PROJECT MALACHI

Final Report

Collaborative Project

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1.0 Introduction

The problem of homelessness influences every society and governments of different countries try and provide policies to help such people. In the UK, this situation has a severe impact on the nation. The homeless often face the harsh conditions of living on the streets, but the reason for the problem lies in a number of the factors that influence people's lives. Today's situation shows that one in every 200 people in the UK is a homeless person. The total amount of the people without shelter has increased over the last year and accounted for 307,000 people (Butler, 2017). This figure reflects only the official recorded data; the actual number is probably much higher. The reasons for people to live on the streets vary and have no particular pattern (Butler, 2017). The most widely spread factors are the poverty, inequality, housing supply and affordability, unemployment, welfare, and income policies as well as the personal circumstances (JR Foundation, 2003). For this reason, the Salvation Army established the Project Malachi which receives its name after five year old Malachi Justin, who requested his £5 gift from the tooth fairy be given to the homeless. This project aims at providing the comfortable conditions for the rough sleepers who want to start a new period in their lives. The project can give the opportunity for the people who are ready to change their lives for the better.

So far, community has raised £10,000 charity donations. Moreover, the local authority provided the plot of land for rent (Fenton, 2017). The project supporters plan to build a new hostel made of the metal containers (Project Malachi) which will help house people who have uncertain perspectives for the future. These modernized containers are a suitable alternative for the hostels and other accommodation services.

The following study that is undertaken will help Project Malachi be a more sustainable project that can educate the local community and also modify the existing steel containers so that they are habitable.

2.0 Background

Homelessness is a serious problem worldwide, and there are 170,000 rough sleepers in London today (Hill, 2016). One solution for this problem would be a temporary housing project for homeless people which is why Project Malachi was started. When transforming shipping containers into accommodation, they must be adapted for human comfort which is where UCL comes into it.

The Chartered Institution of Building Services Engineers states that "Building services engineering is all about making buildings meet the needs of the people who live and work in them" (CIBSE, n.d.). According to Hawkins (2011), this includes achieving regional standards in the key areas of thermal comfort, indoor air quality, lighting, energy consumption and water consumption. In the UK, building services standards for new residential buildings are set out by Building Regulations Part L1A & Part F (HMG, 2013). The two documents cover the Conservation of fuel and power in new dwellings and Means of ventilation respectively and define the necessary conditions to be achieved and a limit on energy consumption. The most important metrics to be reported against are the:

- Target CO2 Emission Rate (TER)
- Target Fabric Energy Efficiency (TFEE)
- Minimum insulating fabric standards & system efficiencies
- Limiting summer overheating
- Ventilation rates

The previous research is of vital importance for the application of project Malachi, which provided the idea of the final design of project. Air quality should be concerned in a temporary housing project, especially in London, air quality is a significant health-correlated problem, long-term exposure to air pollutants can result in chronic respiratory diseases and shortening the life span of humans (London.gov.uk, 2018). Major air pollutants include sulfur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), Particulate Matter (PM_{10} and $PM_{2.5}$), Volatile Organic Compounds (VOCs) and Ozone. Air quality varies from location to location, for example, the concentration of NOx and PM is relatively higher than other pollutants at roadside locations in urban areas in London, due to the emissions from traffic, tyre and brake wear and resuspension of dust from road surfaces (Font and Fuller, 2015).

For a roof garden to be used for the project, aquaculture represents a fish farming system, where fish are nurtured in containers, ponds or tanks (Goodman, 2011). Hydroponics, on the other hand, represents a plant production system without the use of soil (ibid.). Aquaponics is a portmanteau term, where it combines the aquaculture and hydroponics symbiotically (Mohamad, et al., 2013). This hybrid combination allows the vegetables to absorb the nutrient waste produced from fish and to clean the water needed by fish simultaneously (Tokunaga, et al., 2015). Aquaponics system is also widely known due to its high-water efficiency, where it uses less than 10% of water as compared to conventional agriculture (Goddek, et al., 2015). As water is being circulated between the vegetable bed and fish tank, only a small amount of water is lost due to evaporation (Somerville & Cohen, 2014).

For the energy system, both wind power and solar power are required to provide an adequate energy supply. Wind power refers to energy produced from wind-powered turbines (Rekioua, 2014). Wind power generation plants comprise of wind turbines with two or three blades fixed around a rotor. The rotor is usually connected to the main shaft intended for spinning a generator to create electricity. Wind power is renewable, clean with no greenhouse emissions, no water consumption, and acts as an alternative to burning fossil fuel, therefore numerous countries have adopted this type of energy.

Solar power is the mechanism of making use of the light from the sun to produce energy needed, which is normally electricity. A solar power system consists of a set of solar panels which allows the sunlight to excite the electrons inside the semiconductor and a converter which converts the AC/ DC electricity for usage. (International Energy Agent,2014). In this report, the future of solar power usage is described as the primary renewable resources for future development. This report also mentions the current process of achieving the future climate change for the temperature plan by limiting the rising temperature by 2 degrees (EUROPEAN COMMISSION, 2015).

A heating system is a device used to keep indoor temperature consistent (CIBSE GUIDE A). In cold climates the provision of heating is important for creating comfortable indoor environments. Therefore, a well-designed heating system design is essential for building design, especially in countries that have cold weather such as the UK. Surveys indicate that more than 9 million radiators in domestic gas-fired heating systems have been installed since 2005 with about 1.65 million new boilers installed per year (CIBSE KS08), which shows the importance of heating systems. Since the shipping containers are used to build housing in this project, the materials are usually steel with a much bigger thermal conductivity than commonly used building materials such as concrete (Engineering ToolBox), the heat loss is larger in such a shipping-container-house than a normal building. Therefore, choosing a proper type of heating system and making improvements to the thermal performance of the building is a fundamental part for achieving the thermal comfort in shipping container rooms.

Water systems include using a rainwater harvesting system (RWHS), a potable water treatment system and also a grey water treatment system. The RHWS is used to reduce the demand on the mains water supply which will also allow resilience from local supply problems which is the case in the water stressed area of South East England. The UK standards state that rainwater that is collected can only be used for non-potable purposes which accounts for 66% of domestic water use. RWHS are also a way of diverting surface run off which is a main issue that the UK government highlighted in Flood Water and Management act 2010 (DEFRA, 2010).

When designing the rainwater harvesting system it is necessary to refer to previous literature so the design would be best suited to the consumer it is being designed for. In order to look at water consumption for low income households, Ramulongo et al (2017) discuss the different consumption patterns, which further differs between male and females. It was also necessary to understand the public perception of rainwater harvesting and whether the consumer will have any preconceptions about using rainwater for domestic activities. Ward et al (2012) did a study exploring user perception of rainwater harvesting systems which emphasised the need for education on RWHS and the system designed for this project will display that. As there is a specific budget to the present project, it was necessary to see if literature commented on the savings from the system. Two detailed studies (Roebuck et al., 2010 and Gao et al., 2014) monitored different RWHS over time and their payback times. It was shown that a well-designed RWHS has quicker payback times but if not well designed the maintenance costs can outweigh the cost of water savings.

Grey water, which refers to the water from washing basins, baths, showers and the kitchen, usually makes up about 55%-65% of a household's waste water. In order to relieve the increasing water demand and provide adequate water in a sustainable way, grey water recycling has become a significant part of water solutions in many areas due to the low pollutant content compared with other types of wastewater (Burnat et al. 2007). For instance, a study applied the grey water treatment system in an apartment in Haifa, Israel and tried to use the treated grey water for toilet flushing. The system was estimated to be able to reduce the urban water demand by about 10%-25% in that area (E. Friedleret. al., 2005).

On the other hand, treating water and safely storing it for the household use is significant to reduce burden and disease to the residents. After the germ theory was well established, potable water treatment systems became more important to ensure that drinking water is safety for human health (WHO, 2013). Biological pathogen could grow during the water storage, the main problem and disease is related to diarrhoea-causing pathogens, which kill roughly 1.9 million people each year in the world (WHO, 2005). It could also cause emergency risk like cholera and shigellosis (bacillary, dysentery) to the region (WHO, 2013). For other waterborne pathogens, typhoid and paratyphoid also cause serious problems to human health, which leads to about 216000 deaths annually (Crump et al, 2004). In London, Cryptosporidium and Campylobacter could become serious waterborne disease to the residence (Smith et al, 2006). Hence, it is important to install potable treatment system to prevent disease in the shipping container community of project Malachi.

3.0 Building Information

In this section, the basic information of the building is introduced which consists of location and building structure that will be built.

Location and Site

As can be seen from the map below (Figure 3.1), the building area highlighted in red is located in Ilford, a town in east London. It is near the Chadwick Road and Postway Mews with a nearby large-sized car park, and it is surrounded by several resident buildings.

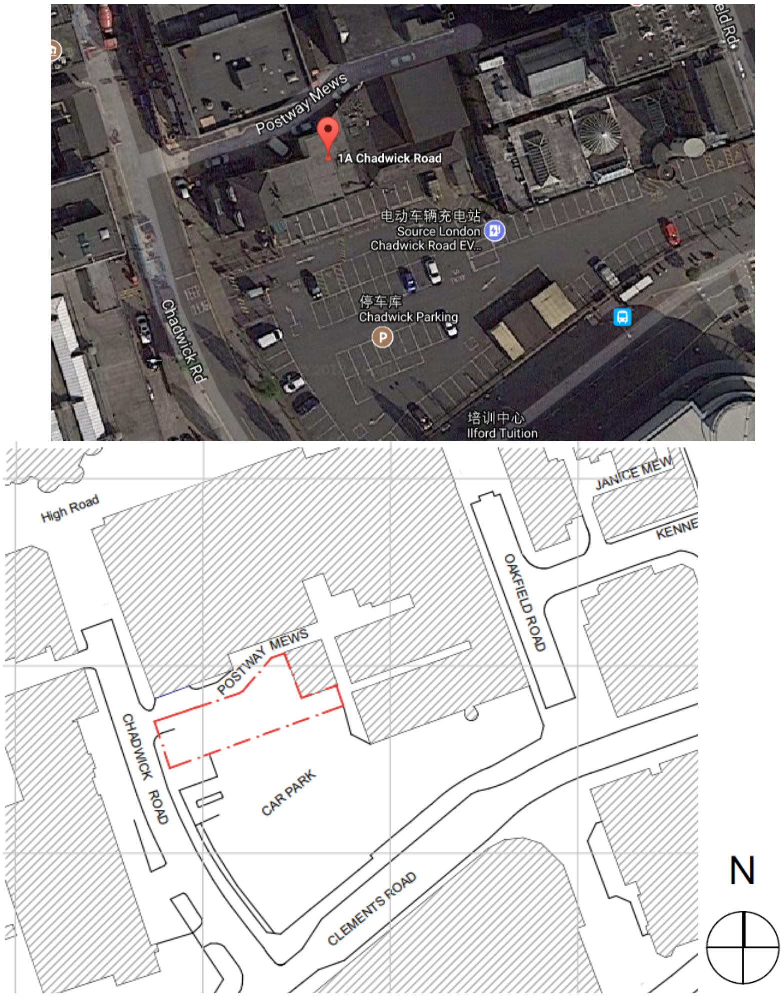

Figure 3.1 Location of the building (Salvation Army)

Building plan layout

The residence for the homeless will be built as a four-storey building made up by standard 20ft shipping containers. In the design scheme given by the SA, there are three types of rooms where Type 1, Type 2 and Type 3 have 1, 2 and 4 bed space, respectively. With the aim to accommodate as many people as possible, it was decided to have thirty-two Type 1, eight Type 2 and four Type 3 rooms in this four-storey building. For the ground floor, there is already a large cycle centre which is used for skill training and recycled bike storage, besides which is a laundry and an office (reception) with an access to the main entry. In contrast, in order to provide a quiet environment for rest, there are full of be restroom in first floor to third floor. The roof is planar which can be used to install solar panel, wind turbine or for roof garden. The detailed layouts of the exterior and the four storeys are showed below.

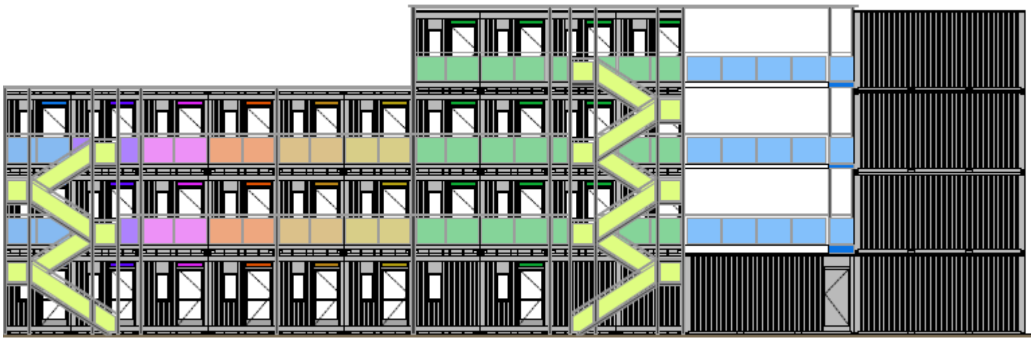

Figure 3.2: Cross-section layout of the building (View from North)

