



**Department of Mechanical, Materials
& Manufacturing Engineering**

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Comparison of New and Old Autonomous
Houses in Hockerton

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DECLARATION OF ORIGINALITY

Title of Dissertation

Comparison of New and Old Autonomous
Houses in Hockerton.
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Material from any outside source that I have used directly or indirectly is
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has been used.

Name Kunning Yang

Signed Kunning Yang

Dated 10/09/2019

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1. Abstract

This project compared between two autonomous houses at Hockerton Housing Project, HHP house was built 20 years ago, H3 house was newly built 2 years ago. By comparison between actual thermal performance in conservatory and lounge of each house, we initially assumed that: due to overheating and less thermal mass, temperature inside HHP conservatory is not able to keep stable; because both houses have heavyweight thermal mass in building envelope, internal temperature of each house's lounge can be kept at a stable level with very small fluctuation. We used thermal simulation software IESVE to conduct temperature simulation for both houses, result showed a good proof of our previous assumption, finally we calculated thermal resistance and thermal mass of each house to explain some difference between simulated and actual data.

2. Introduction

2.1 Background

Nowadays, human beings are confronting a serious problem: the climate change. Our world is becoming warmer and icebergs in the North Pole are melting, which results in the rise of the sea level and great impact to natural environment. The main reason is that the modern society is consuming far too much conventional fuels, which leads to huge amounts of greenhouse gas emission. According to Provisional UK greenhouse gas emissions national statistics 2018[1], in 2018, the CO₂ net emission of UK is estimated to be 364.1 Mt, 18% of it is from residential sector, which is the third most among main sectors. The main source of emission in residential sector is the use of natural gas for space heating. Although UK already has a target of reducing GHG emission by at least 80% of 1990 level before 2050[2], but the actual terminology used by the government is “net zero” GHG by 2050[3], so if the energy required for space heating in houses can be vastly reduced or completely avoided, it would contribute greatly to the zero carbon progress

2.2 Hockerton Housing Project

Hockerton Housing Project is a small community of energy efficient autonomous houses on the outskirts of Hockerton, two decades ago 5 HHP houses were built, based on the principles used in these houses, 7 more H3 houses have been built in the same area since 2 years ago. Three key design principles of HHP house are[4]:

- thermal mass to absorb heat from sunlight over summer and early autumn, which will be released over the winter.
- passive solar design to use sunlight for space heating and lighting.
- super-insulation and buffer zones to keep stored heat from moving outwards.

Since the energy requirement for space heating is reduced, the remaining energy demand can be met by solar PV and onsite wind turbine, HHP houses are a good example for energy efficient building that can help UK to achieve its “net zero” GHG emission target.

2.3 Aims and Objectives

The aim for this project is to compare the thermal performance of two new and old

autonomous houses at Hockerton Housing Project. First we will use data provided from staff to compare temperature in conservatory and lounge, so that we can have a preliminary understanding of two houses. Then we will build model of each house and conduct temperature simulation under the same condition, by changing some setting we try to make simulation result more valid and comparable. Finally when all required data is obtained, compare between them to explain simulated and actual thermal performance of both houses, this will also need some calculation to be more precise.

2.4 Project Plan

Before submitting interim report, a GANTT chart for project plan was made in July, which is shown in Appendix 1. Table 1 shows the update deliverables and milestones of the project.

Table 1. Deliverable/milestones of the project

Deliverable/Milestone	Method
Simulation software	Get help from Professor Alex to purchase the software IESVE
Tinytag software	Download a free demo of it from website, this demo can open temperature data files
Software learning	There are some free training videos in IESVE's official website
Data of two houses	Provided by staff in Hockerton Housing Project company
House modelling	HHP and H3 are modelled according to the drawings sent by the company
House simulation	After modelling and setting parameters, simulation is conducted in IESVE
Actual temperature distribution (Milestone 1)	Input recorded data into MS Excel to get graphs of temperature distribution
Simulated temperature distribution (Milestone 2)	Input simulated data into MS Excel to get graphs of temperature distribution
An illustration for thermal performance in each house	By comparison between all obtained data and make some calculation
Factsheet for HHP company (Milestone 3)	Write the whole work and result for the project (due to the word limit I will not attach it here but send it to the staff)
Dissertation of the project (Milestone 4)	All the work, data, simulation and deliverables will be accumulated and composed to complete the dissertation of the project

3. Literature Review

3.1 Thermal Mass

Thermal mass describes the ability of a certain material to store heat, in SAP (Standard Assessment Procedure) the Thermal Mass Parameter (TMP) is measured in $\text{kJ/m}^2\text{K}$ [5], where “ m^2 ” refers to a dwelling’s floor area. A material with a useful level of thermal mass should have three basic properties[6]:

- High specific heat capacity to buffer temperature change.
- High density to store more heat.
- Moderate thermal conductivity to make the rate heat flows in and out of the material roughly in step with the daily heating and cooling cycle of the building.

In a heavyweight building, thermal mass can work in summer and winter to make internal temperature more stabilized. A. Reilly and O. Kinnane[7] modelled two wall sections in Madrid, Spain in August, high thermal mass one was 250mm solid blockwork wall with 12.5mm internal plaster and 25mm external render, low thermal mass one was 20mm of timber. In a well-sealed building with no space cooling or heating, the temperature change curve is shown in Figure 1:

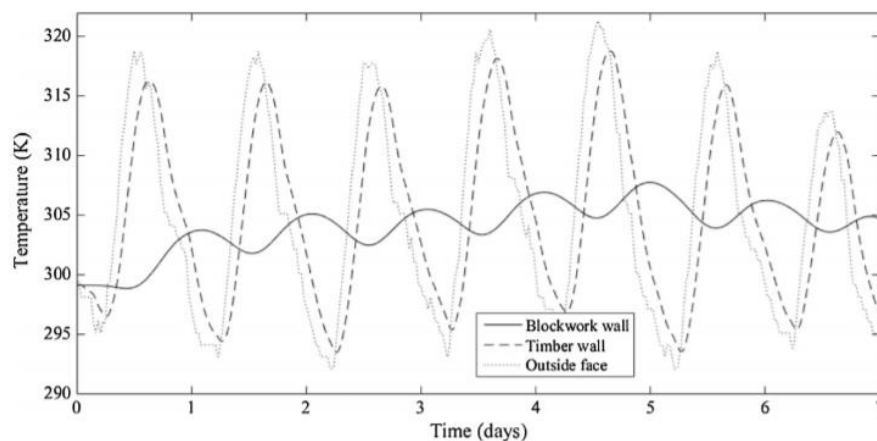


Figure 1. Indoor and outdoor temperature for buildings with different thermal mass

It is clear that blockwork wall with high thermal mass can effectively control temperature fluctuation and maintain indoor temperature at a comfortable level, while timber wall with low thermal mass has no moderating effect on indoor temperature change.

Applying high thermal mass to buildings can significantly reduce cooling and heating load. In a summer day, thermal mass in the building envelope can absorb a large part of heat gain, preventing an excessive temperature rise, so internal temperature can be lower, which make residents more comfortable. L. Rodrigues et al.[8] investigated how thermal mass can reduce the risk of overheating in a timber house. Nottingham HOUSE (Home with Optimized Use of Solar Energy), which is designed to meet most criteria of zero-carbon and Passivhaus standards, was simulated in a thermal analysis software EDSL Tas Engineering. It was found that by using additional layer of 3 different PCM (phase change materials) and concrete on the walls and ceilings, the percentage of time when

internal temperature exceeds 26°C reduced to a certain degree in most places, and concrete with the same thickness was slightly more effective than PCM because of its higher mass.

In a winter day, thermal mass in the building envelope can absorb solar heat from south facing windows, along with internal heat produced by people and appliances. At night the thermal mass will give off its stored heat slowly as the temperature drops, maintaining the room temperature, thus reduce the need of space heating.

3.2 Passive Solar Design

Passive solar design uses solar energy to maintain thermal comfort inside the house without any active mechanical devices for heat collection or distribution. By optimising a building's form, fabric and orientation, passive solar design can maximise solar gain in cold climate while minimise it in hot climate. The basic requirements for passive solar design are[9]:

- Clear view of the sky from the south.
- High insulation and air tightness.
- South (or within 30° of south) facing windows to maximise solar gain during heating season. Area of glazing should be limited to around 15% of the floor area.
- Medium to high level thermal mass with the SAP Thermal Mass parameter more than 200kJ/m²K.
- Adequate ventilation and shading.

There are three types of passive solar design[10]: direct gain system, indirect gain system and isolated gain system. The one adopted by HHP and H3 house is isolated gain system, and they both have a sunspace, the back of the sunspace is a thermal mass wall, usually concrete masonry wall, to store and transfer heat to adjacent living or working space. Solar heat can enter the building by conduction through connection wall or convection through window openings in the wall. Figure 2 shows the passive solar design in a HHP house, the opening between conservatory and inside space is a triple glazing door.

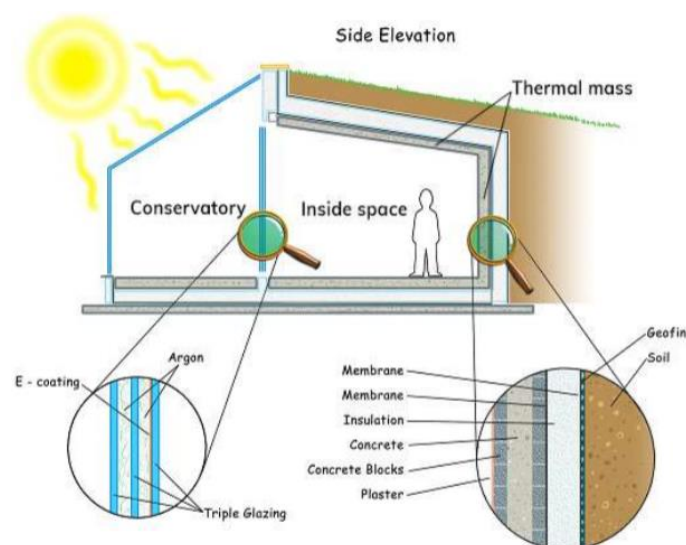


Figure 2. Passive solar design in a HHP house

G. Mihalakakou[11] investigated the thermal performance of a building connected with a sunspace. Simulation was conducted in programme TRNSYS for a single room building connected with a sunspace on its south side, which is shown in Figure 3. In 4 European cities the air temperature distribution in a building with and without sunspace is shown in Figure 4. It is suggested that by connecting with a sunspace, inside temperature can have a rise of about 3-5°C in summer, which means sunspace can significantly reduce the heating load during the winter.

