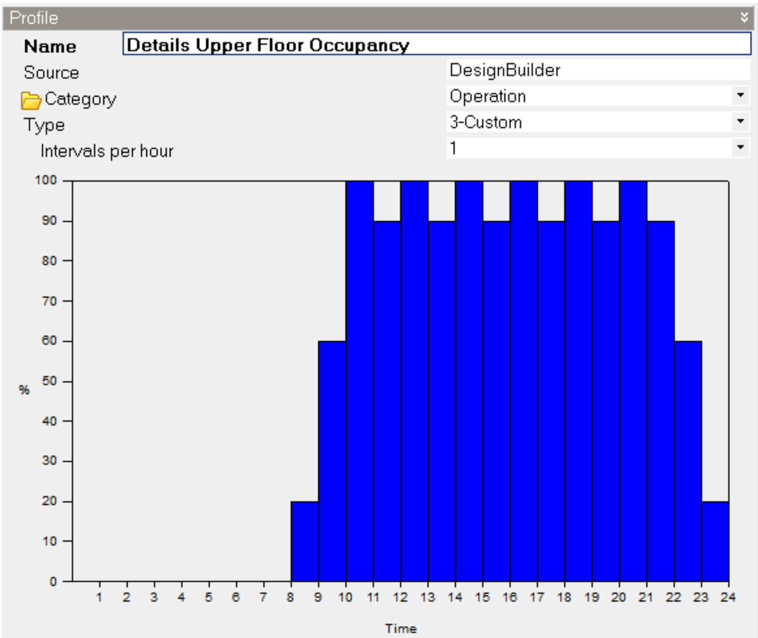


Figure 26: Occupancy of the upper floor area

Further characteristics of this model follow the Proposed Fabric-model, which includes the used fabric during construction. More detailed schedules of the Proposed Schedules-model can be found in Appendix IV: Detailed Schedules.

3.4. Heat Transfer Underfloor Heating System

In het already constructed Heffron Hall building, an underfloor heating is present in the ground floor of the Multi-Purpose Hall #2 and of the Study Area. As already indicated in Chapter 1, an important insulation layer was not installed in the ground floor, therefore leaving the ground floor uninsulated. As reinstalling the ground floor would lead to large exceedance of the budget, other solutions have to be found to find a form of insulation. The proposed solution for the insulation can be found in a so-called thermal equilibrium, in which layers beneath the underfloor heating system have already reached a sufficient temperature, causing the heat flux to mainly go up in the designated direction.

To be able to calculate the amount of time it takes to reach a thermal equilibrium in the layers below the underfloor heating, several assumptions need to be made. This is necessary as it the forecasted effect of heat loss due to lack of insulation is not efficiently modelled in Design Builder and EnergyPlus [10].

- Firstly, the characteristics of the underfloor heating are already known, with a heat flow of 100 W/m^2 at 40 °C. It is assumed that half of this heat flow will flow in the downwards direction (50 W/m^2).
- Different layers are present below the underfloor heating system. The underfloor heating system is placed in 35 mm light concrete layer with a k-value of 0.55 W/m-K, a density of 2400 kg/m^3 and a c_p-value of 880 J/kg-K. Below that, a 200 mm dense concrete layer is situated with a k-value of 1.4 W/m-K, a density of 2400 kg/m^3 and a c_p-value of 880 J/kg-K. Finally, a 500 mm ground layer is present with a k-value of 1.1 W/m-K, a density of 1600 kg/m^3 and a c_p-value of 800 J/kg-K. This leads to average values of <u>k = 1.11 W/m-K</u>, <u>ρ = 1860 kg/m^3</u> and <u>c_p = 840 J/kg-K</u> with a total length of <u>735 mm.</u>
- It is assumed that one layer is present below the underfloor heating system, with the average values given above, in order to make modelling easier with boundary conditions on end sides of the total system.
- The initial temperature conditions are set at 14 °C, while the temperature equilibrium is reached as the outer side of the lowest layer reached a temperature of 25 °C. At that moment is assumed that due to small temperature gradient at the downside of the underfloor heating system, almost all of the heat flux will flow upwards towards the room space.

With the above assumptions, the amount of time it takes to reach thermal equilibrium can be calculated. As two values of the heat flow are known, two different calculations can be made to estimate this time period. First, the amount of heat flux will be used using the following formula [20]:

$$\frac{T - T_i}{\frac{\dot{Q}}{2k}x} = \frac{e^{-\eta^2}}{\sqrt{\pi}x} + \mathrm{erf}(\eta) - sgn(\eta)$$

With

$$\eta = \frac{x}{\sqrt{4 \propto t}}$$

And

$$\propto = \frac{k}{c_p \rho}$$

Equation 8: Set of equations for the heat transfer in layers underneath underfloor heating system using the heat flux Q as input variable [20].

Using the what if-function in Excel, an estimated time period of 1,256,342 seconds is needed to reach a thermal equilibrium. With a more visual representation, this leads to the following graphs for the result in time at x = 0.735 m (outer edge of the lowest layer) and in space at 1,250,000 s (assumed equilibrium):

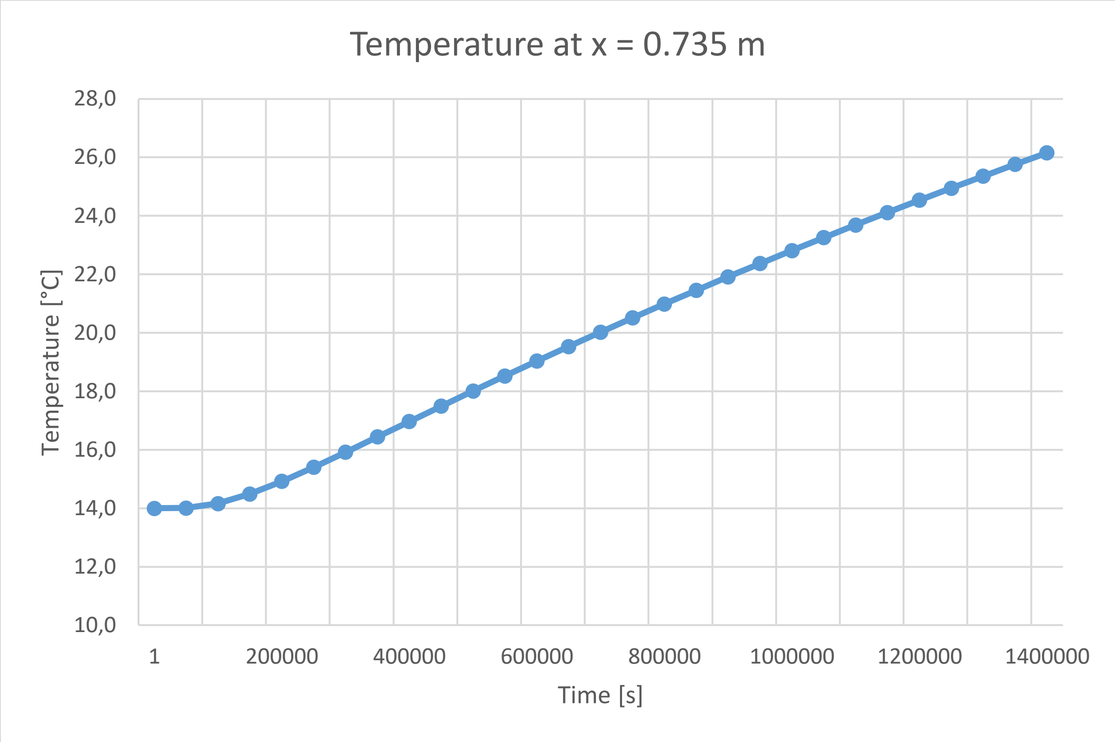


Figure 27: Rise of the temperature over time at the outer layer of the system

As visible, the system needs a short initial period to settle afterwards it steadily starts heating up. A temperature of 25 °C is reached at an estimate period of 1,250,000 seconds after turning on the underfloor heating system.

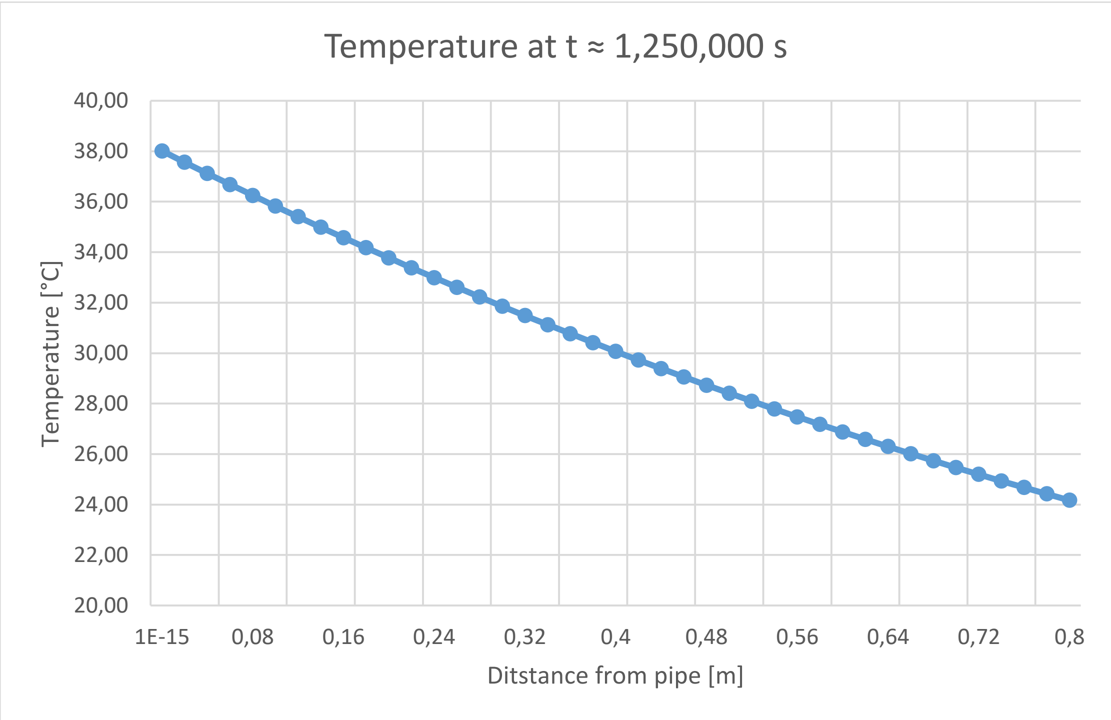


Figure 28: Temperature profile along the layers below the underfloor heating system at t = 1,250,000 s

There is a clear temperature gradient present, while this estimation also is very close to the provided temperature of 40 °C, which indicates that the formula represents the reality very accurately.

Another way to calculate the estimated amount of time is via the temperature of the provided heat of 40 °C. This can be done via the following formula [21]:

$$\frac{T - T_0}{T_1 - T_0} = 1 - \mathrm{erf}(\eta)$$

With

$$\eta = \frac{x}{\sqrt{4 \propto t}}$$

And

$$\propto = \frac{k}{c_p \rho}$$

Equation 9: Set of equations for the heat transfer in layers underneath underfloor heating system using the provided temperature of the heat flow T_1 as input variable [21].

Using the what if-function in Excel, this leads to an estimated time period of 592,439 seconds. This result is clearly lower than the result using the provided heat flux as an input. If we take a look at the graphs, the results are as following:

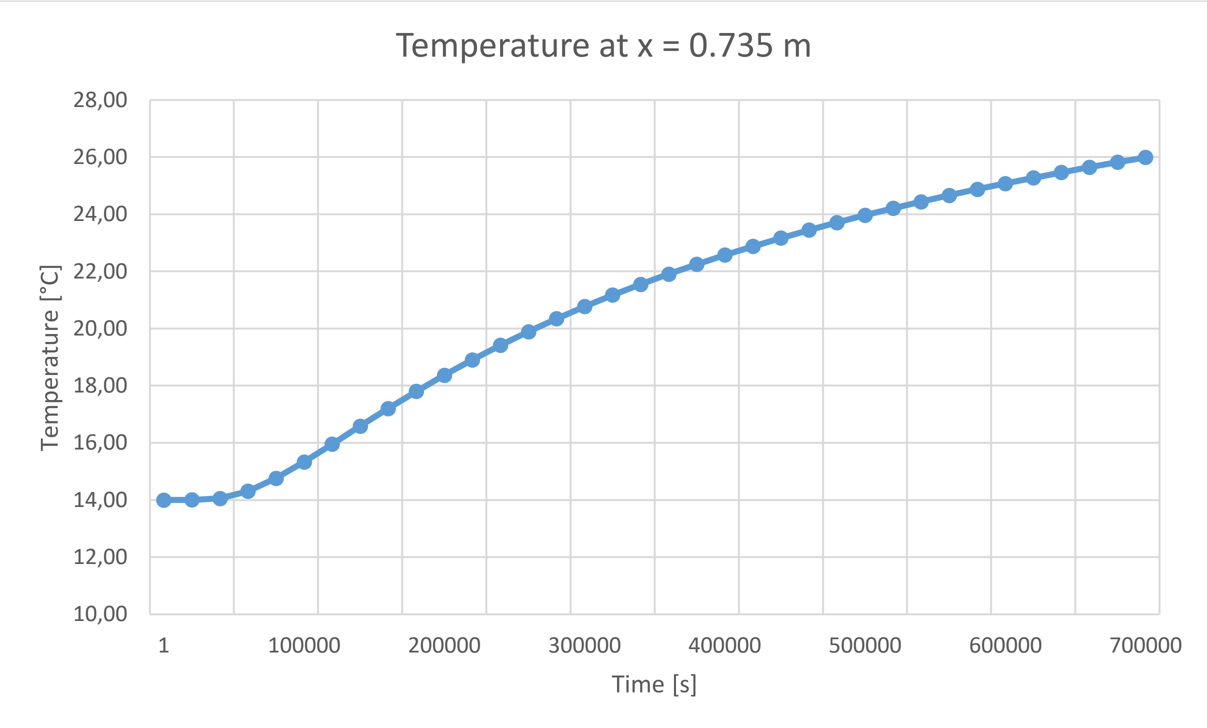


Figure 29: Rise of temperature over time at the edge of the system

This graph is looking very similar to the graph produced by using heat flux as an input. It shows as well the start-up period that the outer edge needs before the heating up really starts to take off.

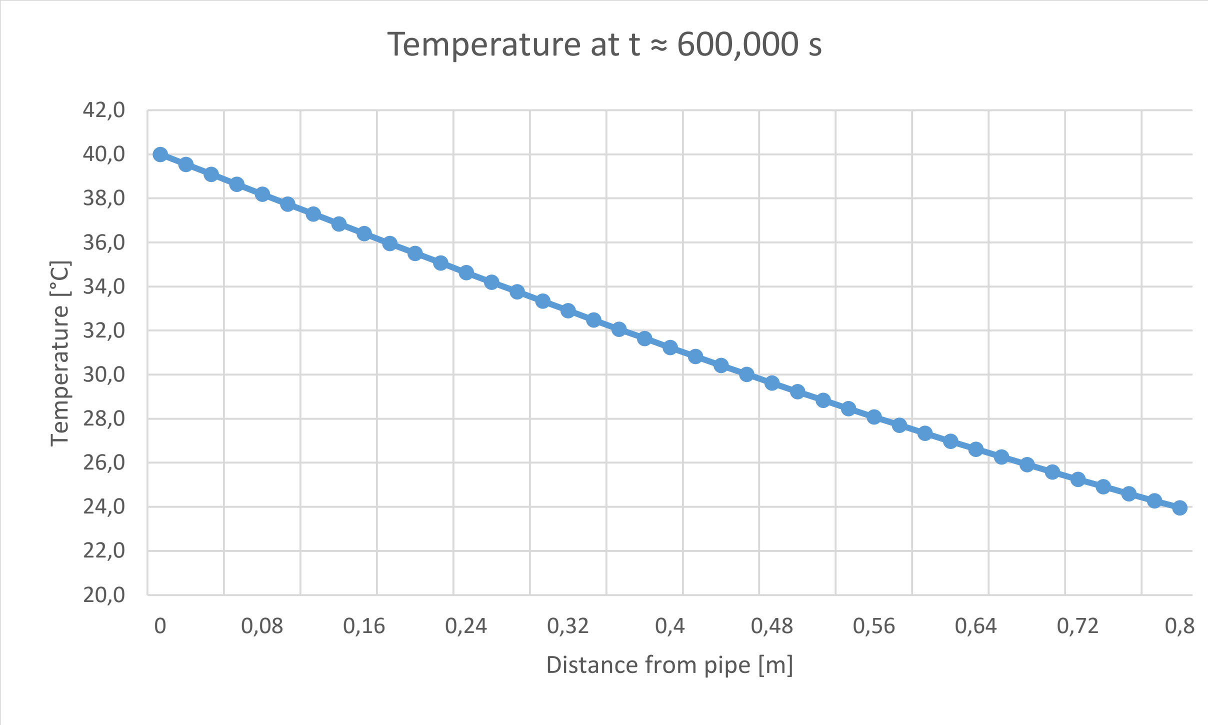


Figure 30: Temperature profile along the layers with a boundary condition of 40 °C at the inner edge

Although the previous graphs show an exact temperature profile along the system, the heat flux still is unused. It is therefore assumed that the first way of calculating the estimated amount of time for the thermal equilibrium is more reliable. As 1,250,000 seconds is close to two weeks, a period of **two weeks of preheating** is assumed to be needed before thermal equilibrium is reached and a thermal insulation is present.

3.5. Solar Potential

In Section 2.3 the solar potential for the Heffron Hall building was calculated, taking into account the 42 solar PV panels currently being installed at the roof of the building. The generated electricity can be used during the day for the lighting, equipment and other installations in the building. However, the amount of solar potential differs throughout the year, while the needed electricity during the day differs along the week. Therefore, it is important to assess the electricity profiles during several days throughout the year.

Six scenarios are to be considered, having three seasons (summer, winter, spring & autumn) and two types of days (weekdays, weekend). Most importantly are the scenarios for summer and for winter, as they provide the range of variations that can be present. First, the scenarios during the winter are assessed:

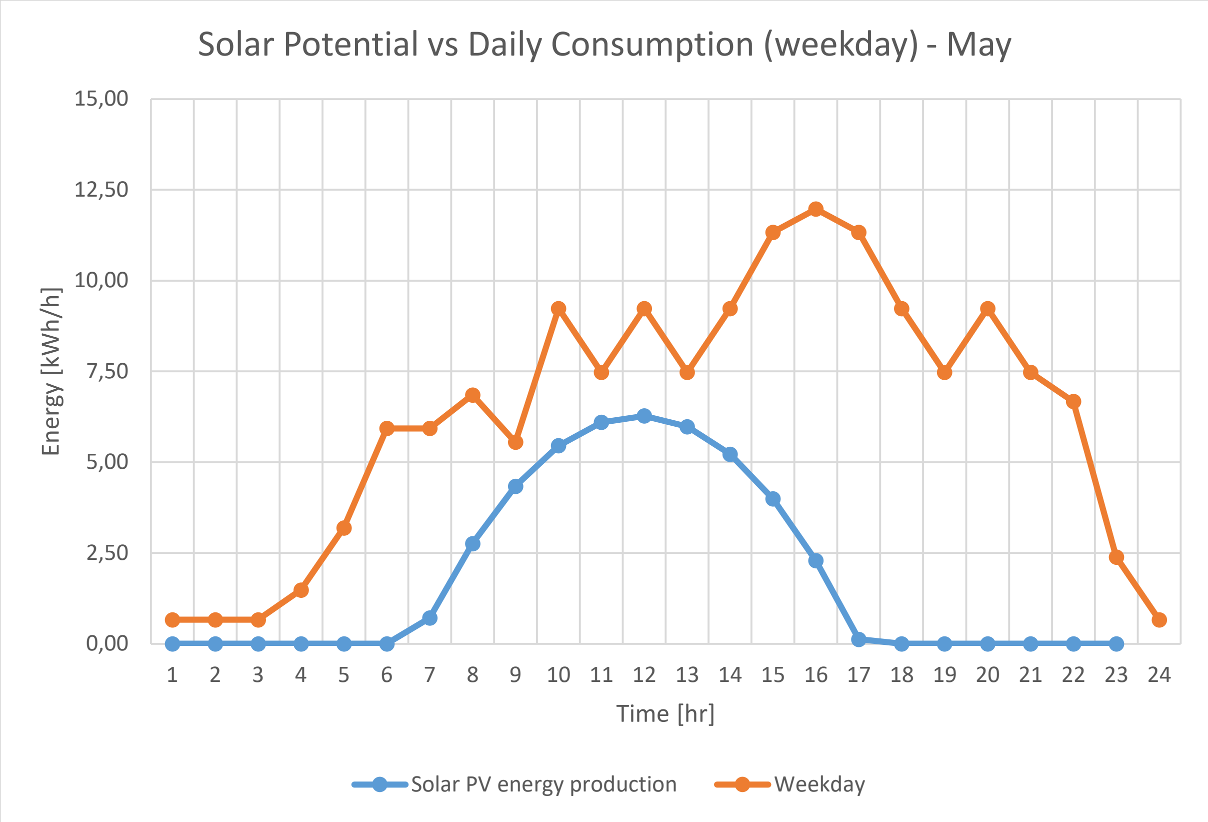


Figure 31: Solar potential plotted with the daily consumption for a winter day during weekdays

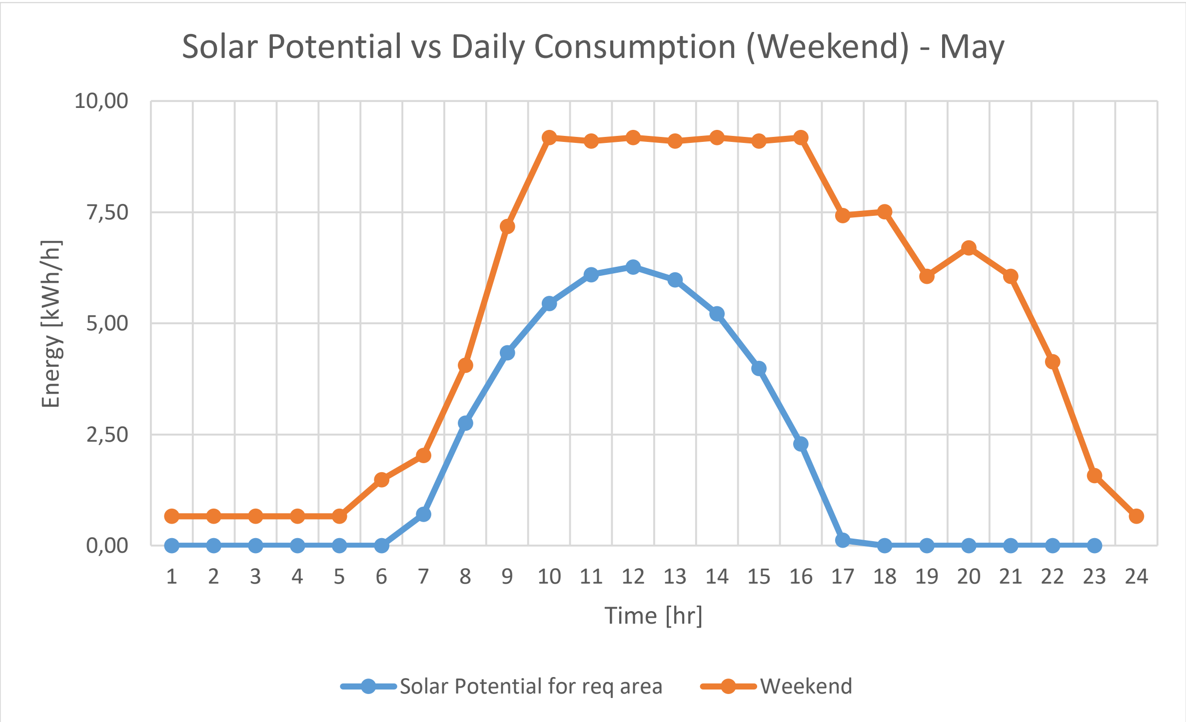


Figure 32: Solar potential plotted with the daily consumption for a winter day during the weekend

As visible in the graphs, the solar potential is at no point during the day sufficient to be able to fully replace the electricity consumption of the Heffron Hall building. However, between 9 am and 2 pm, a large part of the needed energy can be provided by the solar PV panels on the roof. If we take a look at the summer days, the patterns are similar, however the total provided electricity is higher and available during a longer period of the day.