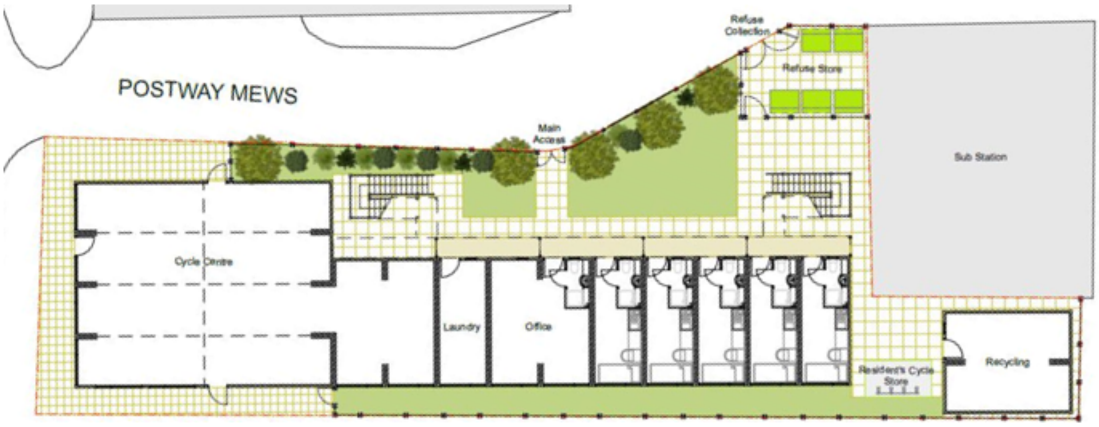

Figure 3.3 Ground floor layout

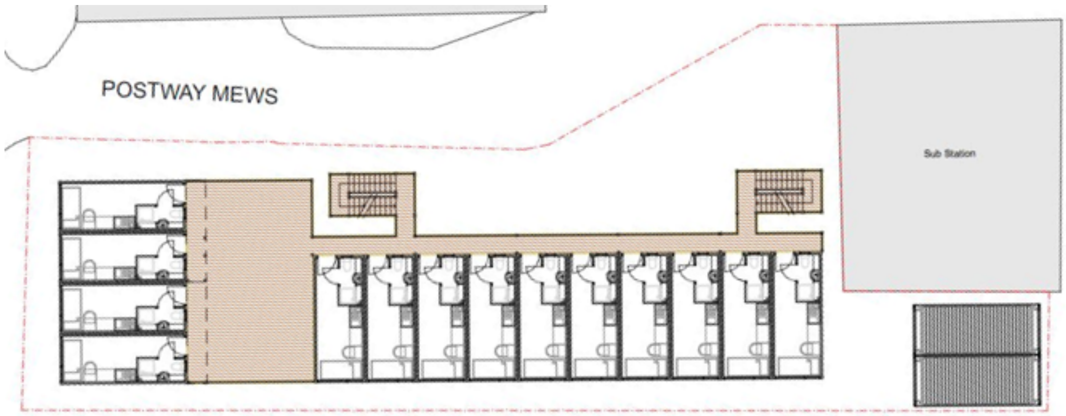

Figure 3.4 First floor layout

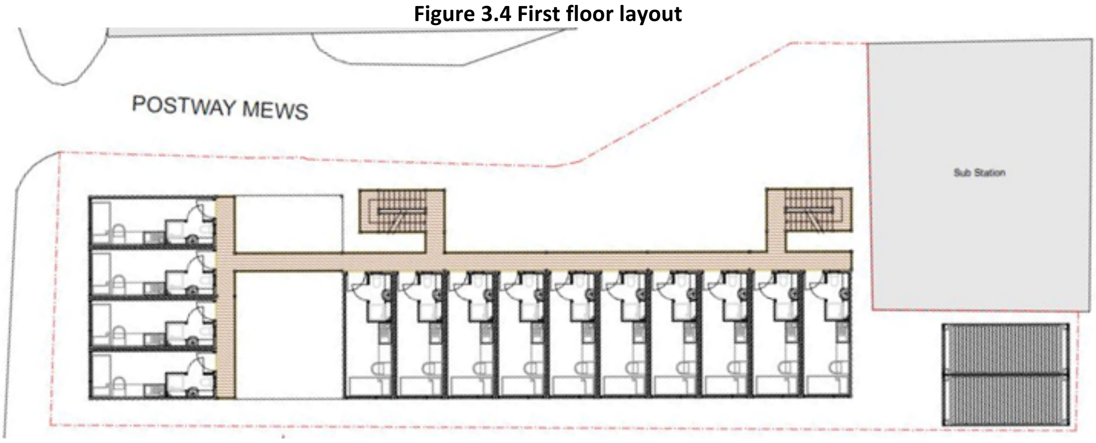

Figure 3.5 Second floor layout

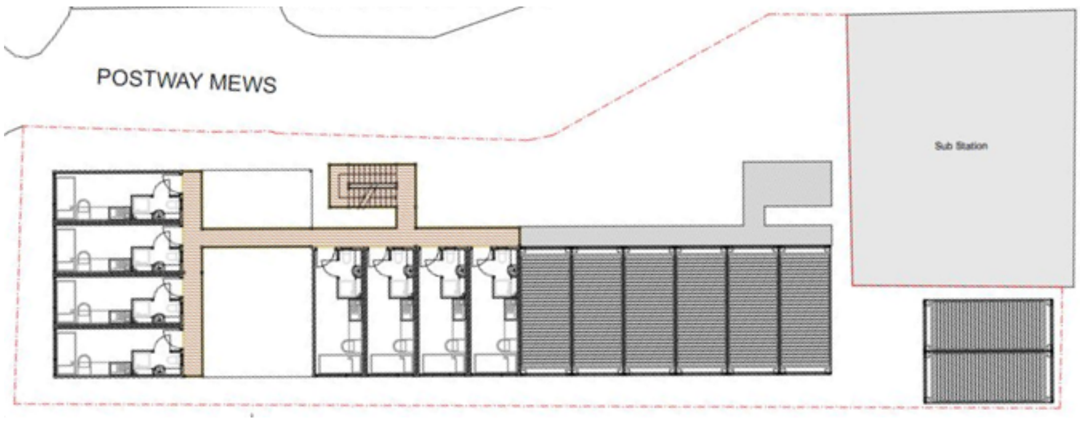

Figure 3.6 Third floor layout

Dimensions of three types of bedroom are listed in Table 3.1.

Table 3.1 Dimensions of 3 types of bedroom

Type	Total area (m^2)	Kitchen area (m^2)	Bathroom area (m^2)	Bedroom (m^2)	GIA less kitchen & bathroom (m^2)
Type 1	12	0.6	2.25	/	9.15
Type 2	24	1.2	2.25	8	21.15
Type 3	36	1.2	2.25	8+9	21.15
Standard 20 ft shipping container		Internal: L-5.85m, W-2.2m, H-2.3m External: L-6.06m. W-2.44m, H-2.89m			

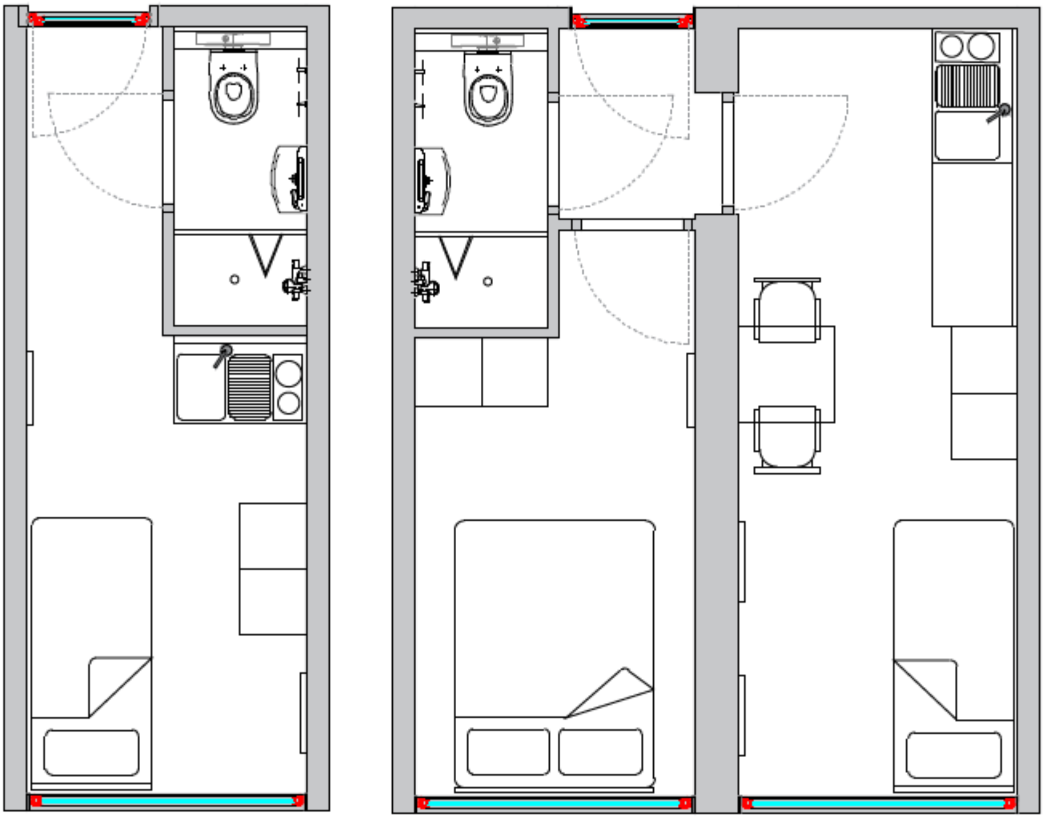

Figure 3.7 Type 1 bedroom (left) & Type 2 bedroom (right)

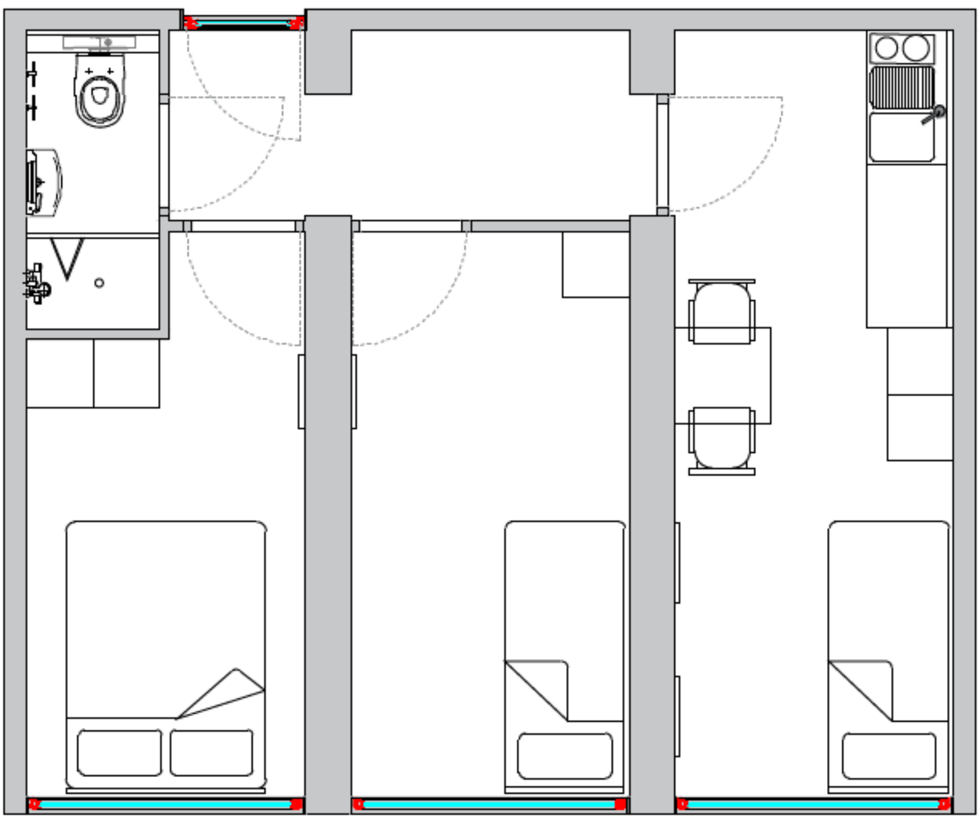

Figure 3.8 Type 3 bedroom

4.0 System Design

4.1 Building Services

This study will define and propose building services which will enable the development to achieve the relevant building regulations using industry standard methods. Key areas covered include maintaining thermal comfort, adequate indoor air quality, and appropriate lighting.

Compliance

To calculate energy consumption in buildings and report against the above metrics, the Energy Performance of Buildings Directive (EPBD, 2008) defines approved software. The software used to perform this analysis was Standard Assessment Procedure (SAP 2012) by Elmhurst Energy (previously NHER). Architectural dimensions, insulating values, and system efficiencies were put into the software and based on these the containers were able to pass, these inputs are demonstrated in Appendix D. The EPBD considers mainly the energy consumed when heating, cooling, lighting, ventilating, and pumping water (BRE, 2014), the results of these are illustrated below (Figure 4.1). As energy consumption regarding water on this site is relatively small, it is not included in the analysis.

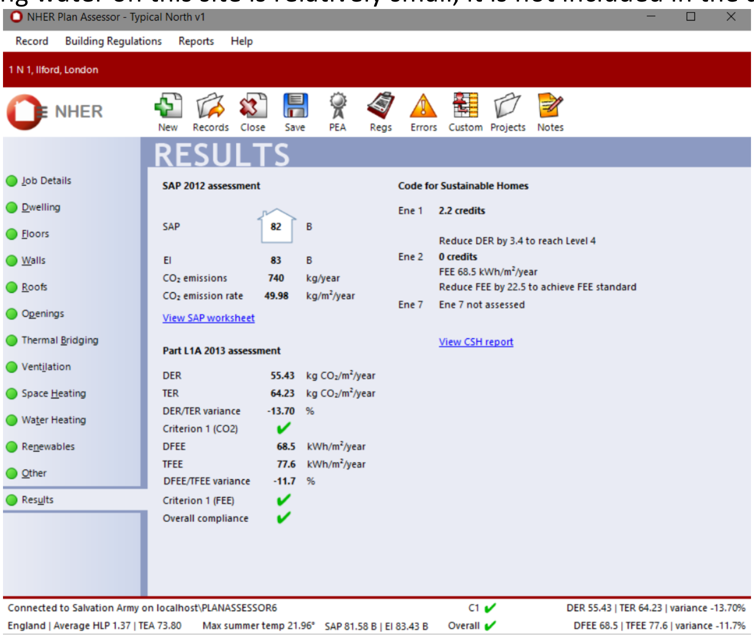

Figure 4.1: SAP 2012 Compliance Confirmation

Figure 4.1 shows the output of SAP 2012 indicating the TER and TFEE are compliant. The key elements to enabling this building services design to pass on TER and TFEE are the fabric insulation u-values, the system efficiencies and the energy consumption and air change rate of the ventilation system.

System efficiencies for each flat were able to achieve 740 kg of CO2 emissions per Year. These systems assumed were: on-demand electric heating & hot water, natural ventilation for summer cooling and background Mechanical Ventilation with Heat Recovery (MVHR). The modelled u-values are listed below and construction with accredited thermal bridging was assumed (Energy Saving Trust, 2009).

Walls – 0.14 W/m2k

Floor & Roof – 0.1 W/m2k

Windows – 1.4 W/m2k

Door – 1.5 W/m2k

The following section will describe in more detail the key services of the building and how they were achieved.

Key Services

Insulation

It is considered best practice to reduce the demand for heating by insulating as well as being feasibly possible (Leveque & Robertson, 2014), for this reason fabric u-values were reduced to the lowest realistic and feasible levels possible. The u-values defined in the previous section were all within building regulation guidelines (Hawkins, 2011), and achievable using widely available insulation (Kingspan, 2011). In such efficient buildings, especially when used with a MVHR, demand for heating is low.