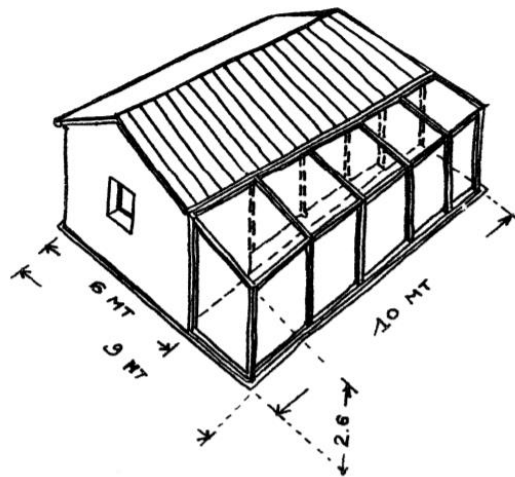


Figure 3. The simulated building connected with a sunspace

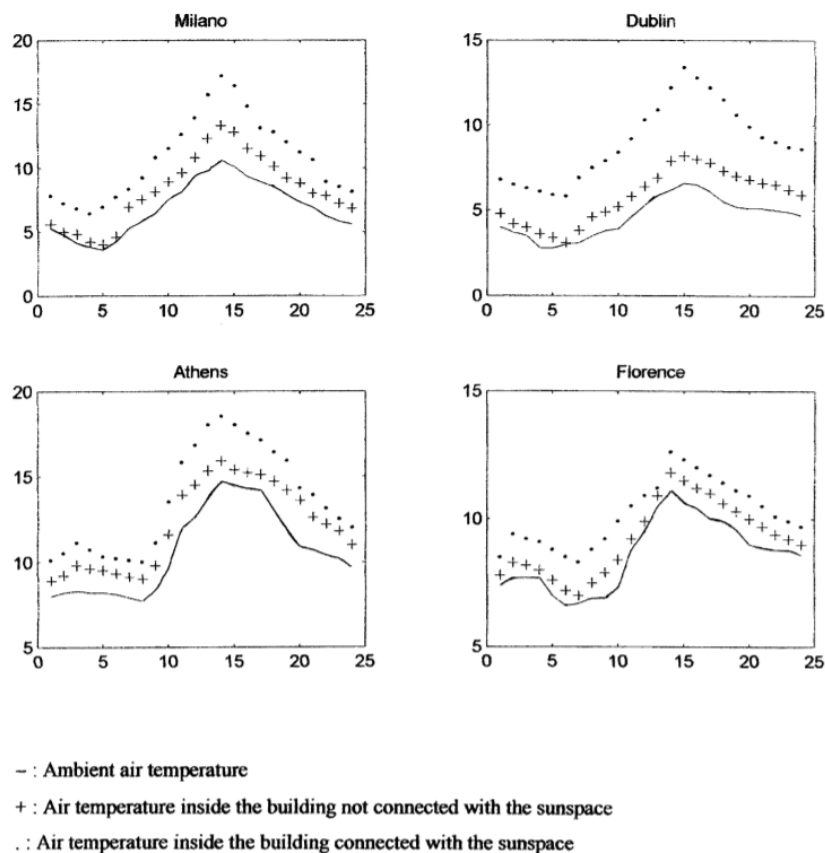


Figure 4. Air temperature distribution for 4 European cities in January

Passive solar design can be used around the world. Zirnhelt and Richman[12] assessed the energy saving potential of passive solar design in Canada, they found that a basic passive solar design can use excessive solar gain to fulfil 21-32% of a typical single-family dwelling's heating requirements in cold climate, if it is optimized this percentage could be up to 32-74%. Chris C.S. Lau et al.[13] collected daily global solar radiation data from 123 measuring station in China, they indicated that in regions with cold and freezing cold climates, proper passive solar design has good energy saving potentials. In south and east China, passive solar design can also help reduce cooling and heating load, if proper orientation and shading measures are considered. Neville Peterkin[14] analysed houses rated at BCA (Building Code of Australia) 5 star, he checked the influence from construction materials and passive solar design, concluded that passive solar design can help BCA 5 star regulations deliver improved energy efficiency better.

4. Thermal Performance of Hockerton Houses (Old vs. New)

4.1 Data Source

In this project, we will compare thermal performance between HHP house and H3 house. Hockerton Housing Project company provided a series of temperature data measured by themselves. Both houses have 3 measuring points, which are shown in Figure 5 and Figure 6. These are axonometric views of each house that will later be built in simulation software IESVE. Green frame represents window, pink for door and blue for hole (HHP house is facing SSW or 22.5 degree of south towards the west and H3 house is facing south):

- HHP house: in the back wall of the kitchen at east side; on a head-height shelf in the back of lounge; 1 metre high in shade behind a box in the east end of conservatory.
- H3 house: outside north wall and next to the front door; on a heat-height shelf in south end of lounge; behind south wall of conservatory and at the east end of it.

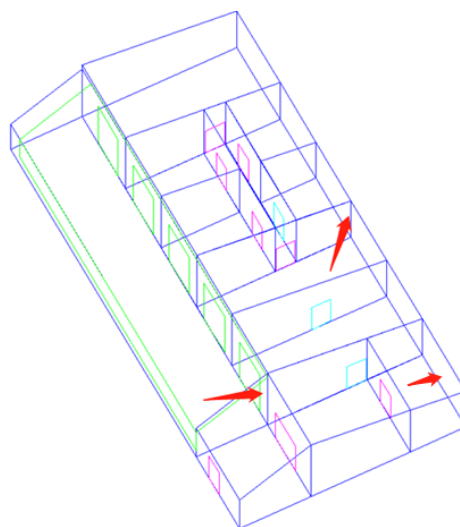


Figure 5. Wireframe of HHP house at axonometric view

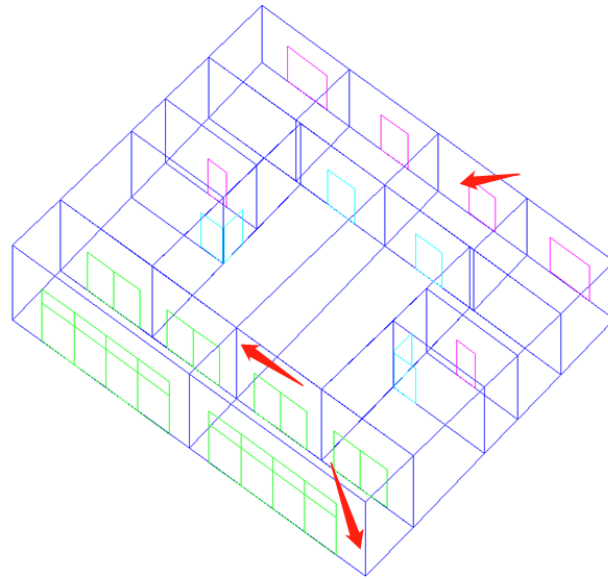


Figure 6. Wireframe of H3 house at axonometric view

Staff in Hockerton Housing Project company used Tinytag data loggers to record the ambient temperature in high accuracy and resolution. Then they exported the recorded data in Tinytag format, which can be opened in Tinytag Explorer. Finally all the data were sorted and transferred into MS Excel spreadsheet.

The measuring period for HHP house is from November 9th, 2018 to July 12th, 2019, while for H3 house it is from November 9th, 2018 to April 19th, 2019. In order to make two sets of data comparable and representative, we made the ambient temperature recorded from both houses' conservatory and lounge into two group, then chose January and April to represent both houses' thermal performance in winter and spring, or cold climate and warm climate. Because we did not have the access to outdoor temperature in January and April of 2019, we used the external temperature measured outside H3 house to make a comparison with the indoor temperature in conservatory and lounge.

After allocating data into different spreadsheet, we got 4 spreadsheets, each contains temperature distributions in three places: conservatory or lounge of H3, conservatory or lounge of HHP and external.

4.2 Temperature Distribution in Conservatory

The actual temperature distribution for two conservatories and external is shown in Figure 7 and Figure 8.

According to Figure 7, in January, the average external temperature is 8.133°C, average recorded temperature in H3 conservatory is 12.917°C, in HHP conservatory it is 11.851°C, a temperature rise of about 4-5°C proves that each conservatory can let in enough sunlight to get a significant heat gain. Although HHP conservatory has the lower average temperature, we can tell from the graph that at some days its maximum temperature is higher than H3, while its minimum temperature is always lower. We can

find these two temperature curves of HHP conservatory and H3 conservatory is very similar with what is shown in Figure 1, this means the thermal mass in HHP conservatory should be less than H3 conservatory so that the internal temperature inside HHP conservatory cannot be maintained at a more stable level. If we calculate the average maximum temperature fluctuation (the temperature difference between maximum and minimum temperature) for each day, for H3 conservatory it is 2.517°C , HHP doubles it to be 5.413°C , so it is confirmed that temperature distribution inside HHP conservatory is more volatile.

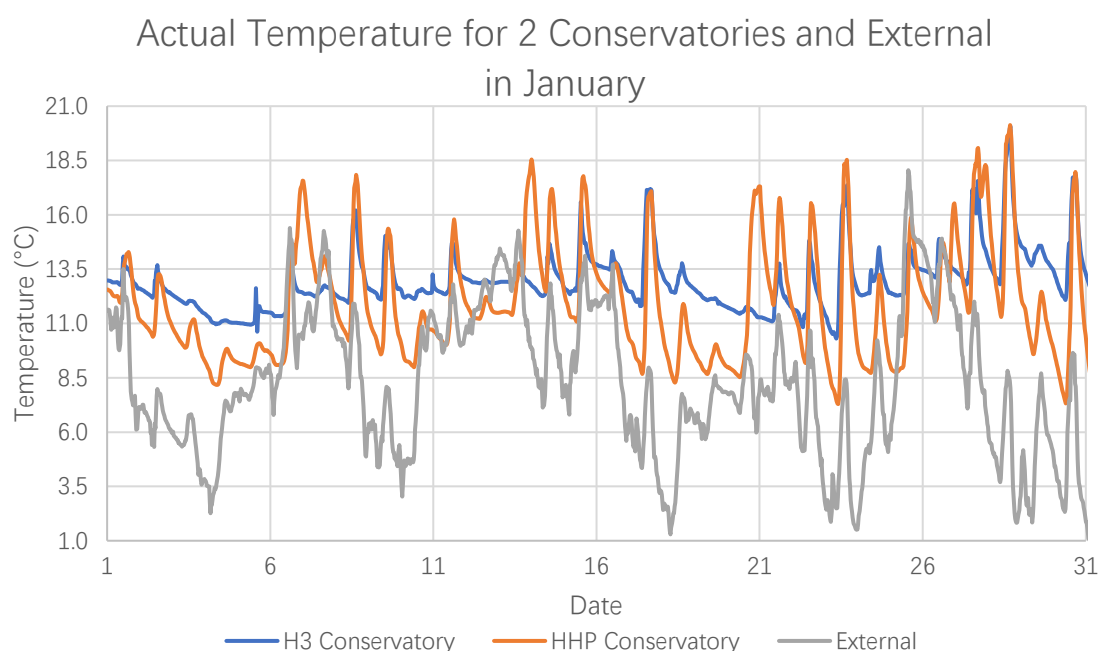


Figure 7. Actual ambient temperature for 2 conservatories and external in January 2019

From Figure 8, the variation tendency is rather more obvious, temperature inside HHP conservatory is largely influenced by external temperature, which perfectly matches with Figure 1. During this period the average external temperature is 8.159°C , average recorded temperature in H3 conservatory is 19.505°C , in HHP conservatory is 18.881°C . Because of more intense sunlight radiation in April, the indoor temperature has risen to a much higher level. The daily average maximum temperature fluctuation inside H3 conservatory is 3.755°C , while for HHP this number is 14.394°C . This means during daytime the air temperature in HHP conservatory will often rise to more than 27°C , but at night it will drop to as low as 11°C . Although residents do not live in conservatory, during the daytime, it is uncomfortable to sit on chairs in the conservatory with such a high temperature for a rest, especially in UK. Comparatively, air temperature in H3 conservatory can be continuously kept in a comfortable range, so that people can always go out from inside to refresh themselves.

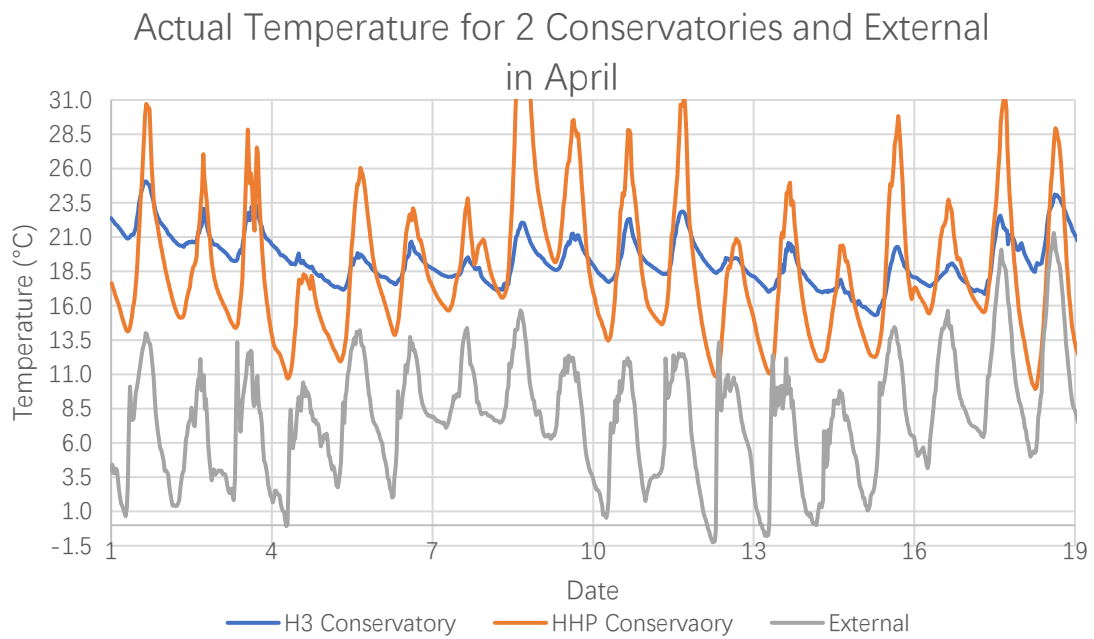


Figure 8. Actual ambient temperature for 2 conservatories and external in April 2019