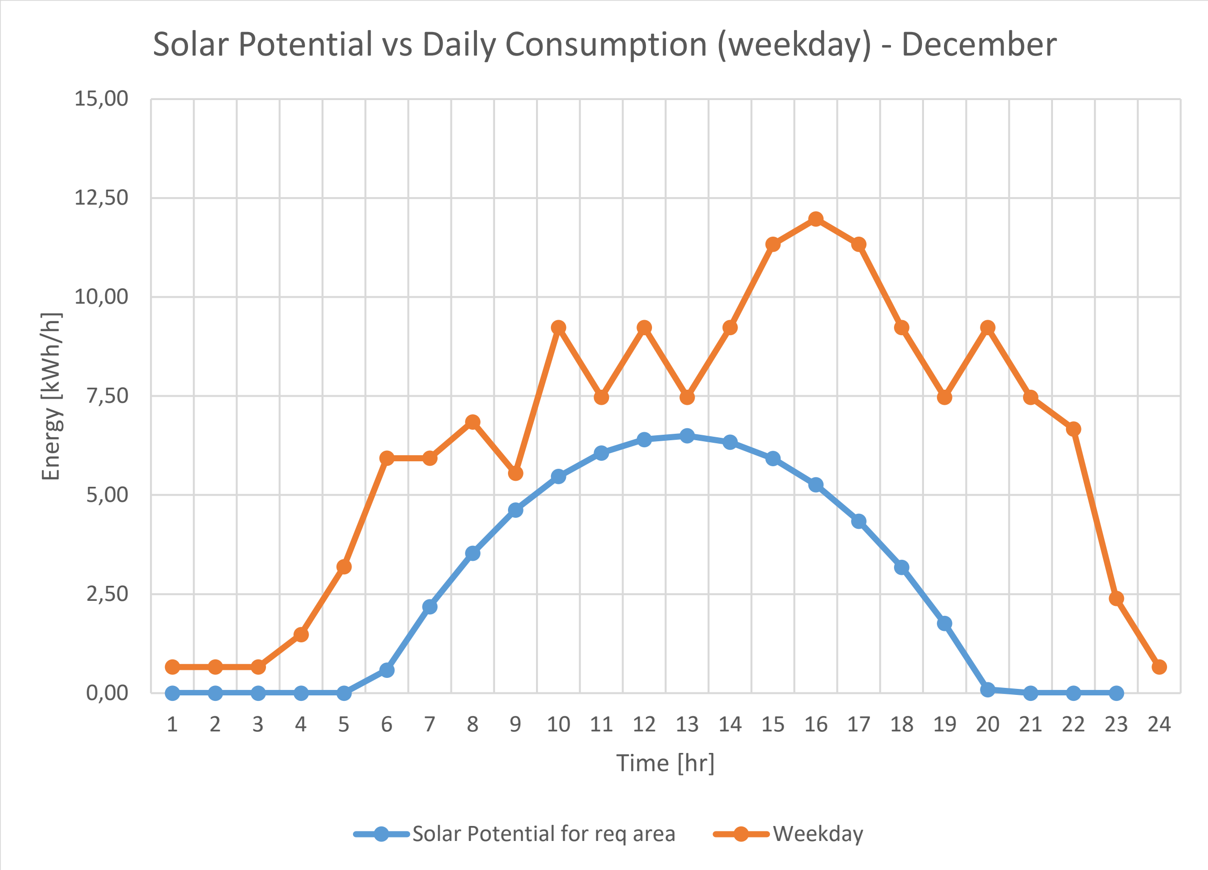


Figure 33: Solar potential plotted with the daily consumption for a summer day during weekdays

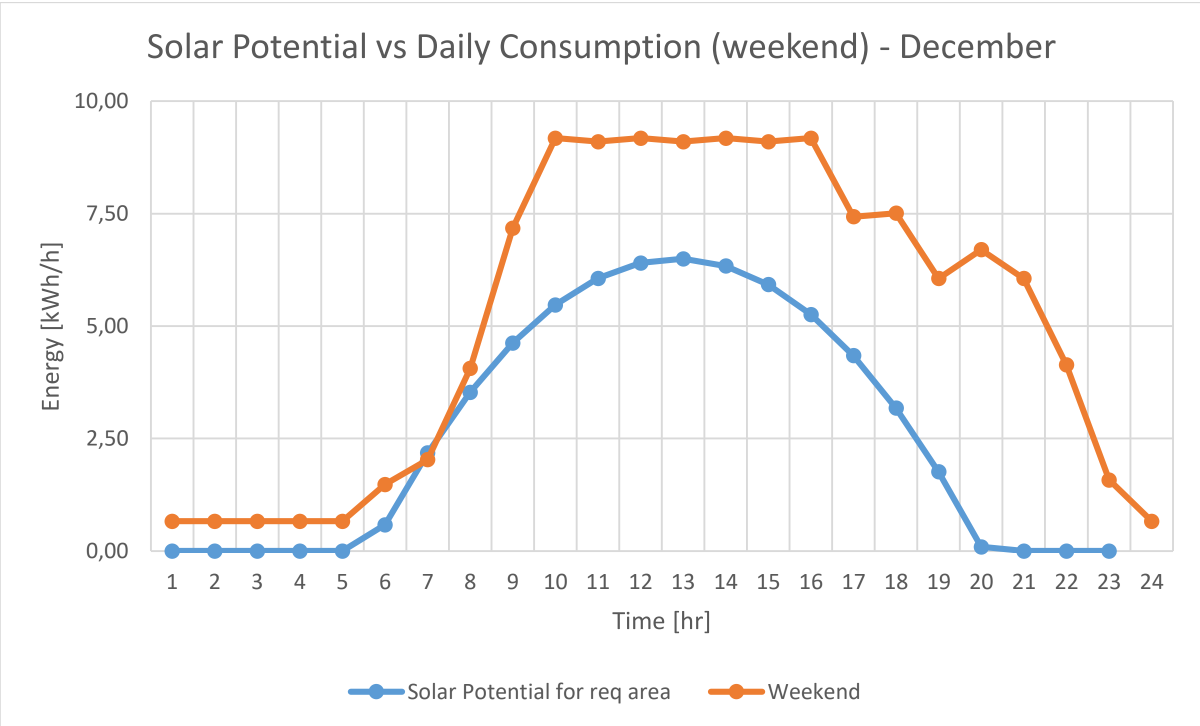


Figure 34: Solar potential plotted with the daily consumption for a summer day during the weekend

As expected, the solar potential is higher and more spread throughout the day. Still, the daily consumption is at (almost) all moments during the day higher than the potential given by the PV panels. More solar potential scenarios can be found in Appendix VI: Solar Potential Scenarios.

4. RESULTS & ANALYSIS

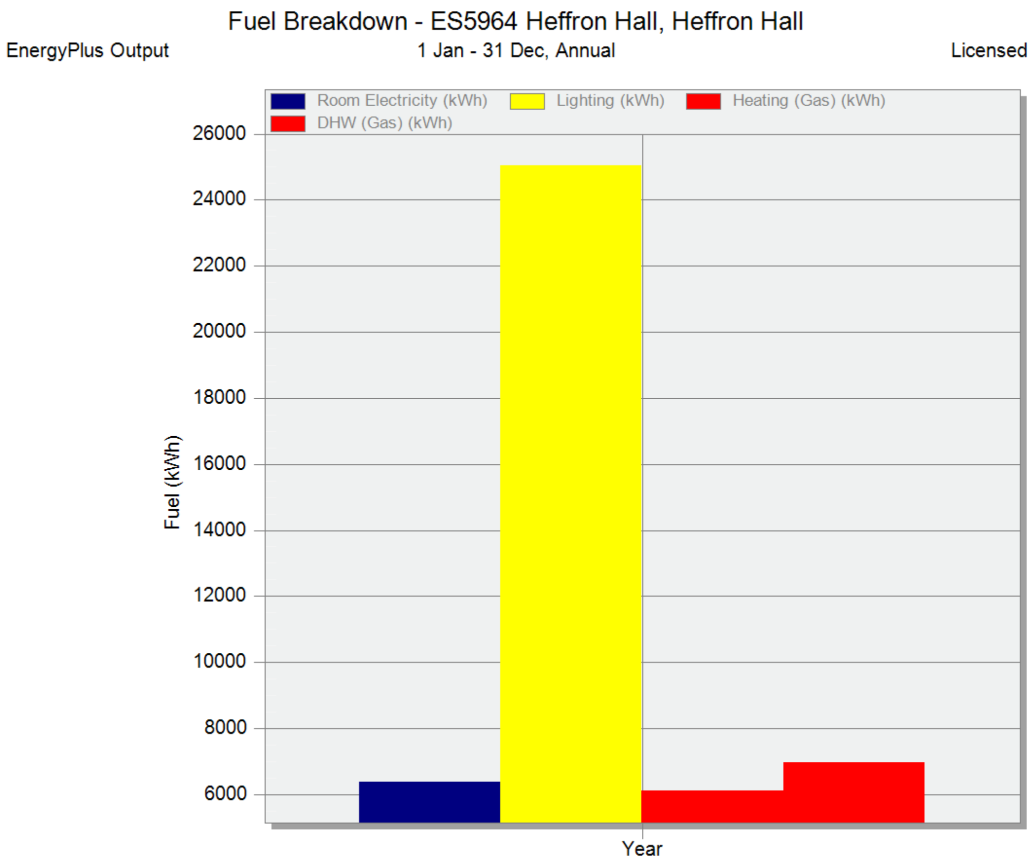
In this Chapter, the results from the model constructions will be presented and subsequently analyzed. In this analysis the sub-questions of the research will be leading. In Section 4.1, the compliance to Section J of the BCA will be analyzed by the results of the DTS-model and the Proposed Fabric-model. Following, the actual forecasted energy consumption will be presented by the use of two variations of the Proposed Services-model (§ 4.2). Finally, in Section 4.3, solutions will be provided in order to enhance the sustainability of the Heffron Hall building and compensate for the additional energy consumption due to the lack of insulation in the ground floor of the building.

4.1. JV3 Analysis

With all the models being constructed and their characteristics being specified, results from the model runs can be shown in order to investigate whether or not the current Heffron Hall building complies to Section J of the 2016 NCC. This will lead to an answer on the first sub-question:

1. "Does the current construction of Heffron Hall building comply to section J of the BCA?"

In order to answer this question, the DTS-model and Proposed Fabric-model are run and the results are compared. First, the results of the DTS-model run can be shown. Many results are available in Design Builder by using the EnergyPlus software. It has been chosen to compare the fuel breakdown output of the whole building, which gives an adequate and fast insight in the energy consumption of the building:

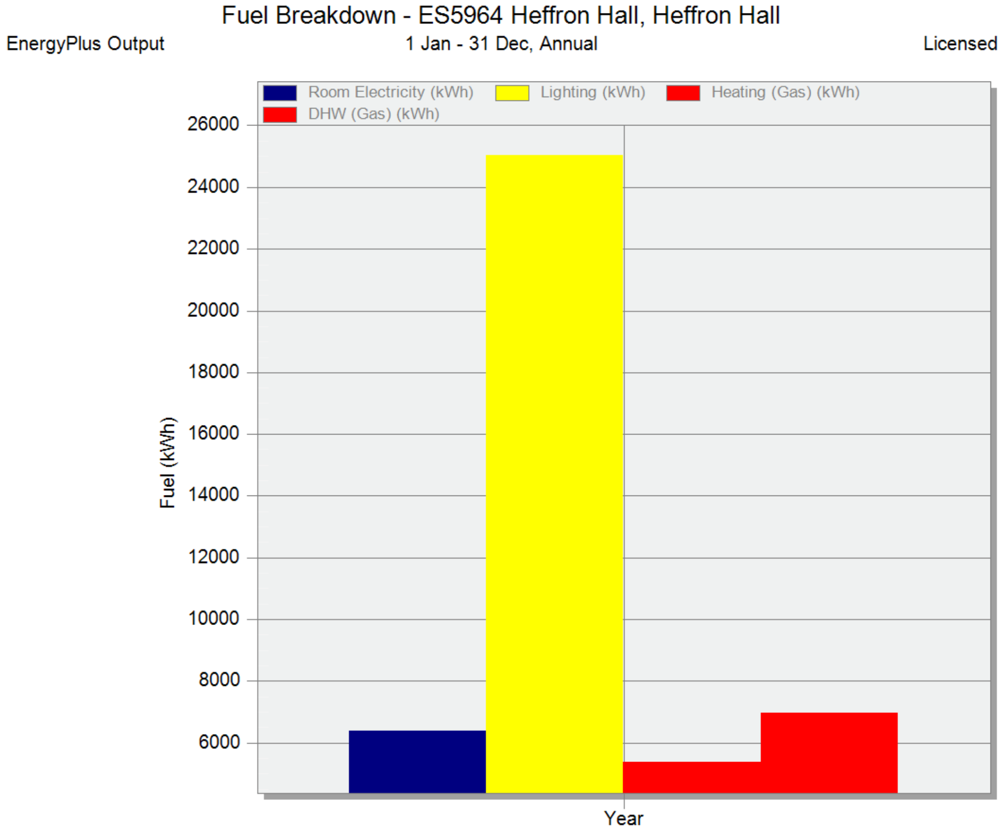


Room Electricity (kWh)	6388
Lighting (kWh)	25049
Heating (Gas) (kWh)	6105
DHW (Gas) (kWh)	6975

Figure 35: Energy consumption of Heffron Hall building with DTS characteristics

In the graph, the energy consumption of the four main activities is given. As the Heffron Hall building supplies its heat by natural gas, the heating and DHW (Domestic Hot Water) is provided by natural gas. As indicated before, no cooling is present in the whole building, therefore no output is given for that type of energy consumption. The largest part of the energy use is due to lighting, which is influenced by the Occupancy schedule and the lighting specifications.

Subsequently, the results of the Proposed Fabric-model run can be presented:



Room Electricity (kWh)	6388
Lighting (kWh)	25049
Heating (Gas) (kWh)	5367
DHW (Gas) (kWh)	6975

Figure 36: Energy consumption of Heffron Hall building with proposed fabric and DTS services characteristics

Comparing both results, it is noticeable that only one of the four main activities output has changed. This indicates that the models are similar, as with changes in building fabric the Room Electricity, Lighting and DHW outputs are not supposed to change. These outputs are dependent on the service schedules, which in both runs are DTS based. However, the energy use for heating purposes has changed due to the changes in fabric.

With a lower result in heating energy use, the Heffron Hall building consumes less energy in its already constructed form than with DTS-characteristics. This results in the fact that the constructed building performs better than the guidelines from Section J of the BCA and therefore **complies to Section J**. A large factor in this results is the better insulation of exterior walls and roofs, compensating for the lack of insulation in the ground floor.

Furthermore, it is noticeable that lighting is the highest contributor to the energy use of the Heffron Hall building. In the JV3 analysis, no further attention is given to this fact, but several suggestions can be made regarding this fact. With lighting being such a large part of the total energy use, it could be beneficial using energy reducing measures in order to lower the lighting energy use. This could be found in the use of sensors, different types of lighting or the use of dimmers.

4.2. Energy Modelling Analysis

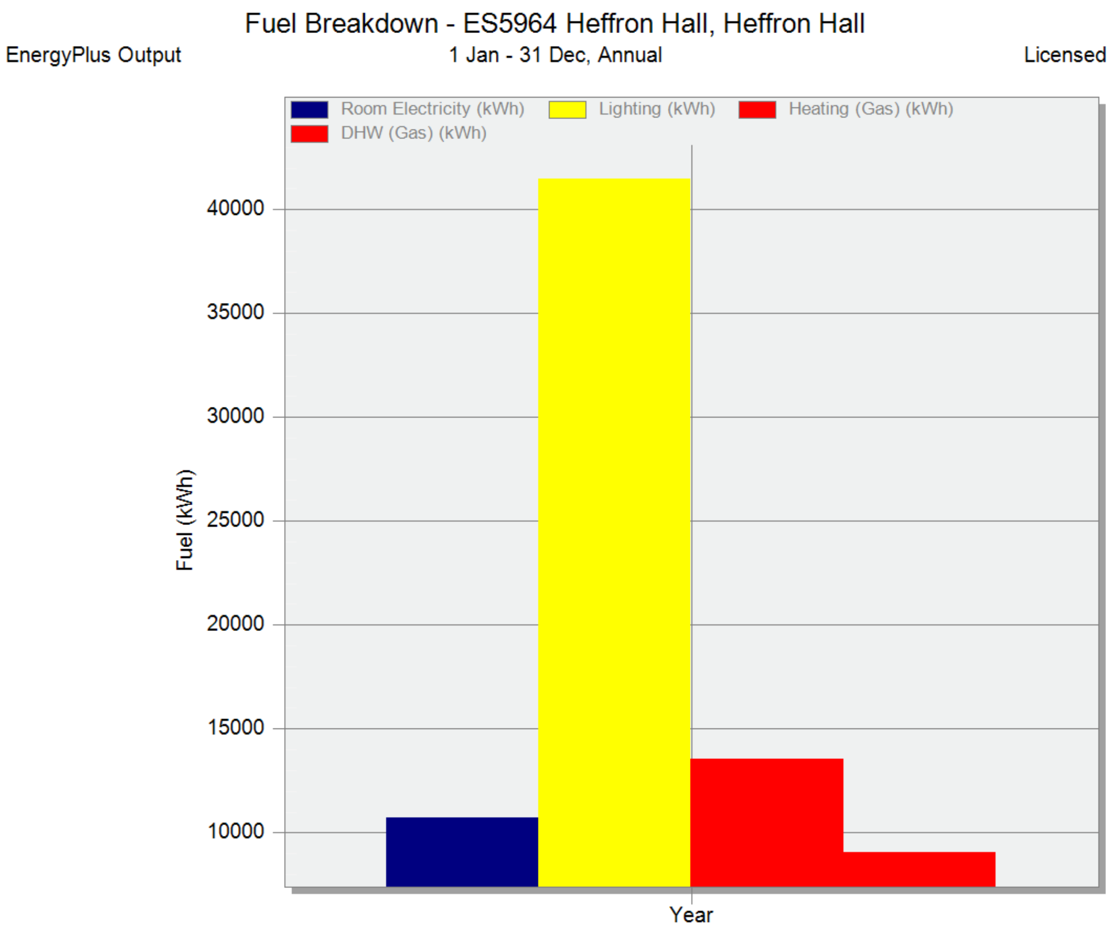
Having the knowledge that the current, already being constructed, Heffron Hall building is compliant to Section J, attention is shifted towards the real energy consumption of the building. As stated in Chapter 3, the Section J comparison relies solely on DTS-services, which is not representing the reality. To be able to assess the actual energy consumption, the Proposed Service-model needs to be run. This will directly provide an answer for the second sub-question of this research:

2. "What is the actual energy consumption of the constructed Heffron Hall building and what amount of energy needs to be compensated due to the lack of insulation in the ground floor slab?"

In Chapter 1, the lack of insulation in the ground floor of the Heffron Hall building is stated. Due to this fact, uncertainty arose about the sustainability and the compliance to Section J of the building. In order to assess the additional energy consumption due to the lack of insulation, two Proposed Services-models are run.

- A Proposed Services Base-model in which the "forgotten" insulation is present. This model represents the building as it should have been.
- A Proposed Services-model without the insulation, representing the current reality of the Heffron Hall building and showing the additional energy consumption of the building.

Using these models, the following results are obtained. First, the Proposed Services Base-model:

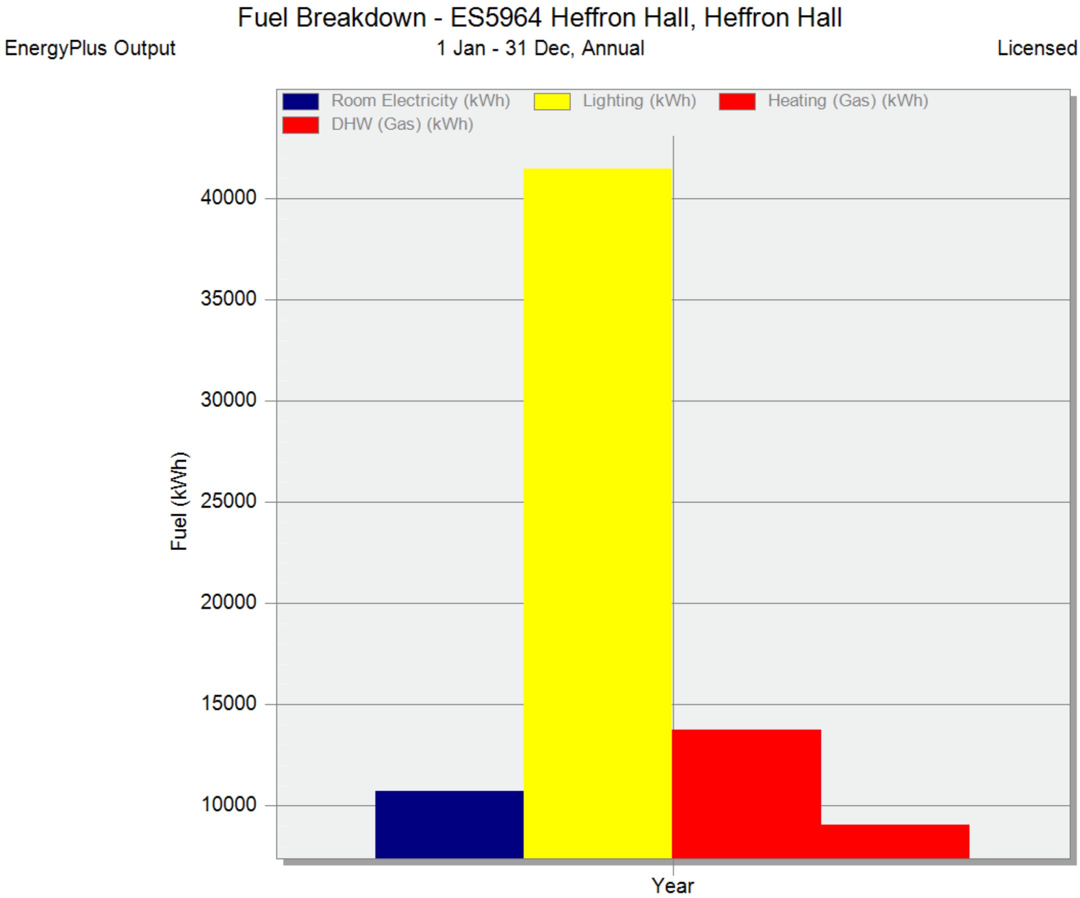


Room Electricity (kWh)	10698
Lighting (kWh)	41495
Heating (Gas) (kWh)	13539
DHW (Gas) (kWh)	9038

Figure 37: Energy consumption of Heffron Hall building with Proposed Services and ground floor insulation

Due to the service schedules being more extensive, the total energy consumption of the building is significantly higher than in the DTS-services model runs. Also, lighting still is the largest contributor to the energy consumption.

Secondly, the results of the Proposed Services-model without insulation can be presented:



Room Electricity (kWh)	10698
Lighting (kWh)	41495
Heating (Gas) (kWh)	13770
DHW (Gas) (kWh)	9038

Figure 38: Energy consumption of the actual Heffron Hall building with Proposed Services

When a comparison is made of Figure 37 and Figure 38, it is clear that only a difference energy consumption is visible in the Heating energy section. As both models use the same service schedules (Proposed Services) and differ in the insulation in the ground floor, this result is logical. The difference caused by the lack of insulation is estimated at **231 kWh/year**.