Lighting

Daylight Analysis was performed using IES Virtual Environment 2017 to measure light levels and the contribution to overheating by solar gains. Pilkington Glass – Suncool Range was used with a u-value of 1.0 1/m2k and a transmittance of 0.49. The proposed energy efficient luminaires were Thorn CETUS LEDs and have an efficacy of 111 lm/w which is well within performance guidelines (European Standards, 2006).

Ventilation, Air Quality and Cooling

The system selected for maximum energy efficiency whilst maintaining good thermal, and air quality control was a MVHR with opening windows to allow summer cooling and purge ventilation. The MVHR will provide trickle ventilation allowing minimum air change to be met and filter air (HM Government, 2013). The window opening area and MVHR can together achieve a minimum of 23 l/s which allows for purge ventilation to remove smells and odours.

Overheating analysis

Using the TM59 Design Methodology (CIBSE, 2017), and the temperature and heat gain assessment tools in IES Virtual Environment, the containers were found to not overheat in summer based on the u-values and systems described above and the architecture provided. Figure 4.2 shows the peak temperatures for the hottest day of the year using approved weather files.

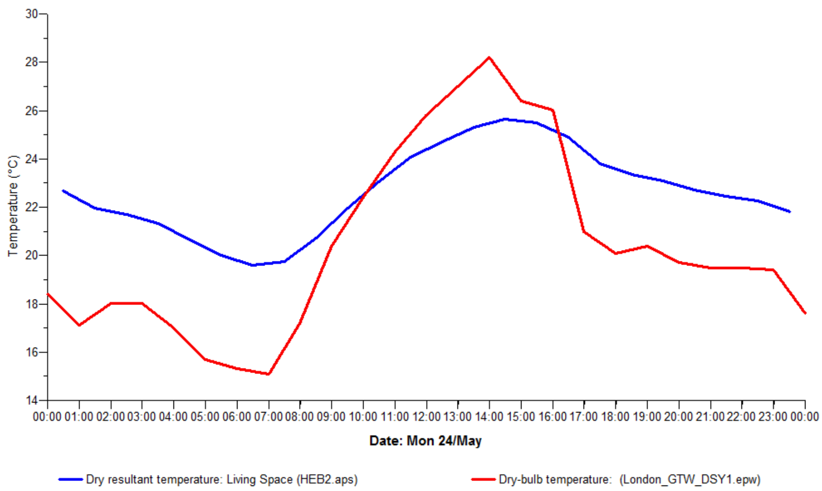

Figure 4.2 Peak summer temperatures

4.2 Heating Services

Selection of system type

For a heating system, there are many possible options that can be considered, and classification of these three categories are shown in Table 4.1.

Table 4.1: Options of heating system (CIBSE KS08)

Category	Types			
Heat source	gas	solar	electricity	heat pump
	oil	coal	wind	
Distribution medium	water	air	steam	electricity
Emitter	radiators	ceiling panels	forced convector	
	panel heaters	Underfloor heating	natural convectors	

The choices of these options depend on several factors such as the space and location of the plants, cost, comfort, control and convenience. Based on these criteria, the advantages and disadvantages of various distribution media and emitter types are given in the table below (CIBSE KS08).

Table 4.2: Characteristics of distribution media (CIBSE KS08)

Medium	Features	Advantages	Disadvantages
Air	Low specific heat capacity; low density; large volume is needed	No need of emitters, intermediate medium and heat exchanger	Need more space; High energy consumption of fans
Water	High specific heat capacity; Smaller volume is needed (vs air)	Little distribution space	Need heat emitters
Steam	Very high transfer capacity; Operates at high pressures		High requirement of maintenance and water treatment
LTHW (LPHW): **Low temperature/pressure hot water systems**	Operates at temperature<90°C; Requirement of pressure is low	Easy to install; Generally safe; High energy efficiency with condensing boilers	Output temperatures has constraint
MTHW (MPHW): **Medium temperature/pressure hot water systems**			
HTHW (HPHW): **High temperature/pressure hot water systems**			

Table 4.3: Characteristics of heat emitters (CIBSE KS08)

Types	Advantages	Disadvantages
Radiators	Good temperature control; Low maintenance; Easy and cheap to install; Good thermal comfort	Slow response to control and temperature change
Underfloor heating	Good space temperature distribution	Slow response to control; Heat output is limited
Fan convectors	Quick response to thermal change	Noisy; Higher maintenance; Need more space
Warm air heaters	Quick response to thermal change	Noisy; Temperature stratification

It can be found from Table 4.2 and Table 4.3 that water/LTHW combined with radiators is more suitable for this project with limited space and simple structure, which also has little impact on the environment (e.g. reduced noise) and lower technical requirements compared with MTHM and HTHM. For a heat source, solar and wind energy can be obtained intermittently; oil and coal have great impact on climate change and air pollution; and despite the high efficiency of electricity and heat pump (Chua et al, 2010), the price (including capital cost and daily consumption) cannot compete with that of gas. So, it can be concluded that a gas-fired hot water heating system combined with radiators is adopted in the design in this project. One thing should be noted is that for this design, only the maximum size (i.e. power of boiler) would be calculated to ensure that the system can meet the heating requirement under worst conditions, so, radiators should have a valve to control their output separately when there are other heat gains (e.g. heat gain from occupants).

A simple hot water heating system can be presented by Figure 4.3 (greenspec). With a continuous supply of natural gas, boiler can heat the cold water and passes it through each radiator to warm each space. After passing through radiators, lower-temperature water is driven back to storage tank by a pump and then heated again.

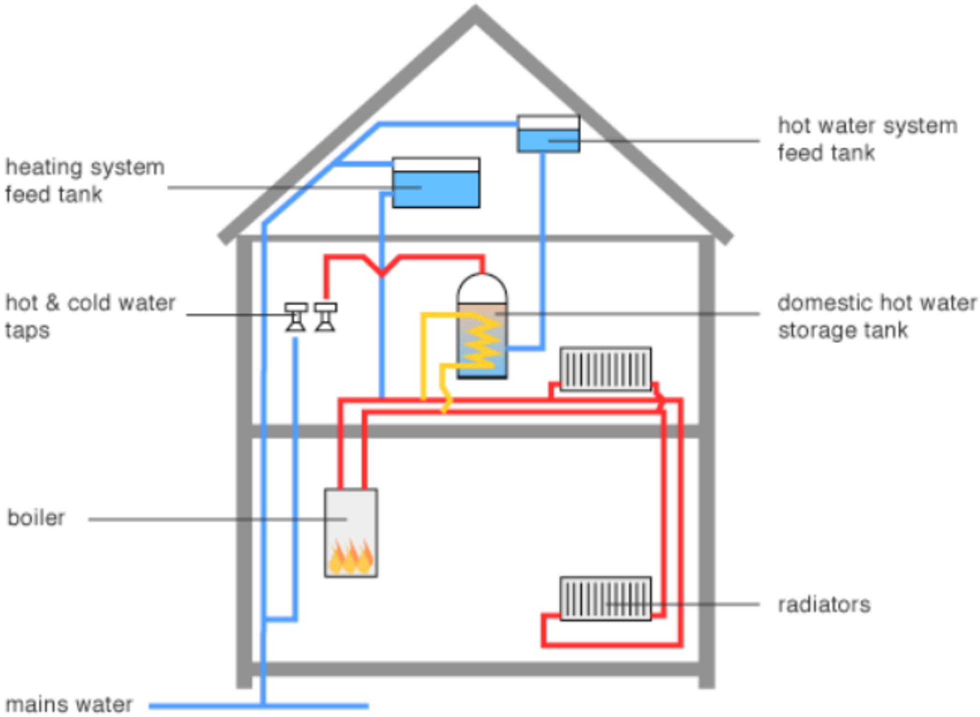

Figure 4.3: Graphic of a regular boiler heating system (greenspec) – Note: for tanks and boiler there need a plant room to install them

Heating load calculation

The main part of the heating system design is the size of the boiler which is correlated with the heat load and total space heat losses. Therefore, a maximized heat loss which consists of ventilation loss and fabric loss under the steady-state is calculated in this section. In order to ensure that the system can keep the required temperature under the worst situation (i.e. there is no other heat gain except heat from radiators and temperature difference is highest), all other heat gain is neglected in the calculation. Moreover, since the requirements from the SA are incomplete, several assumptions needed to be made to accomplish the calculation. (The load may be much larger than the actual value because of the overestimated temperature difference.)

Assumptions:

(1) Designed indoor comfort temperature is **20**°C in all rooms (CIBSE GUIDE A)

(2) Assume the lowest outdoor temperature is **-3**°C (CIBSE GUIDE A)

(3) For a TYPE 3 (3 BEDROOM UNIT) room, assume the size of windows is 2Mx2M*3

(4) U-values (thermal transmittance) of the wall and windows are 5.14 W/m^{2}K and 2 W/m^{2}K, respectively (CONTAINER CONTAINER, PILKINGTON)

(5) Any other values for the parameters are explained in the calculation

Peak heating load calculation:

Heat loss = Fabric loss+ Ventilation loss

$$Q_h = \sum (UA + C_v) \times (T_{in} - T_{out})$$

Q_h = Peak heating load W]
U = Thermal transmittance of surfaces [W/m^{2}K]
A = Surface area (wall & windows) [m^2]
UA = Fabric thermal conductance [W/K]
C_v = Ventilation conductance [W/K]
T_{in} = Designed indoor comfort temperature in winter [°C]
T_{out} = Designed the lowest outdoor temperature in winter [°C]

Peak fabric loss (Q_f):

$Q_f = \sum(AU) \times (T_{w,r} - T_{w,o}) = (154.06 \times 5.14 + 12 \times 2)[\mathrm{W/K}] \times (20 - (-3))[\mathrm{K}] = 18764.97[\mathrm{W}]$

Peak ventilation loss (Q_v):

$$Q_v = C_v \times (T_{in} - T_{out})$$
$$C_v = NV/3$$

N = Air change rate (h^{-1})
V = Volume of the building [m^3]
Ventilation loss consists of aimed ventilation (basic requirement of fresh air) and infiltration.
For aimed ventilation, the air change rate is designed to be 1 ACH;
For infiltration, the air change rate is designed to be 0.4 ACH

$$C_{v,a} = 1 \times 82.8/3[\mathrm{W/K}] = 27.6[\mathrm{W/K}]$$
$$C_{v,i} = 0.4 \times 82.8/3[\mathrm{W/K}] = 11.04[\mathrm{W/K}]$$
$$Q_v = C_v \times (T_{in} - T_{out}) = (27.6 + 11.04)[\mathrm{W/K}] \times (20 - (-3))[\mathrm{K}] = 888.72[\mathrm{W}]$$

Peak heating load (Q_h):

$$Q_h = Q_f + Q_v = 18764.97[W] + 888.72[\mathrm{W}] = 19653.69[\mathrm{W}]$$

Heating load (W/m^2):

$$Q_h/floor\ area = 19653.69[W]/36[m^2] = 545.94\ [W/m^2]$$

As recommended in CIBSE Guide F, the heating load for residential is 60 W/m^2, so, improvement methods should be applied to reduce the heat loss.

Note: All the values of parameters are from CIBSE Guide A except the building information and those indicated coming from other sources.

Software simulation

In this section, a simplified simulation is run with a software called Passive Design Assistant (ARUP). The detailed settings can be found in Appendix A and results are shown below.

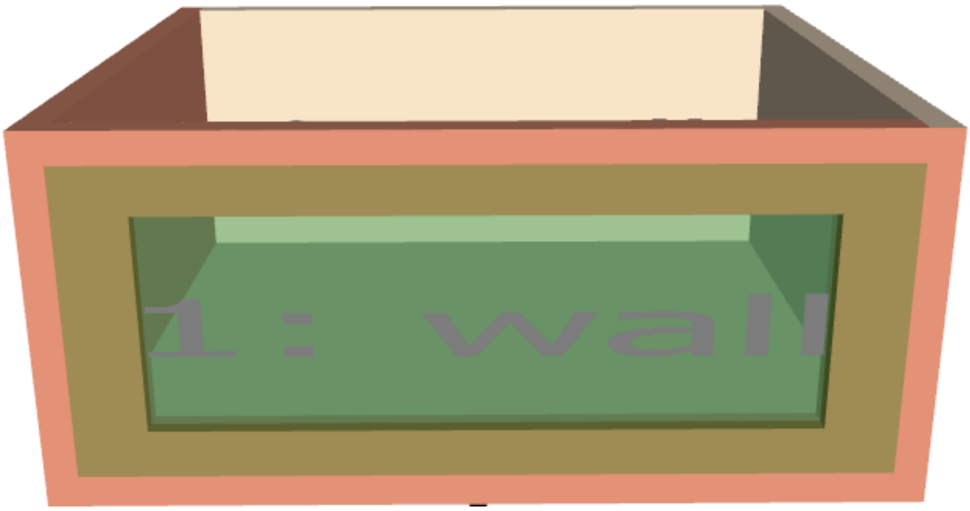

Figure 4.4: Model of TYPE 3 room

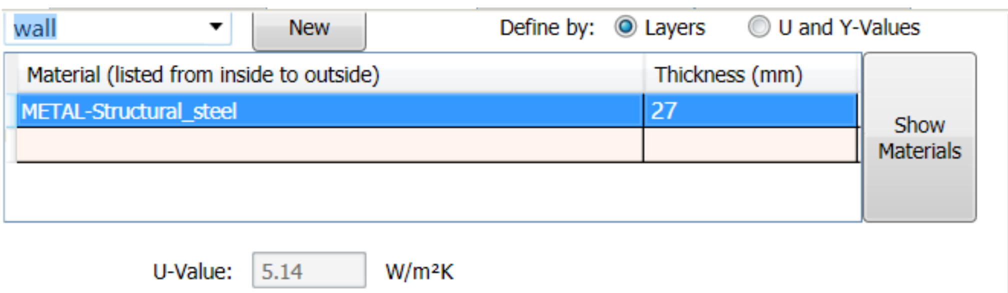

Figure 4.5: Material and U-value of wall setting

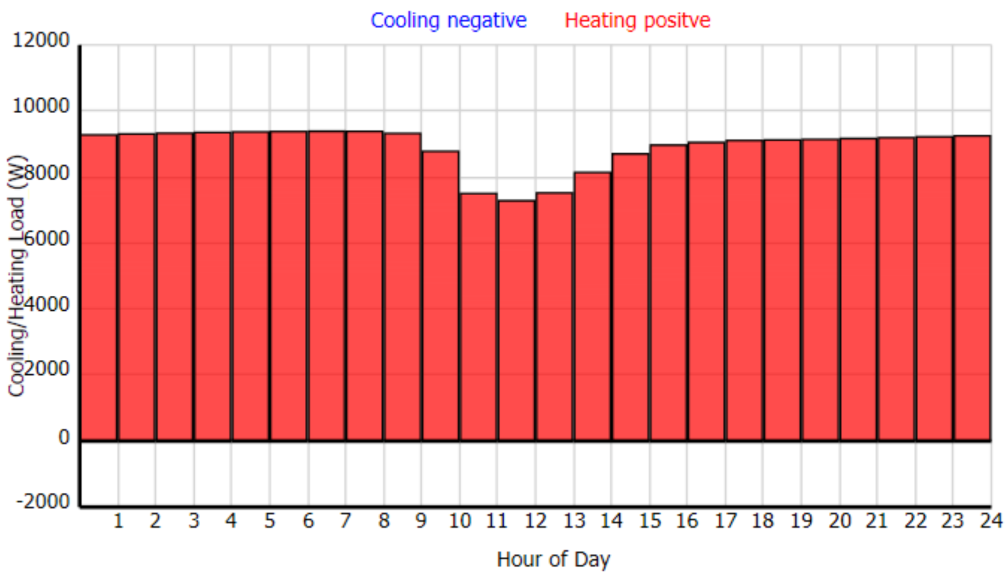

Figure 4.6: Heating load from simulation

Because the indoor temperature is the same in each room, internal wall here is ignored. For convenience, three windows are put together with the same total volume. The boiler is open the whole day in this simulation to see the distribution of heating load in a day.