4.3 Temperature Distribution in Lounge

The actual temperature distribution for two conservatories and external is shown in Figure 9 and Figure 10:

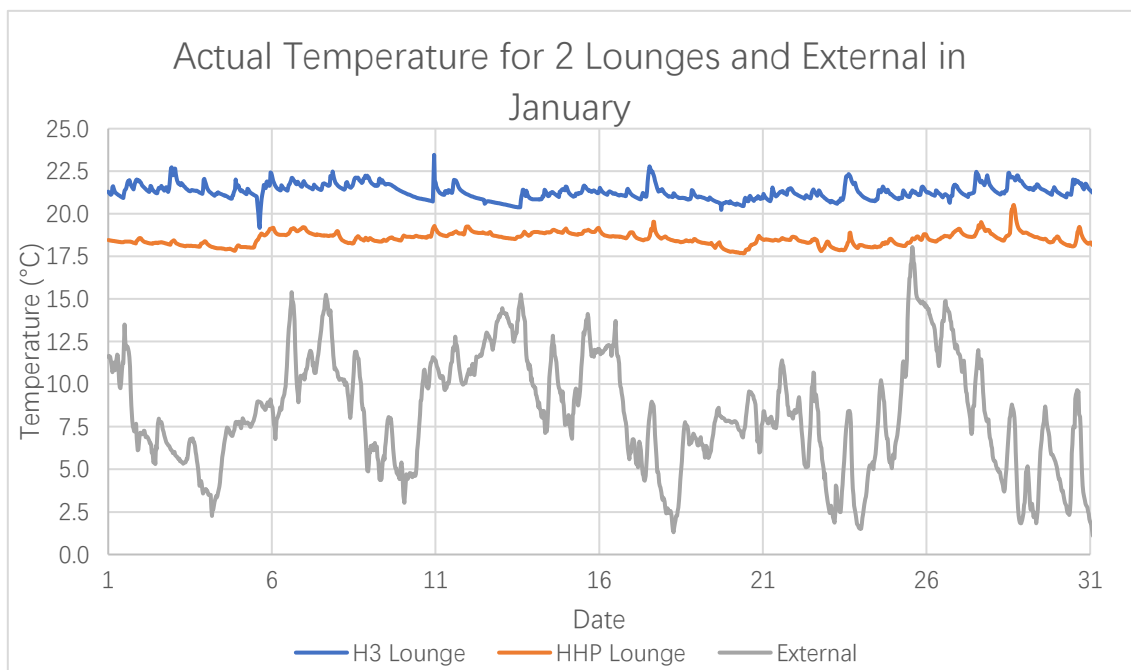


Figure 9. Actual ambient temperature for 2 lounges and external in January 2019

In January, daily average maximum temperature fluctuation for H3 lounge is 1.095°C and for HHP lounge is 0.660°C, there is only some small fluctuation on temperature inside both

houses' lounge. Average recorded temperature in H3 lounge is 21.290°C, in HHP lounge it is 18.518°C. Comparing to temperature inside conservatory, there is a significant temperature rise of 6-8°C in lounge. This proves that it would be warm and comfortable to live inside HHP house and H3 house, especially in January when outdoor temperature is always cold. Another important feature is that external temperature change has little influence on each lounge. Keeping indoor temperature at a stable level means there is no need for space heating because temperature will never drop down to let residents feel freezing.

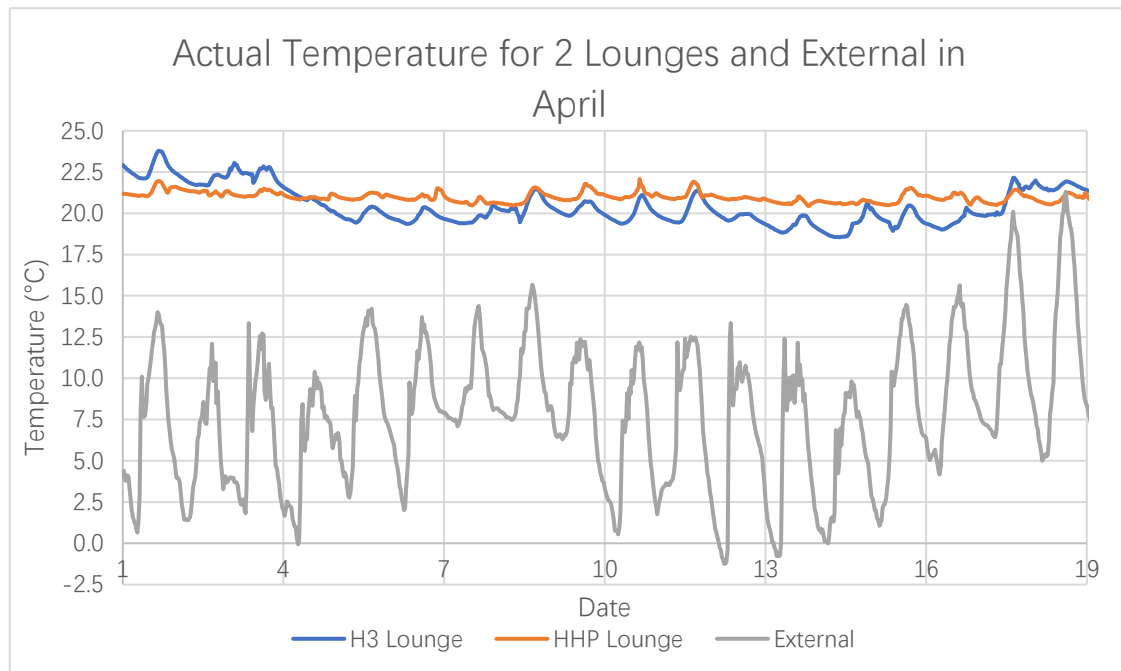


Figure 10. Actual ambient temperature for 2 lounges and external in April 2019

In Figure 10, the temperature distribution is almost the same as in January. The only difference is that, at this time, H3 lounge has a more volatile temperature fluctuation, while temperature inside HHP lounge is roughly kept at 21°C throughout April. In this graph, average recorded temperature in H3 lounge is 20.498°C, in HHP lounge it is 20.97°C, daily average maximum temperature fluctuation for H3 lounge and HHP lounge is 1.35°C and 0.75°C respectively, it can be determined that both houses' lounge are very suitable to live inside.

5. Development of A Complete Simulation Model

5.1 Integrated Environmental Solutions Virtual Environment (IESVE)

ISEVE is a fast, accurate, sub-hourly, thermal simulation suite that can model new and existing buildings of any size and complexity, it can perfectly meet with all the requirements of this project by using it to build model of HHP house and H3 house then make a simulation to the internal temperature. ISEVE consists with applications of different usage, main applications that will be used in this project are:

- ModellT: the application used to create a single, central 3D model for the building, it also enables import of models from other software.
- SunCast: the application used to calculate the position of sun and sky, it tracks solar movement and solar penetration throughout building area.
- ApacheSim: the application used for advanced dynamic thermal simulation, in which time-steps can range from 1 minute to 1 month.
- Building Template Manager (BTM): combination of construction template and thermal template, the former is the library of construction materials, the latter can make definitions of space conditions, internal gains and air exchanges.

5.2 Geometry Creation

The first step of simulation is to build a 3D wireframe model of each house. Hockerton Housing Project company provided many elevations and drawings of HHP house and H3 house (see Appendix 3-7). By amplifying to the same scale as shown in drawings, the 3D models for each house were built in ModellT, the axonometric view is shown before in 3.1.

HHP house has a large conservatory with glazing roof, two kitchens, three bedrooms, a utility room, a bathroom, dining area and a lounge, the windows on conservatory is facing SSW so that it can let in great amount of sunlight and avoid overheating to some degree.

H3 house has a conservatory with smaller glazing area, a kitchen, a lounge, a utility room, a store room, a bathroom and a bedroom, the windows on conservatory is due south. (the model in Figure combines two H3 houses together)

One thing needs to mention is that during the progress of modelling, we found that in ModellT it is unable to define the wall and roof with a thickness, which can be done in other BIM (Building Information Modelling) software such as EDSL Tas Engineering and Revit, so we assumed each cube in the model includes the wall of the corresponding room because the thickness of it cannot be ignored. For example, if a room has a $1\text{m} \times 1\text{m} \times 1\text{m}$ internal space and the thickness of 4 walls and roof is 0.5m , then in the model the cube of this room should be $2\text{m} \times 2\text{m} \times 1.5\text{m}$. In the case of two connected room, we assumed each room take half of the internal partition.

5.3 Construction Material Definition

In order to make the simulation as accurate and practical as possible, the construction material in building envelope should be defined in BTM. When material type and thickness of each layer is confirmed, IESVE can give the conductivity, density, specific heat capacity and resistance of every type of material from its system material library. Then the U-value, R-value and estimated thermal mass for a whole will be calculated and given by IESVE. An example for 1300mm roof of H3 house is shown in Appendix 8.

According to drawings and elevations provided by Hockerton Housing Project company, the components of each house's back wall, side wall, roof and floor can be chosen from material library.

5.3.1 Main Structure of HHP House

The back wall, or the north wall of HHP house has super-high insulation that the company is proud of. From outside to inside, it consists of 300mm expanded polystyrene (material for high insulation), 100mm concrete block, 300mm reinforced concrete and 100mm concrete block. All materials were selected from system material library, and we had tried to make it as same as shown in drawings. After defining, BTM construction template gave the performance characteristics of the back wall:

Table 2. Thermal characteristics of HHP backwall

Total thickness	800 mm
Mass	1157.5 kg/m ²
U-value	0.1112 W/m ² K
Total R-value	8.8246 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

The floor of HHP house consists of (from underground to surface) 150mm reinforced concrete, 300mm expanded polystyrene and 300mm reinforced concrete:

Table 3. Thermal characteristics of HHP floor

Total thickness	750 mm
Mass	1042.5 kg/m ²
U-value	0.1114 W/m ² K
Total R-value	8.7671 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

On the floor the internal partition that separate conservatory and inside space is made of 150mm expanded polystyrene between 100mm face brick and 200mm concrete block, this wall can store the solar heat from conservatory and convey to internal space. Internal partitions in other places were all assumed to be a 200mm concrete block wall.