However, the above result is not the only difference in energy consumption. The models above do not take into account the thermal equilibrium needed for the underfloor heating system. This equilibrium and its characteristics is explained in Section 3.4. In that Section it is also stated that a period of about two weeks is needed to preheat the layers below the underfloor heating system and create a thermal equilibrium. It is assumed that, in order to create enough heat transfer into the layers below the system, the system needs to be turned during half of that period [10]. With the heat for the underfloor heating system being provided by an 18 kW boiler, the amount of energy needed to obtain a thermal equilibrium is estimated at 2,592 kWh. Due to the fact that preheating is only needed for one period in a year, at the beginning of fall, before needing any heating in the building, this leads an additional energy consumption of **2,592 kWh/year**.

This leads to a total additional energy consumption of **2,823 kWh/year** or **10,163 MJ/year** at a cost of **$ 295** (0.029 $/MJ average gas price in NSW [22]). Subsequently, as natural gas is used for the heating purposes in the building, an amount of **0.66 ton of extra CO_2** is emitted due to the lack of insulation. This is an additional energy consumption that needs to be compensated, both in sustainable as in financial ways.

4.3. Potential Energy Off-sets

As stated in Section 4.2, a compensation is needed for the additional energy consumption of natural gas due to the lack of insulation in the ground floor of the Heffron Hall building. As the construction has already been built and installations have been installed, altering the insulation and fabric characteristics is not a viable option. However, the building has a solar PV installation on the roof, consisting of 42 solar PV panels (71.4 m^2). Using the generated electricity of the solar PV panels can reduce the amount of energy needed and also have a positive impact on the total emissions emitted. This will consequently provide an answer for the final sub-question:

3. "What solution is proposed to make maximal use of the renewable energy potential of Heffron Hall?"

If another look is given to the solar potential pattern and the daily electricity consumption pattern, several things are noticeable. In the figure below, it is clear that the largest amount of electricity is generated before 2 pm, while the largest amount of energy is needed after 2 pm. Furthermore, the electricity tariffs in the state of NSW state that there is shoulder tariff between 7 am and 2 pm (0.222 $/kWh) and a peak tariff between 2 pm and 8 pm (0.464 $/kWh) [23]. Also, the feed-in tariff for domestic generated solar electricity is 0.06 $/kWh [24]. More information about the energy tariffs can be found in Appendix VII: Detailed Energy Tariffs.

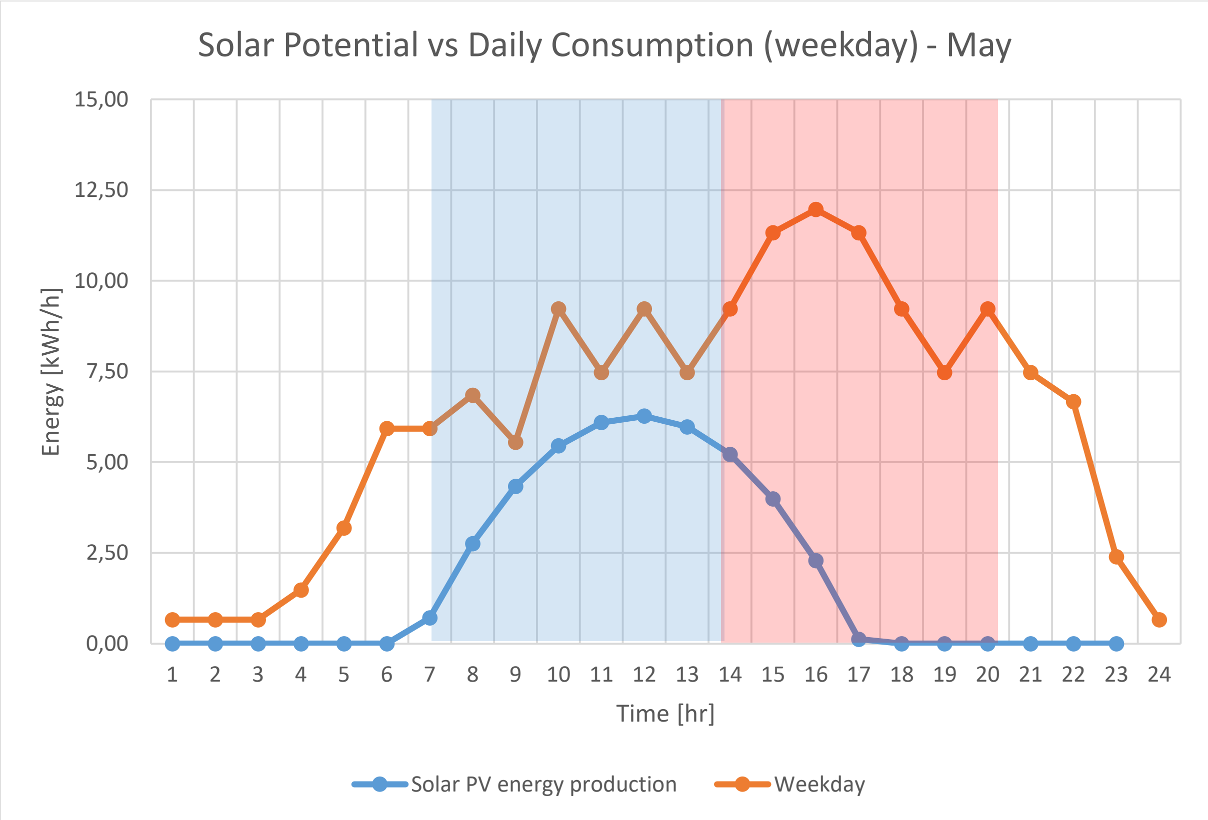


Figure 39: Solar potential and daily consumption patterns, with shoulder electricity tariff (blue area) and peak electricity tariff (red area)

As these tariffs are known, it might seem a good idea to directly use the generated electricity of the solar PV panels, therefore reducing the electricity used during the daytime and generating income at the feed-in tariff. However, due to the large difference in costs between the shoulder tariff and the peak tariff, possibilities arise to create more and longer-term benefits.

With **a battery storage system**, the electricity generated during the shoulder tariff period could be used during the peak tariff period, saving 0.242 $/kWh. As one battery storage system (type: Tesla PowerWall or equivalent) is considered, an amount of 13.5 kWh/day can be stored and used during peak hours (note: 13.5 kWh/day is the usable capacity). This leads to a maximum amount of **4.93 MWh/year**, resulting in saving a maximum of **1,192 $/year** in electricity costs. Also, the peak demand of the Heffron Hall building will be decreased, reducing the costs for peak demand electricity costs. It is assumed that the peak demand will decrease by 1 kW on average (0.37 $/kw), leading to an additional cost reduction of **135 $/year**. This results in a total maximum saving in electricity costs of **1,328 $/year**.

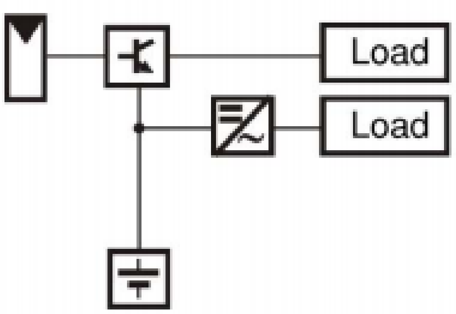


Figure 40: Suggested solar hybrid system with battery storage [18]

In the current construction of the Heffron Hall building, no storage system is installed. Therefore, a storage system needs to be purchased in order to be able to generate the above calculated savings. Currently, the retail prices of the Tesla PowerWall (or equivalent) is around **$ 8,000**, which results in a payback time for the storage system of a little more than five years. With the extra heating costs by natural gas heating being of $ 295 being considered, the total payback time will amount around 7 years and 9 months. Past that moment in time, the installation will provide profit for the owners. With a given warranty of 10 years and a probable life span of at least 15 years, this option is possible very profitable for the Heffron Hall building owners.

With the solar potential during the daily period of 9 am to 2 pm of 28 kWh, it is possible to employ another Tesla PowerWall (or equivalent) in order to fully maximize the solar potential. However, this involves double the investment costs thus leading to higher risks. At this moment, the solar PV installation still has to prove its potential, therefore it is recommended to evaluate the performance of the storage system with one Tesla PowerWall first, before going further with fully making use of the solar potential.

As earlier mentioned, the lighting electricity consumption is the largest factor in the total building energy consumption. Establishing a reduction in this area would contribute largely to reducing the total energy consumption. It is estimated that using **a daylight sensor system** for lighting adjacent to windows will reduce the operating hours of this lighting by 1300 hours per year. This results in a saving of **500 kWh/year** and a financial saving of **$ 170 per year**. The installation costs for the daylight sensor-system are estimated around $ 2,500, which results in a payback period of 14.7 years. Additionally, it reduces the emission of CO_2 by **0.52 ton/year**, almost eliminating the extra emissions due to the lack of insulation. This is a very important result, as one of the main wishes of the clients was to reduce the additional CO_2 emission caused by the additional energy consumption.

Furthermore, another effective solution is **the addition of two solar PV panels** to the current solar PV system on top of the Heffron Hall building. The purchasing and installment costs of these two solar panels would amount an estimated $ 1,000, while the annual financial benefits account for **$ 209** resulting in a payback period of 4.8 years. More importantly, the reduction of CO_2 emissions is estimated to be around **0.77 ton/year**, resulting in totally eliminating the initial additional emissions. Also, it provides incentive to, if the first battery storage system is successful, install and operate a second battery storage system and creating an even more self-sustainable building.

Finally, another considered option was reinstalling the ground floor with insulation. However, as mentioned, it was not preferable to make any more changes to the construction and the fabric of the Heffron Hall building. Also, this is not a viable option as the demolishment of the current ground floor and installation of a new ground floor would lead to excessive amounts of additional financial and environmental costs. Therefore, this option is considered to be unviable under all circumstances.

5. CONCLUSIONS

In this chapter the conclusions will be presented, coming from the Heffron Hall building project executed by Blue Green Engineering. In Section 5.1 the general conclusions will be drawn, based on the insights given in the previous chapters. Subsequently, in Section 5.2 the recommendations for the project management team of Heffron Hall will be provided, helping them find a sustainable way of solving the forgotten insulation problem. Finally, in Section 5.3 the project and the report will be discussed, paying attention to uncertainties, assumptions and possibilities for further research.

5.1. Conclusions

In order to find compliance with Section J of the BCA, four different Design Builder models are built. The Design Builder models provide an interface to use the dynamic thermal simulation engine of EnergyPlus. Using the first two constructed models (DTS-model & Proposed Fabric-model) it can be concluded that the current construction of the Heffron Hall building **complies to Section J**. Due to the insulated exterior walls, roofs and the designated glazing, the lack of ground floor insulation is compensated with as result that the energy use of the building is lower with the current construction than with a construction following the guidelines of government of NSW. To be more specific, a difference of 738 kWh/year is present in the heating energy consumption in favor of the Proposed Fabric-model.

Table 5: Overview of the total energy consumption of the DTS- and the Proposed Fabric-model, indicating the <u>compliance</u> to Section J.

Energy type	DTS-model	Proposed Fabric-model
Electricity (kWh/year)	31,437	31,437
Natural gas (kWh/year)	13,080	12,342

Secondly, the forecasted energy consumption of the Heffron Hall building is modelled, using two models. One model provides the baseline, in which the ground floor insulation is present, while the other represents the actual construction. Using Proposed Services in both models leads to an energy consumption difference, which has to be compensated. Following the model runs, the additional annual energy consumption due to the lack of insulation amounts **2,823 kWh/year** or 10,163 MJ/year in natural gas. The total amount of additional energy consumption is built up out of two parts. Firstly, there is the extra energy consumption as part of the energy dissipates by the uninsulated ground floor (231 kWh/year). Secondly, due to no present insulation, the underfloor heating system needs a preheating period (two weeks) to reach a thermal equilibrium in order to prevent huge losses while operational (2,592 kWh/year).

Table 6: Illustration of the additional energy consumption due to lack of insulation in the ground floor.

Energy type	'Base' model	'No insulation' model
Electricity (kWh/year)	52,193	52,193
Natural gas (kWh/year)	22,576	22,576
Relative insulation losses (kWh/year)	-	231
Preheating (kWh/year)	-	2,592

The additional energy consumption results in $ 295 extra annual financial costs and extra carbon emissions of 0.66 CO_2 ton/year. The lack of insulation therefore not only leads to additional, unnecessary energy consumption, but as well to unacceptable higher financial and environmental costs.

To be able to compensate these additional costs, several options are analyzed. Using the current construction and the wish from the project management team of Heffron Hall to not make changes to the current construction, the solution with the largest potential involves making effective use of the already present solar PV panels on the roof of Heffron Hall. With the current 71.4 m^2 solar PV setup and an additional investment of $ 8,000 for **a battery storage system** (Tesla PowerWall), the electricity generated from 9 am to 2 pm can be used between 2 pm and 8 pm when the energy tariffs are significantly higher. This leads to a net saving of 1,035 $/year and a payback period of less than 8 years for the storage system. With a guaranteed warranty of 10 years for the storage system and 15 years for the solar PV panels, it is obvious that the solution is both environmentally beneficial as profitable.

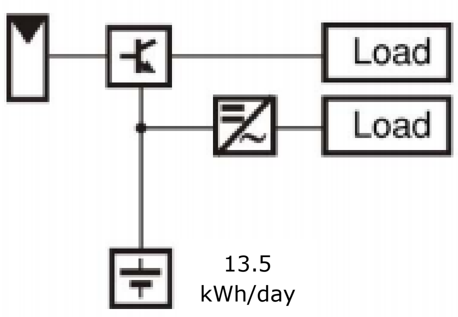


Figure 41: Preferred solution with 13.5 kWh/day battery storage and 2 additional solar PV panels [18]

Considering the other options, the use of **daylight sensors** for the lighting is a viable option, which will lead to additional savings of 500 kWh/year, 170 $/year and 0.54 CO_2 ton/year. Furthermore, it is suggested to **add two solar PV panels (3.4 m²)** to the current system in order to totally eliminate the additional CO_2 emissions caused by the additional energy consumption. Installing these two solar PV panels leads to an estimated to financial benefits of 207 $/year and a reduction in CO_2 emissions of 0.77 ton/year. With respect to the reinstallation of the insulation in the ground floor, it can be concluded that there is no need or wish to make any changes to current fabric of the construction. Also, the costs would be excessive and exceeding the benefits. Therefore, this option is disregarded.

The solutions mentioned above shape the sustainable solution for the Heffron Hall building, in order to compensate the lack of insulation in the ground floor. The current construction complies to Section J and therefore needs no radical changes. Furthermore, the solar PV potential provides the Heffron Hall building with all the tools to improve the sustainability of the building and lower its fossil fuel energy consumption.

5.2. Recommendations

Before the project management team of Heffron Hall consulted the team of Blue Green Engineering, the main focus was to replace the ground floor of the building without a large excess of the current budget as they were convinced the current construction was not compliant to Section J of the BCA. However, as stated in the conclusions the construction is compliant and therefore does not need any alterations to the current fabric. It is recommended that the current construction stays in place, in order to avoid unnecessary financial and environmental costs. Also this will lead to a sooner delivery of the final construction and more societal benefits as Heffron Hall is a multi-functional building.

Furthermore, it is advised to consider an additional investment in a battery storage system in order to be able to store the generated electricity by the solar PV system. Although a battery storage system represents a large investment, it is quite certain that it will lead to high financial benefits on the long term. Also, if this storage system is a success, it would be a good option to consider an additional Tesla PowerWall (or equivalent) to double the capacity of the storage. The solar potential available amounts 27 kWh/day in electricity and therefore the financial savings and the sustainable impact can be (more than) doubled.

It is also recommended to install perimeter daylight sensor systems in order to reduce the electricity costs of lighting purposes and reduce the CO_2 emissions. This is a cheap and very efficient solution, adding more savings and environmental benefits to the total solution. However, this solution cannot stand alone in order to compensate the additional energy consumption due to the lack of insulation. This accounts as well for the suggested solution to install two additional solar PV panels to the current system. Although these solar PV panels cannot undo the additional energy consumption, they provide a total reduction in CO_2 emissions and therefore are a vital addition to the total solution. It is recommended to install these additional solar PV panels as they can also provide an incentive to increase the battery storage capacity (and install a second PowerWall) in future years.

After instalment of the above solutions, there is a strong need for monitoring and evaluating the setup. It is advised to evaluate the financial, energy and environmental savings every half year in order to assess whether or not the solutions live up to the expectations. Although it is concluded that the storage system will provide large benefits, solar energy remains intermittent and can fluctuate a lot. Also, the operations of the storage system should be monitored closely in order to be able to access the full capacity of the system and therefore reap the maximum amount of savings and benefits. Furthermore, the models represent an estimation of the reality and not the reality itself. Close monitoring of the actual energy consumption is therefore necessary and using these data in order to assess possible improvements is advisable.

Finally, it is recommended to further investigate the possibilities of domestic solar PV panels in combination with battery storage systems in order to lower the peak electricity demand in urban areas. As illustrated by this project, the energy consumption is usually larger in the evening period while the solar potential is present during the daytime. Therefore, local storage systems could have a large influence on the peak demand, resulting in smaller dimensions for electrical power systems.

5.3. Discussion

As the assessment of the compliance of Heffron Hall and the estimated annual energy consumption is based on several models in Design Builder using the EnergyPlus engine, assumptions are a large part of the involved calculations. It is important to critically assess these assumptions as well as other parts of the suggested solution.

First of all, the annual energy consumption of the building is based on the average yearly weather conditions for the Sydney center site, which obviously can fluctuate a lot between years, Therefore, the annual energy consumption values are more an estimation than a solid prediction. Also, as explained in Chapter 2, the models are based on the dynamic thermal simulation engine EnergyPlus. Many assumptions are made regarding the heat transfer and conduction within a building, which may not always fully represent the reality. However, the compliance of the current construction to Section J seems pretty certain as the energy consumption difference is relatively large.

Furthermore, the implemented service schedules are still an estimation of the future reality. With changing opening hours, the daily energy consumption profile might change radically. This can lead to the fact that it might be advisable not to store electricity anymore, but use it directly as the peak demand can change. Obviously, this is still unclear, but it is an aspect worth considering and monitoring.

An important point of discussion is the used estimation for the heat transfer of the underfloor heating system. As a different output value is present between the two used models, it is hard to exactly predict the time needed for the preheating of the underlying layers for the thermal equilibrium. However, as is shown, the model using the heat flux shows a valid temperature profile, giving almost a 40 °C temperature at $x = 0$. It is clear that both heat transfer models are used in order to roughly predict the needed time for preheating. Another part of the obtained values, is the only 50% use of the natural gas boiler in order to provide the needed heat during preheating. This assumption is based on practical information regarding the use of these systems, but can lead to larger or smaller values if the use is altered. Further applicable research in this topic is recommendable.

Finally, it has to be stated that the amount of energy and financial savings due to the storage system is the maximum amount, meaning that every day the full capacity of the Tesla PowerWall (13.45 kW) is used. Obviously, this is in reality not achievable and this value is given as an indication what the range of energy savings are that can be achieved. It is very probable that the amount of stored electricity lies more in the range of 3.9 MWh/year [10], being 1 MWh/year lower than the maximum value.

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APPENDIX I: CONSTRUCTION DRAWINGS HEFFRON HALL

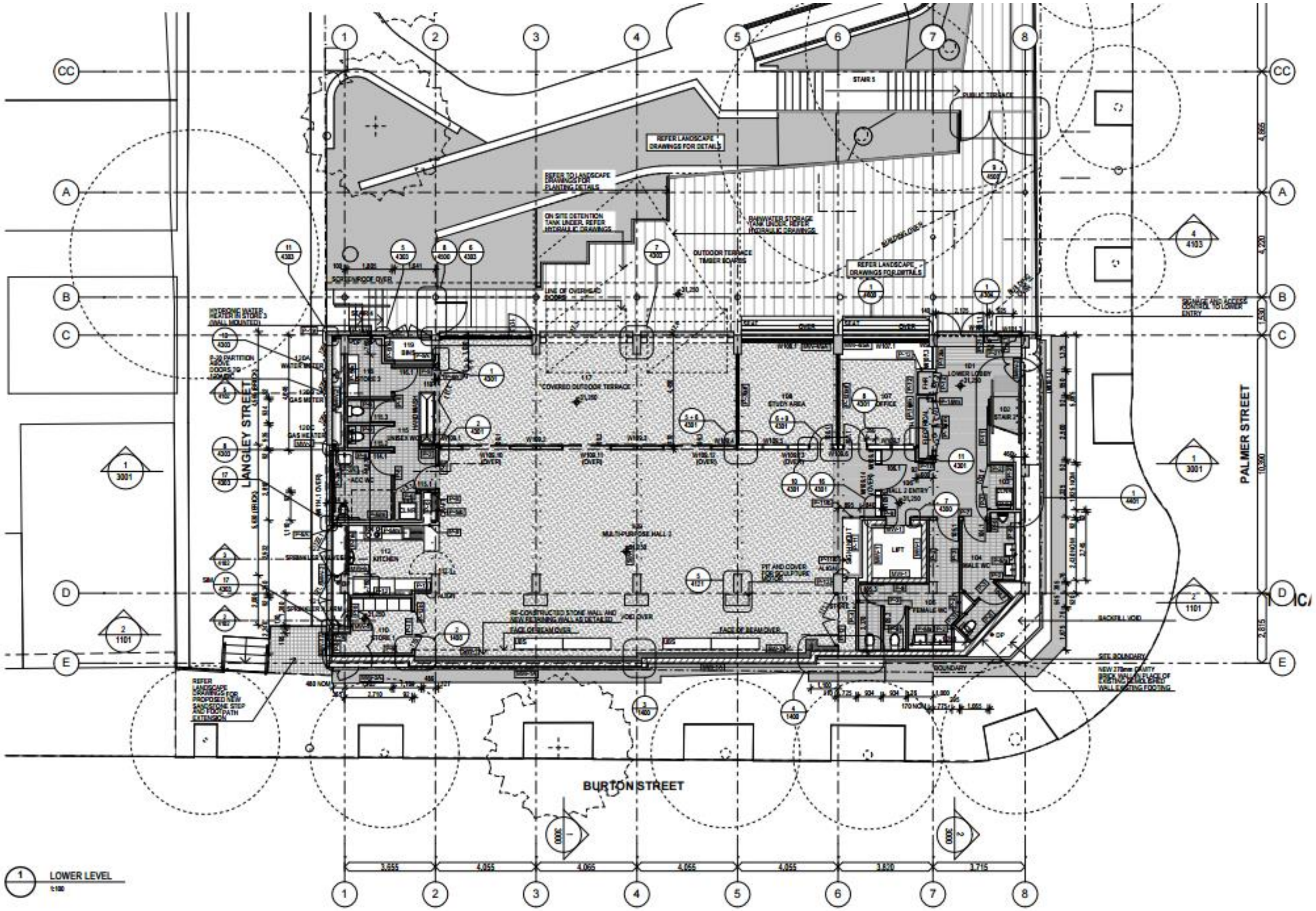

Figure 42: Lower floor construction drawing detailed [9]