Comparing the results between the calculation and the simulation, there is a large difference between the values. The main reason for this may be the outdoor temperature. If we suppose it to be 3℃ outside, then the calculation results will be closer to the simulation results. Another reason may can be the different plant type (in this software there is no radiator but only ceiling/floor heater and air conditioning) which may cause non-uniform temperature distribution leading to lower heat loss. However, both of the two results exceed the recommended value of heating load.

Improvement suggestion

From the calculation, it can be found that the main heat loss comes from fabric loss due to high heat transmittance of steel. So, the most effective way to improve the heat performance is to change that value of the wall, for instance, adding a covering on the wall with low heat transmittance. When the structure of the wall is changed as shown in Figure 4.7, the heating load shows a rapid reduction as Figure 4.8 shows. Other methods such as adding insulation paint can also help to reduce the heat loss.

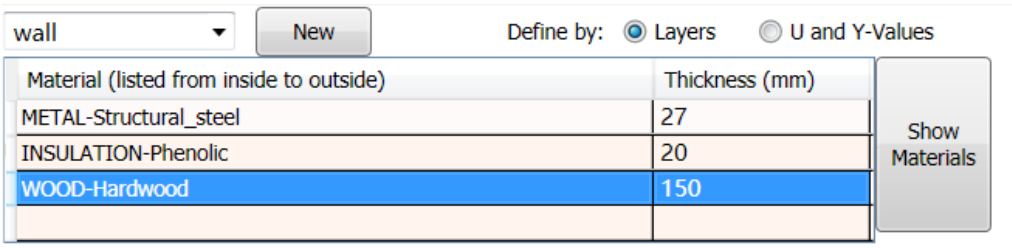

Figure 4.7: Improved structure of wall

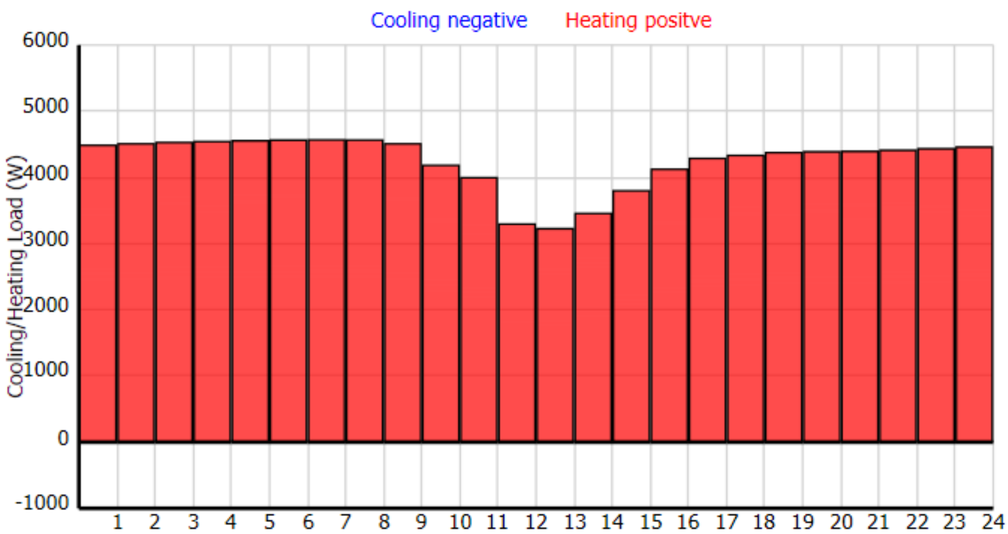

Figure 4.8: Improved heating load

Size of boiler

Choose $Q_h = 5000[\mathrm{W}]$ as the final maximum heating load for this room,

$$Q_{boiler} = Q_h \times F_3$$

Q_{boiler} = Boiler capacity [W]

F_3 = Correction factor for intermittent heating

Because radiators will not open for the whole day, so a pre-heating is required. Although the peak heating load can meet the maximum heat loss, additional capacity is needed to overcome thermal inertia so that the building may reach equilibrium in a reasonable time. Suppose the heating hour is 10 hours, then $F_3 = 1.4$ (CIBSE Guide B), and the efficiency of gas condensing boiler can reach 90% (CIBSE Guide F),

So, boiler size (W) = $Q_{boiler}/\eta = Q_h \times F_3/\eta = 5000[W] \times 1.4/0.9 = 7777.78W$

This shows the calculation of boiler size of one room, and when it comes to the whole building, heat loss will be more complex, for instance the heat exchange between the ground (earth) and ground floor can be quite different with that between wall and air. However, the method of calculation would be the same. Finally, the total heating loss will be the reference to decide the size of the boiler for the whole building.

4.3 Outdoor Air Quality

Background

The containers described in section 3 are put in a fixed place, which means that the outdoor environment is fixed, as a result, it is beneficial to look at the outdoor situation first. Since the furniture has not been moved into the containers yet, it is highly unfeasible to measure the indoor air quality as it will be the same as the outdoor air quality for the moment.

Outdoor air quality

In this section, the outdoor air quality will be evaluated by looking at the NO_2 value over a period of time. Figure 4.9 illustrates that NO_2 concentration is highest in the artery roadside locations in Redbridge in 2011. In 2013, the Environmental Research Group of King's College London ran the air pollution research (Font and Fuller, 2015), as shown in Figure 4.10 below. It is also clear that the NO_2 concentration is higher at roadsides compared with other locations. However, in Ilford, where the containers will be put, the concentration is unexpectedly low and has moderate pollution, probably due to less traffic and fewer exhaust emissions. Figure 4.11 provides the real-time air quality data in Redbridge in 2018. Despite some large fluctuations in NO_2 concentration and PM2.5 values, the overall air quality is 'good'.

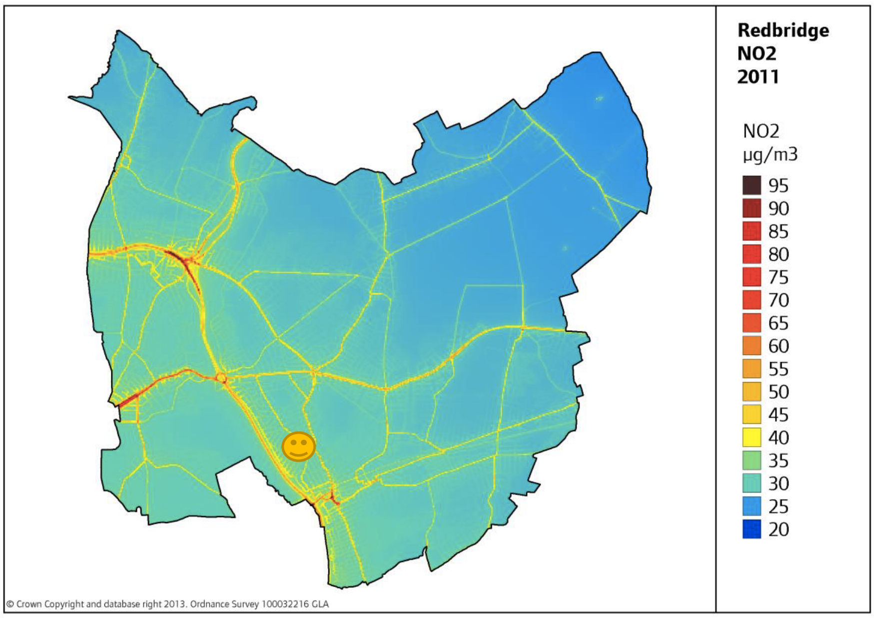

Figure 4.9 Model of annual mean NO_2 concentration in LB Redbridge in 2011. The smiley face is where the containers are put. Accessed from: https://data.london.gov.uk/dataset/laei-2008

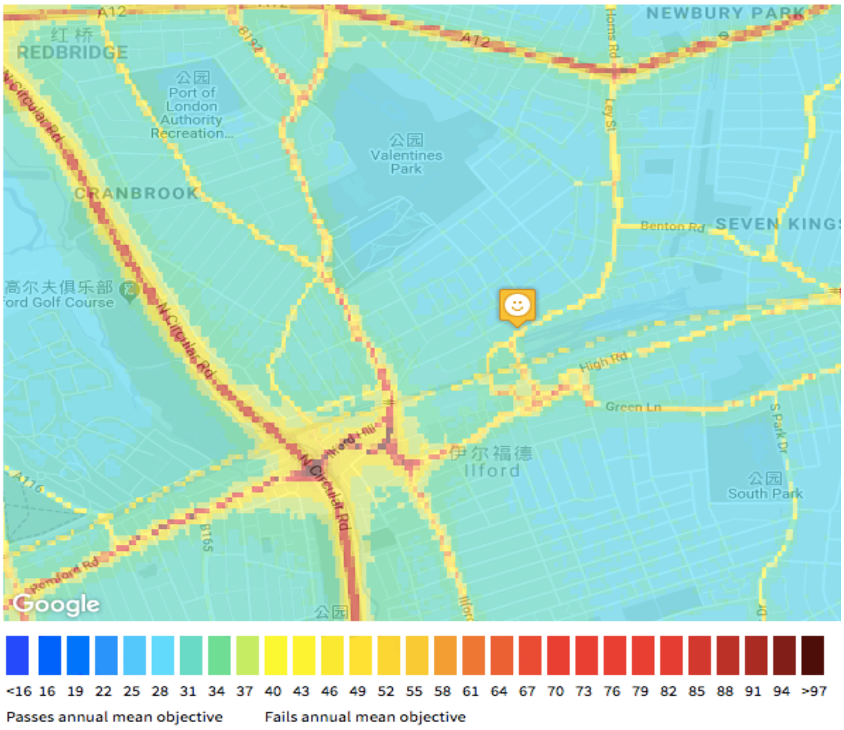

Figure 4.10: Model of annual mean NO_2 air pollution in 2013. The smiley face on the map indicates where the containers are put by searching the post code 'IG1'. Accessed from: londonair.org.uk

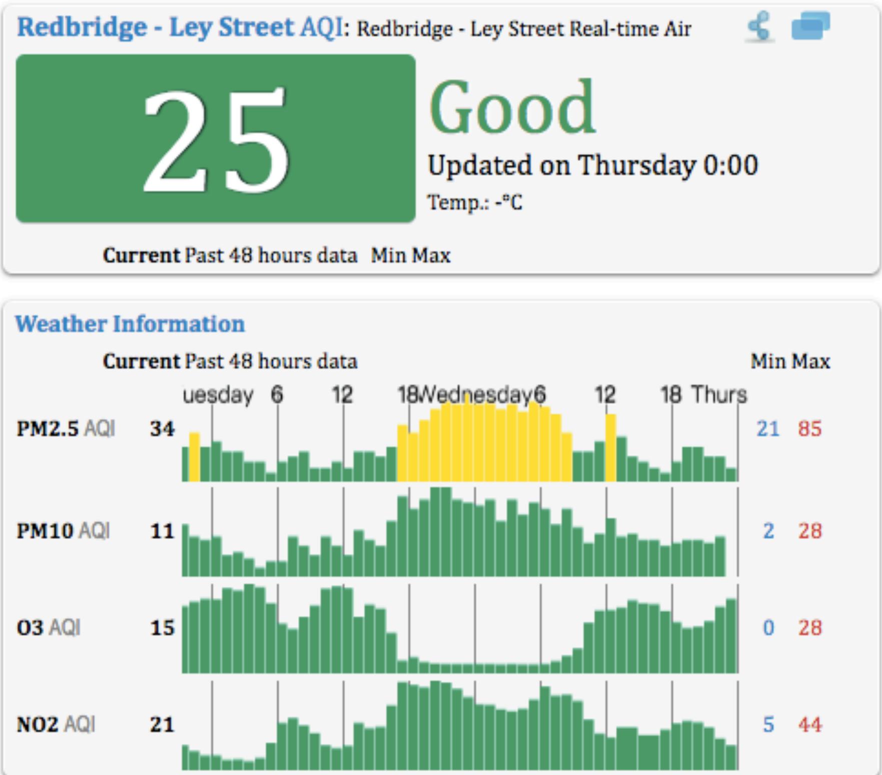

Figure 4.11: Real-time AQI at 0:00 08/03/2018. Accessed from: aqicn.org

Based on the time period between 2011 and 2018, the overall outdoor air quality is 'good'. It can be assumed that there will not be any significant changes to the outside surroundings, hence, the air quality is predicted to remain 'good', over the following 5-year lease period.

Another variable that might influence the air quality is the nearby car park. CO is the most crucial pollutant in the car park areas, mainly due to the incomplete combustion of car engines (Ho et al., 2004). The pollutants may concentrate and reach dangerous levels because of the dense movements of vehicles, if no sufficient ventilation is provided. But the influence of high pollutants concentration to people can be eliminated by using ventilation systems in car parks (Demir, 2015), such as providing ventilation in the underground and aboveground multi-storey car parks.

Indoor air quality

There are many factors that can affect the indoor air quality, for example, building materials (e.g., paint and carpet), furniture, adhesives and cushions can emit VOCs (Bari et al., 2015). Hence, the indoor air quality can be improved by controlling the source (use formaldehyde-free products and wooden furniture), applying Heating Ventilation and Air Conditioning (HVAC) to help air circulate (Shaughnessy, 2006), using High-Efficiency Particulate Arrestance (HEPA) filters that can capture fine particles (Wang and Zhang, 2011).