Table 4. Thermal characteristics of HHP internal partition

Total thickness	450 mm
Mass	672.05 kg/m ²
U-value	0.2108 W/m ² K
Total R-value	4.4847 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

Left side and right side wall of HHP house have roughly the same composition as the back wall. For the roof on inside space, it consists of, from outside to inside, 400mm cultivated sandy soil on the top, 300mm expanded polystyrene, 100mm reinforced concrete and 150mm cast concrete:

Table 5. Thermal characteristics of HHP roof

Total thickness	950 mm
Mass	1337.5 kg/m ²
U-value	0.1103 W/m ² K
Total R-value	8.7477 m ² K/W
Thermal mass (Estimated)	200 kJ/m ² K (Mediumweight)

Another part of the roof is all made by double glazing used on conservatory, it has softwood frames, and the 12mm cavity between two 6mm glass is filled by argon. On the wall connecting conservatory and inside space, or the 450mm internal partition, there are also openings on it to let air and sunlight come in, because there are no other openings on side walls or back wall. Those openings use triple glazing as doors for 5 rooms, and also have softwood frames. The thermal characteristics of glazing are:

Table 6. Thermal characteristics of HHP glazing

	Double glazing	Triple glazing
Net U-value (including frame)	2.2986 W/m ² K	1.7953 W/m ² K
Net R-value	0.7996 m ² K/W	1.0912 m ² K/W

5.3.2 Main Structure of H3 House

H3 house does not have a very thick back wall, but its conservatory has higher insulation and thermal mass to store heat gain. The front wall and side wall have the same composition (from outside to inside): 100mm brickwork on the building surface, 300mm expanded polystyrene and 100mm reinforced concrete. The thermal characteristics of this 500mm external wall are:

Table 7. Thermal characteristics of H3 external wall

Total thickness	500 mm
Mass	407.5 kg/m ²
U-value	0.1123 W/m ² K
Total R-value	8.7340 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

The back wall of H3 house just used thinner insulation, it is made of, from outside to inside, 100mm brickwork, 100mm expanded polystyrene and 100mm reinforced concrete:

Table 8. Thermal characteristics of H3 back wall

Total thickness	300 mm
Mass	402.5 kg/m ²
U-value	0.3135 W/m ² K
Total R-value	3.0197 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

For the roof of H3 house, it is more complicated because there are 3 different thickness of them: from front to back, 1150mm roof on conservatory, 1300mm roof covers lounge and adjacent rooms, then 1100 roof on utility and storeroom. The common material of them are (from outside to inside) 400mm cultivated sandy soil and 200mm reinforced concrete, the difference is that 1150mm roof then uses 350mm expanded polystyrene and 200mm reinforced concrete, 1300mm roof uses 550mm and 150mm of each, 1100mm roof uses 350mm and 150mm of each. The thermal characteristics of three roofs are:

Table 9. Thermal characteristics of H3 roof

Total thickness	1100 mm	1150 mm	1300 mm
Mass	1613.75 kg/m ²	1728.75 kg/m ²	1618.75 kg/m ²
U-value	0.0955 W/m ² K	0.0953 W/m ² K	0.0618 W/m ² K
Total R-value	10.1522 m ² K/W	10.1739 m ² K/W	15.8665 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)	230 kJ/m ² K (Heavyweight)	230 kJ/m ² K (Heavyweight)

Internal partition of H3 also have three types, 300mm and 400mm walls are made of 100mm or 200mm expanded polystyrene connecting two 100mm reinforced concrete, while 100mm partition wall is just made of reinforced concrete. For the floor of H3 house, from underground to surface, it consists of 250mm expanded polystyrene and 200mm reinforced concrete:

Table 10. Thermal characteristics of H3 floor

Total thickness	450 mm
Mass	466.25 kg/m ²
U-value	0.1159 W/m ² K
Total R-value	8.4203 m ² K/W
Thermal mass (Estimated)	230 kJ/m ² K (Heavyweight)

The glazing used on H3 house is the same as HHP house, 2 large window area on front wall of conservatory are filled by double glazing framed in softwood, 4 openings on 300mm internal partition, between conservatory and lounge, are made of triple glazing with software frame.

An important point for glazing is that we had to consider glass to frame ratio, because of softwood frames on every glazing, sunlight can not pass through 100% of all glazing area. When defining glazing in BTM, there was a setting for percentage and type of frame, we estimated this percentage to be 30%, so that glass to frame ratio is 7:3, this will be applied to all glazing area. The settings are shown in Appendix 9.

5.4 Location, Weather Data and Project Profiles Definition

ApLocate is the application used in IESVE to set location and weather data. From ASHRAE database we selected the location to be Nottingham East Midlands, UK, the

latitude and longitude of it are 52.83°N, 1.33°W.

Select ASHRAE Weather Data...

Region:

- Africa
- Asia
- Central/South America
- Canada
- USA
- Europe**
- Australasia/Pacific
- Antarctica

Country:

- Kosovo
- Latvia
- Lebanon
- Liechtenstein
- Lithuania
- Luxembourg
- Macedonia (former Yugoslav rep c
- Malta
- Moldova (Republic of)
- Montenegro
- Netherlands
- Norway
- Palestinian Territory (Occupied)
- Poland
- Portugal
- Romania
- Russian Federation
- Serbia
- Slovakia
- Slovenia
- Spain
- Svalbard and Jan Mayen
- Sweden
- Switzerland
- Syrian Arab Republic
- Turkey
- Ukraine
- United Kingdom**

City:

- Madley
- Manchester
- Manston
- Marham
- Middle Wallop
- Mildenhall
- Milford Haven Port Authority
- Muckle Flugga
- Muckle Holm
- Mumbles Head
- Newcastle Intl Airport
- Newcastle Weather Centre
- Newhaven Lighthouse
- Newquay Cornwall
- North Rona Island
- Northolt
- Norwich Intl Airport
- Nottingham East Midlands**
- Nottingham Wathall

ASHRAE climate zone: 5A

Latitude: 52.83° N

Longitude: 1.33° W

Height Above Sea Level (m): 93.0

Fuel Factor Region: N/A

Filter: All in country

OK Cancel Help

Figure 11. Location selection for both HHP house and H3 house

Then it comes to weather data, since the database can only give climate data of Birmingham, the nearest city, we imported weather data from PROMETHEUS weather files, a project held by University of Exeter that has weather files for 45 locations in UK, including Nottingham[15]. We were not able to compare simulated and actual temperature, because external temperature in 1999 and 2019 are very different from each other. After setting weather data, we got the solar radiation (W/m^2) for 15th of each month in SunCast application, which is shown in Appendix 10.

APpro is the application in which we can define time period in a day for an activity, for example, all the windows open from 8am to 6pm while the refrigerator works continuous for a whole day. In APpro, we can define three time period for some main activities.

First, according to the message provided by staff, residents will always go out from 9am to 2pm. If we use “1” to represent at home and “0” for absent, then the human activity during a day can be represented as Figure 12:

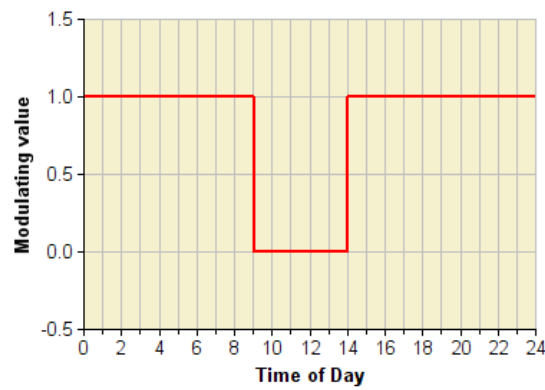


Figure 12. Timetable for “people”

Lighting is a main contributor to internal gain, we assumed internal light will only be on from 5pm to 11pm, which is common for a typical residential building in UK:

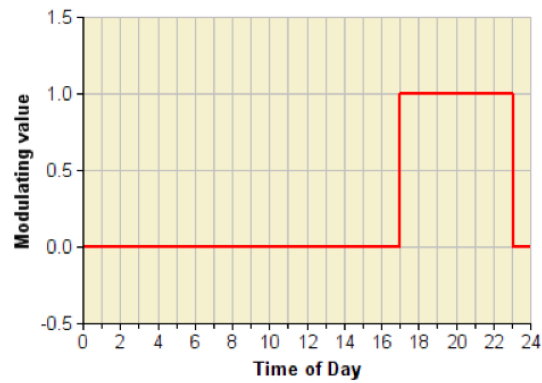


Figure 13. Timetable for “lighting”

Then we assumed the auxiliary ventilation, natural ventilation and refrigeration to be on continuously, this time period can be represented by Figure 13, and corresponding to it there are “off continuously” for heating and cooling load because there is no need of them in both houses:

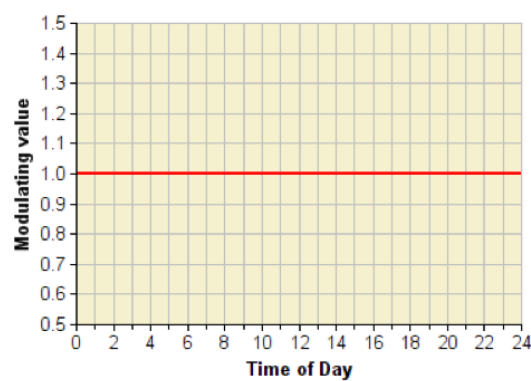


Figure 14. Timetable for “on continuously”

Finally, all the windows will be open from 8am to 6pm. In the morning when people wake up, they open windows for fresh air, while at night, they shut them to keep warm:

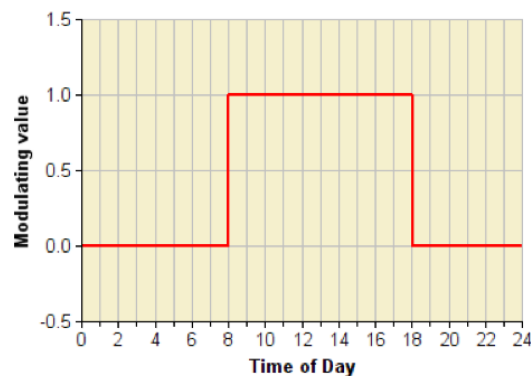


Figure 15. Timetable for “window opening”

5.5 Space Condition, Internal Gains and Ventilation Definitions

Since HHP house and H3 house are near zero energy building, they can maintain the inside temperature at a comfortable level, thus heating or cooling devices will not be used inside. So we set operation profile to be “off continuously”. Domestic hot water (DHW) is heated by electricity generated from PV panels on the roof, so its energy consumption can be set to 0. Figure 16 shows the definition of space condition:

Heating	
Operation profile	off continuously
Setpoint (°C)	Constant 19.0
DHW	
DHW consumption	0.0000 l/(h·pers)
Pattern of use	Linked to occupancy
Cooling	
Operation profile	off continuously
Setpoint (°C)	Constant 23.0

Figure 16. Space condition setting for both houses

Internal gain is of great importance in thermal simulation. At first we added cooking as one type of internal gain, but the problem was that in IESVE we were not able to give corresponding functioning to each room like bedroom, bathroom and kitchen, so that the software cannot concentrate heat produced by cooking only in the area for kitchen, what it did is to make the heat evenly distributed throughout the whole building. In the simulation result, when people start to cook, there would be a sharp rise on temperature anywhere of the house even in conservatory. This is unrealistic because temperature rise would only happen inside or near the kitchen. Considering these houses are more like a

co-housing community and residents always have meal together in the garden outside, we did not count in the heat gain produced by cooking.

Except cooking, the main types of internal gains were: general lighting, thermal radiation of human body and always-on refrigerator. By referring to “*Internal Heat Gains*” published by University of Cambridge[16], general lighting was set to be 10W/m² for the reason that light is able to cover all the ground floor, it follows operation profile “lighting”. Radiation generated by one resident was set to be 70W sensible gain plus 45W latent gain, we assumed there are 4 people in a house, and this follows operation profile “people”. The refrigerator is working without stop and the heat generated from it was set to be 31W/m². Setting for internal gain is shown in Figure 17:

Type	Gain Reference	Maximum Sensible Gain	Maximum Latent Gain	Occupancy	Max Power C	Radiant Fraction	Meter	Variation Profile
People	People	70.000 W/person	45.000 W/person	4.000 people	-	-	-	People
Refrigeration	Refrigeration	31.000 W/m ²	0.000 W/m ²	-	31.000 W/m ²	0.60	Electr	on continuously
General Lighting	General Lighting	10.000 W/m ²	-	-	10.000 W/m ²	0.45	Electr	Lighting

Figure 17. Internal gains for each house

Finally, for air exchange, Hockerton Housing Project company published a technical factsheet about ventilation and air tightness, we got information from it that the mechanical ventilation system inside HHP house has a flow rate of 40 litre/s, and it is working continuously. Due to its high air tightness, natural ventilation was estimated to be 1 air exchange per 4 hour, or 0.25 ac/h, and it was also assumed to be on continuously. Air exchange setting is shown in Figure 18:

Type	Exchange Reference	Max Flow	Unit	Variation Profile	Adjacent Condition
Auxiliary Ventilation	Auxiliary ventilation	40.0000	l/s	on continuously	External Air
Natural Ventilation	Natural ventilation	0.250	ach	on continuously	External Air

Figure 18. Air exchange profile for each house

One additional setting is the window opening type, we assumed that from 8am to 6pm, which is predetermined as “window opening” profile. When inside temperature exceeds opening threshold of 23°C, all the window will opened to a max angle of 45°, openable area was set to be 15%.