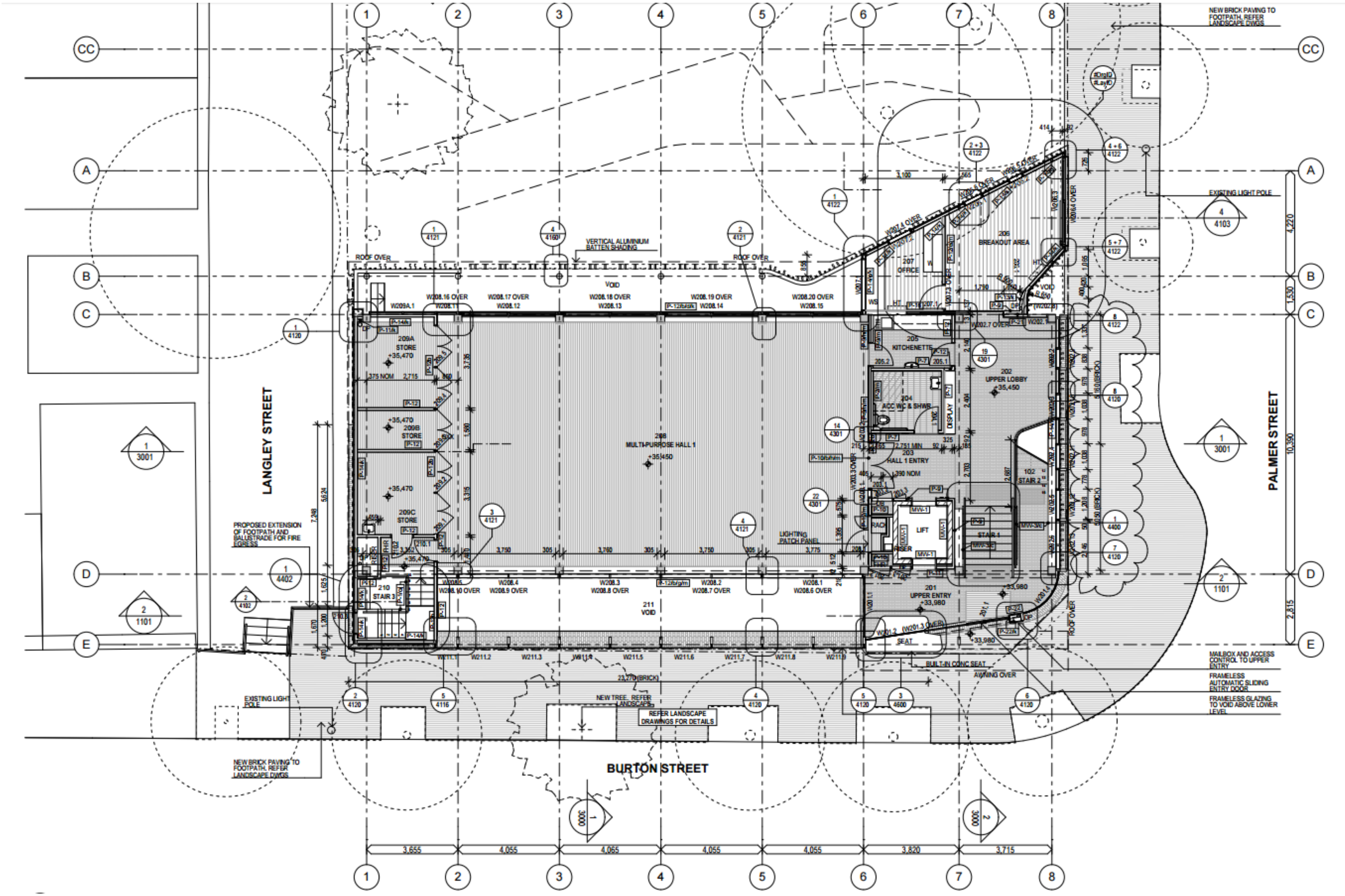

Figure 43: Upper floor construction drawings detailed [9]

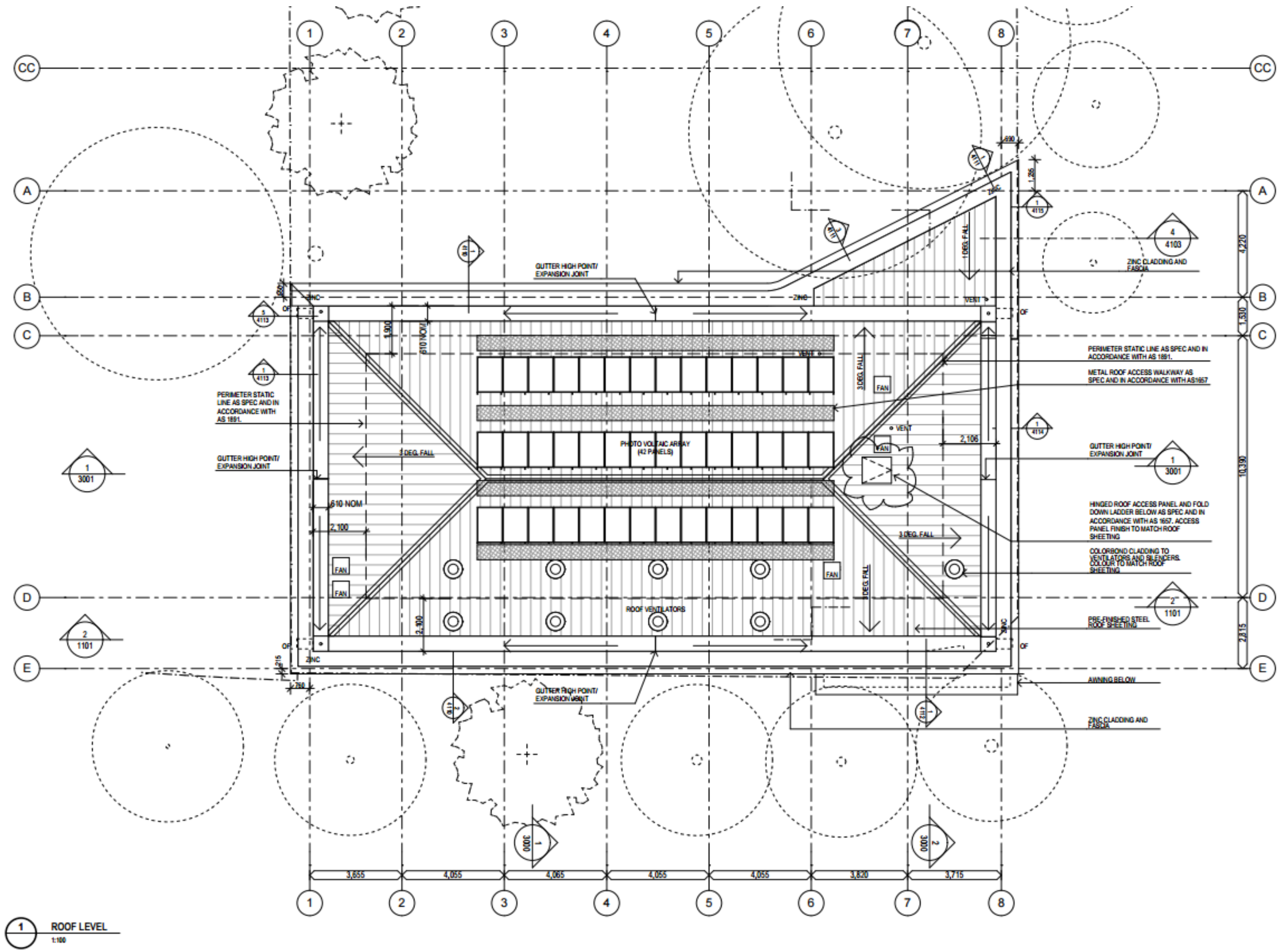

Figure 44: Roof construction drawings detailed [9]

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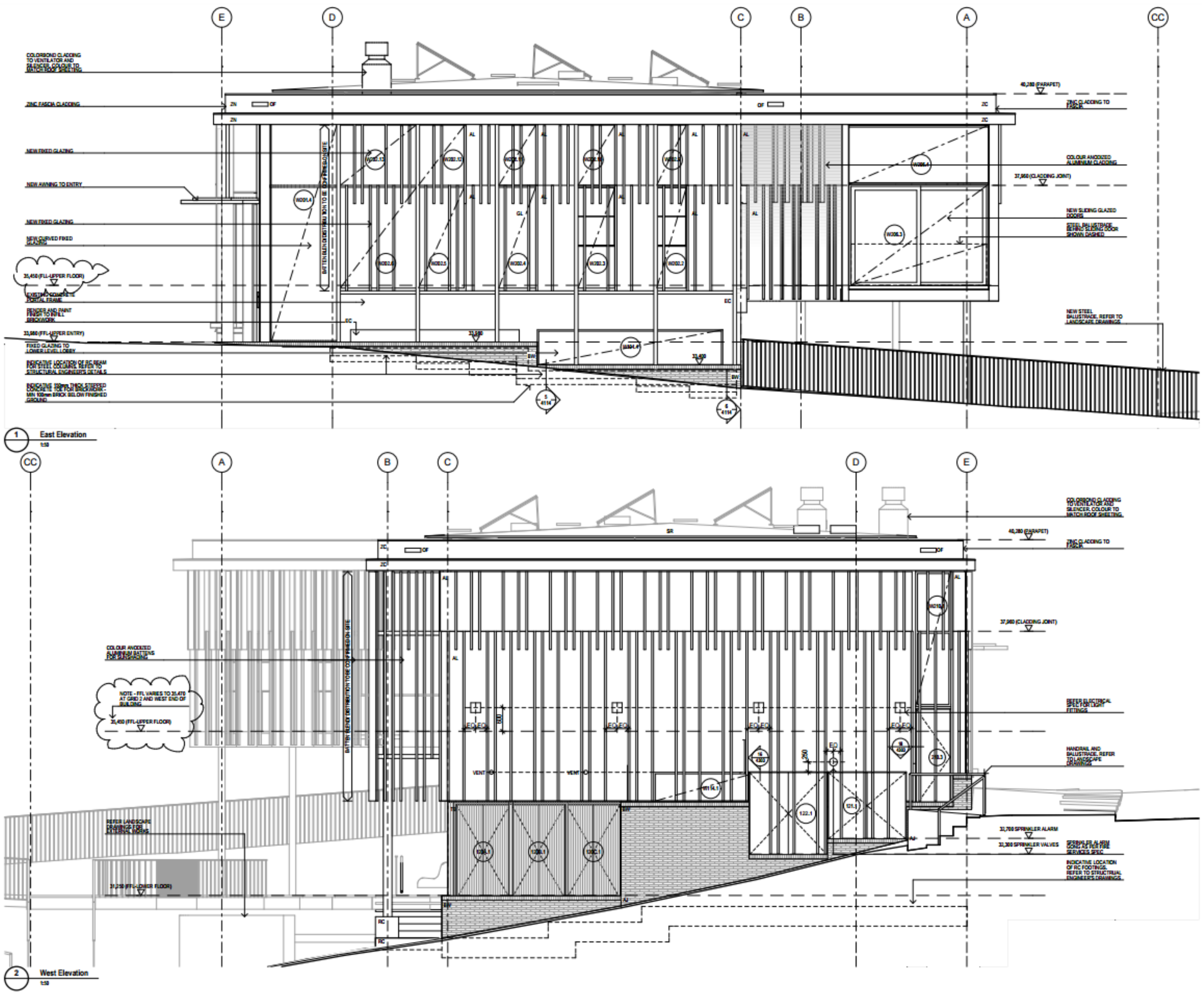

Figure 45: East & West elevations detailed [9]

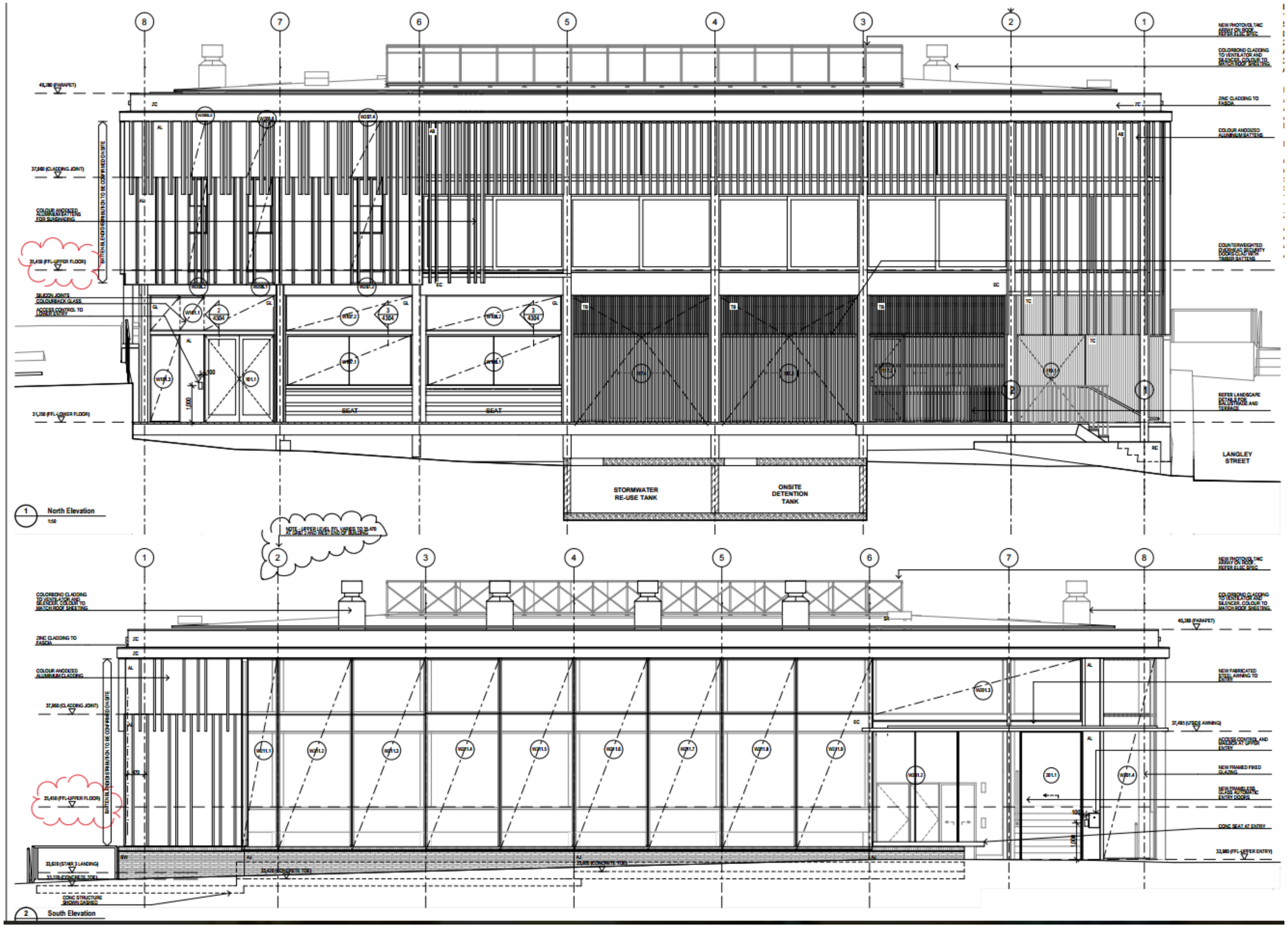

Figure 46: North & South elevations detailed

APPENDIX II: DETAILED CALCULATIONS SOLAR IRRADIANCE

ES 5964 **Heffron Hall**

Average irradiance levels Sydney

	56°	71°		Sun up		Sun down								
Jan	5,38	5,78	kWh/m2-day	06:01:00	6,02	20:10:00	20,17	hr	14:09:00	hr	14,15	hr	0,38	kWh/h
Feb	5,11	5,32	kWh/m2-day	06:31:00	6,52	19:49:00	19,82	hr	13:18:00	hr	13,30	hr	0,38	kWh/h
Mrt	4,84	4,82	kWh/m2-day	06:56:00	6,93	19:14:00	19,23	hr	12:18:00	hr	12,30	hr	0,39	kWh/h
Apr	4,42	4,16	kWh/m2-day	06:18:00	6,3	17:34:00	17,57	hr	11:16:00	hr	11,27	hr	0,39	kWh/h
Mei	3,87	3,46	kWh/m2-day	06:42:00	6,7	17:03:00	17,05	hr	10:21:00	hr	10,35	hr	0,37	kWh/h
Jun	3,90	3,37	kWh/m2-day	06:59:00	6,98	16:54:00	16,9	hr	09:55:00	hr	9,92	hr	0,39	kWh/h
Jul	4,04	3,54	kWh/m2-day	06:58:00	6,96	17:05:00	17,08	hr	10:07:00	hr	10,12	hr	0,40	kWh/h
Aug	4,68	4,28	kWh/m2-day	06:34:00	6,57	17:27:00	17,45	hr	10:53:00	hr	10,88	hr	0,43	kWh/h
Sep	5,33	5,16	kWh/m2-day	05:56:00	5,93	17:47:00	17,78	hr	11:51:00	hr	11,85	hr	0,45	kWh/h
Okt	5,50	5,63	kWh/m2-day	06:13:00	6,22	19:09:00	19,15	hr	12:56:00	hr	12,93	hr	0,43	kWh/h
Nov	5,43	5,80	kWh/m2-day	05:45:00	5,75	19:37:00	19,62	hr	13:52:00	hr	13,87	hr	0,39	kWh/h
Dec	5,57	6,04	kWh/m2-day	05:40:00	5,67	20:03:00	20,05	hr	14:23:00	hr	14,38	hr	0,39	kWh/h
	4,84	4,78												

	x^2	x	-	value	a
Jan	1	-26,19	121,42	-472,240	-0,01139
Feb	1	-26,34	129,23	-392,06	-0,01303
Mrt	1	-26,16	133,26	-310,19	-0,01560
Apr	1	-23,87	110,69	-238,58	-0,01853
Mei	1	-23,75	114,24	-184,74	-0,02095
Jun	1	-23,88	117,96	-162,72	-0,02397
Jul	1	-24,04	118,88	-172,71	-0,02339
Aug	1	-24,02	114,65	-214,61	-0,02181
Sep	1	-23,71	105,44	-277,28	-0,01922
Okt	1	-25,37	119,11	-360,32	-0,01526
Nov	1	-25,37	112,82	-444,64	-0,01221
Dec	1	-25,72	113,68	-495,64	-0,01124

	jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	
1	-1,10	-1,35	-1,69	-1,63	-1,92	-2,28	-2,24	-2,00	-1,59	-1,45	-1,08	-1,00	kW/m^2
2	-0,83	-1,05	-1,33	-1,24	-1,48	-1,78	-1,75	-1,54	-1,19	-1,10	-0,81	-0,74	kW/m^2
3	-0,59	-0,77	-1,00	-0,89	-1,09	-1,33	-1,30	-1,12	-0,83	-0,79	-0,56	-0,51	kW/m^2
4	-0,37	-0,52	-0,70	-0,58	-0,74	-0,92	-0,91	-0,75	-0,51	-0,51	-0,33	-0,30	kW/m^2
5	-0,18	-0,29	-0,43	-0,30	-0,43	-0,56	-0,55	-0,43	-0,23	-0,26	-0,13	-0,11	kW/m^2
6	0,00	-0,09	-0,19	-0,06	-0,16	-0,26	-0,25	-0,14	0,02	-0,04	0,04	0,05	kW/m^2
7	0,15	0,08	0,01	0,14	0,06	0,00	0,01	0,10	0,22	0,14	0,19	0,20	kW/m^2
8	0,27	0,23	0,19	0,30	0,25	0,22	0,22	0,29	0,39	0,30	0,32	0,32	kW/m^2
9	0,38	0,35	0,33	0,43	0,39	0,38	0,39	0,45	0,52	0,43	0,42	0,41	kW/m^2
10	0,46	0,45	0,44	0,52	0,49	0,50	0,50	0,56	0,61	0,53	0,50	0,49	kW/m^2
11	0,52	0,52	0,52	0,57	0,54	0,57	0,57	0,62	0,66	0,59	0,55	0,54	kW/m^2
12	0,56	0,56	0,57	0,59	0,56	0,59	0,60	0,65	0,67	0,63	0,58	0,57	kW/m^2
13	0,57	0,58	0,59	0,57	0,53	0,56	0,58	0,62	0,65	0,64	0,59	0,58	kW/m^2
14	0,56	0,57	0,58	0,51	0,47	0,49	0,51	0,56	0,59	0,61	0,57	0,57	kW/m^2
15	0,53	0,53	0,53	0,41	0,36	0,37	0,39	0,45	0,48	0,56	0,52	0,53	kW/m^2
16	0,47	0,47	0,46	0,28	0,20	0,19	0,23	0,30	0,34	0,47	0,45	0,47	kW/m^2
17	0,40	0,39	0,35	0,11	0,01	-0,02	0,02	0,10	0,17	0,35	0,36	0,39	kW/m^2
18	0,30	0,27	0,21	-0,09	-0,22	-0,29	-0,24	-0,14	-0,05	0,21	0,24	0,28	kW/m^2
19	0,17	0,13	0,04	-0,34	-0,50	-0,60	-0,54	-0,42	-0,31	0,03	0,10	0,16	kW/m^2
20	0,03	-0,03	-0,16	-0,62	-0,82	-0,97	-0,89	-0,75	-0,60	-0,18	-0,07	0,01	kW/m^2
21	-0,14	-0,22	-0,39	-0,93	-1,18	-1,38	-1,29	-1,12	-0,93	-0,42	-0,26	-0,16	kW/m^2
22	-0,33	-0,44	-0,65	-1,29	-1,59	-1,84	-1,73	-1,53	-1,30	-0,69	-0,47	-0,36	kW/m^2
23	-0,55	-0,68	-0,95	-1,68	-2,03	-2,34	-2,22	-1,99	-1,71	-0,99	-0,71	-0,57	kW/m^2
	5,37	5,12	4,83	4,43	3,86	3,87	4,01	4,70	5,32	5,50	5,44	5,56	kWh/m^2

0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,33	0,00	0,87	1,09
3,09	1,68	0,28	2,88	1,33	0,10	0,20	2,06	4,65	3,04	4,04	4,09
5,76	4,79	3,94	6,33	5,17	4,57	4,64	6,19	8,17	6,36	6,70	6,62
7,96	7,34	6,93	9,00	8,14	8,03	8,09	9,40	10,87	9,04	8,85	8,68
9,68	9,35	9,28	10,89	10,23	10,48	10,57	11,70	12,78	11,08	10,48	10,26
10,92	10,81	10,97	12,01	11,44	11,93	12,06	13,08	13,87	12,48	11,60	11,38
11,68	11,72	12,00	12,35	11,77	12,37	12,57	13,54	14,15	13,24	12,21	12,02
11,97	12,09	12,38	11,91	11,22	11,81	12,10	13,10	13,63	13,36	12,30	12,19
11,77	11,91	12,11	10,69	9,79	10,24	10,65	11,73	12,31	12,84	11,88	11,89
11,10	11,18	11,18	8,69	7,48	7,67	8,21	9,45	10,17	11,67	10,95	11,11
9,95	9,91	9,59	5,92	4,29	4,08	4,79	6,26	7,23	9,87	9,51	9,87
8,32	8,08	7,35	2,37	0,23	0,00	0,39	2,15	3,48	7,43	7,55	8,15
6,22	5,72	4,46	0,00	0,00	0,00	0,00	0,00	0,00	4,34	5,09	5,96
3,63	2,80	0,91	0,00	0,00	0,00	0,00	0,00	0,00	0,61	2,11	3,30
0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,17
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

APPENDIX III: GLAZING CALCULATOR

Table 7: Glazing details for the lower floor

BCA VOLUME ONE GLAZING CALCULATOR (first issued with BCA 2013) HELP

Building name/description	Application	Climate zone
Heffron Hall	other	5

Storey: Ground

Facade areas

	N	NE	E	SE	S	SW	W	NW	internal
Option A	101m²		10.7m²						
Option B									n/a
Glazing area (A)	47.4m²	…………	4.1m²						

Number of rows preferred in table below 10 (as currently displayed)

GLAZING ELEMENTS, ORIENTATION SECTOR, SIZE and PERFORMANCE CHARACTERISTICS									SHADING		CALCULATED OUTCOMES OK (if inputs are valid)					
Glazing element		Facing sector		Size			Performance		P&H or device		Shading		Multipliers		Size	Outcomes
ID	Description (optional)	Option A facades	Option B facades	Height (m)	Width (m)	Area (m²)	Total System U-Value (AFRC)	Total System SHGC (AFRC)	P (m)	H (m)	P/H	G (m)	Heating (S_H)	Cooling (S_C)	Area used (m²)	Element share of % of allowance used
1											ROW SKIPPED (OK if intentional)					
2	WC Grid C-D	E		0.87	4.71		4.3	0.29				0.00	1.00	1.00	4.10	100% of 73%
3	Multipurpose Hall2 Grid	N		3.39	11.19		3.3	0.63	device		2.00	0.00	0.00	0.19	37.93	56% of 42%
4	Office Grid 5.7	N		1.49	3.70		3.3	0.29	4.400	4.000	0.00	2.51	1.00	1.00	5.51	26% of 42%
5	Study Area Grid 5.7	N		1.06	3.70		3.3	0.29	4.400	4.000	0.00	2.95	1.00	1.00	3.90	18% of 42%
6																
7																
8																
10																