Conclusion

Good air quality is very important to human health. Based on the outdoor air quality evaluations, it can be concluded that the outdoor air quality in the area where the units will be set up is good. Hence, it is very possible that indoor air quality will also be good. It is not possible to improve the outdoor air quality, but indoor air quality can be enhanced by applying various systems, such as source control, HVAC system and filtration.

4.4 Wind Energy Design

The following study discusses wind power with special emphasis on single small turbines to be installed on the shipping containers used as homes for project Malachi. A thorough dissection of all aspects pertaining to the turbines will be tackled.

Turbines

Two types of turbines were proposed for Project Malachi. Single small turbines and utility scale turbines.

Table 4.4: Types of turbines

Turbines	Capacity	Used for
Single Small Scale	< 100 kW	Homes, water pumps, off grid location, and many others
Utility Scale	100 kW – 1 MW	Provide bulk power to electrical grid

The feasible turbine for the project would be the single small-scale.

Wind Speed

Since the turbines cannot be installed in any area provided unless it meets the threshold of the required wind speeds, data were gathered from world weather online that shows the wind speed at the location of the site meets the minimum required start up speed of a small-scale turbine.

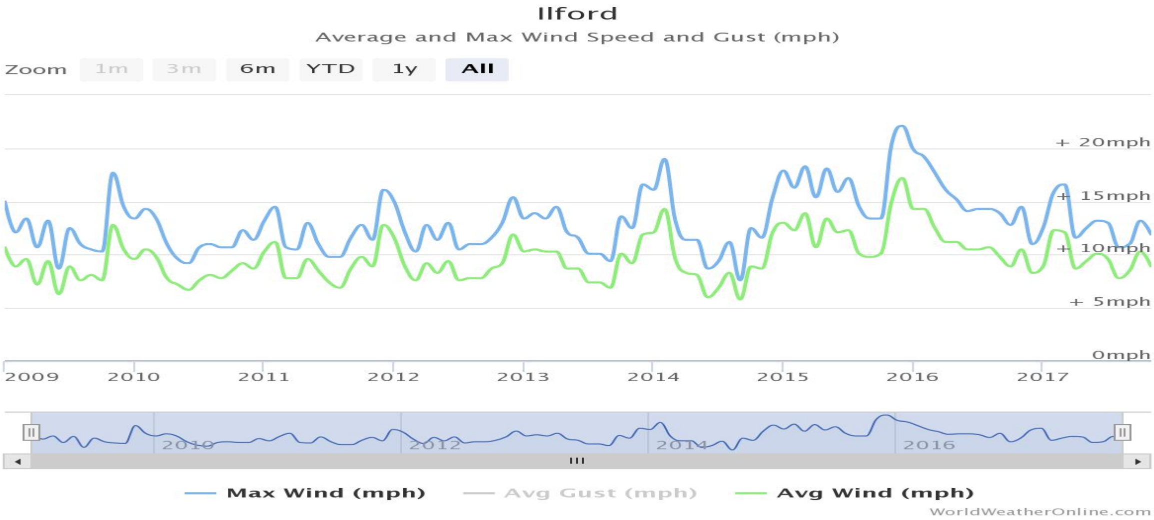

Figure 4.12: Average and max Wind Speed

Source: www.worldweatheronline.com

The chart indicates that for the past 8 years, the average wind speed in Ilford has been 9.75 mph which exceeds the minimum required start up speed for small-scale turbines which is 5.15 mph (renewabledevices.com, n.d.). Data gathered are from the GLA weather station in Ilford.

Rationale

Two types of small scale turbines were researched for project Malachi, roofmounted and stand-alone turbines. The reason why roof mounted turbines over stand alone were considered, is by simply because the planning guidelines suggested by the UK government for the installation of micro wind turbines were followed (shown in Table 4.5).

Table 4.5: Planning Guidelines suggested by the UK Government for the installation of small scale turbines Source: Peacock et al (2008), p. 1325, adapted from DCLG (2007).

Roof Mounted Turbines	Stand Alone Turbines
Wind turbines on building permitted if:	
< 3 m above ridge (including blade)	<11 m high (including blade)
	Min distance of 12m from a boundary
< 2 m diameter blades	< 2m diameter blades
Noise	Noise
• Internal noise <30 dB • External noise <40 dB • Garden noise <40 dB	• Internal noise <30 dB • External noise < 40 dB • Garden noise <40 dB
Up to 4 turbines on building	Min distance of 12m from a boundary
Vibration <0.5 mm/s	Vibration < 0.5 mm/s
Not permitted on buildings in conservation areas or world heritage sites	Permitted beside buildings in world heritage sites or conservation areas as normal except in front of principal elevation.

The stand-alone turbine requires a minimum of 12 metres distance from any boundary and should be less than 11 metres high. Both requirements do not conform to the guidelines. On the other hand, roof mounted turbines meet all the requirements needed for installation. Hence, roof mounted turbines were chosen.

After conducting research on several roof mounted turbine options, It was concluded that the most economical and suitable option for Project Malachi was the SWIFT 1.5.

Table 4.6: Specifications for Wind Turbine Design

Specifiation	Swift
Rated power (W)	1500
Cost (£/W)	1
Diameter (m)	2
Turbine mass (kg)	50
Headline payback time	8 years
Anticipated lifetime	20 years
Claimed annual yield	4,000kWh
Estimated annual yield	1,753kWh
Immersion heater system	Standard
Extreme wind level	65 m/s

Source: www.renewabledevices.com

Installation

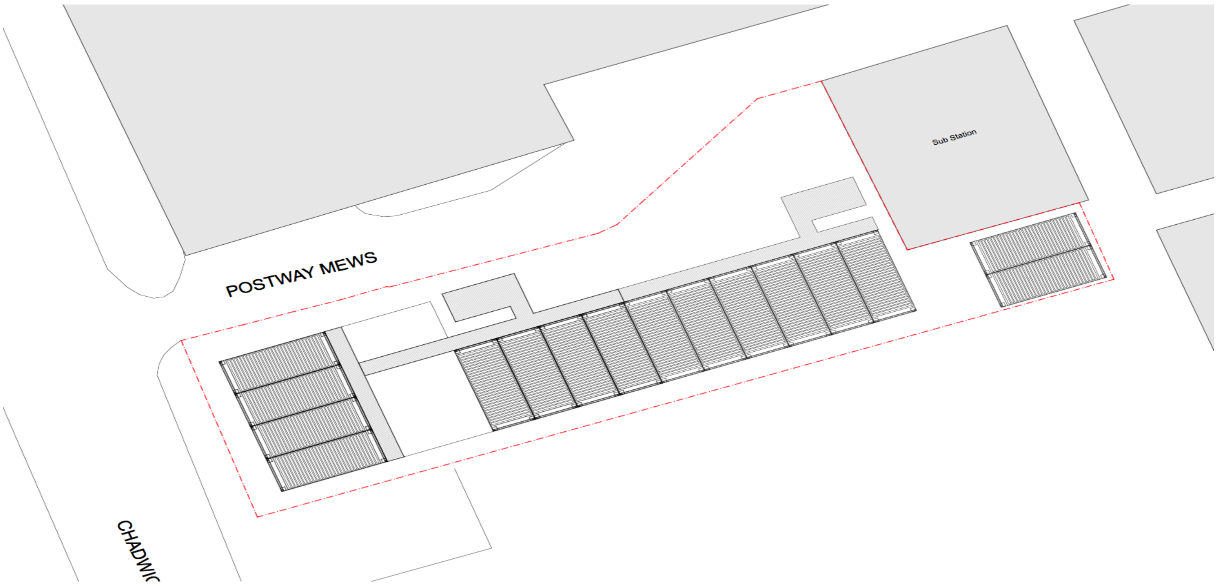

Figure 4.13: Top view of container homes

Standard 20 foot containers with height of 2.59m and an area of 14.79 m^2 are to be used for the project. The total swept area of the SWIFT turbines Is 3.47 m^2, so a total of 4 SWIFT turbines (14.79/3.47) could be installed on one container.

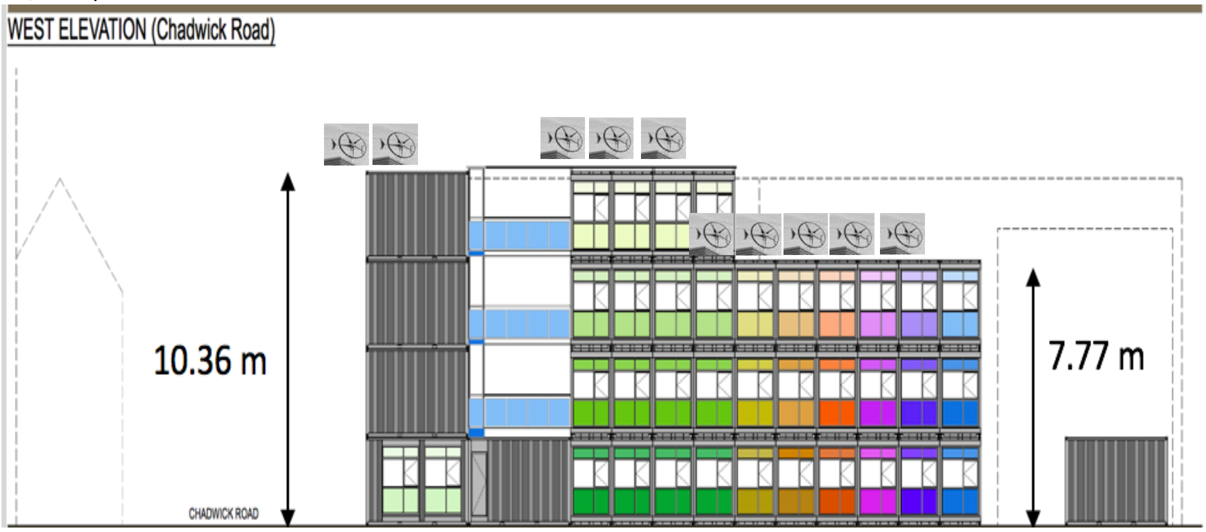

Figure 4.14: Side View showing proposed positions of turbines

Feasibility

A single unit of the SWIFT 1.5 will cost £1,500 with a payback period of just under 8 years. Therefore this will be just outside the tenure of the land, but if the plans to transport the scheme to multiple locations remain then the benefits will outweigh the costs.

Conclusion

Single small turbines, especially roof mounted ones are one of the fastest growing sources of energy globally. Moreover, the roof mounted turbines designated for project Malachi fall within the parameters of specification. It is also an environmentally friendly way of producing electricity. The numerous benefits of wind power over other sources of energy explains its simultaneous successes.

4.5 Solar Energy Design

Introduction

Solar power has become one of the most proliferated renewable energies in the world. As the name mentioned, this technology utilise sunlight and convert it into energy by exciting the electron in a semiconductor material that can be efficiently applied into normal usage such as sunlight to electricity and sunlight to heat up water (Worden and Zuercher-Martison, 2009). In this section, solar power system application on homeless shelter will be described in the design, installation and financial analysis as well as future application will also be mentioned.

System Design

There are mainly two types of solar panel that are relatively well developed nowadays which are namely solar thermal and solar photovoltaic. After a deliberated research on the two types of solar panel, solar photovoltaic will be the best candidate for the Malachi project in terms of finance and efficiency. A solar photovoltaic system normally consists of 14 to 18 panels and provide roughly 3400kWh of power in London, UK (Louwen et al., 2016). A total number of 6 systems can be installed based on the roof top area of the shelter campsite. This number of system not only can provide enough energy for 40 containers and the energy needed for the site, there are excess energy produced to power other application suggested by my colleague.

Installation

Figure 4.15: Roof plan for the installation of solar panel

Figure 4.15 above shows the area of the roof that allow solar panels to be installed. The installation will be settled on top of the aquaponic system's ceiling. An indoor system will also be installed during the construction of the container and maintenance of the solar panel can be done yearly as the need of maintenance for solar panels is relatively low. Solar panels will be installed at an angle of 15 degrees and facing in a south orientation to optimize the sunlight absorption.

Financial analysis

Table 4.7: Cost analysis for the installation of photovoltaic solar system

	Photovoltaic Solar Panel

Initial Cost/ Unit	£6500
Initial Cost for Malachi	£39000
Total energy production for Malachi	100,400 kWh
Feed-in-Tariff subsidies pay(as in 2018 Jan-Mar)	4.151 pence/ kWh
Feed-in-Tariff total pay for Malachi	£4170
Electricity saving from PV for Malachi (based on avg. electricity price/ kWh from the Big Six)	£12900
Money gained/lost for Malachi	-£21900
Total energy production for avg. life span	391,800 kWh
Feed-in-Tariff total pay for avg. life span	£16300
Electricity saving from PV for avg. life span	£50400
Money gained/lost for avg. life span	£27700

Table 4.7 shows the analysis of the cost and revenue for the installation of the solar systems. The FIT subsidies pay is based on the document provided by OFGEM.GOV.UK on the average pay of medium solar power production in the period of Jan to Mar 2018 (OFGEM,2018). The subsidies pay every kWh, either used or unused, produced by the solar system. The electricity saving is the total energy that being utilized by the site as this electricity is ‘free’ after the installation of solar system. The average life span of a solar panel is around 20 years which the project will gain revenue of future application is considered.

4.6 Potable Water Treatment

Design of potable water treatment facility

Due to the importance of safe drinking water quality, the potable water treatment system has been designed for Project Malachi. The aim is to prevent waterborne diseases such as diarrhoea, cryptosporidium and campylobacter in London, and to ensure to reduce risk level to human health (Smith et al, 2006).

In project Malachi, drinking water will be treated in a point-of-use system before delivery to tap, and comparing with different methods and technologies, a reverse osmosis (RO) system and UV primary disinfection method is suitable for the temporary housing in Ilford. Comparing other disinfection methods such as ozonation and chlorination, UV disinfection is more costly and effective than other methods in small scale communities, moreover, there is no chemical or environmentally hazard by-product in the UV disinfection process. From a previous review, RO systems can remove almost 80% arsenic from water (Walker et al, 2008). For other potentially toxic pathogens in water, it can remove more than 95% pathogens, furthermore, the table 4.8 shows the removal efficiency of an RO system, it could effectively remove smaller fine particles and heavy metals, which could be calcium and iron from main water supply in the project, rather than ultra-filtration and any carbon filter (Wimalawansa, 2013). There are two water sources of potable water treatment, one is rainwater collected from rainwater harvesting system, and another is from the main water supply system in Ilford.