Reference ID	XTRN0000
Description	External window opening
Exposure Type	01. exposed wall
Opening Category	Window / door - side hung
Openable Area %	15
Max Angle Open °	45
Proportions	Length/Height < 0.5
Equivalent orifice	12.097 % of gross
Crack Flow	0.000 $l/(s \cdot m \cdot Pa^{0.6})$
Crack Length	0 % of opening perimeter
Opening threshold	23.00 °C
Degree of Opening (Modulating Profile)	Window Opening

Figure 19. Opening type for window

5.6 Simulation Result and Data Analysing

After all the settings are determined, we chose Apache to conduct thermal simulation, and then we set time period for January and April, reporting interval for 30 minutes in order to match with actual data (Tinytag record temperature data once per 30 minutes). Click “simulation”, when simulation is done, we chose conservatory on building model and got one graph for air temperature distribution in Figure 21:

Results file:

HHP.aps

Description:

Apache results

Weather file:

cntr_Nottingham_TRY.epw

Model Links

☒ Enable SunCast Link?
 ☒ MacroFlo Link?
 ☐ ApacheHVAC - No HVAC files found
 ☐ Run RadianceIES? (Assign default sensors)
 ☒ Auxiliary ventilation air exchange?
 ☒ Natural ventilation air exchange?
 ☒ Apply Diversity Factors for internal gains?

Simulation

From

1

January

To

31

January

Simulation Time Step

10

minutes

Reporting Interval

30

minutes

Preconditioning Period

10

days

Simulation Options

Output Options

Add to Queue

Estimated results file size

5.6 Mb

Help

Parallel Simulation Settings

[What's this?](#)

Simulate

Save & exit

Cancel

Figure 20. Simulation setting in Apache

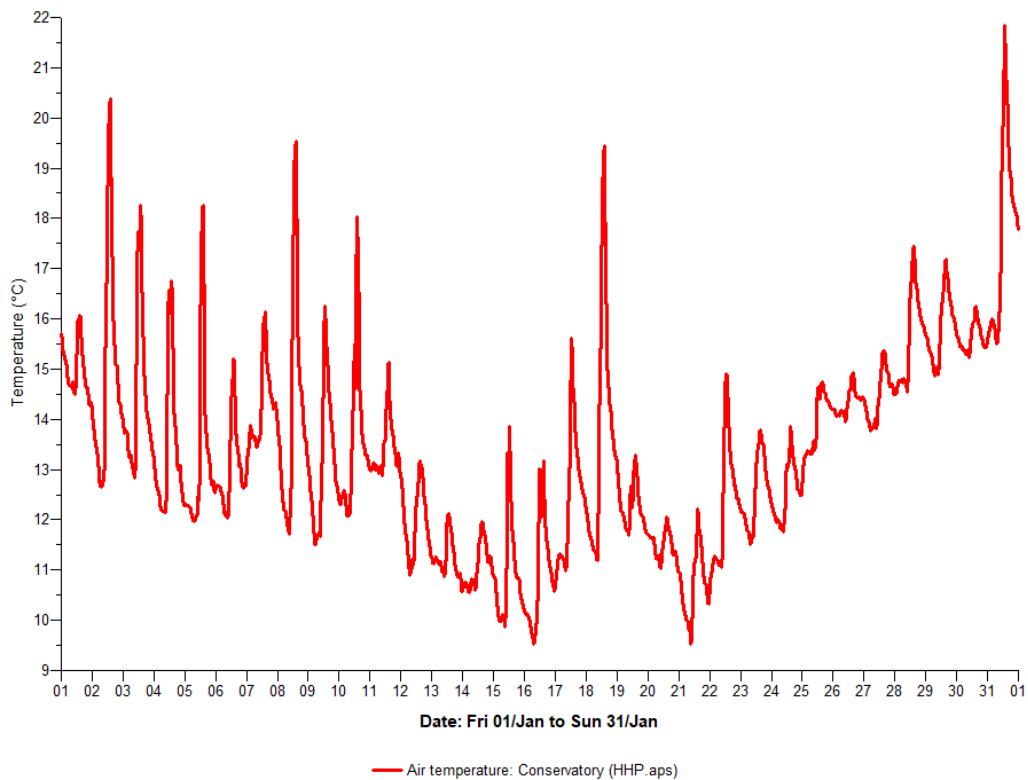


Figure 21. Simulated air temperature in HHP conservatory

Follow the same step, we obtained simulated air temperature in conservatory and lounge for each house, in January and April respectively. In order to compare weather data in corresponding month, we used dry-bulb temperature to represent it, and this weather data was recorded in 1999. After we extracted all the temperature data and transferred them into MS Excel spreadsheet, we could start to compare air temperature in two rooms of H3 house and HHP house with the outdoor temperature.

5.6.1 Simulated Air Temperature in Conservatory

The simulated temperature distribution for two conservatories and external is shown in Figure 22 and 23.

According to simulation result in Figure 22, average external temperature in January 1999 is 3.6°C, which is much lower than 8.133°C in 2019. This reflects the influence of global warming. Average simulated temperature in H3 conservatory is 11.87°C, in HHP conservatory it is 13.38°C, inside temperature is about 4-5°C higher than outside. Daily average maximum temperature fluctuation for H3 conservatory and HHP conservatory is 1.32°C and 3.12°C respectively, this matches with the graph because temperature fluctuation in most days HHP conservatory is obviously higher than H3 conservatory.

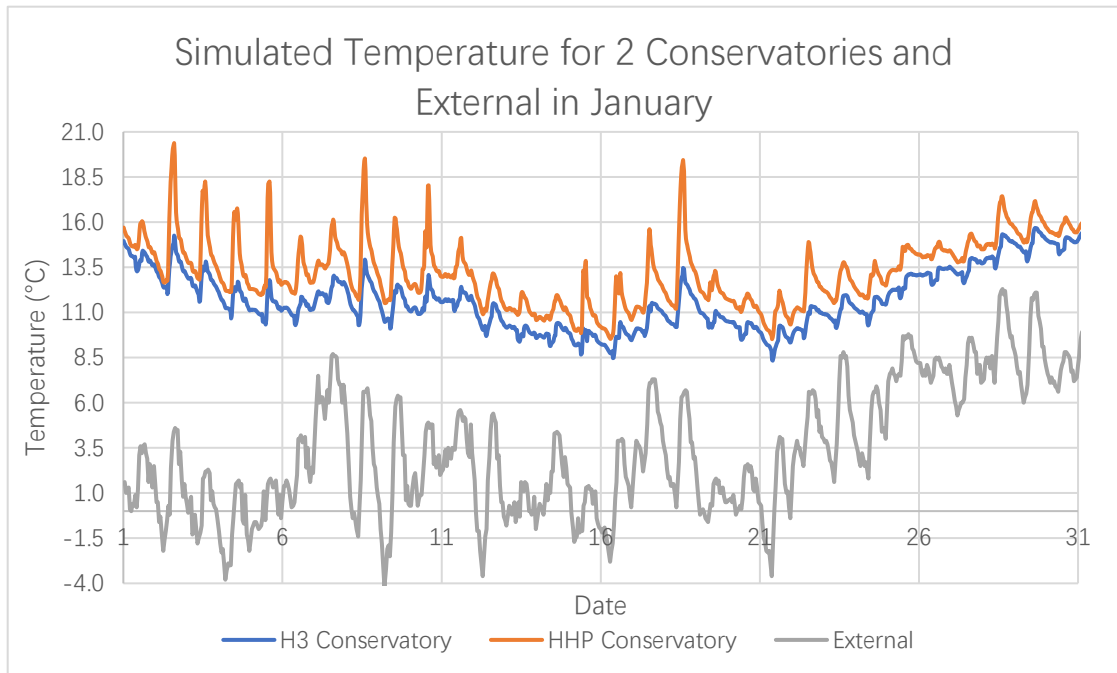


Figure 22. Simulated air temperature for 2 conservatories and external in January 1999

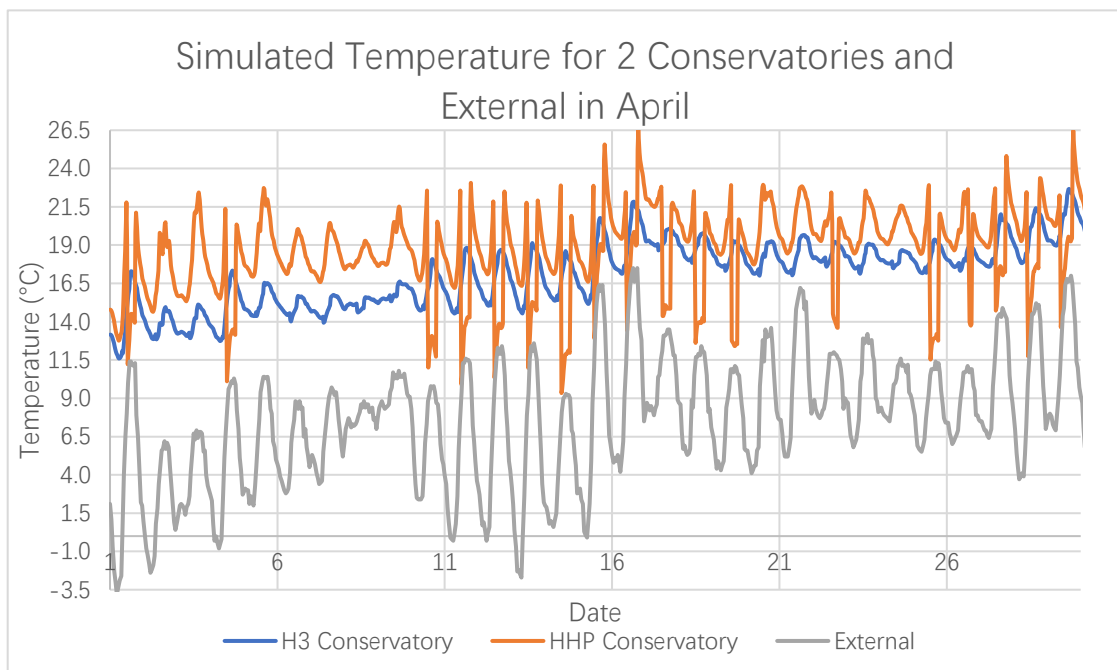


Figure 23. Simulated air temperature for 2 conservatories and external in April 1999

In April 1999, external temperature changed dramatically every day. From the graph it is obvious that it has put great influence on internal temperature in HHP conservatory. Daily average maximum temperature fluctuation in it has risen to 7.26°C, while in H3 conservatory it is 1.70°C, only about a quarter. Average simulated temperature in H3 conservatory is 17.22°C, in HHP conservatory 18.62°C.

5.6.2 Simulated Air Temperature in Lounge

The simulated temperature distribution for two conservatories and external is shown in Figure 24 and 25.

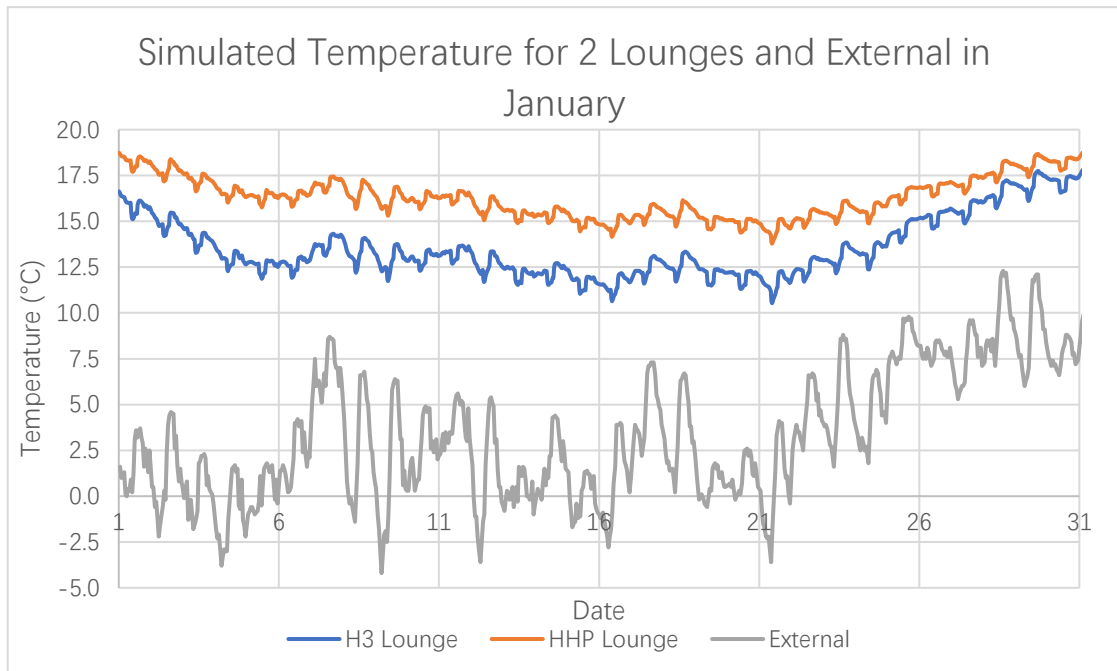


Figure 24. Simulated air temperature for 2 lounges and external in January 1999

The simulation result in January 1999 can roughly match with the actual temperature distribution in January, daily average maximum temperature fluctuation is 1.03°C and 0.78°C for H3 lounge and HHP lounge respectively, which can be ignored. Average simulated temperature inside H3 lounge is 13.69°C, which is lower than 16.36°C in HHP conservatory.