IMPORTANT NOTICE AND DISCLAIMER IN RESPECT OF THE GLAZING CALCULATOR
The Glazing Calculator has been developed by the ABCB to assist in developing a better understanding of glazing energy efficiency parameters.
While the ABCB believes that the Glazing Calculator, if used correctly, will produce accurate results, it is provided "as is" and without any representation or warranty of any kind, including that it is fit for any purpose or of merchantable quality, or functions as intended or at all.
Your use of the Glazing Calculator is entirely at your own risk and the ABCB accepts no liability of any kind.

if inputs are valid

Table 8: Glazing details for upper floor

BCA VOLUME ONE GLAZING CALCULATOR (first issued with BCA 2013) HELP

Building name/description: Heffron Hall
Application: other
Climate zone: 5

Storey: Level 1

Facade areas	N	NE	E	SE	S	SW	W	NW	internal
Option A	134m²		81.7m²	26m²	172m²		78.5m²		
Option B									n/a
Glazing area (A)	*19.8m²*	*...........*	*39.6m²*	*12.4m²*	*118m²*	*...........*	*5.43m²*		

Number of rows preferred in table below: 20 *(as currently displayed)*

GLAZING ELEMENTS, ORIENTATION SECTOR, SIZE and PERFORMANCE CHARACTERISTICS										SHADING		CALCULATED OUTCOMES OK (if inputs are valid)					
Glazing element		Facing sector		Size			Performance			P&H or device		Shading		Multipliers		Size	Outcomes
ID	Description (optional)	Option A facades	Option B facades	Height (m)	Width (m)	Area (m²)	Total System U-Value (AFRC)	Total System SHGC (AFRC)		P (m)	H (m)	P/H	G (m)	Heating (S_H)	Cooling (S_C)	Area used (m²)	Element share of % of allowance used
1												*ROW SKIPPED (OK if intentional)*					
2	Stairs Grid D	E		4.20	3.35		3.2	0.29					0.00	1.00	1.00	14.07	36% of 92%
3	Stairs Grid D	E		4.20	1.18		3.2	0.29					0.00	1.00	1.00	4.96	13% of 92%
4	Upper Lobby Grid C	E		4.20	0.98		3.2	0.29					0.00	1.00	1.00	4.12	10% of 92%
5	Upper Lobby Grid C	E		4.20	0.73		3.2	0.29					0.00	1.00	1.00	3.07	8% of 92%
6	Breakout Space Grid A-E	E		3.85	3.47		3.2	0.29					0.00	1.00	1.00	13.36	34% of 92%
7	Void/Upper Entry	S				105.28	3.6	0.63					0.00	1.00	1.00	######	89% of 85%
8	Entrance Door	S				13.02	3.6	0.63					0.00	1.00	1.00	13.02	11% of 85%
9	Multipurpose Hall1 Grid	N		1.94	3.70		4.3	0.63		1.500	4.400	0.00	2.46	1.00	1.00	7.18	36% of 68%
10	Multipurpose Hall1 Grid	N		1.39	3.70		4.3	0.63		1.500	4.400	0.00	3.01	1.00	1.00	5.14	26% of 68%
11	Multipurpose Hall1 Grid	N		1.94	0.73		4.3	0.63		1.500	4.400	0.00	2.46	1.00	1.00	1.42	7% of 68%
12	Multipurpose Hall1 Grid	N		1.39	0.73		4.3	0.63		1.500	4.400	0.00	3.01	1.00	1.00	1.01	5% of 68%
13	Breakout Area grid 7-8	N		4.46	0.45		4.3	0.63					0.00	1.00	1.00	2.01	10% of 68%
14	Office 207 grid 7-8	N		4.46	0.69		4.3	0.63					0.00	1.00	1.00	3.08	16% of 68%
15	Horizontal Window	W		0.73	4.07		4.3	0.63					0.00	1.00	1.00	2.96	55% of 25%
16	Vertical Window	W		3.20	0.77		4.3	0.63					0.00	1.00	1.00	2.46	45% of 25%
17	Upper Entry Grid E-D	SE		5.51	1.78		3.6	0.63					0.00	1.00	1.00	9.81	85% of 100%
18	Breakout Area grid 7-8	SE		4.40	0.60		3.2	0.29					0.00	1.00	1.00	2.64	15% of 100%
19																	
20																	

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if inputs are valid ✓

APPENDIX IV: DETAILED SCHEDULES

DTS-model

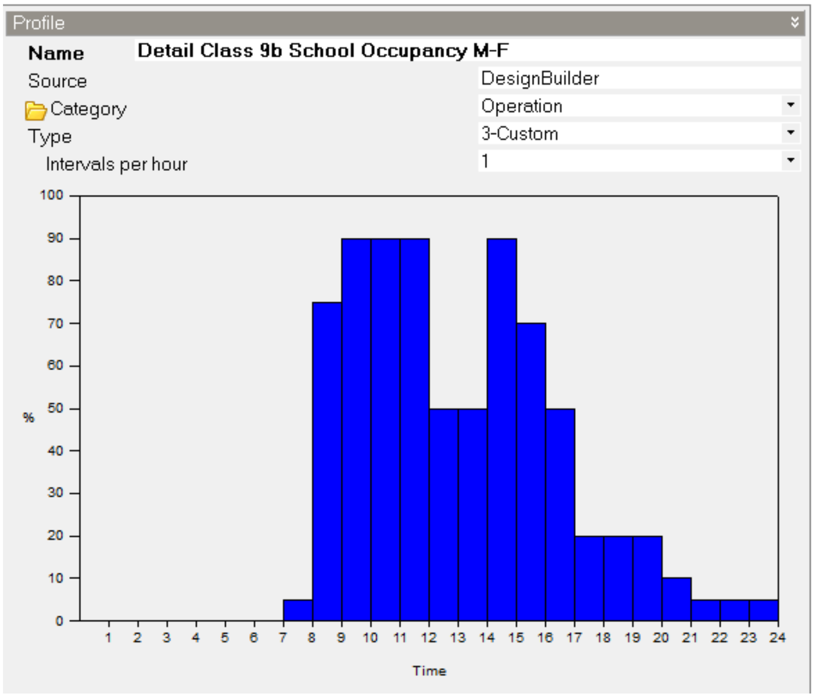

Figure 47: Occupancy schedule Class 9b during weekdays (DTS)

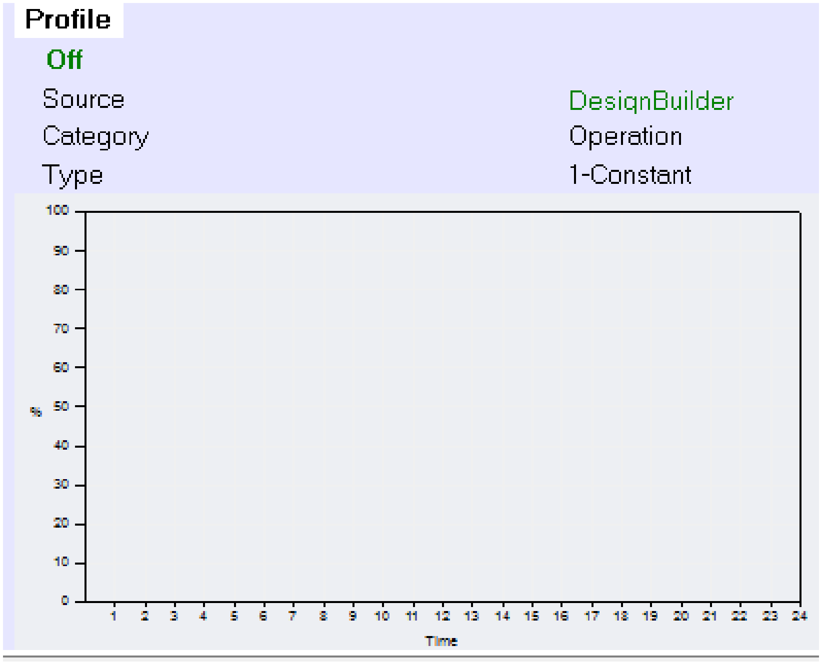

Figure 48: Occupancy schedule Class 9b during the weekend (DTS)

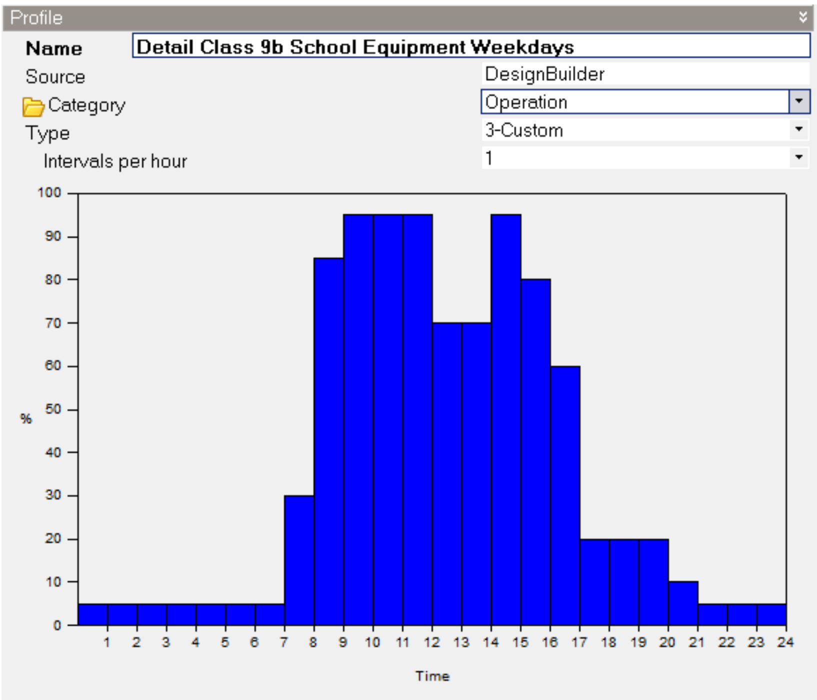

Figure 49: Equipment schedule Class 9b during weekdays (DTS)

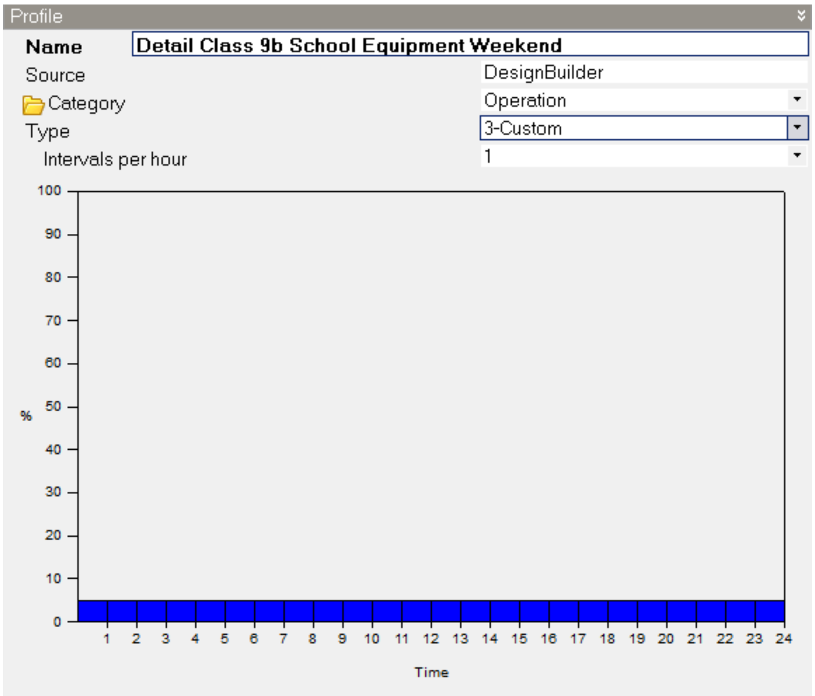

Figure 50: Equipment schedule Class 9b during the weekend (DTS)

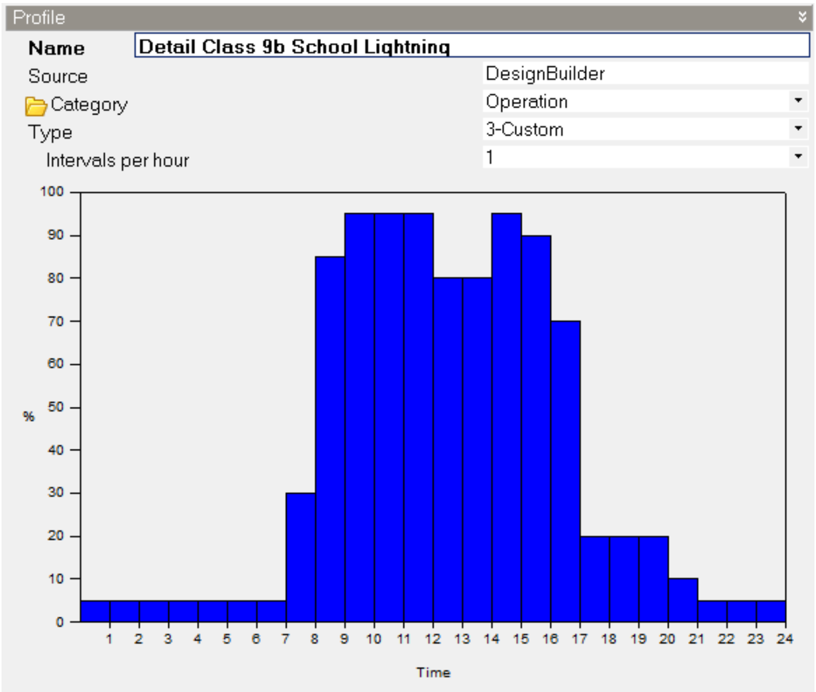

Figure 51: Lighting schedule Class 9b during weekdays (DTS)

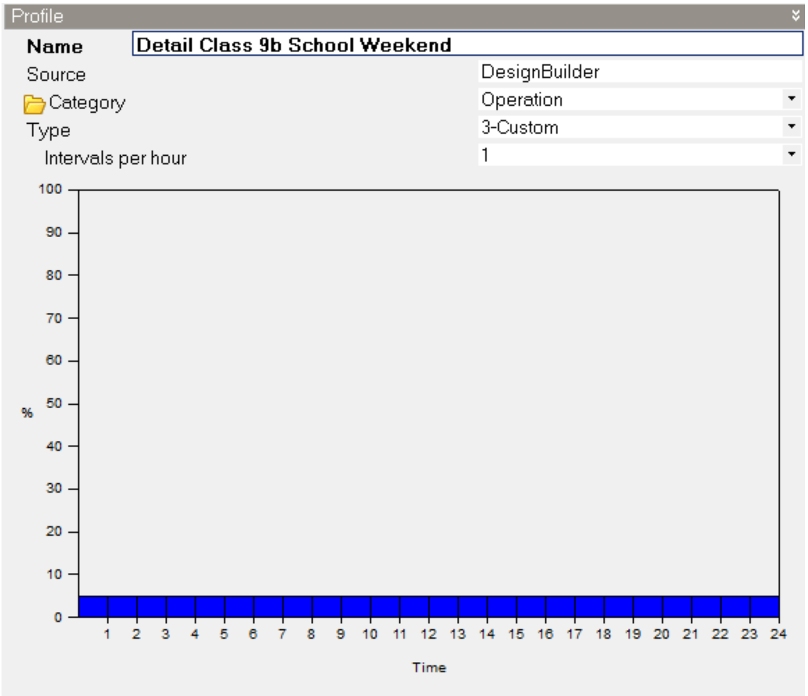

Figure 52: Lighting schedule Class 9b during the weekend (DTS)

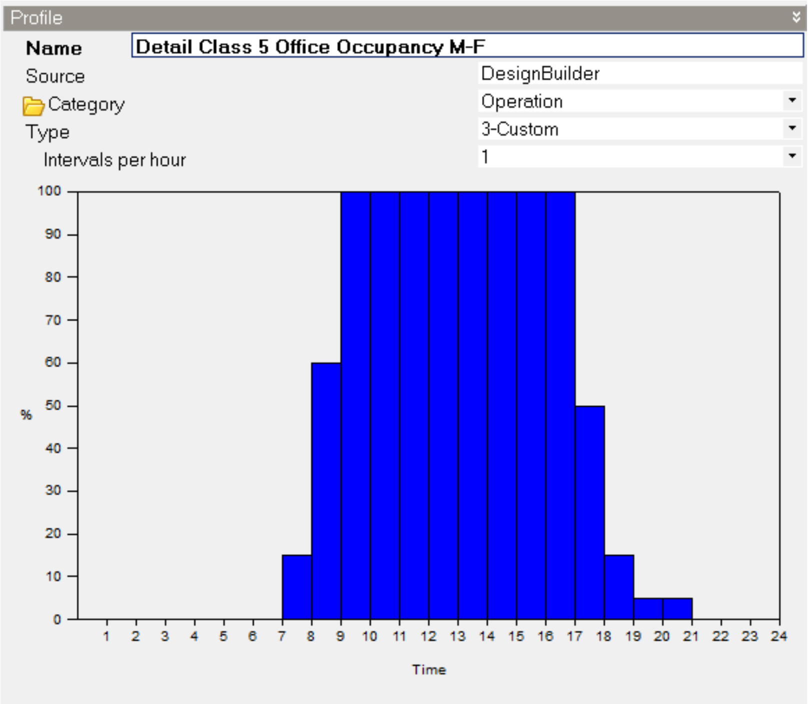

Figure 53: Occupancy schedule Class 5 during weekdays (DTS)

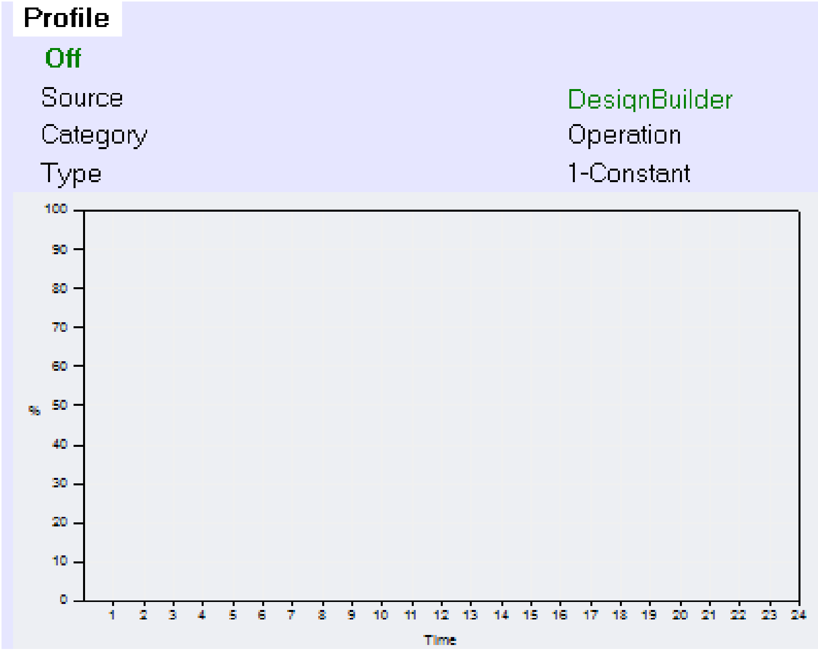

Figure 54: Occupancy schedule Class 5 during the weekend (DTS)

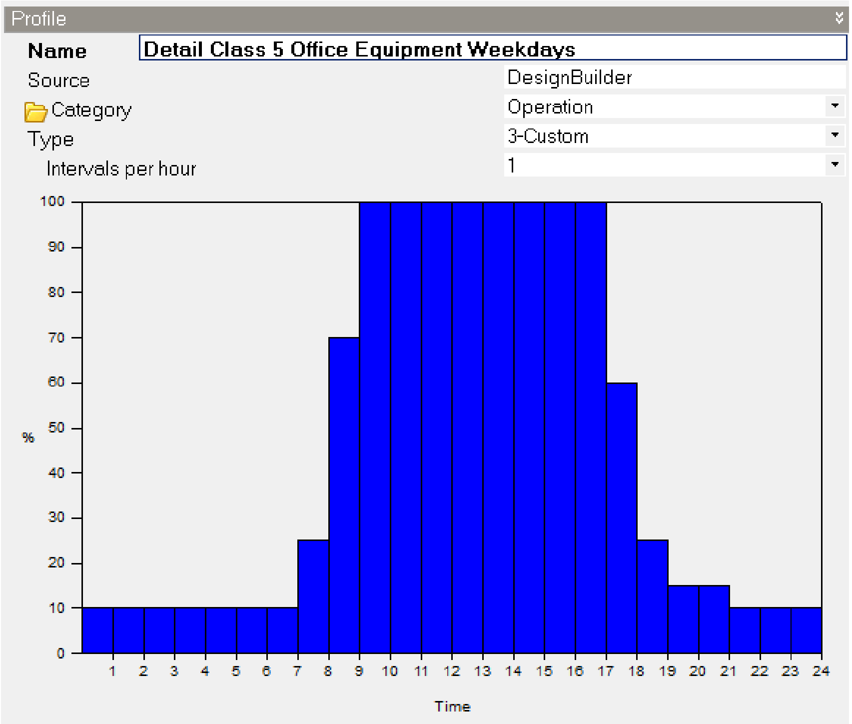

Figure 55: Equipment schedule Class 5 during weekdays (DTS)

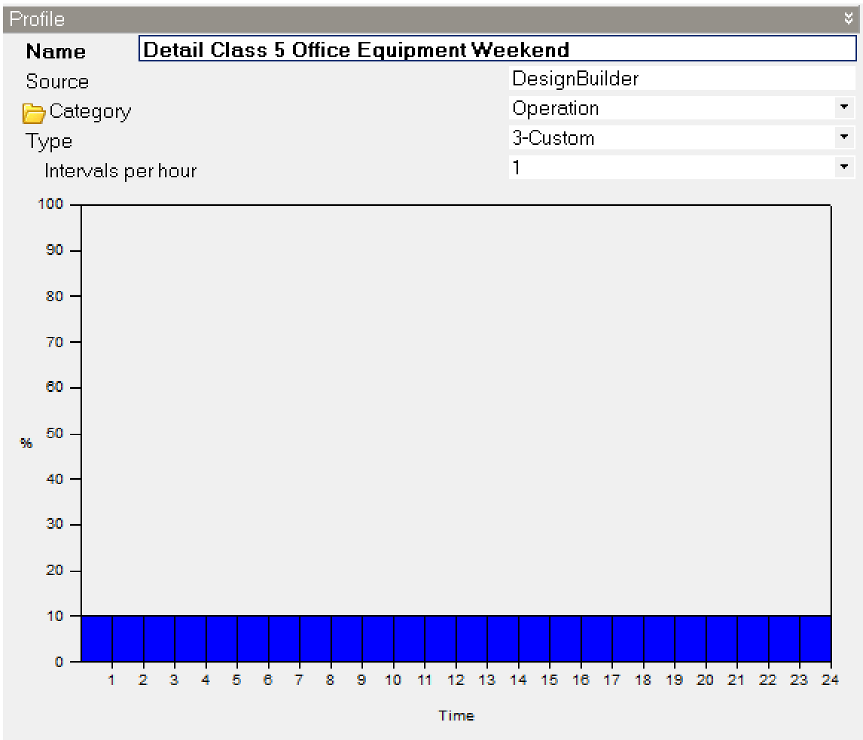

Figure 56: Equipment schedule Class 5 during the weekend (DTS)