Table 4.8: Average purification efficiency of RO membranes

Component	Efficiency %		Component	Efficiency %
Sodium	94		Lead	93
Sulphate	94		Arsenic	95
Calcium	97		Magnesium	96
Potassium	93		Nickel	95
Nitrate	90		Fluoride	95
Iron	95		Manganese	96
Zinc	95		Cadmium	95
Mercury	94		Barium	95
Selenium	94		Cyanide	92
Phosphate	95		Chloride	92
Agrochemicals	98		Petrochemicals	95
Organic compou	98		Particulate matt	99

The whole device containing both a UV disinfection and RO system will be installed near the greywater system which is situated at the back of the shipping container building (Figure 4.16). Although it can also be installed underground, the extra underground operation cost is higher for a temporary housing project. The final design will use one integrated RO device outside the building, and treated water will be then transported to faucets of each single room. The reason for supplying water using a larger device is the cost of an integrated RO device is cheaper than several small devices for each room.

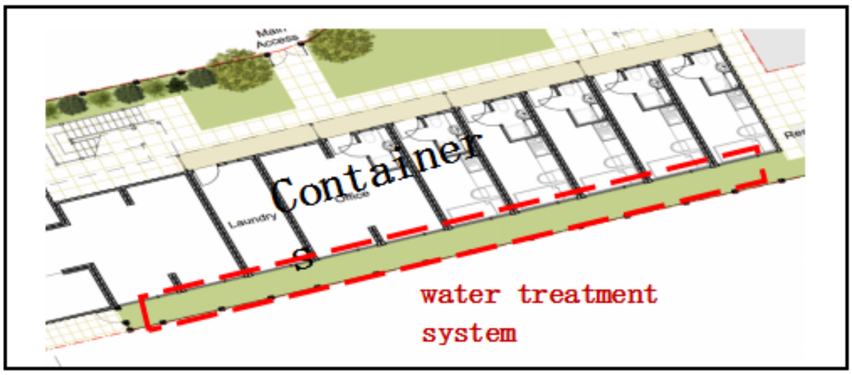

Figure 4.16: Potential position of treatment system

The cost of an RO system with 1000 litres capacity is about £1000, and the UV disinfection device is about £900, thus the total cost of installing a potable water system is roughly £2000. The maintenance cost of the whole system is about £120 per year, and the RO membrane can normally last two to five years. After 5 years, all the equipment of potable water system could be sold to other temporary housing users, or if project Malachi will be delivered to other sites, it still can be used for the project.

Conclusion

A potable water system is essential for the project Malachi to deliver a sustainable supply of water temporary housing. Both UV disinfection and RO systems could ensure drinking water quality is at the national standard, and the final design system has no hazardous chemical by-products that could harm environment.

4.7 Grey water Recycling

Introduction

The following part will introduce the design of grey water treatment system which is used to improve the water system in project Malachi and decrease water usage.

Principles

The system is designed based on the principles of grey water treatment as shown below (Nolde, 2005):

- Black water shall not be reused or recycled;
- The treated grey water should be used for non-potable use, such as toilet flushing and irrigation.
- The grey water shall not have an adverse impact on public health (through contact, ingestion, or inhalation) and the environment.
- The equipment and devices should be labelled to show that the water in such equipment/devices is not for potable use.

Technologies for grey water treatment and final design

The common technologies applied for grey water treatment and the features are shown in table 4.9. It mainly includes physical, chemical and biological systems. For basic physical and chemical treatment systems, it usually includes a filtration process in order to remove debris in grey water, and disinfection step would be introduced to avoid the growth of bacteria during storage. However, The Environment Agency's study (NWDMC 2000) revealed that it was very difficult for the basic physical and chemical treatment systems to avoid some problems such as blockages, odour and noise issues. The payback was also estimated to be in a very long period, which is not a good choice for a short-term program (the Environment Agency, 2011). However, the biological treatment systems were found to be able to achieve excellent removal of organic substances in grey water. Therefore, it was decided to use a bio-mechanical system to treat grey water before recycling it in Project Malachi.

The bio-mechanical treatment system chosen for project Malachi combined the physical and biological treatment system. Specifically, the grey water from washing basins, bath rooms and washing machines would be collected using separate dedicated grey water pipe, and the grey water would flow into an 'all-in-one' over-ground treatment system. The system includes physical filters as pre-treatments in order to remove debris, followed by biological treatment to reduce the organic matter, and a disinfection step to achieve the microbiological standards. The treated grey water would be used for toilet flushing and garden watering.

Table 4.9: Grey water treatment technologies

Categories	Main Technologies	Features
Physical Treatment	Coarse sand/ soil filtration/ membrane filtration	No guarantee of an adequate reduction of the organics, nutrients and surfactants
Chemical Treatment	Coagulation/ photo-catalytic oxidation/ ion exchange and granular activated carbon	Suitable for the low strength grey water (with low level of soap and detergent) treatment
Biological Treatment	Rotating biological contactor (RBC)/ membrane bioreactors (MBR)	Can achieve excellent removal on organic substances

Installation
The equipment would be installed at the back of the shipping containers (as shown in figure 4.17). Considering it is a short-term project, the equipment may need to be moved after five years, it would be installed above the ground. And the special coloured pipes would be hung outside of the shipping containers in order to differentiate them from the pipe used for transporting potable water.

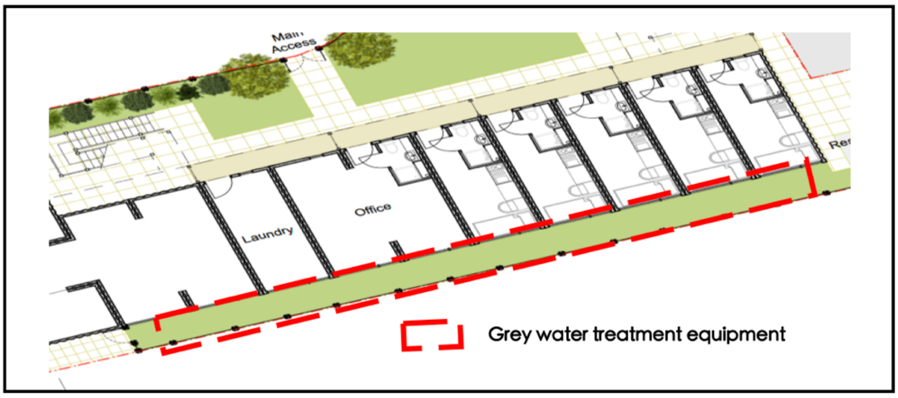

Figure 4.17: Location of the grey water treatment equipment

Feasibility
The estimated cost of the treatment system is about £3000 in total, including £2500 for purchase and £500 for installation, and the maintenance fee is uncertain. The system is estimated to be able to save about 51.8 litres of water per person per day for toilet flushing (with a standard toilet). Moreover, because the water charges tend to increase year on year, the payback period is estimated to be under 5 years (Surendran et al.,1998).

Conclusion
Grey water which makes up about 55%-60% of waste water would be recycled in project Malachi. It is estimated to be able to reduce the water usage by about 40% in this project. The bio-mechanical treatment system, which is considered to be the most efficient system was chosen in this project to avoid the odour and noise issues during treatment.

4.8 Rainwater Harvesting System

A Rainwater Harvesting System (RHWS) would be an ideal way to sustainably manage water in Project Malachi. As well as low cost accommodation one of the main aims was to educate the local community on potential ways to improve the sustainability of the local area. The RWHS will allow rainwater that is collected to be used for non-potable purposes such as laundry, toilet/urinal flushing and for gardening services. It may also be used in the bicycle repair social enterprise for cleaning. Other existing systems that are discussed in this report that will be working in conjunction with the RWHS are the grey water recycling system.

Figure 4.18: Example of Rainwater Harvesting System design (Source: Stormsaver, 2016)

Design of System

In order to determine the type of system to be used it is necessary to understand the water demand. Homeless and low-income people typically use less water in the range of 40-60 litres per day compared to the average person in the UK who uses 150 litres per day (Ramalungo et al., 2017). Water will be collected in a storage tank and pumped directly to places of use (Figure 4.18). To design the system, the average volume of rainfall is needed which was taken from the nearest climate station - Greenwich Park (Met Office, 2018). The storage tank would need to carry a volume of 7,400L, so a storage tank of 7,500 L was chosen (see calculations in Appendix E and Table 4.10). The system would be in compliance with BS 8515:2009.

Table 4.10: Catchment Volume

Design	
Total roof area	270m^2
Average rainfall in Ilford, annual (met.gov.uk, 2018)	755.5mm
Runoff coefficient	0.8
Potential catchment volume	7,400 L

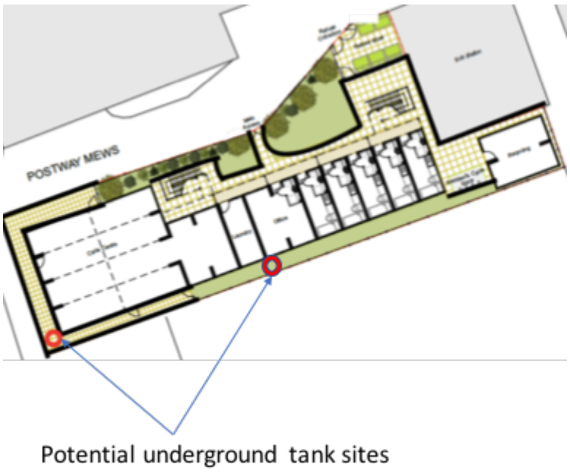

Figure 4.19: Location of underground storage tanks

Costs of System

The cost of the system will be approximately £3800, this was sourced from various RWHS suppliers in the UK.

A cost benefit analysis was carried out to determine how cost effective installing this system for this particular project would be.

Table 4.11: Costs of Installing a RWHS for the 1st year of Project Malachi

Costs	Amount (£)
Rainwater Harvesting System	10,000
Operating and Maintenance	200
Construction	2,000

Table 4.12: Benefits of installing a RWHS for the 1st year of Project Malachi

Benefits	Amount (£)
Water cost savings	2560

The payback time will be 4.8 years, which is within the tenure of the project This analysis only takes into account the first year of operation. It also does not quantify environmental benefits. Higher maintenance costs tend to occur after seven years and may reach up to £1145 in a year (Roebuck et al., 2010).

Studies show when the system is newly constructed the water efficiency is much greater compared when residences that are retrofitted with the system (Waterwise,2009). Water efficiency saving was given as 90% by the manufacturer but Ward (2010) suggests that suppliers tend to overestimate the efficiency of their systems.

Maintenance and Operation

The maintenance of the system will have to be carried out by technicians as this will include cleaning out the filters, cleaning the roof and gutters. Also checking the UV lamps, this will have to be done annually and the water quality will also have to be checked. An example of the maintenance tasks is attached in Appendix B. The regular maintenance of the system is commonly seen as a disincentive for the installation of RHWS where 52% of participants in a study said that maintenance costs of the system would discourage them from purchasing a RWHS (Ward et al., 2012).

Conclusion

The design for RWHS has been carries out in compliance with the British Standards which enable it to be used anywhere else in the UK for temporary housing. The abundance of roof area on the site a great incentive to installing a RWHS, however as it is a temporary accommodation for homeless people who tend not to consume as much water it may be excessive installing the system.

It is also important to note that municipal water supply will be connected to the accommodation if water runs out of the storage tank.

4.9 Aquaponics System

Introduction

For this report, aquaponics system functions not only as a sustainable roof garden, but also as a food source (vegetable production), a leisure platform (fish farming) and a working platform for the homeless people. The system is established in a hope to provide social and technical skills for the homeless people and to prepare them for a job in the future.

System design

The aquaponics system can vary in size, ranging from small indoor units to large commercial units, depending on personal preferences. (Mohamad, et al., 2013). Figure 4.20 shows a common design of an aquaponics system.

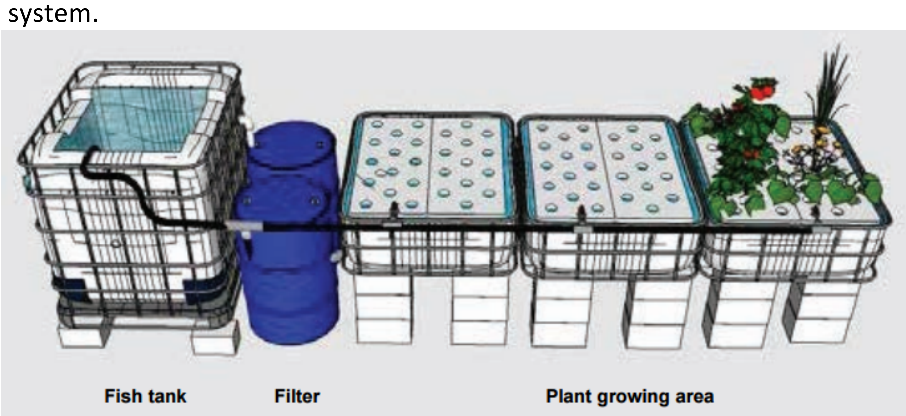

Figure 4.20: Illustration of aquaponics system comprising of fish tank, filter and plant growing bed (Heaven and Earth Aquaponics, 2016)

Based on Figure 4.21, the suggested height and width of the system is 1m and 4m respectively, to allow easy accessibility, with an approximate volume of 750 gallon (refer Table 1 in Appendix). Due to the limited land area at 1a Chadwick Road, the system is suggested to be installed on top of the highest stackable containers. Walls and ceiling covering the system are constructed to be transparent to allow plants to acquire passive sunlight (Despommier, 2009).

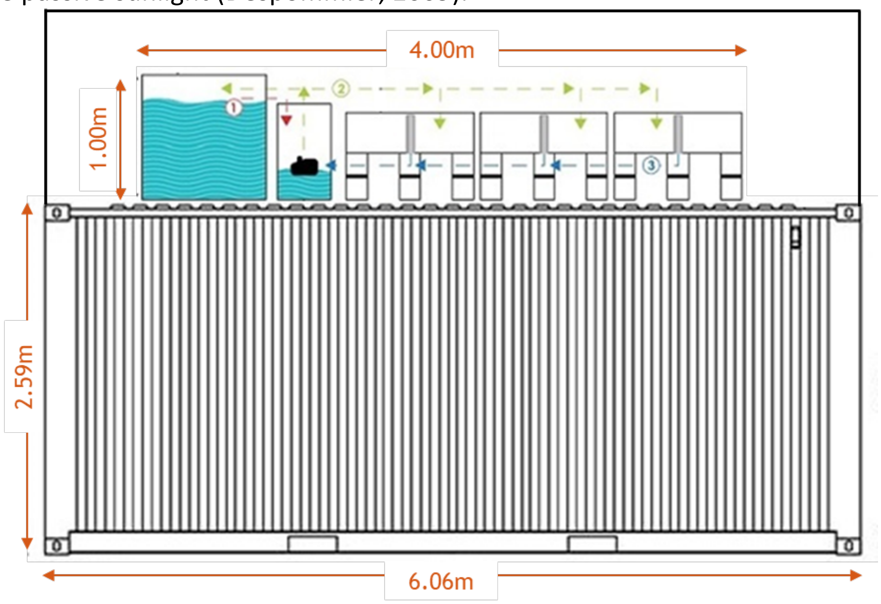

Figure 4.21: The side view of the aquaponics system on the highest stackable containers (Image by Author)

Tilapia is a commonly used fish in aquaponics system due to its high tolerance towards poor water conditions. For vegetables, lettuce is a favourite choice due to its shallow root system. Both fish and vegetable take about 6 months and 1 month respectively to reach maturity (Sawyer, 2013). The food can then be harvested and fresh seeds can be planted as well. Due to the weather conditions in Ilford, supplementary lighting and heating systems are suggested to optimise the surrounding environment (Chatani, et al., 2015). Other vegetables such as herbs and specialty greens can also be grown in the system. However, sufficient time is required to allow the biofilter to ripen before adding a new species (Love, Uhl, & Genello, 2015).