In April 1999, simulated indoor temperature in lounge is affected by volatile change in outdoor temperature, especially in HHP lounge, but this time daily average maximum temperature fluctuation for HHP lounge is 1.73°C, for H3 lounge it is 1.24°C. These small changes would not have much impact on the comfort of living as the average simulated air temperature for H3 and HHP lounge is 17.41°C and 18.75°C.

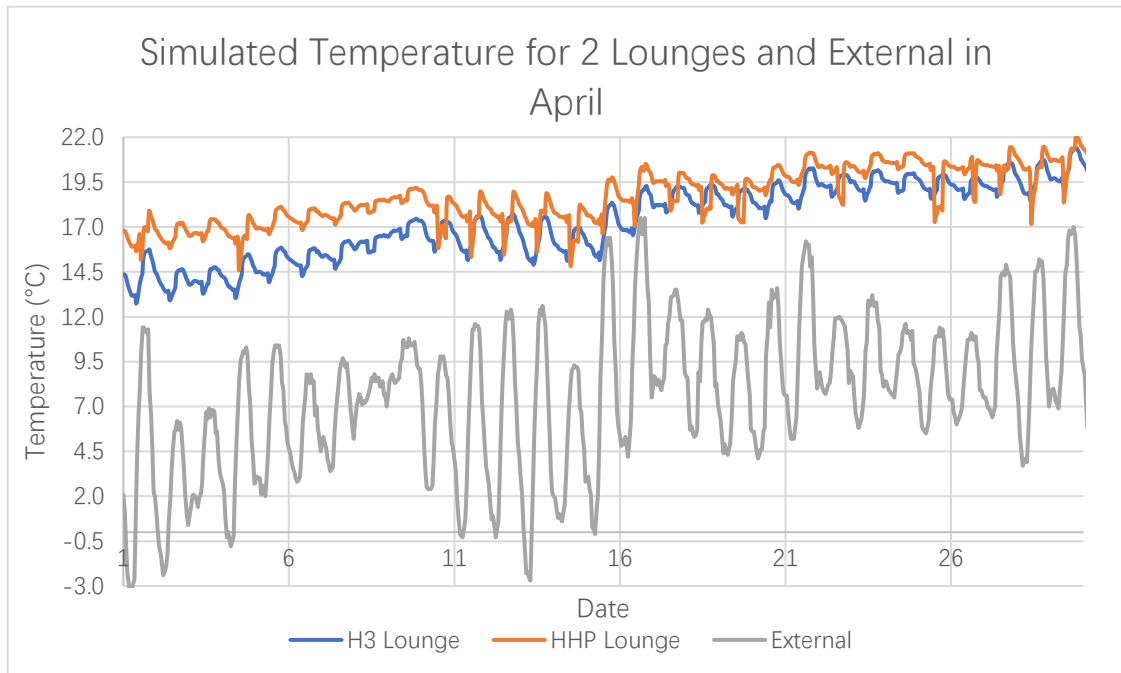


Figure 25. Simulated air temperature for 2 lounges and external in April 1999

5.6.3 Data Analysing

After all the simulation work were finished, we collected all the data and made a general comparison between them in Table 10, AAT is short for actual average temperature, SAT for simulated average temperature and DAMTF for daily average maximum temperature fluctuation.

Table 11. General comparison of H3 house and HHP house

	January	April
External temperature in 2019	8.133°C	8.159°C
AAT/DAMTF in H3 conservatory	12.917°C/2.517°C	19.505°C/3.755°C
AAT/DAMTF in HHP conservatory	11.851°C/5.413°C	18.881°C/14.394°C
AAT/DAMTF in H3 lounge	21.290°C/1.095°C	20.198°C/1.35°C
AAT/DAMTF in HHP lounge	18.518°C/0.660°C	20.97°C/0.75°C
External temperature in 1999	3.6°C	7.7°C
SAT/DAMTF in H3 conservatory	11.87°C/1.32°C	17.22°C/1.70°C
SAT/DAMTF in HHP conservatory	13.38°C/3.12°C	18.62°C/7.26°C
SAT/DAMTF in H3 lounge	13.69°C/1.03°C	17.41°C/1.24°C
SAT/DAMTF in HHP lounge	16.36°C/0.78°C	18.75°C/1.73°C

We would compare by similarities and differences between these data.

Similarities:

- In HHP conservatory, because of large glazing area which can let in sunlight, the highest temperature during daytime can reach a very high level, but due to the lack of a roof with high thermal mass, inside temperature drops quickly after

sunset, so the temperature in HHP conservatory is always volatile, no matter in actual environment or in simulation, in cold climate or in warm climate.

- Because of 1150mm roof and 500mm front wall covering H3 conservatory together, heavyweight thermal mass make the temperature inside always kept at a stable level, although in April the daily average maximum temperature fluctuation in actual environment has risen to 3.755°C, meanwhile this value in HHP conservatory is an astounding 14.394°C.
- The lounges of each house perform very well. The temperature inside the lounge is always about 10°C warmer than outdoor temperature, and the daily average maximum temperature fluctuation has never exceeded 2°C. This means that both houses are comfortable and suitable to live in, even without any space cooling and heating. This feature is very important.

Differences:

Although simulated temperature distribution and changing trend seem to be roughly the same as actual ones, what is significant but unusual is that in simulation the average temperature in HHP house is always higher than H3 house, while the actual temperature inside HHP house is about 1-2°C lower than H3 house. In order to figure out this problem, we can calculate the thermal resistance and thermal mass for each house.

For thermal resistance, we can treat a house as a box, when outside is colder, it begins to emit heat from inside to outside, the higher thermal resistance of the box is, the slower that it will emit heat. In this project we only need to calculate thermal resistance on building envelope, or the combination of external wall and roof. Table 12 and 13 shows the calculation, because there will be different construction used on different parts of a whole wall, we will calculate them separately. From the unit we know that thermal resistance(K/W) equals R-value(m²K/W)/area(m²). Because different material has different R-value, we used area weighted thermal resistance to get the more accurate thermal resistance. R-value and wall area can be found in BTM construction template.

Table 12. Thermal resistance calculation for HHP house

HHP house	R-value (m ² K/W)	Area (m ²)	Area Percentage (%)	Area Weighted Thermal Resistance (K/W)
Front wall (Part 1)	0.80	25.44	6.599	0.0021
Front wall (Part 2)	4.47	19.08	4.949	0.0116
Front wall (Part 3)	6.01	7.38	1.914	0.0156
Side wall (Part 1)	14.57	22.41	5.813	0.0378
Side wall (Part 2)	8.84	48.18	12.498	0.0229
Back wall	8.82	65.10	16.885	0.0229
Roof (Part 1)	0.80	61.50	15.953	0.0021
Roof (Part 2)	0.31	11.99	3.110	0.0008
Roof (Part 3)	8.75	124.44	32.279	0.0227
Total		385.52	100	0.1385

Table 13. Thermal resistance calculation for H3 house

H3 house	R-value (m ² K/W)	Area (m ²)	Area Percentage (%)	Area Weighted Thermal Resistance (K/W)
Front wall (Part 1)	3.02	28.39	8.458	0.009
Front wall (Part 2)	0.80	28.80	8.580	0.002
Side wall (Part 1)	8.73	68.64	20.449	0.026
Side wall (Part 2)	3.02	16.32	4.862	0.009
Back wall	3.02	43.89	13.076	0.009
Roof (Part 1)	10.17	28.73	8.559	0.030
Roof (Part 2)	15.87	88.84	26.468	0.047
Roof (Part 3)	10.15	32.05	9.549	0.030
Total		335.67	100	0.163

For thermal mass, we can calculate the mass of each type of material first, when multiply it with specific heat capacity c_p , so that we can get the corresponding thermal mass in unit of MJ/K. In HHP house and H3 house there is generally 4-5 types of material, but one type material may have different thickness used in different structure. Table 14 and 15 shows that calculation for thermal mass.

Table 14. Thermal mass calculation for HHP house

HHP house	Area (m ²)	Thickness (m)	Density (kg/m ³)	Mass (tonne)	c_p (kJ/kgK)	Thermal mass (MJ/K)
Reinforced Concrete	37.66	0.1	2300	8.66	1	8.66
	223.72	0.2	2300	102.91	1	102.91
	124.44	0.25	2300	71.55	1	71.55
	11.99	0.35	2300	9.65	1	9.65
	22.41	0.4	2300	20.62	1	20.62
	113.28	0.5	2300	130.27	1	130.27
Brickwork	19.08	0.1	1700	3.24	0.8	2.59
	7.38	0.2	1700	2.51	0.8	2.01
Expanded Polystyrene	65.35	0.15	25	0.25	1.4	0.34
	18.58	0.2	25	0.09	1.4	0.13
	237.72	0.3	25	1.78	1.4	2.50
	22.41	0.5	25	0.28	1.4	0.39
Facebrick	79.89	0.1	2083	16.64	0.92	15.33
Cultivated Sandy Soil	124.44	0.4	2000	99.55	1.48	147.34
Total						514.29

Table 15. Thermal mass calculation for H3 house

H3 house	Area (m ²)	Thickness (m)	Density (kg/m ³)	Mass (tonne)	c_p (kJ/kgK)	Thermal mass (MJ/K)
Reinforced Concrete	259.67	0.1	2300	59.72	1	59.72
	142.49	0.2	2300	65.55	1	65.55
	120.89	0.35	2300	97.32	1	97.32
	28.728	0.4	2300	26.43	1	26.43
Brickwork	157.24	0.1	1700	26.73	0.8	21.38
Expanded Polystyrene	168.22	0.1	25	0.42	1.4	0.59
	62.87	0.2	25	0.31	1.4	0.44
	68.64	0.3	25	0.51	1.4	0.72
	60.78	0.35	25	0.53	1.4	0.74
	88.84	0.55	25	1.22	1.4	1.71
Cultivated Sandy Soil	149.63	0.4	2000	119.7	1.48	177.16
Total						451.77

According to calculation result, we know that:

For thermal resistance, the area weighted thermal resistance for H3 house's building envelope is 0.163 K/W, for HHP house 0.1385 K/W, this means if temperature difference between outside and inside is 13.85°C (inside is lower than outside at night), the rate of losing heat in HHP house is 100W, but in H3 house this value is about 85W.

For thermal mass, HHP house has 514.29 MJ/K, while H3 is much smaller, which is 451.77 MJ/K. This means at the same temperature difference, constructions in HHP house can absorb more solar heat during the day than H3 house.

Combining this two together, the reason why average temperature in H3 house is always smaller than HHP house is because that in simulation software, after theoretical calculation, the system treats HHP house has much higher thermal mass than H3 house, but thermal resistance between them do not differ too much. When both houses are in the same weather condition, during the day HHP stored much more heat in its thermal mass, but at night they lose heat to external environment at almost the same rate, thus HHP house can accumulate more heat inside, that's why in simulation its average temperature is always higher than H3 house.