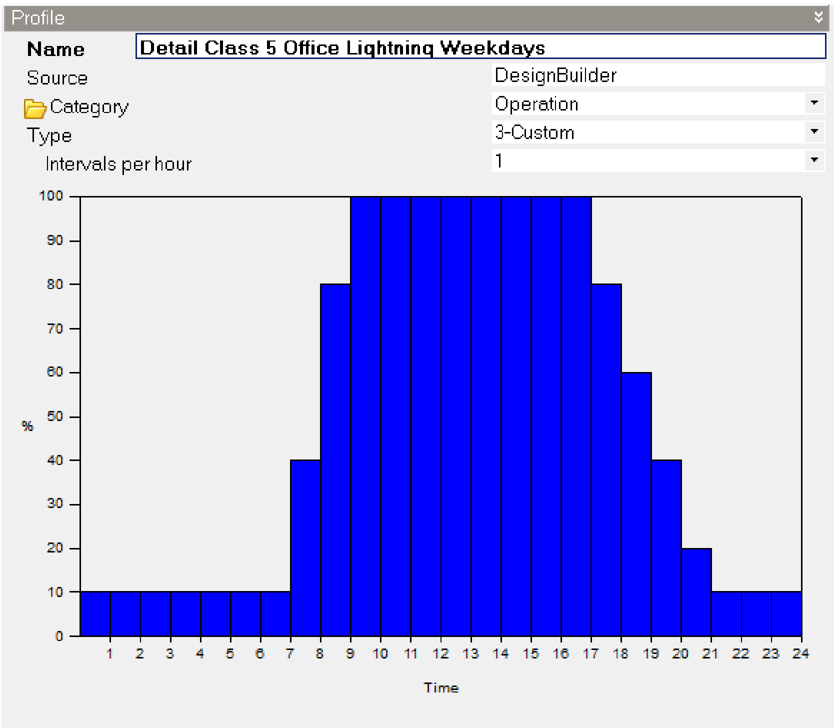

Figure 57: Lighting schedule Class 5 during weekdays (DTS)

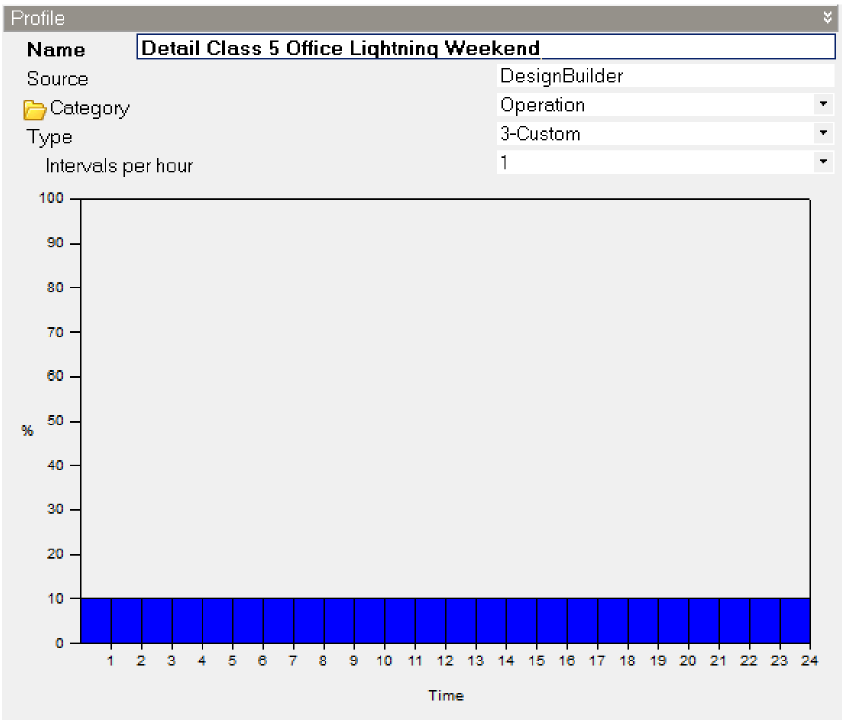

Figure 58: Lighting schedule Class 5 during the weekend (DTS)

Proposed Services-model

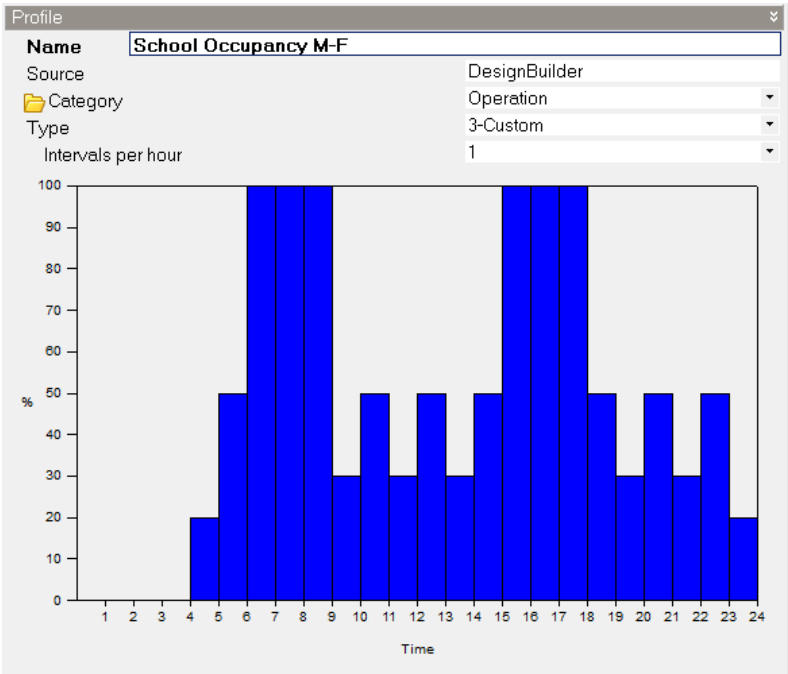

Figure 59: Occupancy schedule during weekdays for school area, lower floor (Proposed)

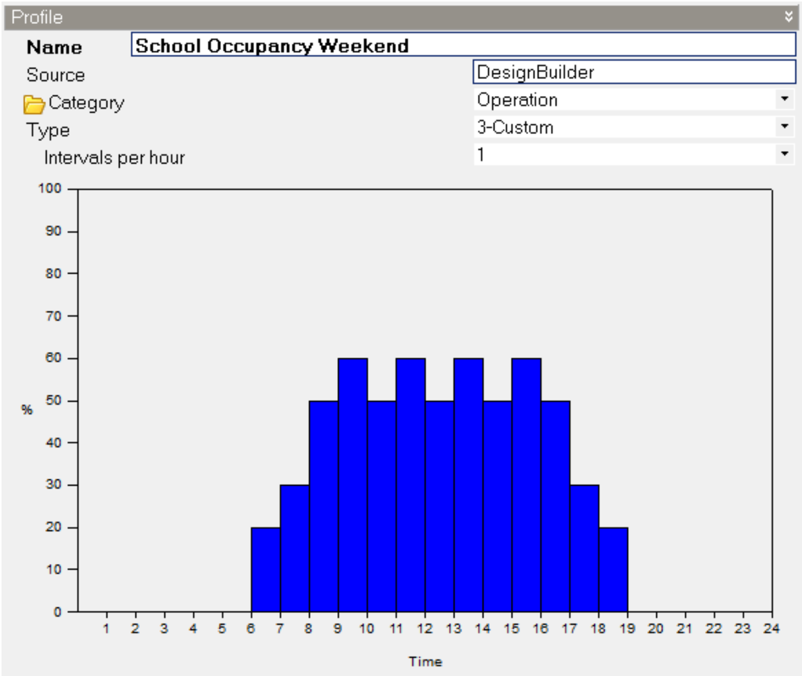

Figure 60: Occupancy schedule during the weekend for school area, lower floor (Proposed)

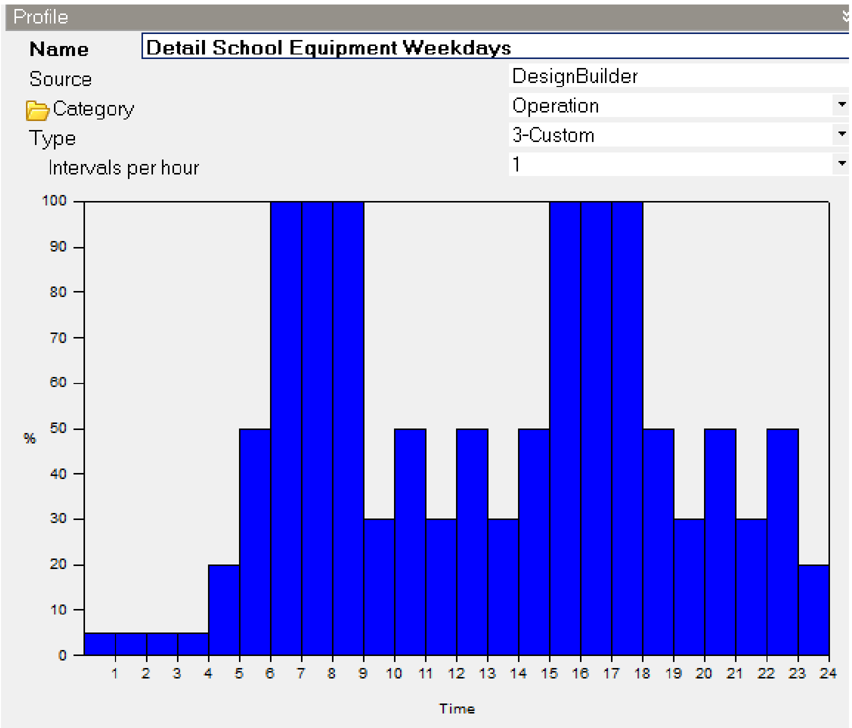

Figure 61: Equipment schedule during weekdays for school area, lower floor (Proposed)

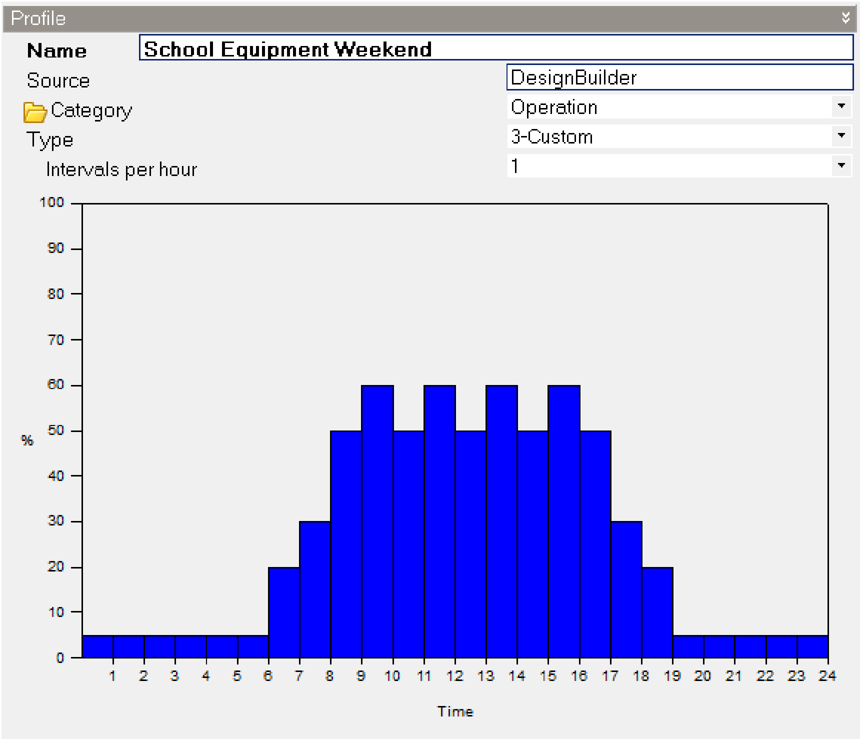

Figure 62: Equipment schedule during the weekend for school area, lower floor (Proposed)

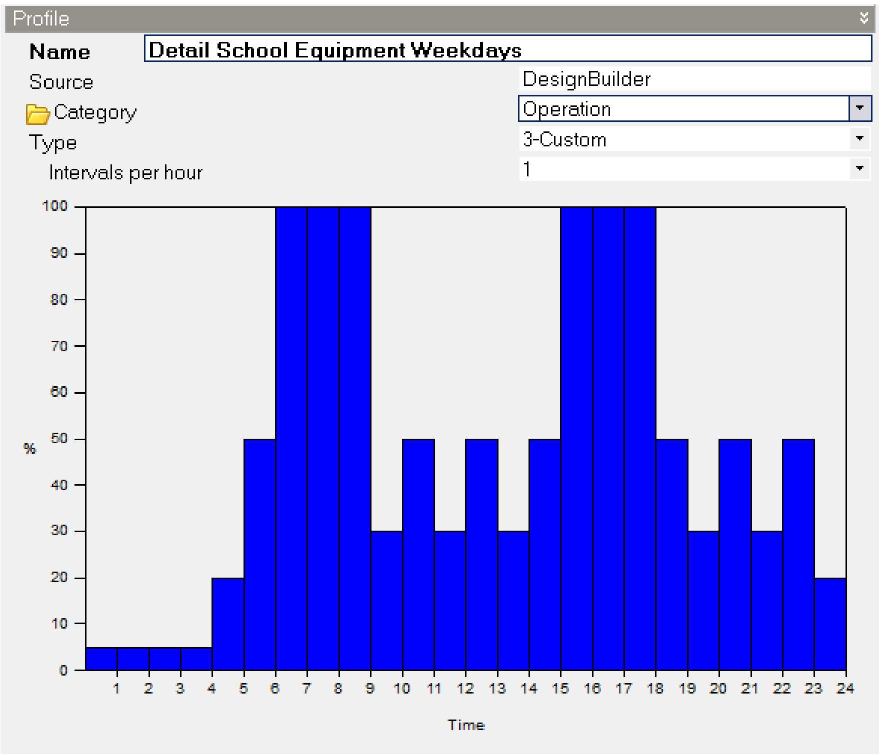

Figure 63: Lighting schedule during weekdays for school area, lower floor (Proposed)

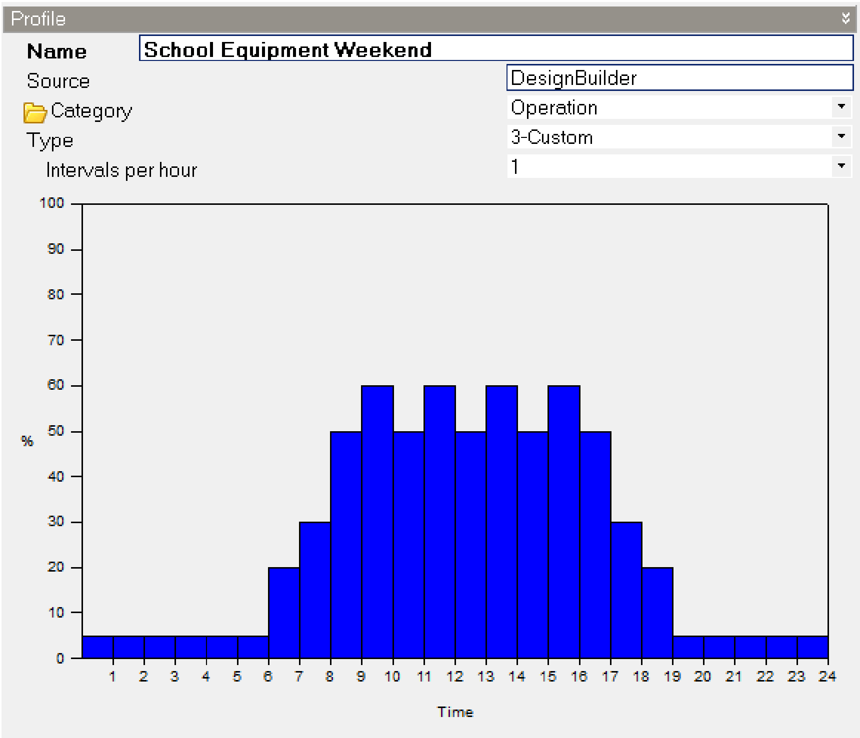

Figure 64: Lighting schedule during the weekend for school area, lower floor (Proposed)

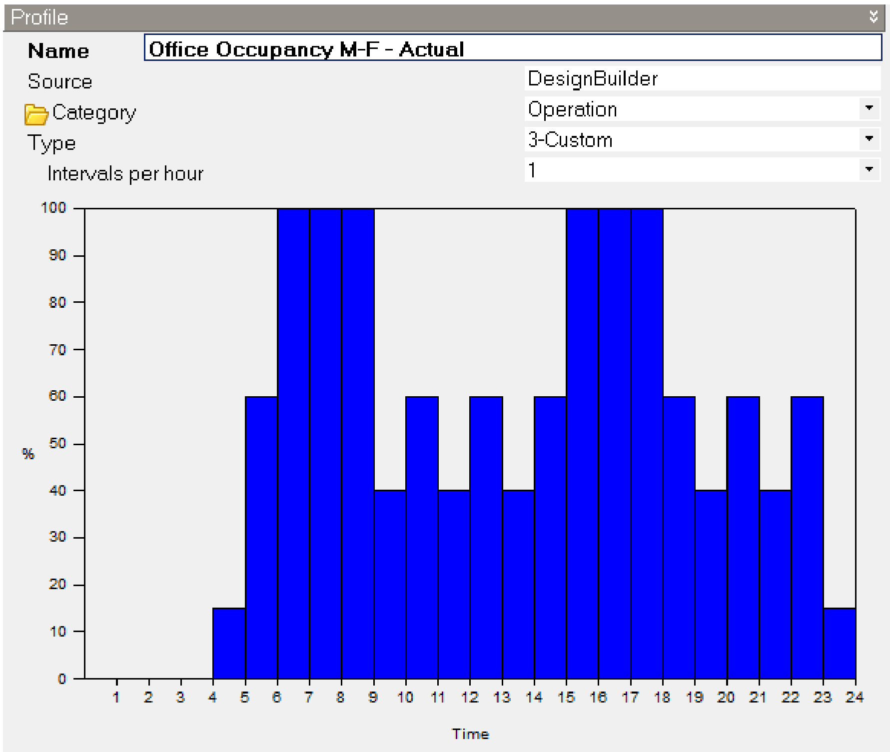

Figure 65: Occupancy schedule during weekdays for office areas (Proposed)

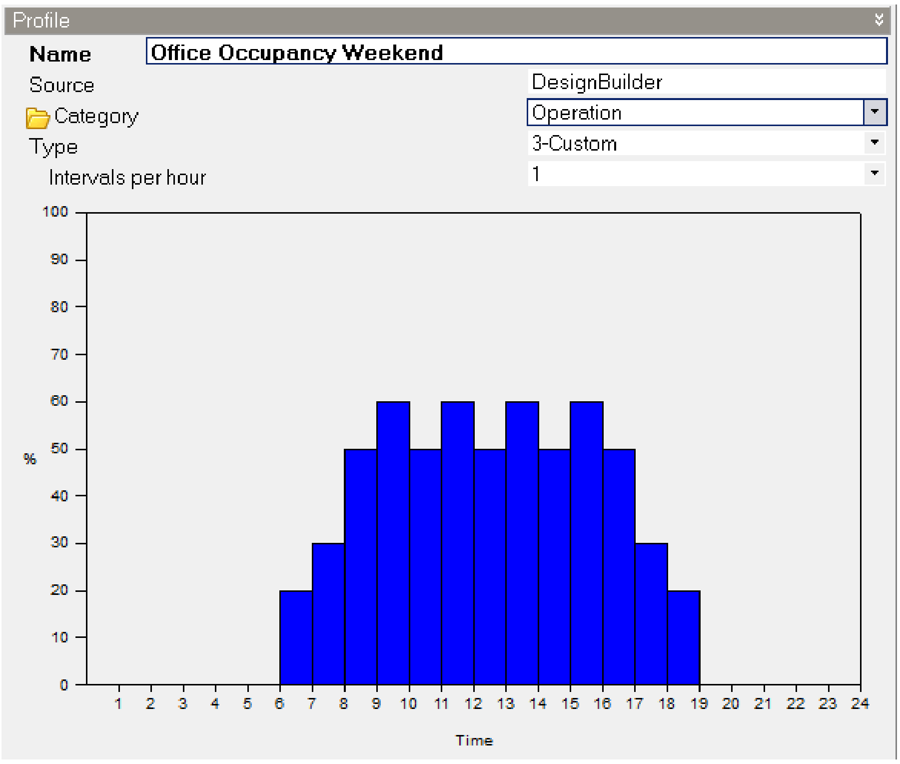

Figure 66: Occupancy schedule during the weekend for office areas (Proposed)

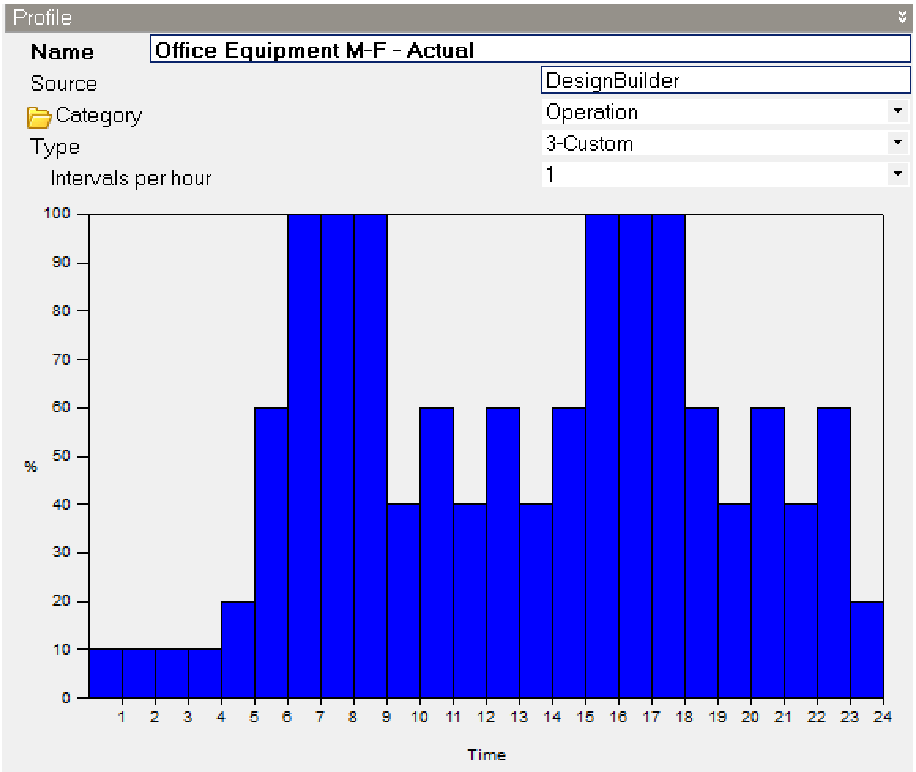

Figure 67: Equipment schedule during weekdays for office areas (Proposed)

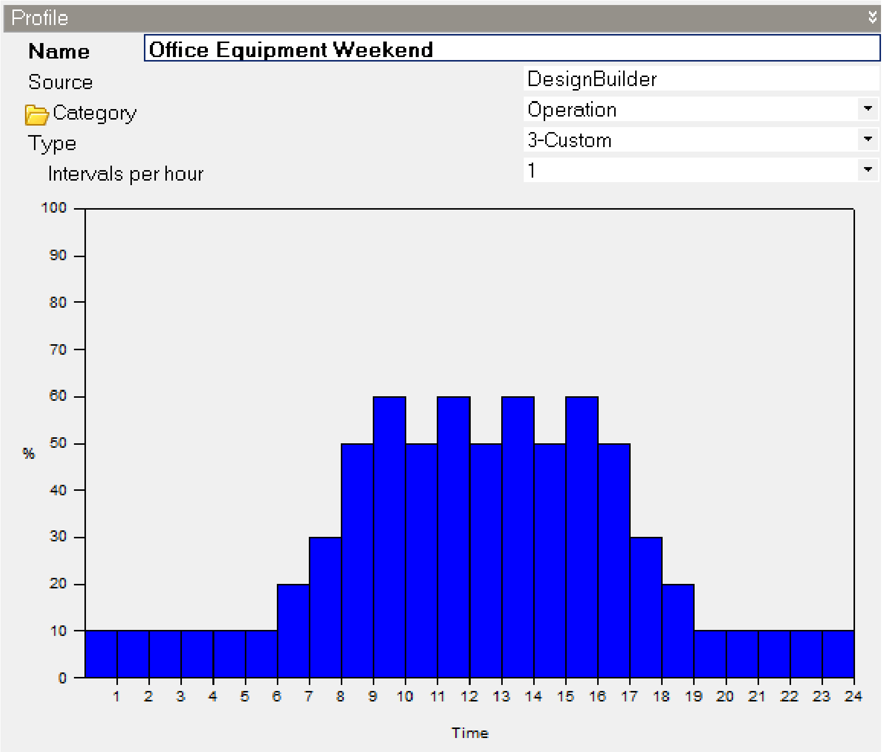

Figure 68: Equipment schedule during the weekend for office areas (Proposed)