Economic analysis

Studies have shown that the construction cost to build up an entire system can vary and depends on the quality of materials used. In 2011, the total construction cost per square meter ranges from USD850 (365 Aquaponics, 2011) to USD2538 (Goodman, 2011). According to Goodman (2011), the labour cost required to operate the system comprised of 56% of the total operating cost. With the suggestion of homeless people partaking in the system operation and maintenance, labour cost can be neglected. Operating costs such as transportation and delivery are not required due to the proximity of production to consumer. In 2011, the operating costs sum up to USD5781 per year. After considering the inflation and exchange rates, the construction and annual operating costs sum up to £2013.62 and £4586.58 respectively. A detailed costing is available in Appendix.

Not much of economic analysis is performed for small-scaled aquaponics system. Although many studies have shown that large-scaled production is more profitable (Goodman, 2011), it is more reasonable to design small aquaponics system due to:

- Less cost
- Easier to control in an experimental study
- Easier to fit in a container
- Easier to scale upwards than to scale down a large unit

System management

To ensure the system operates efficiently, proper care and maintenance are required, and the following tasks can be performed by the homeless people. These skills can be achieved by online learning courses or by hiring a project manager to overlook the system. Approximately 10,000kWh (Love, Uhl, & Genello, 2015) of electricity is required to sustain the system annually, and the energy can be acquired from wind turbines and solar panels.

Table 4.13: Operation and maintenance required for the system (Viladomat, 2012)

Daily Tasks	Weekly Tasks	Monthly Tasks
• Feeding the fish • Checking water pH • Checking plants for pest • Checking the mechanical compartments	• Similar to Daily Tasks • Cleaning the filtration system • Harvesting products	• Cleaning all the pipework • Checking the buffering medium • Checking the fish visually • Stocking new fish if necessary

Conclusion

The aquaponics system will not only address the problems of fresh water usage, but also the problems related to urban employment. The homeless people are able to gain hands on experience and improve their job prospects. Its development will not only change the urban rooftop design, but also the way food production is perceived, where vegetables can be grown without soil. The total cost of running the system is approximated to value at £4586.58 per year. This value can be further reduced with the utilization of renewable energy to support the electricity consumption and heating system.

5.0 Business Plan – potential for overseas application

Most of the systems used in Project Malachi are designed so they could be applied to overseas situations. For the wind power system Swift, it can be applied to other areas based on the wind-speed. With an estimated cost of £1500 per piece and 20 years average life span, no maintenance is required for the 8 years pay-back time. As for the solar power system, future application is needed in order to achieve the payback time. PV solar panels can be reapplied onto public housing, government renewable energy projects or other similar projects. This average lasts around 20 years with a 12 years payback time. This could be very beneficial if the project is applied in some sun-rich areas such as the Netherland and Spain

In terms of the water requirement overseas, the potable water system used in project Malachi can be applied at an international scale. It can be implemented not only for other similar temporary housing projects, but also for long term projects. If it is used for a long-term housing project, the treatment system and water tank could be moved underground, but it would increase the cost in the operation of the system. Due to the low cost and high efficiency of the system, it is better to apply it in a developing country, and it could help to prevent waterborne diseases. Depending on the climate, the potable water system could be combined with the rainwater harvesting system to relieve the shortage of safe drinking water. Hence, under different scenarios, the system could be redesigned to meet local requirements and keep the system sustainable.

For the heating system, the main cost comes from the price of the boiler and radiators which are based on the output power of output and the pipework which depends on the complexity of the building structure. So, the heating capacity demand and how pipeworks can be installed should be applied at first for an economical heating system that can fit local climates, heating requirements and building structures. For instance, in regions with warm climates which have little heating requirement, the heating system could be unnecessary.

Concerning the rainwater harvesting system, if the same scheme was to be set up anywhere with a housing crisis and in need of temporary housing, the same design could be incorporated throughout the UK. As the standards that the system is designed to are UK policy and it is for non-potable water. The volume of the storage tank may have to be amended due to the different rainfall patterns across the UK, so climate in that area will have to be investigated.

Concerning implementation internationally, the system will need to be redesigned to account for the conjunction of the supply of potable and non-potable water. This will be a more economical system and create greater savings for the consumer, especially in areas of water scarcity or where the municipal utility has supply issues. A concern to be aware of would be the electricity required for the water pump, this may be sourced from the existing solar panels/ wind turbines but a battery storage may also be required as backup power supply.

For the choice of containers' locations, outdoor air quality needs to be considered and measured first, based on different local regions. Some polluted regions are not suitable for people to live in, for example, roadside locations have relatively higher pollutants' concentration than non-roadside areas. An optimal option for constructing containers in the future should be in less polluted regions, in order for the residents to have access to a better environment; and it is important for their health too.

Grey water treatment system mainly aims to reduce the water usage through recycling most of the domestic waste water. Therefore, it is vital for those countries /cities which are facing a water crisis due to the increased water demand or climate, such as India and Bangladesh. The technologies could be improved in the future which could provide potable water after treatment.

Aquaponics system is adaptable to installations of different sizes and location (Towers, 2016). The system ranges in different scopes and it can be installed indoors as well as outdoors. As the aquaponics system does not require farmland with fertile soil, or even land with soil, the system can be performed anywhere, with water and light sources as main requirements. With the usage of 90% less water than traditional farming methods, the system does not need much water as well. It can be applied even to lands with water scarcity such as Egypt (Enany, 2015)

6.0 Conclusion and Recommendations for Further Research

The compilation of this report functions to study the application of shipping containers as an accommodation service for the homeless people. The feasibility of various designs such as heating system, grey water system, rainwater harvesting system, potable water system, wind turbines, solar panels and roof garden are analysed, while considering the valuation and functionality of each design at the same time. All the designs are created with the implication that they can be replicated at different venues.

With London's expensive traditional housing market, Project Malachi proved to be an affordable solution. The project is deemed to be beneficial to the homeless people, as it shows a unique way of helping them with not just a place to stay, but also a platform for them to gain valuable skills. With the increase in urban population and resource requirement, Project Malachi shows that modular housing can be both sustainable and affordable. However, there are certain limitations applied to each design due to various factors and various recommendations have been proposed.

For heating system, the design is incomplete. Firstly, heating loads for each type of room and the whole building should be calculated, according to which the size of radiator and boiler can be obtained. Then, the layout of water pipework is to be designed. The size of pump finally can be decided based on the total pressure loss when it pumps hot water to each radiator and back flow of cool water. All the design and calculations should try to achieve energy efficiency and meet users' requirements

Indoor air quality will be monitored once the containers are put in place. Based on that, several suggestions on how to maintain or achieve better indoor air quality can be made, such as, source control, applying HVAC system and filtration.

For the solar panels, after the installation, financial subsidies pay should be monitored closely as the subsidies changes will directly affect the payback time and revenue that solar power system brought to the project. Evaluation on the solar efficiency is also required as the solar power technology is growing daily.

As for the rain water harvesting, when installed it would be of interest to monitor the performance of the RWHS and how efficient the system is and if that compares with manufacturer's statements. Another useful study would be how water consumption differs as homeless people settle into temporary accommodation.

As for the aquaponics system, due to the weather condition in the UK, proper care is required to maintain the surrounding temperature of the system. There are several suggestions for improvements and alterations to overcome the cold weather, such as installation of thermal blanket, solar electric generation system, thermal water heater, automated ventilation system, extruded polystyrene foam and LED grow lights.

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Appendices

Appendix A

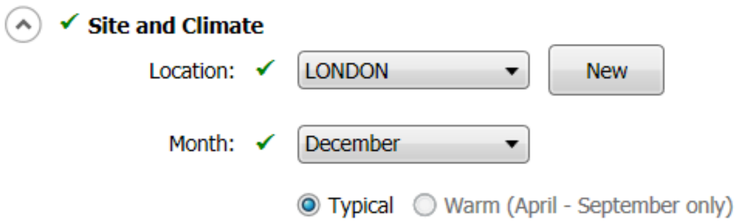


Figure A.1 Location and climate setting

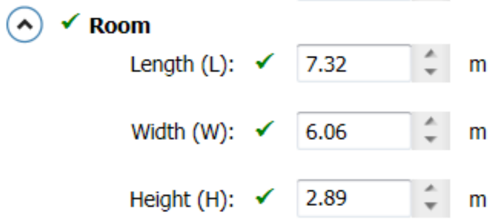


Figure A.2 Room dimension setting

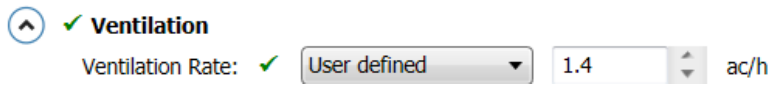


Figure A.3 Ventilation rate setting

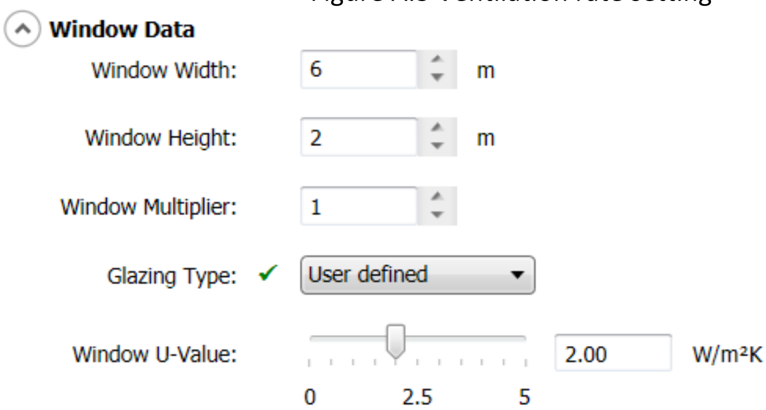


Figure A.4 Dimension and U-value of windows setting

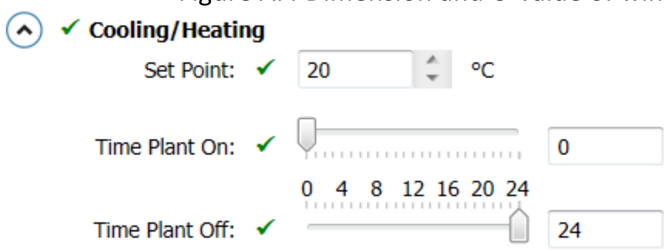


Figure A.5 Set point of indoor temperature

Appendix B

Photovoltaic Solar system performance spreadsheet

	PV Solar system
Application voltage	4kW
Panel type	Flat semiconducting material
No. of panel available/ system	16
Efficiency in terms of converting sunlight into electricity	20%
Power generated per system	3400kWh
Average life span	20 years

Photovoltaic solar system efficiency and financial analysis on Malachi project spreadsheet

	PV solar system
Total energy production for the first year	20,600 kWh
Total energy production for the Malachi project (5 years)	100,372 kWh
Total energy production for the life span (20 years)	391,841 kWh
Estimated Malachi project electricity needed/ per year	42641.73 – 52117.89 kWh
Estimated electricity coverage	48.31%
Estimated Electricity cost for Malachi project	£ 27400 – 33500
Electricity cost saving from solar panel for project Malachi	£12900
Electricity cost saving from solar panel for life span	£50400
Feed-in-tariff for project Malachi	£4160
Feed-in-tariff for the life span	£16300

Electricity cost for the Big six power production company

	Unit price/ kWh	Annual Standing charge
Scottish power	12.376 pence	£114.28
SSE	12.412 pence	£142.82
npower	12.776 pence	£85.78
EDF Energy	12.831	£87.88
E.on UK	12.849	£88.33

Avg. Household electricity consumption for 4 person by = 3638 kWh/year (2017 by Energy saving trust)

Avg. Electricity consumption of naturally ventilated open-plan office (2010 by BREEAM) = 120 kWh/sq. M/year

the total energy production for the usage of solar panel: ∑20600× 〖(1-1%)〗 ^(n-1) with n as the year of usage.

Appendix C

Dimensions of the aquaponics system

Table 2: Characteristics of the suggested aquaponics system

Characteristics	**Value**
Height	1.00 m
Width	0.85 m
Length	4.00 m
Volume	$3.4m^3 \approx 750$ gallon

Calculations of the construction and operating costs

To calculate the inflation rate in the United States since 2011, the inflation rate formula below is used.

$$2018\ USD\ value = \frac{CPI\ in\ 2018}{CPI\ in\ 2011} \times 2011\ USD\ value$$

Consumer price inflation (CPI) in 2018 = 247.867

Consumer price inflation (CPI) in 2011 = 224.939

The exchange rate is based on XE Currency Converter (9th of March 2018), where 1USD = 0.724098GBP.