6. Conclusion and Future Work

Conclusions from this project are:

- In actual environment and simulation, temperature in HHP conservatory fluctuate much more sharply than in H3 conservatory, especially in April 2019, daily average maximum temperature fluctuation reached as high as 14.394°C. The reason is that although large sunspace and window area can let in more sunlight, it may cause overheating inside at days with high solar radiation. At night when external temperature drops, HHP conservatory do not have enough thermal mass to help keep heat from losing to outside. While in H3 conservatory, 1150mm roof and 500mm front wall ensure that heat absorbed in them during the day can keep temperature warm at night.
- Lounge in both houses can be kept at a comfortable temperature level of about 10-12°C higher than outside, which also means there is no need for space heating or cooling in living area. This great feature not only saves money, but more importantly can save huge amount of GHG emission generat when consuming electricity or natural gas. Although temperature changes dramatically in HHP conservatory, adherent lounge has 800mm back wall, 950mm roof to store enough heat. H3 lounge do not have a thick back wall, connecting doors and holes on its wall will make it harder to lock heat inside, that is why it has slightly higher temperature fluctuation than HHP lounge.
- According to data analysing, we found that, in theory, HHP house should be warmer about 2-3°C than H3 house, but this conflicts with the actual temperature performance. We can conclude the reason for it is that HHP house is built 20 years ago, when conducting simulation, the software assumed that all the construction materials in it follow the building standard in 2015, not in 1999. This means if HHP house can use the same material as used on H3 house, it would have a better performance. And this is the thing residents in HHP houses are doing now, they always make refurbishments to structures like internal wall and floor to improve their quality.
- Both houses have good insulation to keep heat from losing to outside, the average weighted thermal resistance in HHP house and H3 house are 0.1385 K/W and 0.163 K/W. By combining heavyweight thermal mass and high insulation together, houses built by Hockerton Housing Project are the true sense of “Zero Energy Buildings”.

There are also many deficiencies during the project need to be improved:

- IESVE can not make the building model in the same parameter as reality, we could build a better model in Revit, but due to time limit we did not have enough time to learn.
- Settings like air exchange rate, internal gains and window opening type can be more detailed if we could search for more information.
- There is no temperature data for H3 house in July but HHP house has, if in the future staff can have a record of it, we could continue to do more comparison in a hot climate.

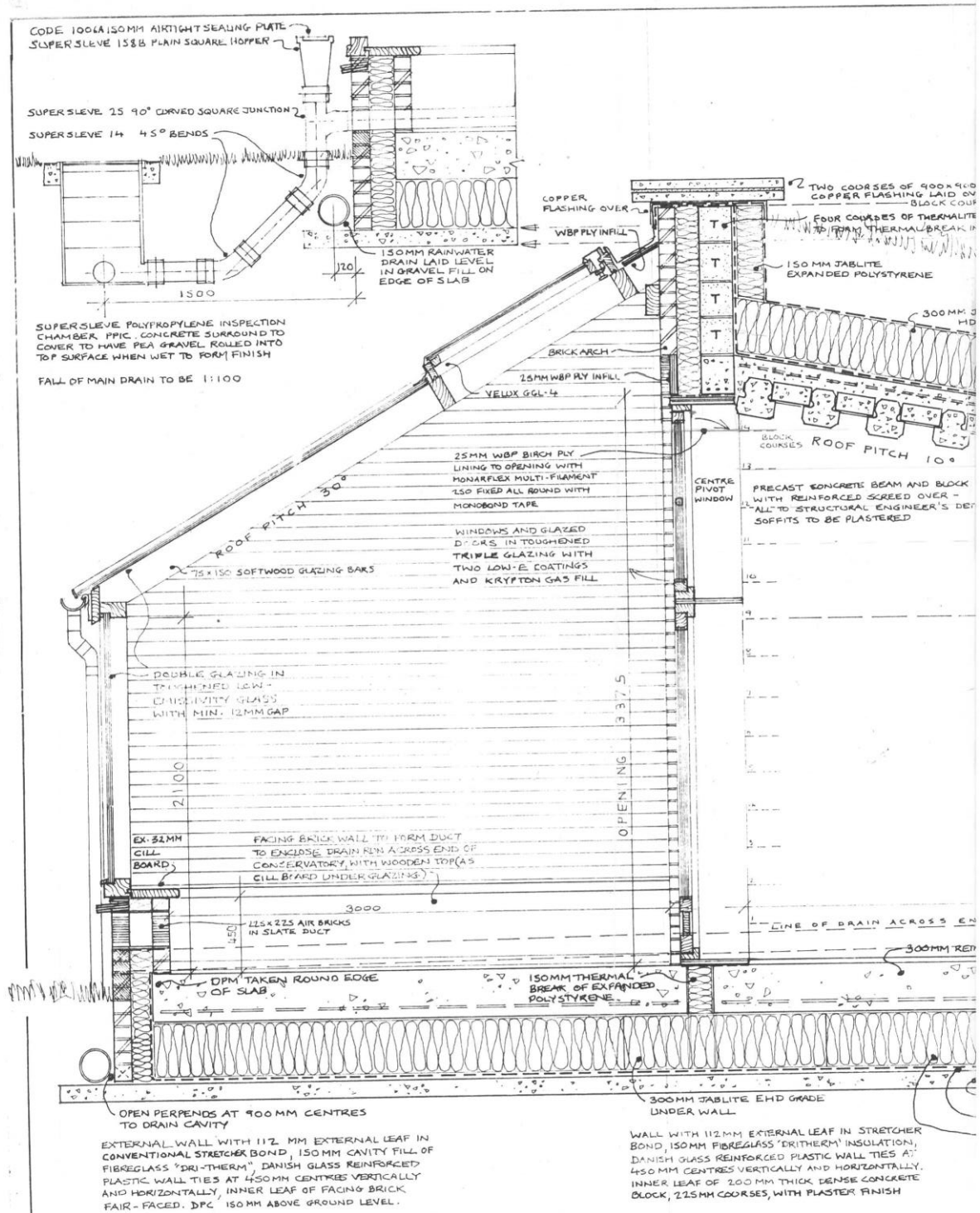
7. Reference

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Appendix 1. GANTT chart of Project Plan (before interim report)

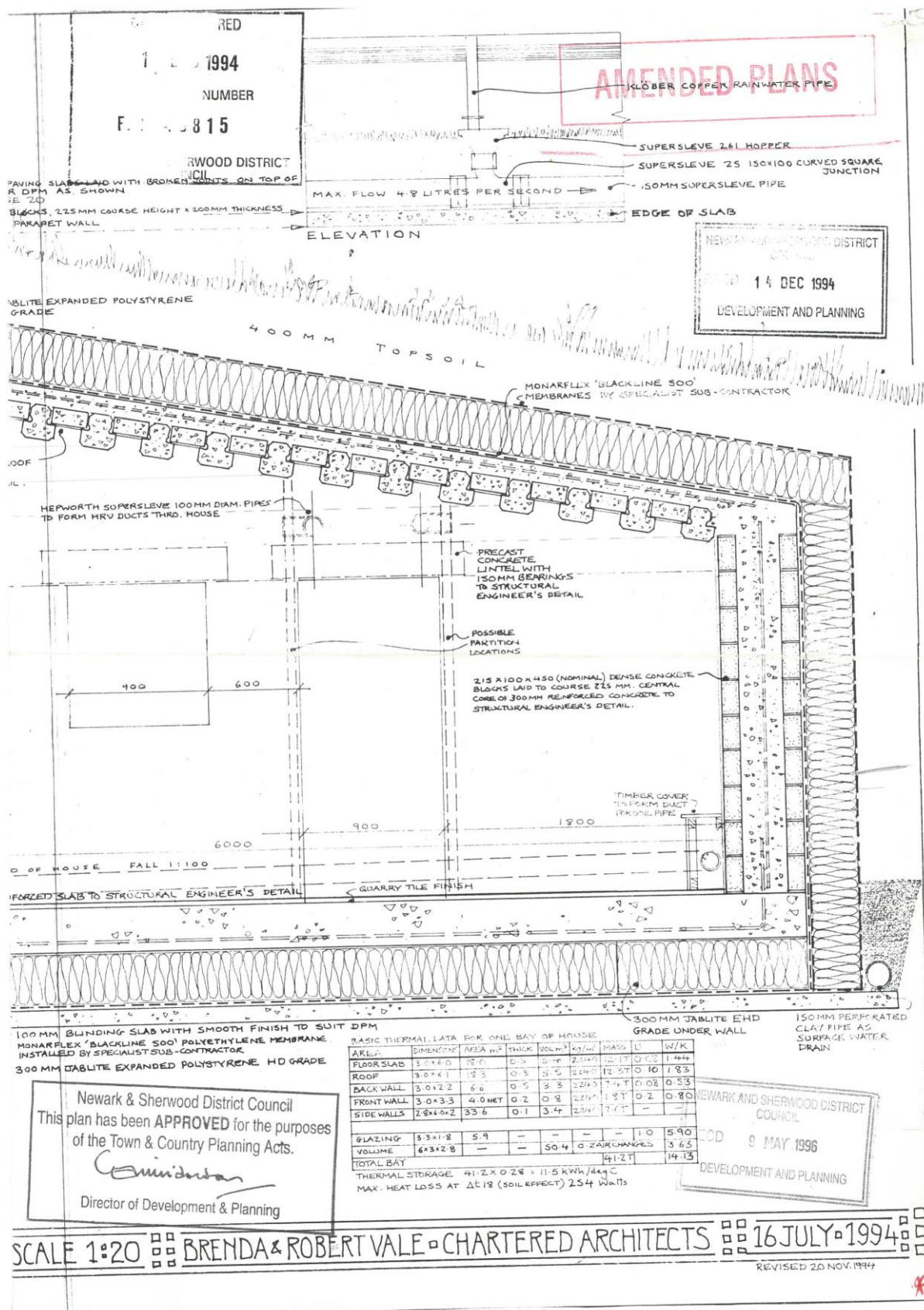
[illegible]