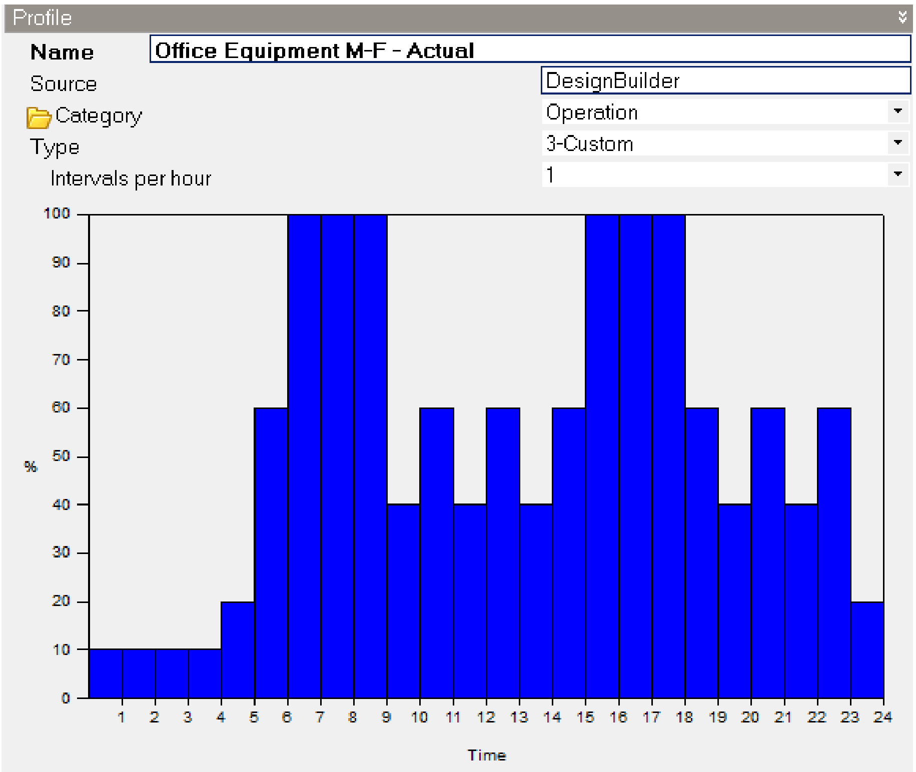

Figure 69: Lighting schedule during weekdays for office areas (Proposed)

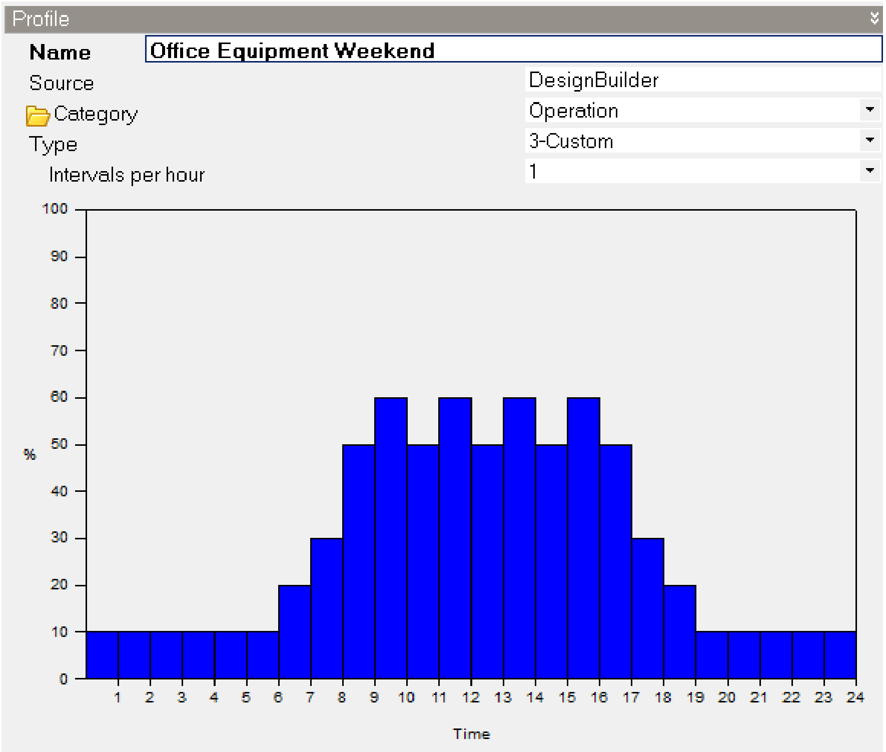

Figure 70: Lighting schedule during the weekend for office areas (Proposed)

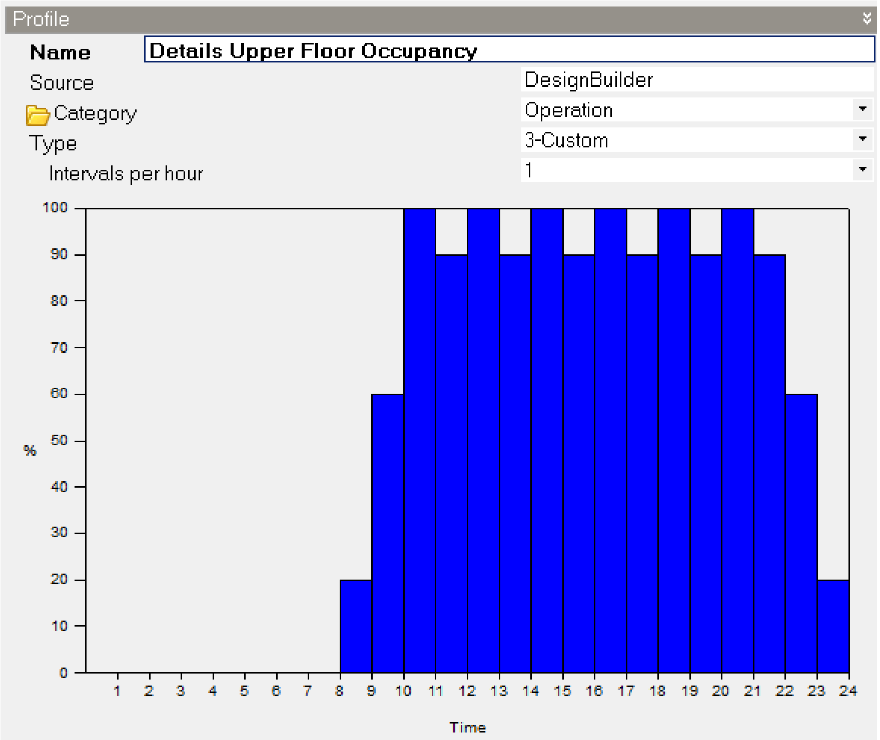

Figure 71: Occupancy schedule during for upper floor areas (Proposed)

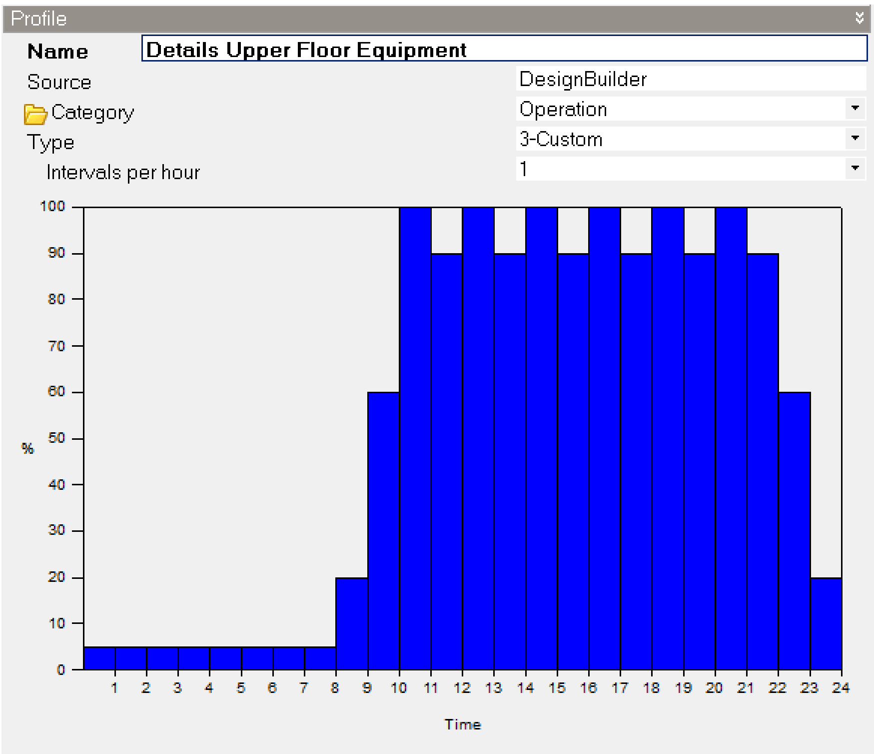

Figure 72: Equipment schedule for upper floor areas (Proposed)

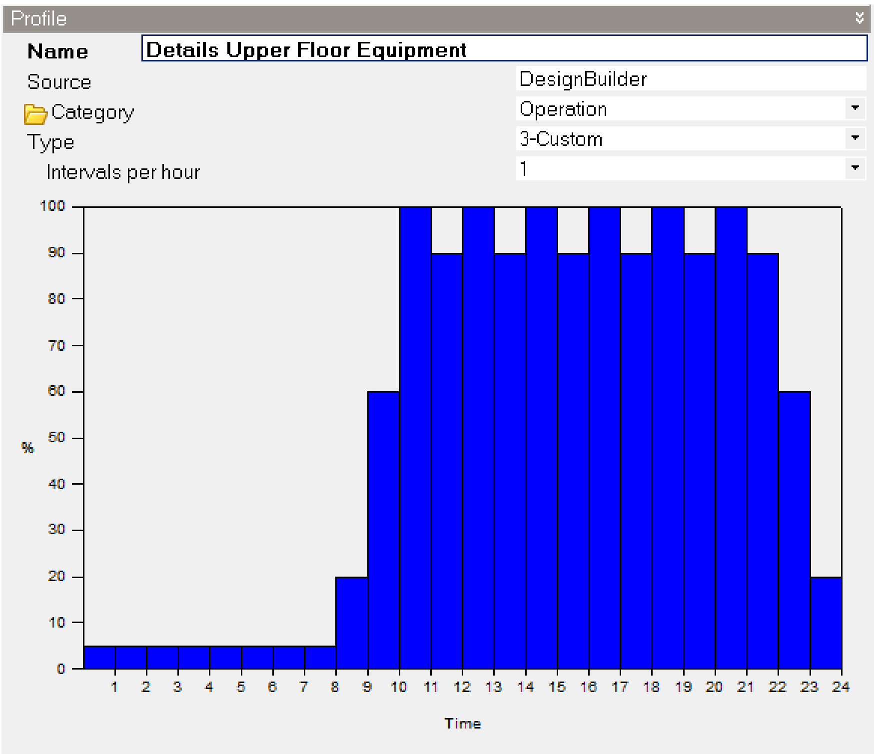

Figure 73: Lighting schedule for upper floor areas (Proposed)

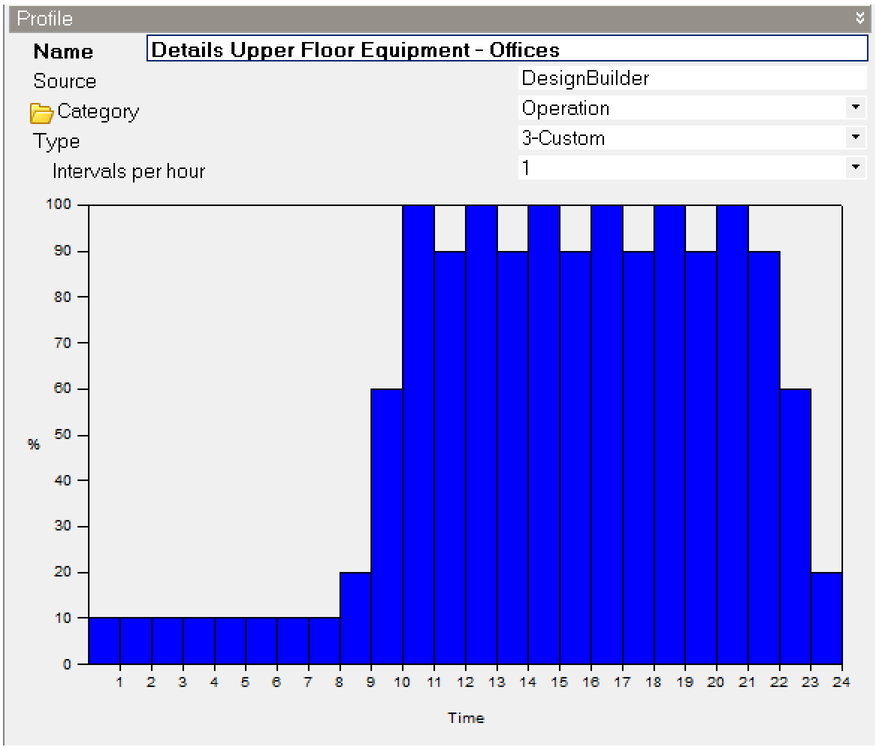

Figure 74: Equipment schedule for upper floor areas, office areas (Proposed)

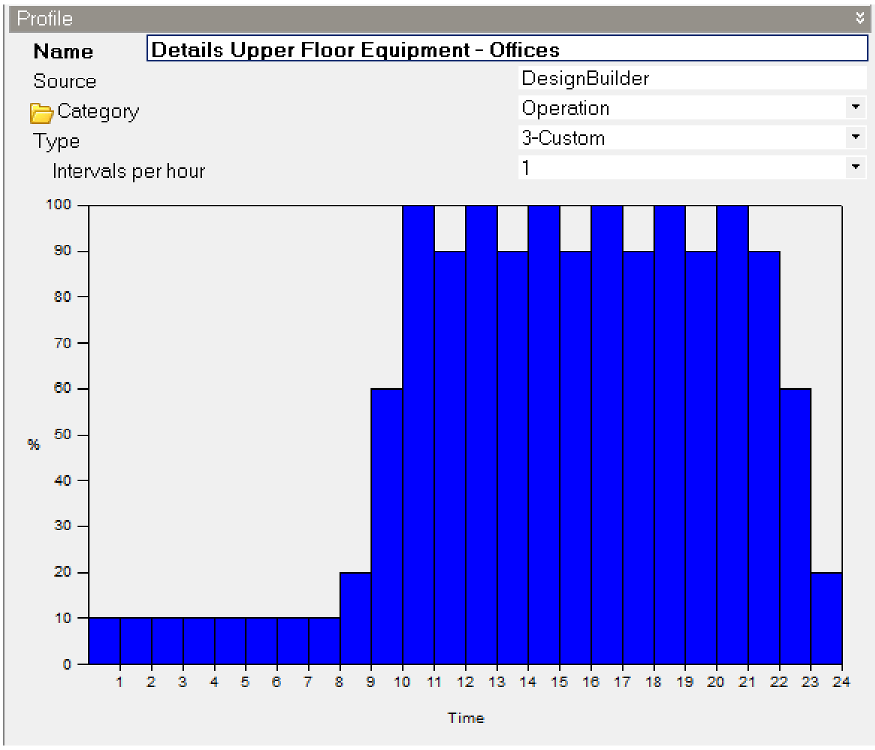

Figure 75: Lighting schedule for upper floor areas, office areas (Proposed)

APPENDIX V: BUILDING FABRIC DETAILS

Proposed fabric exterior wall details

Figure 76: Cross section EW-05 exterior wall, R = 3.10

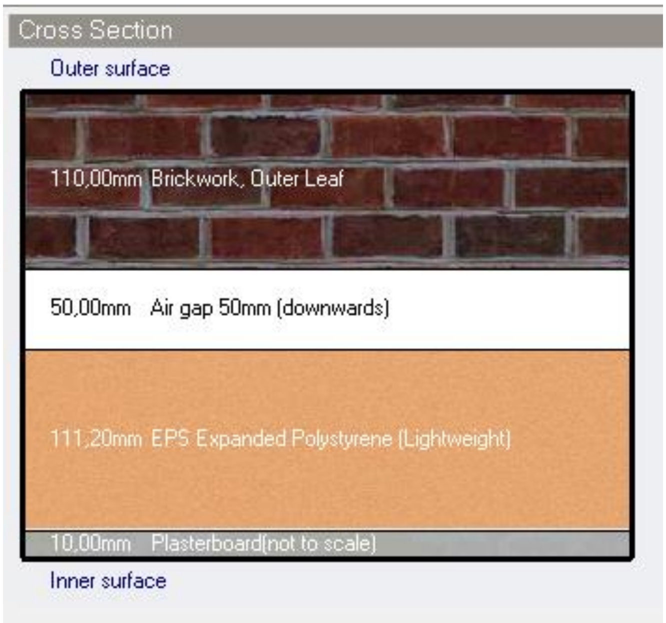

Figure 77: Cross section EW-03 exterior wall, R = 2.97

Proposed fabric roof details

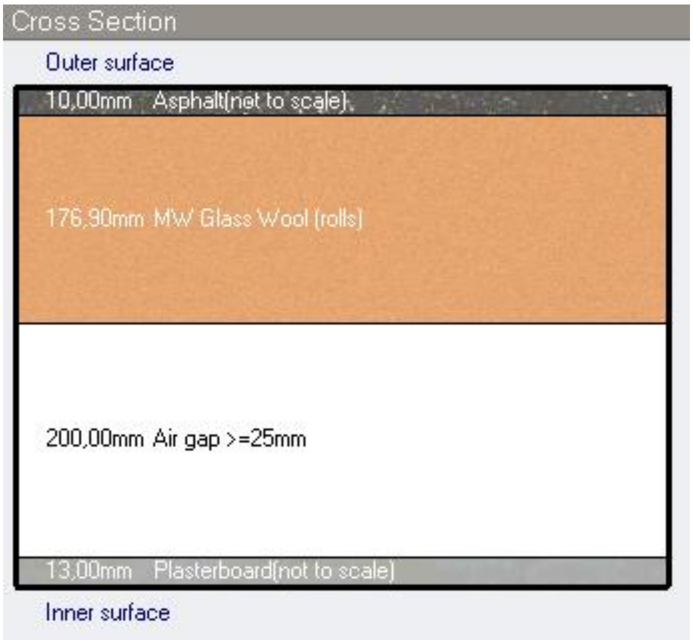

Figure 78: Cross section flat & pitched roof, R = 4.79

Proposed fabric floor details

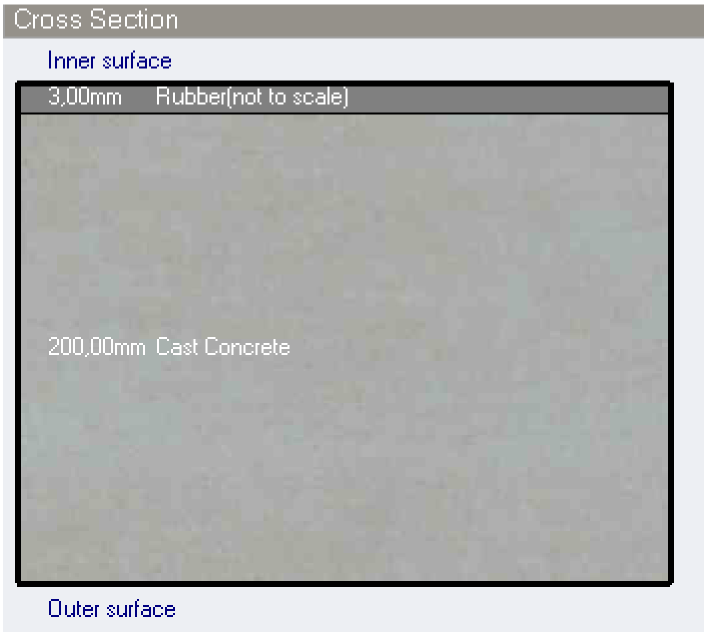

Figure 79: Cross section ground floor (uninsulated), R = 0.40

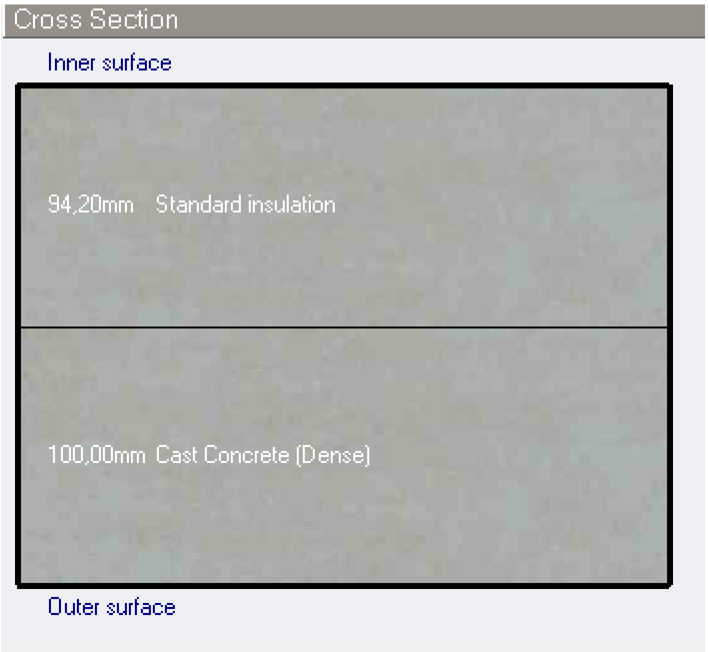

Figure 80: Cross section external & internal floor, R = 2.69

APPENDIX VI: SOLAR POTENTIAL SCENARIOS

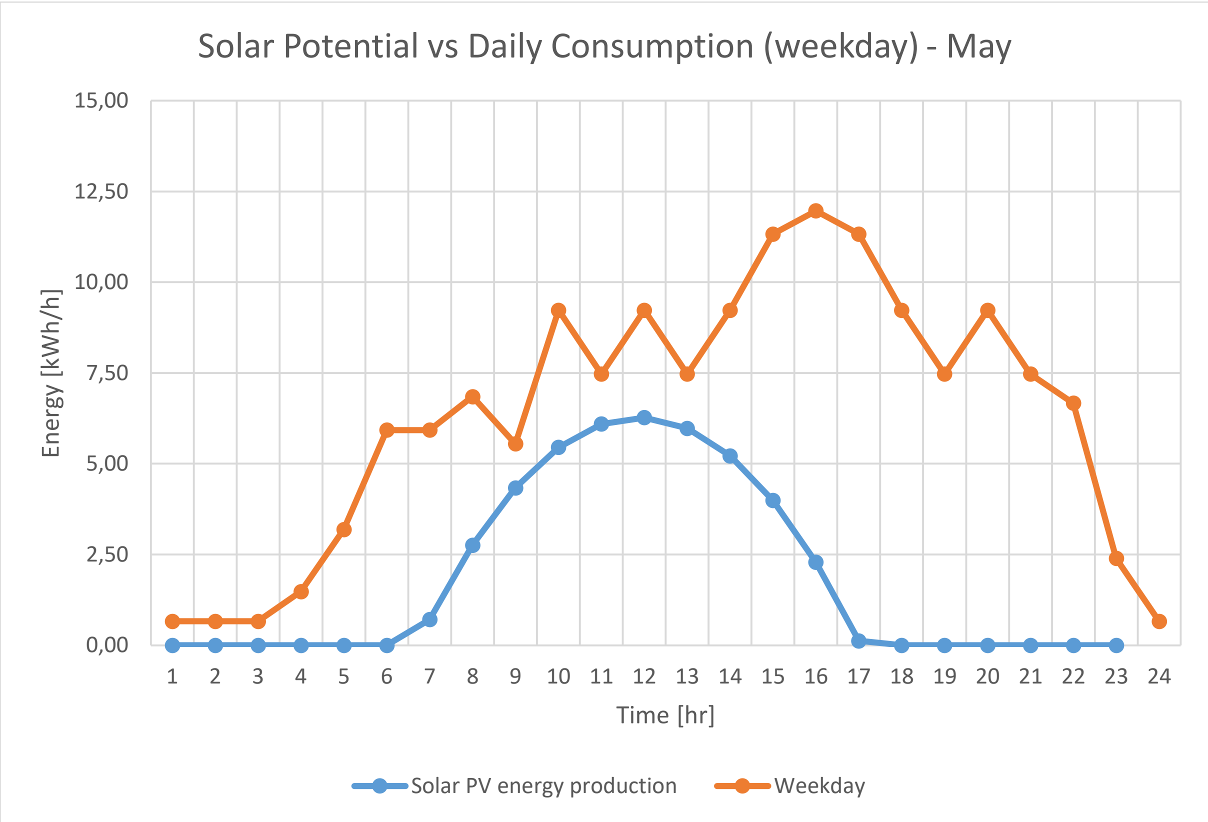

Figure 81: Solar potential plotted with the daily consumption for a winter day during weekdays