Appendix 2

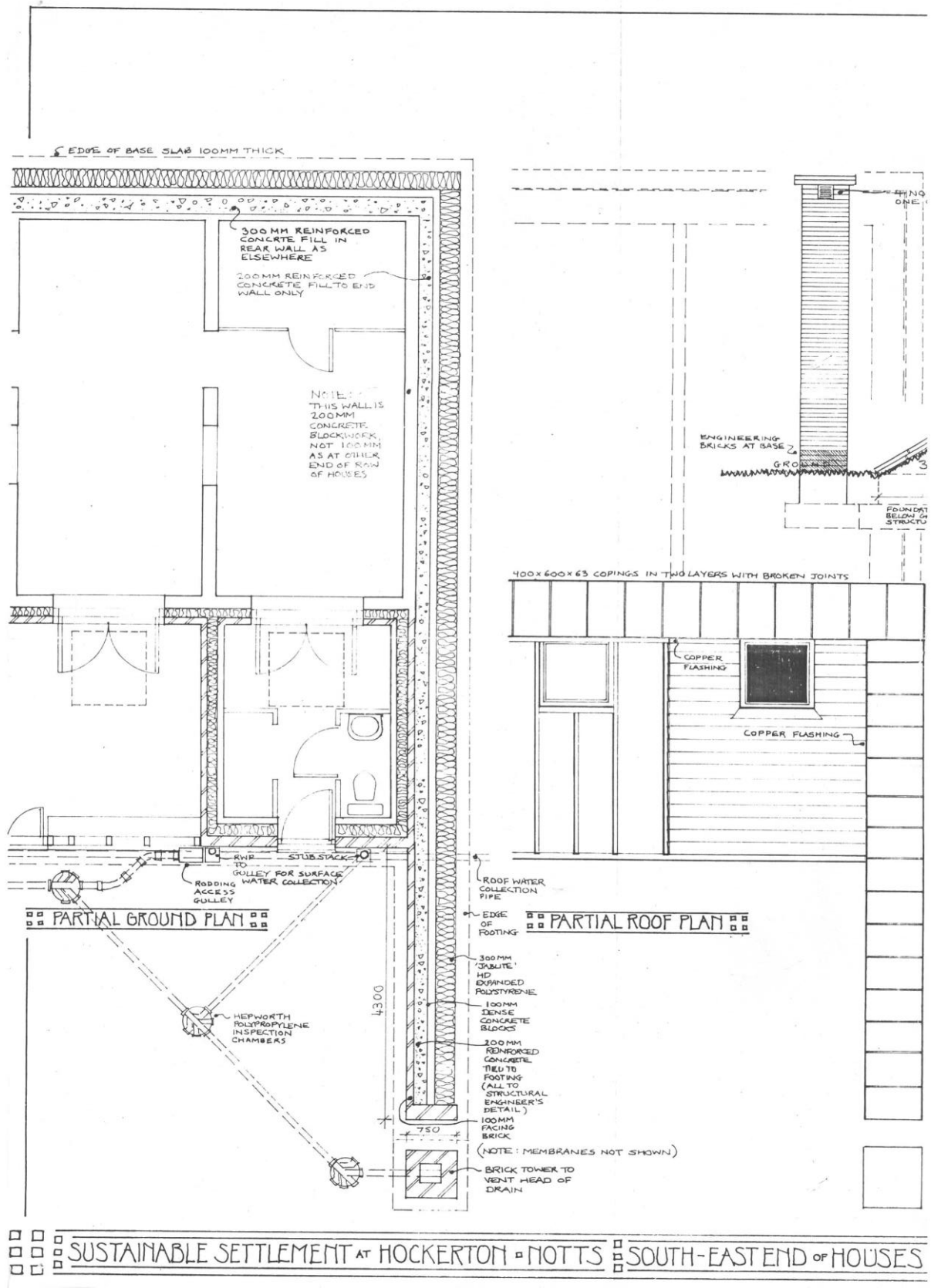


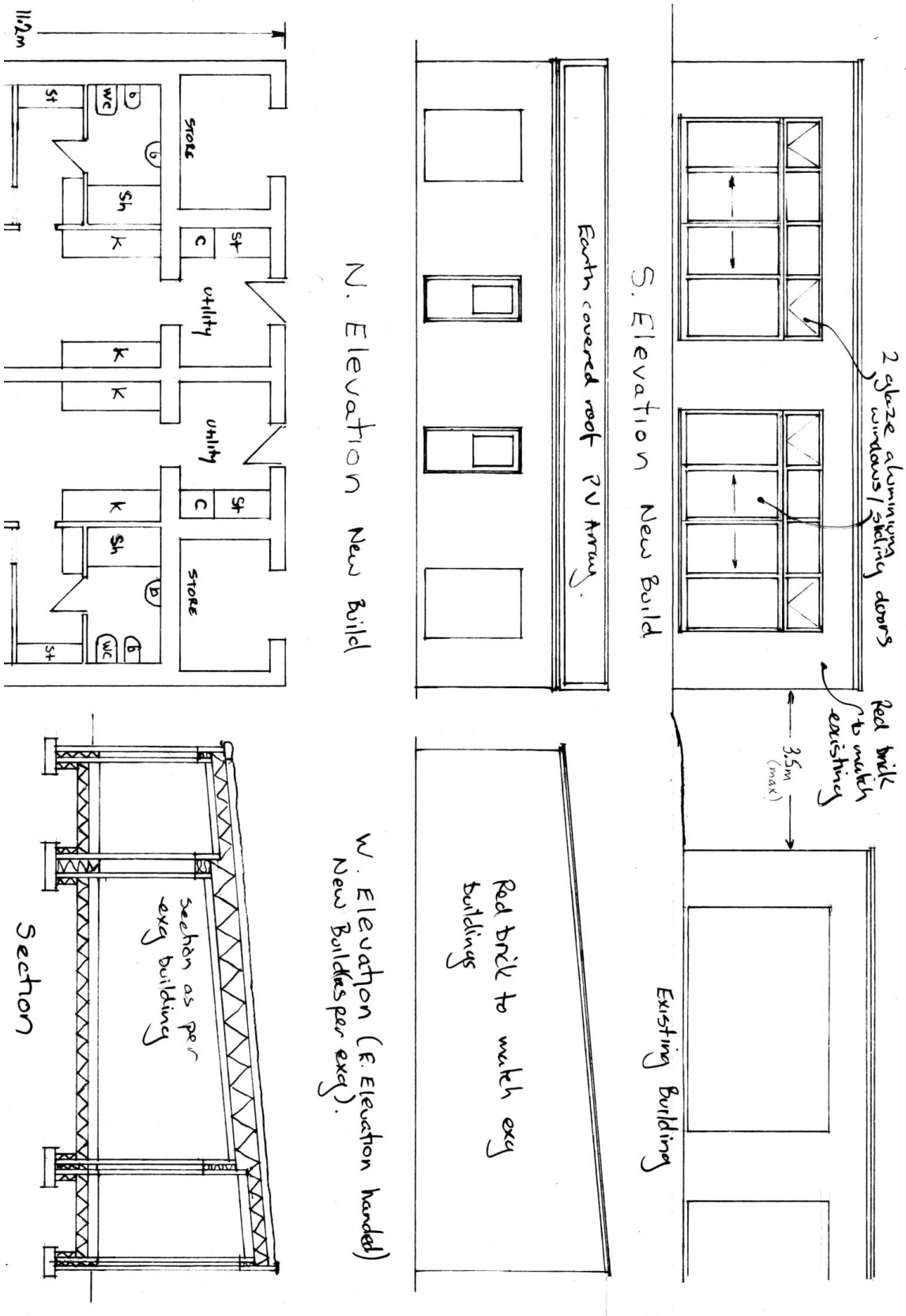
□ □ □ SUSTAINABLE SETTLEMENT AT HOCKERTON □ NOTTS □ □ □ TYPICAL SECTION □

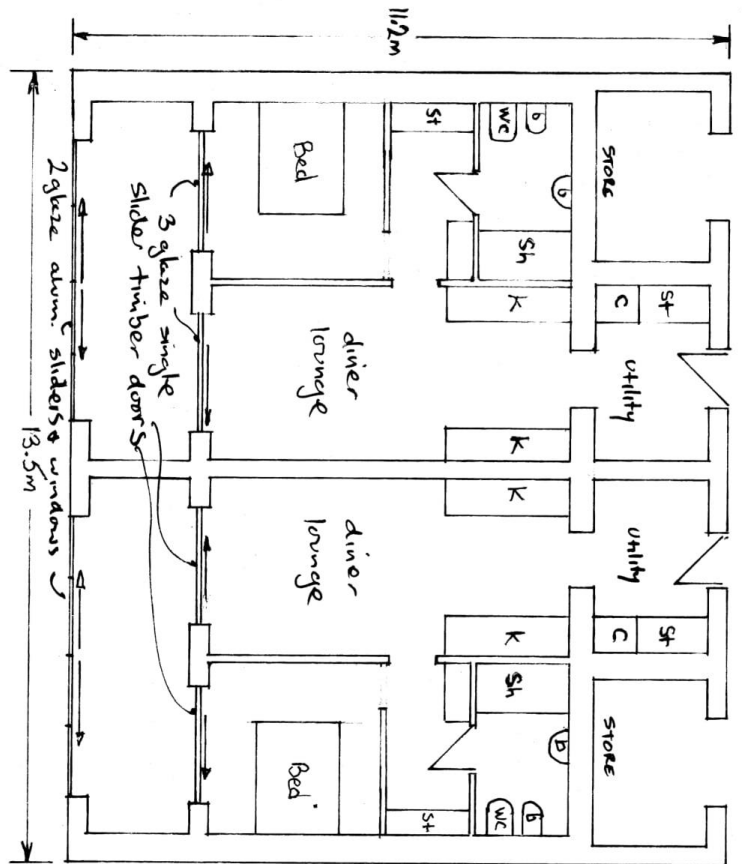
37



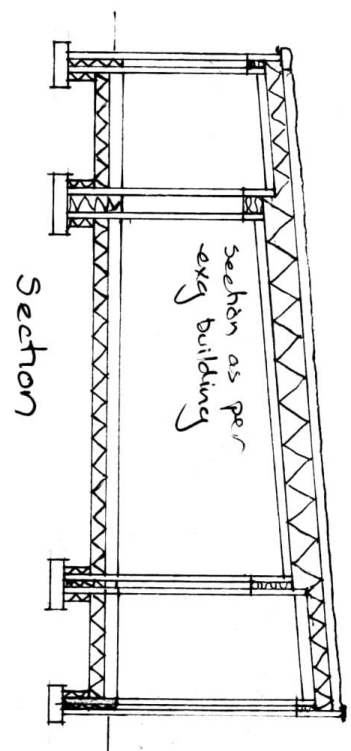
Appendix 4







Plan



SCALE 1:100



- ① Plans Elevations New Single Storey Dwelling
- 4 Zero Carbon Dwellings
- Gables Workshops
- Hokeron
- Notes NG25 OPP
- Contact
- HA
- c/o Nick Martin
- 7 Gables Drive
- Hokeron
- Notes NG25 OPP
- 07824 854498

Description:Roof 1300

ID:ROOF1

Performance:EN-ISO

U-value:0.0618W/m²·K

Thickness:1300.000mm

Thermal mass Cm:230.0000kJ/(m²·K)

Total R-value:15.8665m²K/W

Mass:1618.7500kg/m²

Heavyweight

SurfacesRegulationsRadianceIES

Outside

Emissivity:0.900

Resistance (m²K/W):0.0400

☒ Default

Solar Absorptance:0.700

Inside

Emissivity:0.900

Resistance (m²K/W):

Solar Absorptance:0.550

Construction Layers (Outside To Inside)

System Materials

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[CSAW] CULTIVATED SANDY SOIL 25.0%D.W. MOISTURE	400.0	2.2200	2000.0	1480.0	0.1802	250.000	Sands, Stones and Soils
[STD_CC2] Reinforced Concrete	200.0	2.3000	2300.0	1000.0	0.0870	-	Concretes
[EPFL] Expanded polystyrene (CBSE)	550.0	0.0350	25.0	1400.0	15.7143	200.000	Insulating Materials
[STD_CC2] Reinforced Concrete	150.0	2.3000	2300.0	1000.0	0.0652	-	Concretes

Appendix 8

Description: 2 glaze
ID: STD_EXTW

Performance: EN-ISO

Net U-value (including frame): 2.2986 W/m²·K
U-value (glass only): 1.2507 W/m²·K
Net R-value: 0.7996 m²·K/W
g-value (EN 410): 0.3993
Visible light normal transmittance: 0.71

Surfaces: Frame Shading Device Regulations UK Dwellings RadianceES

Percentage: 30.00
Absorptance: 0.7
Outside surface area ratio: 1.00
Type: Softwood
U-value: 4.7438 W/m²·K
Resistance: 0.0408 m²·K/W
Inside surface area ratio: 1.00
LCA Frame Materials:
Edit

Construction Layers (Outside to Inside):
System Materials...

Material	Thickness mm	Conductivity W/(m·K)	Angular Dependence	Gas	Convection Coefficient W/m ² ·K	Resistance m ² ·K/W	Transmittance	Outside Reflectance	Inside Reflectance	Refractive Index	Outside Emissivity
[STD_EXW] Outer Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.409	0.289	0.414	1.526	0.837
Cavity	12.0	-	-	Argon	1.4033	0.6183	-	-	-	-	-
[STD_INW] Inner Pane	6.0	1.0600	Fresnel	-	-	0.0057	0.783	0.072	0.072	1.526	0.837

Appendix 9

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan									4.75	10.35	14.14	15.83	15.24	12.44	7.68	1.31	1.01							
Feb								3.76	11.24	17.37	21.68	23.74	23.31	20.46	15.49	8.85								
Mar							4.51	13.16	21.02	27.55	32.15	34.26	33.54	30.13	24.48	17.21	8.90	0.01						
Apr						6.66	15.70	24.57	32.78	39.73	44.60	46.57	45.20	40.81	34.18	26.15	17.36	8.32						
May					6.02	14.64	23.64	32.63	41.17	48.59	53.91	55.96	54.11	48.93	41.59	33.09	24.11	15.10	6.45					
Jun				1.51	9.14	17.57	26.48	35.53	44.27	52.09	57.96	60.46	58.72	53.37	45.81	37.18	28.16	19.20	10.65	2.85				
Jul					6.96	15.40	24.31	33.35	42.09	49.92	55.86	58.62	57.30	52.36	45.09	36.60	27.61	18.61	9.95	1.99				
Aug					0.85	9.54	18.56	27.53	35.97	43.28	48.59	50.91	49.68	45.21	38.42	30.26	21.40	12.36	3.52					
Sep						1.82	10.84	19.49	27.29	33.66	37.90	39.39	37.86	33.59	27.20	19.38	10.73	1.71						
Oct							2.60	10.75	17.80	23.28	26.65	27.54	25.82	21.72	15.68	8.22								
Nov								2.53	9.12	14.14	17.19	17.99	16.46	12.76	7.20	0.20								
Dec									4.25	9.38	12.67	13.83	12.77	9.59	4.54									