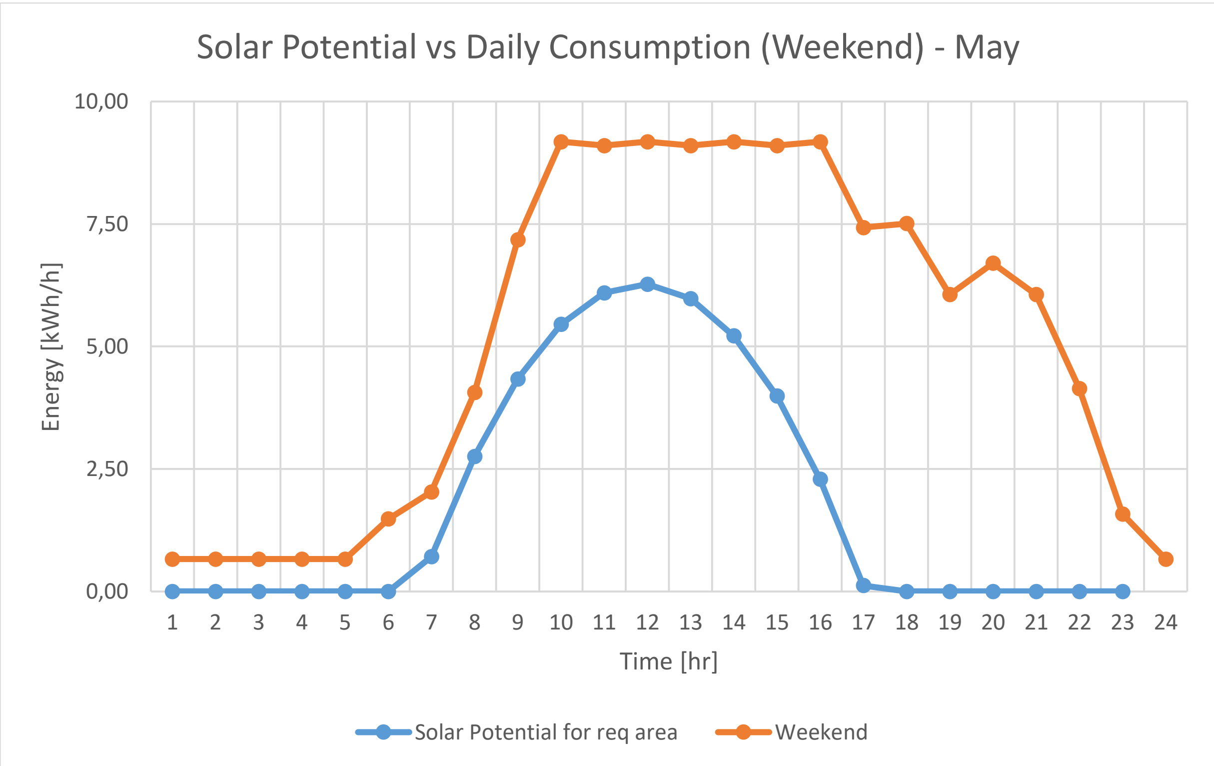

Figure 82: Solar potential plotted with the daily consumption for a winter day during the weekend

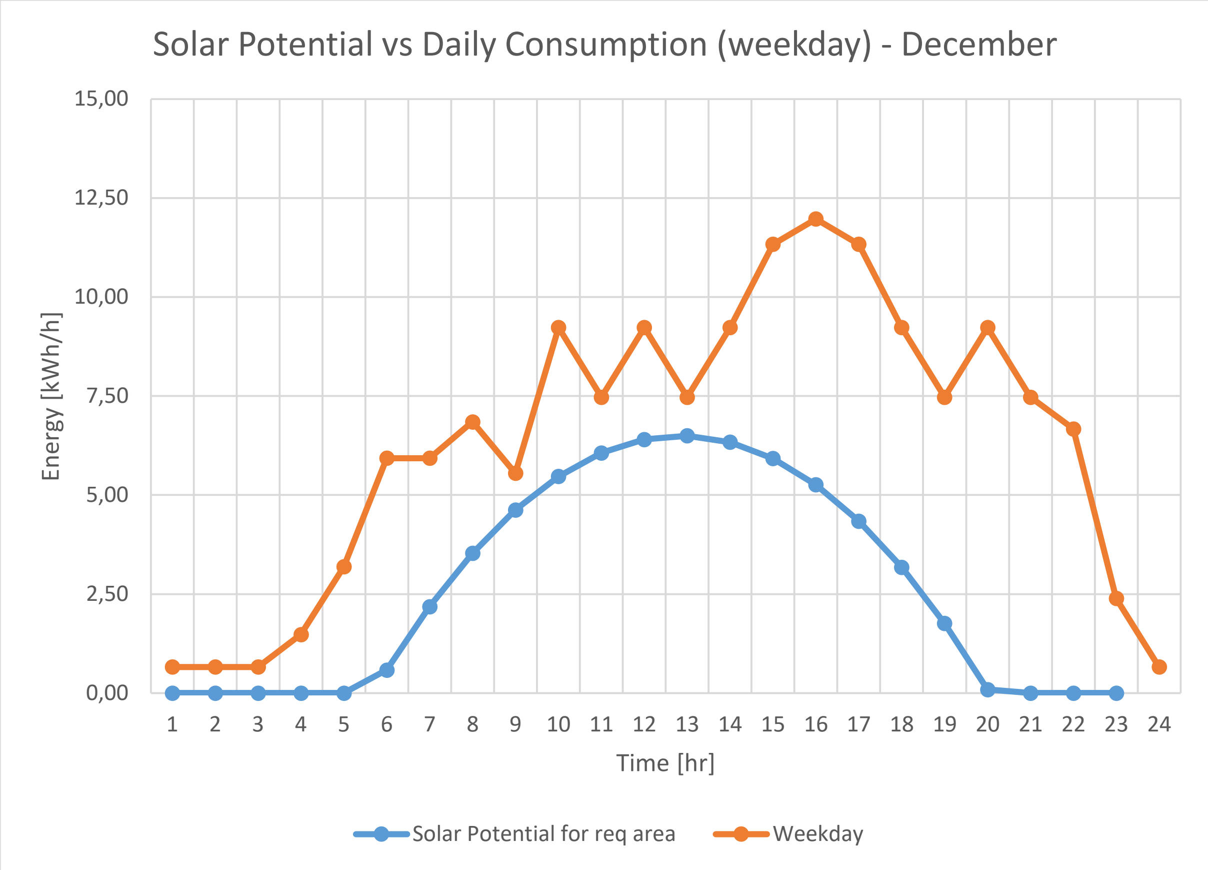

Figure 83: Solar potential plotted with the daily consumption for a summer day during weekdays

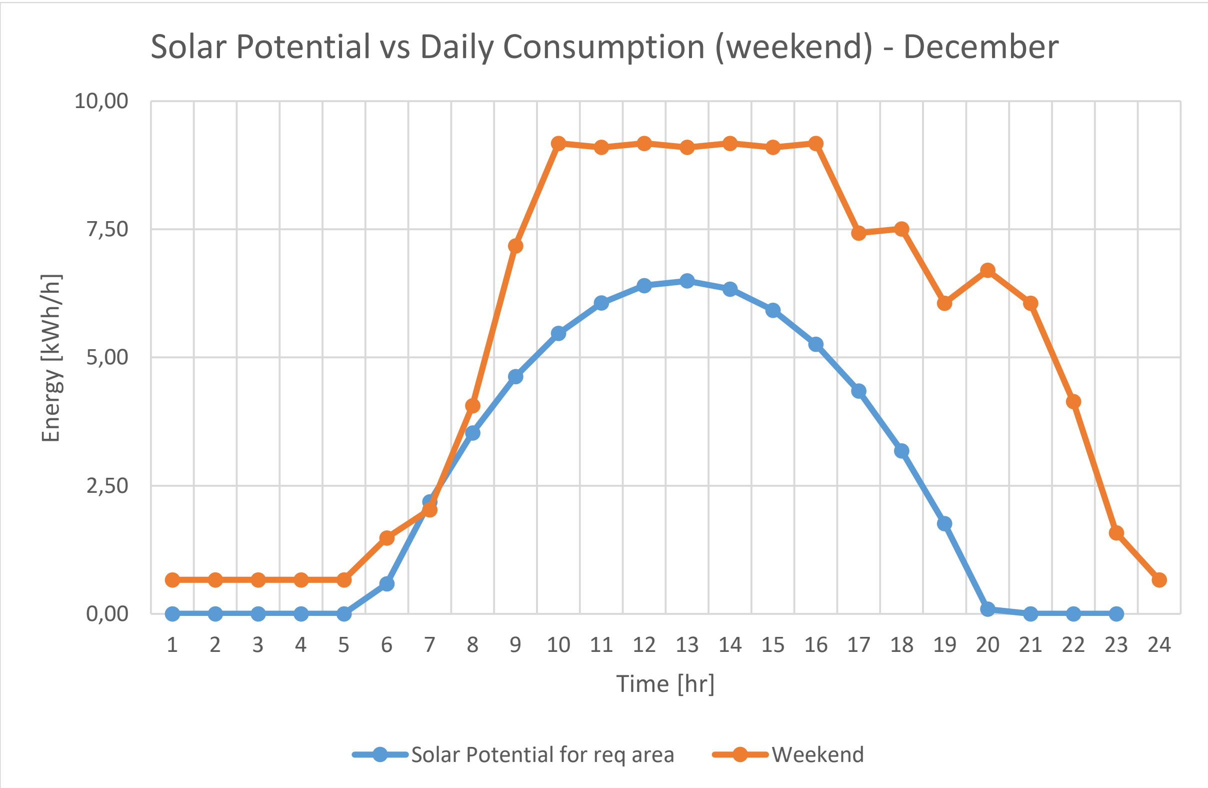

Figure 84: Solar potential plotted with the daily consumption for a summer day during the weekend

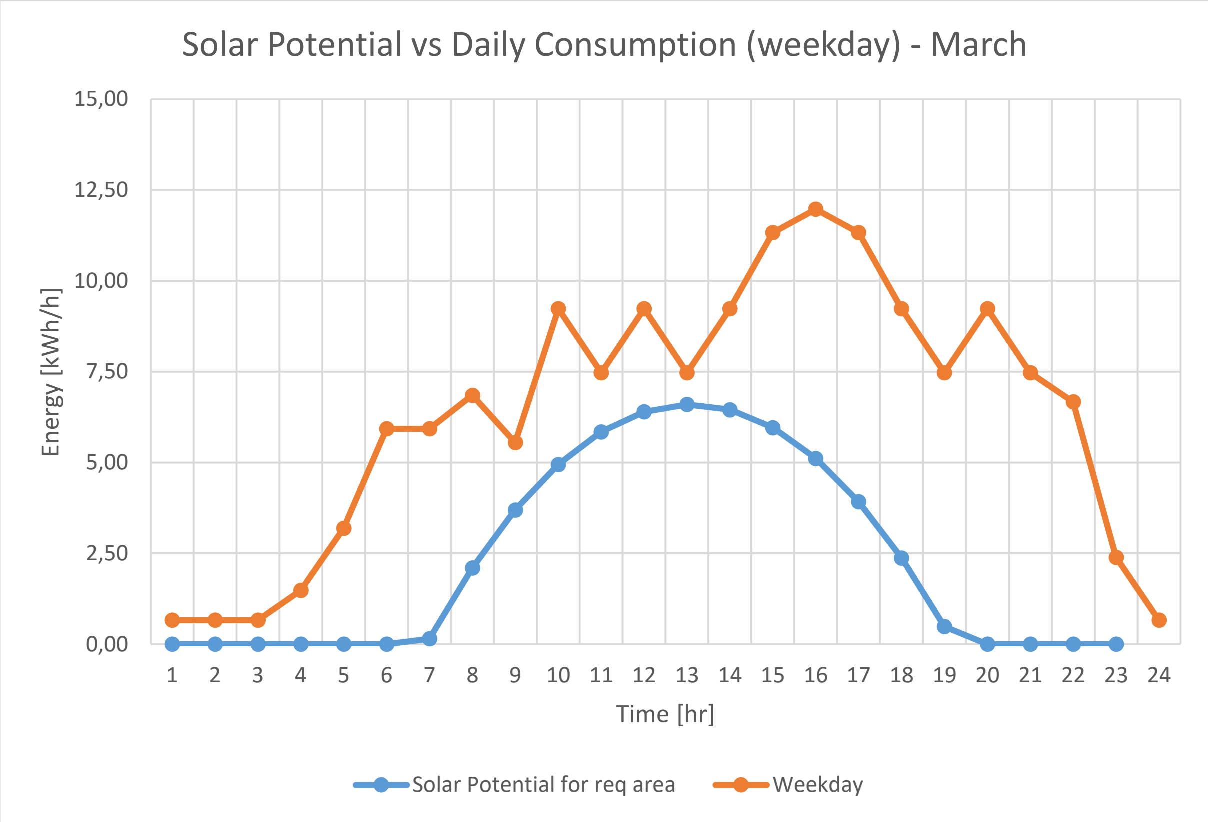

Figure 85: Solar potential plotted with the daily consumption for an autumn day during weekdays

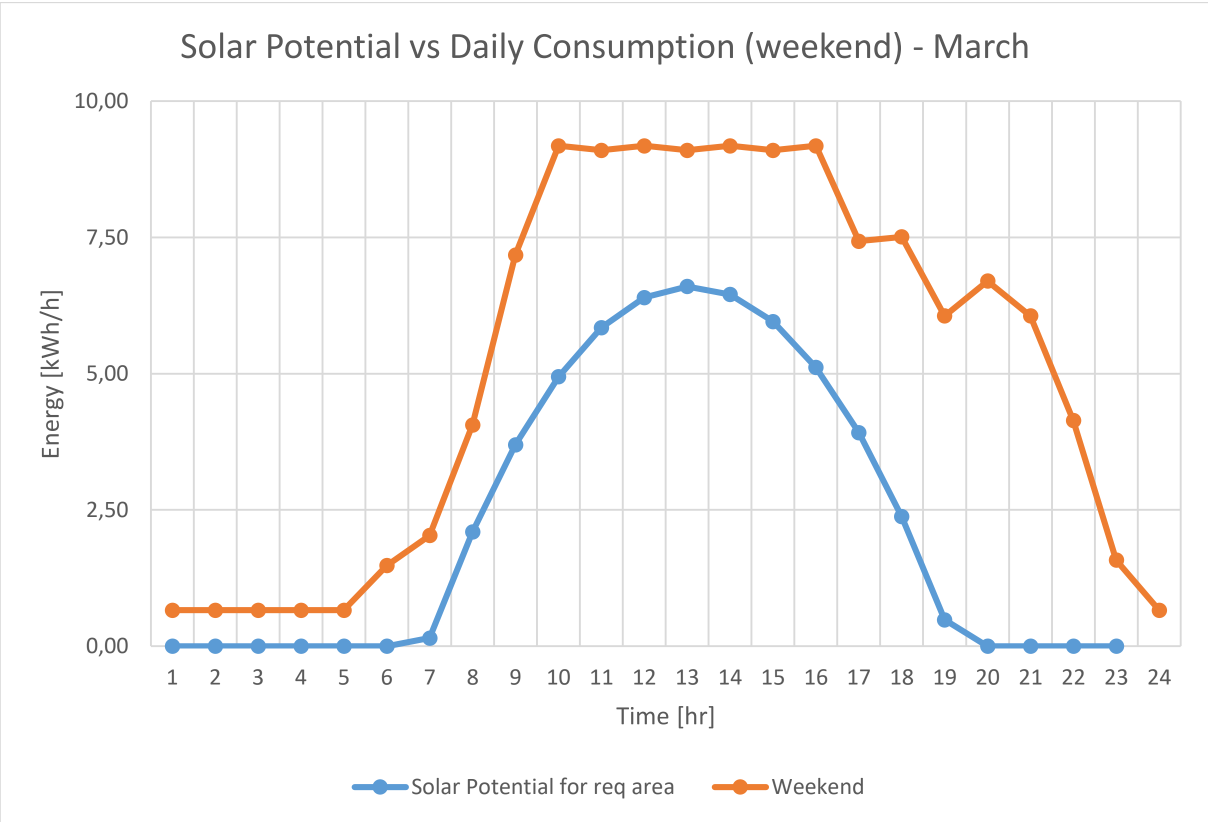

Figure 86: Solar potential plotted with the daily consumption for an autumn day during the weekend

APPENDIX VII: DETAILED ENERGY TARIFFS

Table 9: Electricity tariffs for NSW [23]

Energy component	Tariff value ($/kWh)	Notes
Peak	0.4640	Between 2 pm and 8 pm weekdays
Shoulder	0.2222	Between 7 am and 2 pm, between 8 pm and 10 pm, weekdays and between 7 am and 10 pm weekends.
Off Peak	0.1098	Between 10 pm and 7 am.
Capacity Demand	0.3704 (kW/day)	Peak demand charge for dimensioning costs.
Solar PV feed-in [24]	0.0600	Payment by the retailer for power generated by (domestic) solar PV system.
CO_2 Emissions	1.06 (kg/kWh)	Equivalent to the emissions of 1 kWh of electricity.

Table 10: Natural gas tariffs for NSW [22]

Energy component	Tariff value ($/MJ)	Notes
First 21 MJ/day	0.0374	-
Next 21 MJ/day	0.0255	-
Next 49 MJ/day	0.0240	-
Average tariff	0.0290	Based on average consumption.
CO_2 Emissions	0.064 (kg/MJ)	-

APPENDIX VIII: REFLECTION ANALYSIS

Before I started the master track Sustainable Energy Technology, I did a bachelor degree in Civil Engineering at the same university. Within this bachelor track it is (almost) mandatory that your bachelor thesis is executed at an external organization, e.g. a company, institute or foreign university. In my case, I did a research internship at the large civil engineering firm of Ballast Nedam in Nieuwegein. During that period, I already gained valuable experience about working in another environment than the University of Twente. I have to say that I really liked the way a company works and I consider myself someone who is very much interested in working in large companies as well.

Furthermore, currently I am working at the company of SciSports as a side job during my master at the University of Twente. This is even a larger addition to my experience working in an external organization, as I am a project manager within one of the departments and responsible for executing projects and meeting deadlines. This is also one of the reasons I wanted to experience the company culture abroad. Also, I wanted to further improve my skills in English and not lose too much time getting used to another language and terminology. As a result, I chose to do an internship at the other side of the world, in Sydney, Australia.

Beforehand, I had several Skype meetings with my external supervisor and simultaneously the director of Blue Green Engineering, the company at which I would conduct my internship. My supervisor, Vasilios Giotis, seemed to me as a strict man of whom I could learn a lot regarding the ins and outs of the profession of an engineer. My first impression of him was that of a very serious, business like type. I got the impression that I needed to work fairly hard to make a good impression and to live up to his standards.

At the first day of the internship, I had a meeting with Vasilios in order to make more specific arrangements regarding the working environment. Initially, we made the arrangements that I would start with getting used to Design Builder and 4M software in the first two weeks and after that period would start working on the projects. However, as the Heffron Hall project was a very urgent and complex project, already after three days of training, Vasilios insisted to let me build the involved models. This was a pretty surprising twist but it helped me to better understand the involved software of Design Builder and EnergyPlus than by executing the given tutorials. Also, it directly gave me a feeling being valuable to the company, which was a great plus.

In het weeks succeeding the initial weeks, I worked on the involved models for the Heffron Hall building. This included making the models in Design Builder, but as well making calculations for the glazing, fabric, lighting and occupancy. Also, it involved creating my own models for the solar potential and for the heat transfer of the underfloor heating as these were not available yet. This gave me more insight in setting up such models and gave me opportunities to use the knowledge of the master track in actual real projects. The results of the different models were used to aggregate two reports to the project management team of Heffron Hall. The first, consisting of the JV3 analysis and the compliance to Section J of the BCA, and the second regarding the energy modelling of the actual construction and proposed services. Also, during the creation of the models I have created a manual regarding model construction, providing guidelines for future interns.

Although my first impression was that Vasilios (Vas as I used to call him) was a very business-like person, he was in fact the totally opposite. From day 1, he made me feel comfortable at the company and made sure that I he did not burden me with a too large workload. Actually, I do think that sometimes he could have increased my workload as I like a challenge and it is a way to let me work harder. However, besides the work related discussions, we talked a lot about other topics such as politics, the future of Greece (as we both have Greek origins), healthy lifestyles and so on. I think he valued my opinion on most aspects, which helped gaining mutual respect. This also improved the working relation as most of the times it was the two of us at the office (other employees are working part-time and of other locations around Sydney).

Regarding my professionality at work, I think I am usually very professional. This starts with the appearance as a dress code was in place. Therefore, I usually wore a shirt and a jacket to the office, combined with neat shoes. Furthermore, I think that Vasilios was satisfied with my overall level of engineering skills as well as English communication skills. There were little misunderstandings and I think being for several months in a totally English environment helped me further improve my speaking and writing skills in this globally used language. Vasilios helped me with some small things, like using a locker for my bag, etc., but further nothing major was a source of nuisance in my opinion.

Besides my activities for the Heffron Hall project, I was also involved in several other, smaller projects as business needs to go on. This helped me being able to multitask several activities and improved my planning abilities in order to meet the given deadlines. Furthermore, I tried to start the writing of the internship report as early as possible when the executed activities for the Heffron Hall project were still fresh in my mind and it was easy to access all the relevant files and documents. This resulted in a well-constructed report and the possibility to include the feedback of my external supervisor into my report. Also, as I wanted to travel for two months after finishing my internship, my planning abilities needed to be on point in order to deliver an adequate internship report.

Concluding, reflecting on the internship period at Blue Green Engineering the total experience helped me improve my abilities as an engineer and as an employee. Furthermore, I have gained more insight in the profession of an engineer and my thoughts about which career path I want to pursue after finishing my master degree at the University of Twente. The working relation with my external supervisor was mutually pleasant and I think he is satisfied about my level of engineering as well as my professionalism as an employee of a sustainable energy technology company.