Table 3: Construction costs for a small-sized (750 gallon) aquaponics system (Goodman, 2011)

Operating Factors	**Price in 2011 (USD)**	**Price in 2018 (USD)**	**Price in 2018 (GBP)**
Land	0.00	0.00	0.00
Building	0.00	0.00	0.00
Liner	100.00	110.19	79.34
Wood and fittings	740.00	815.43	587.11
Pump	143.00	157.58	113.45
Piping	50.00	55.10	39.67
Fish tank heater	325.00	358.13	257.85
Thermometer	10.00	11.02	7.93
Grow lights	420.00	462.81	333.22
Refrigerator	500.00	550.96	396.69
Hoses	50.00	55.10	39.67
Other Equipment	200.00	220.39	158.68
Total	2538.00	2796.70	2013.62

Table 4: Yearly operating costs for a small-sized (750 gallon) aquaponics system (Goodman, 2011)

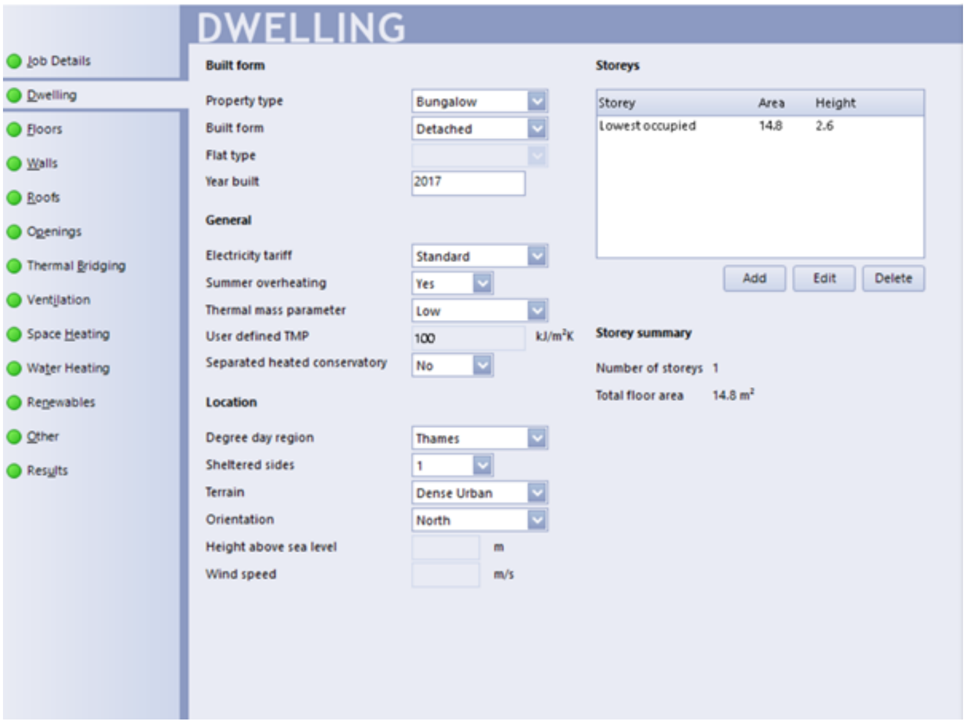
Operating Factors	**Price in 2011 (USD)**	**Price in 2018 (USD)**	**Price in 2018 (GBP)**
Electricity for pump	123.00	135.54	97.59
Electricity for grow lights	893.00	984.02	708.50
Natural gas for water heater	2,252.00	2481.55	1786.71
Water	68.00	74.93	53.95
Fish food	750.00	826.45	595.04
Seeds	120.00	132.23	95.21
Fingerlings	375.00	413.22	297.52
Other agricultural materials	500.00	550.96	396.69

Replacement costs	300.00	330.58	238.02
Operating reserve	400.00	440.77	317.36
Total	5,781.00	6370.26	4586.58

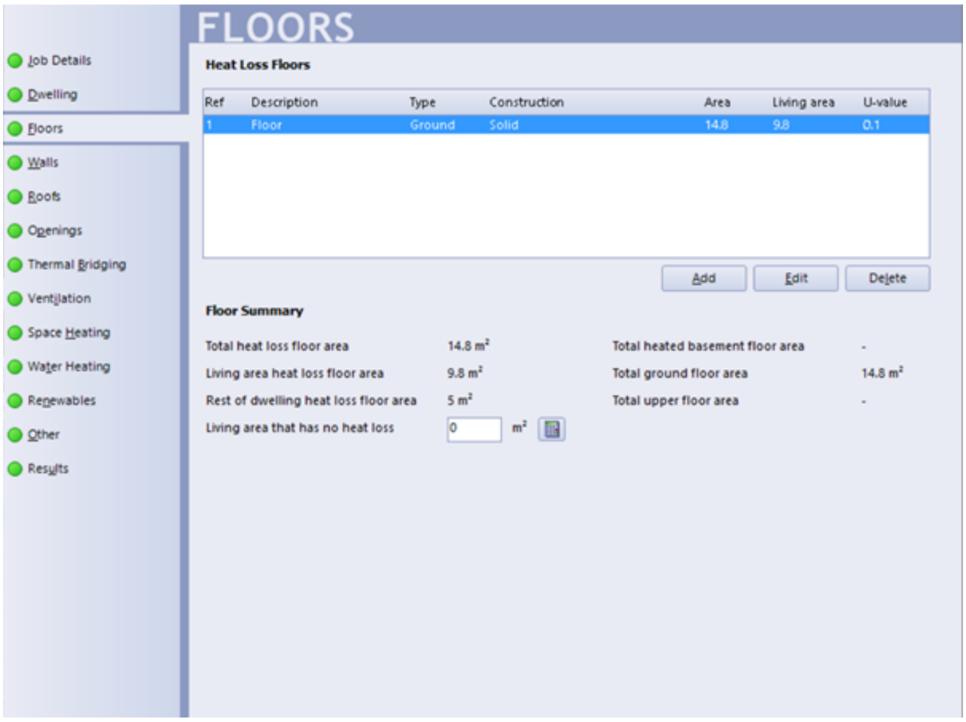
Appendix D

The below images are screen shots showing the data input and assumptions for the building to pass building regulations using SAP 2012 software.

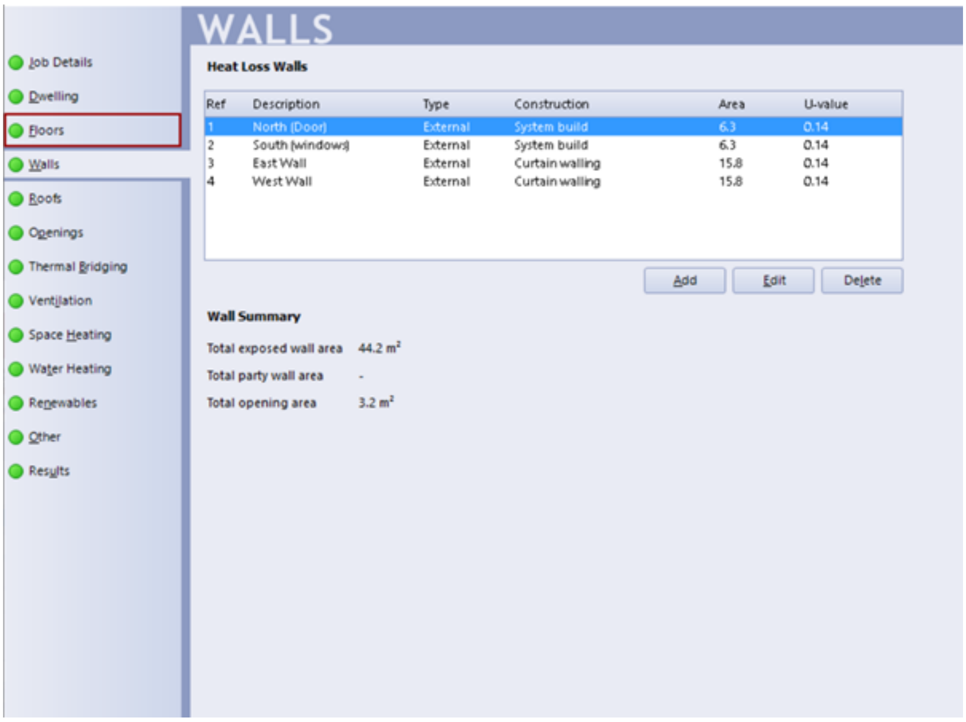
Dwelling



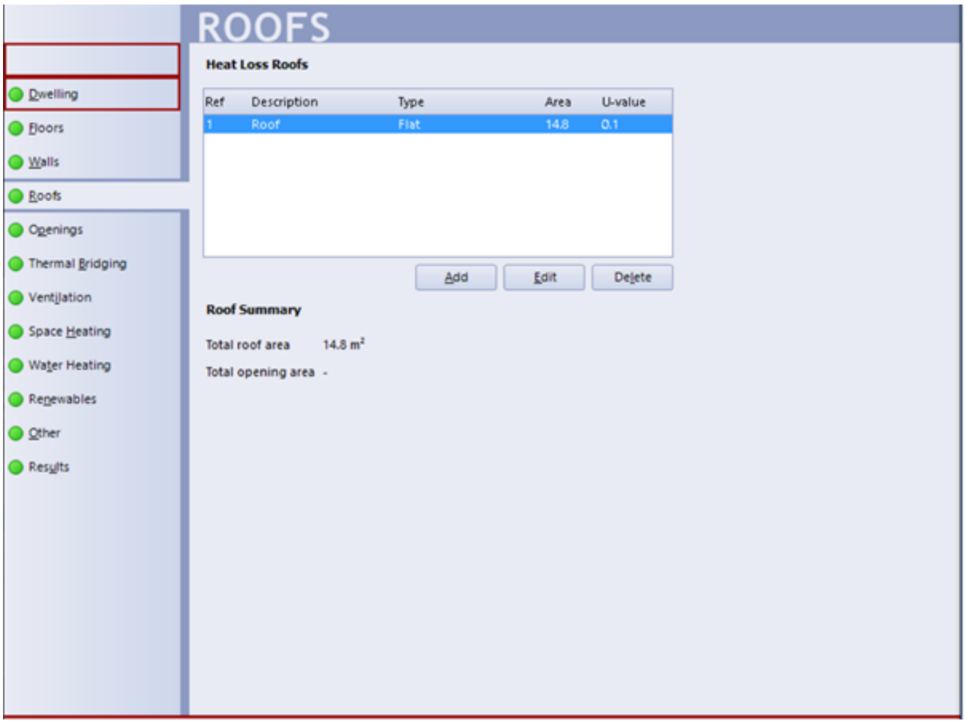
Floors



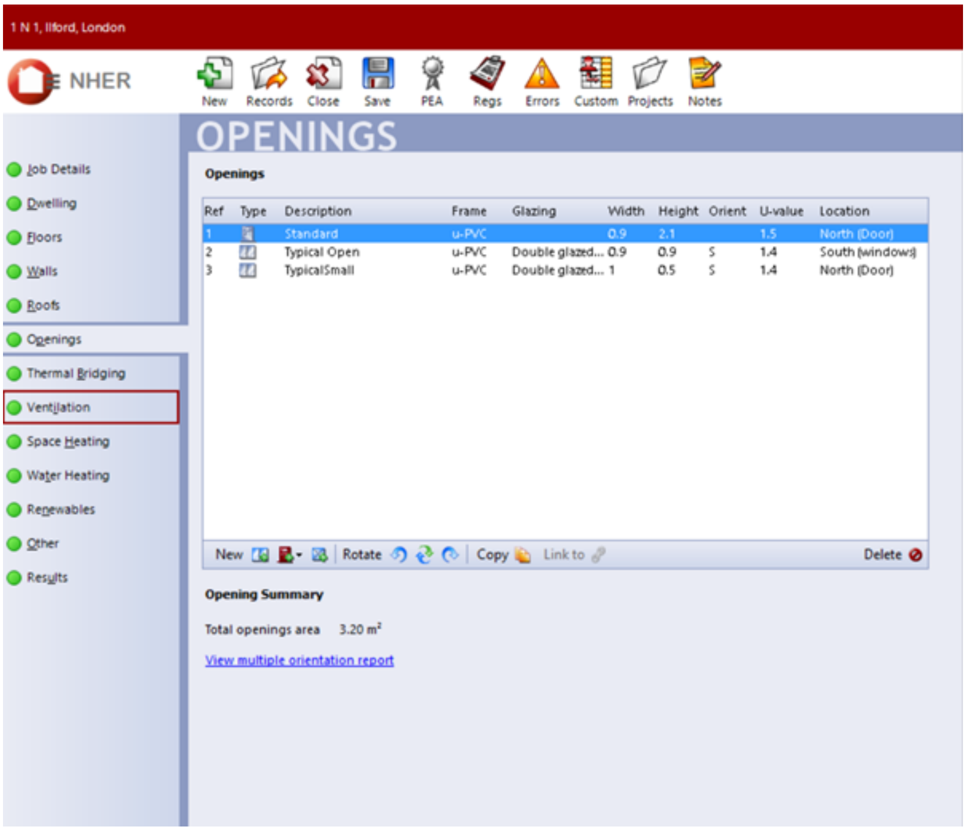
Walls



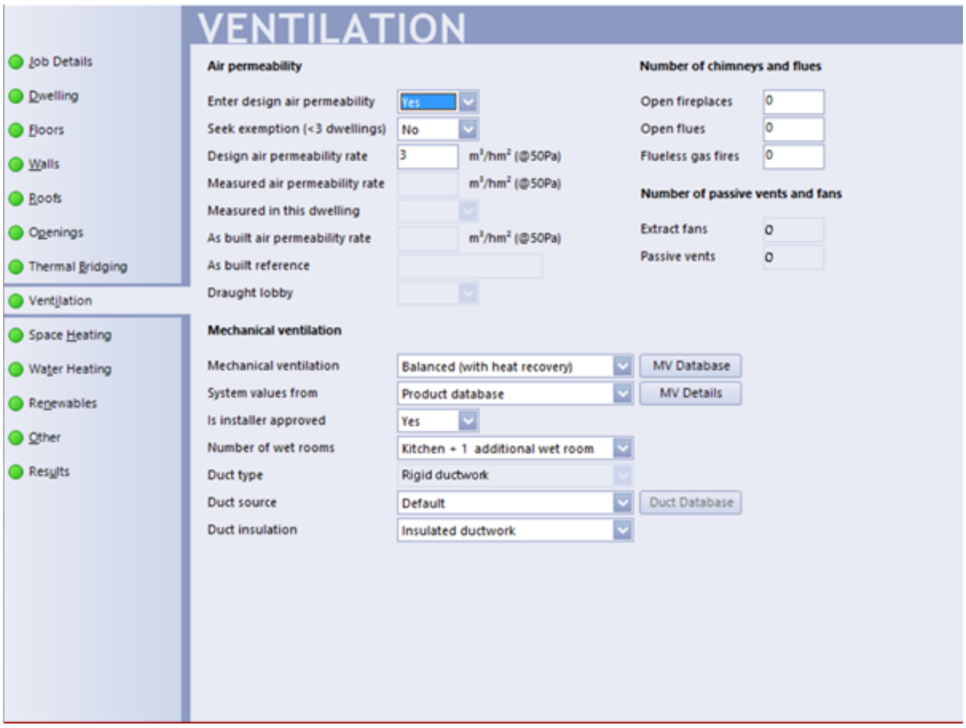
Roofs



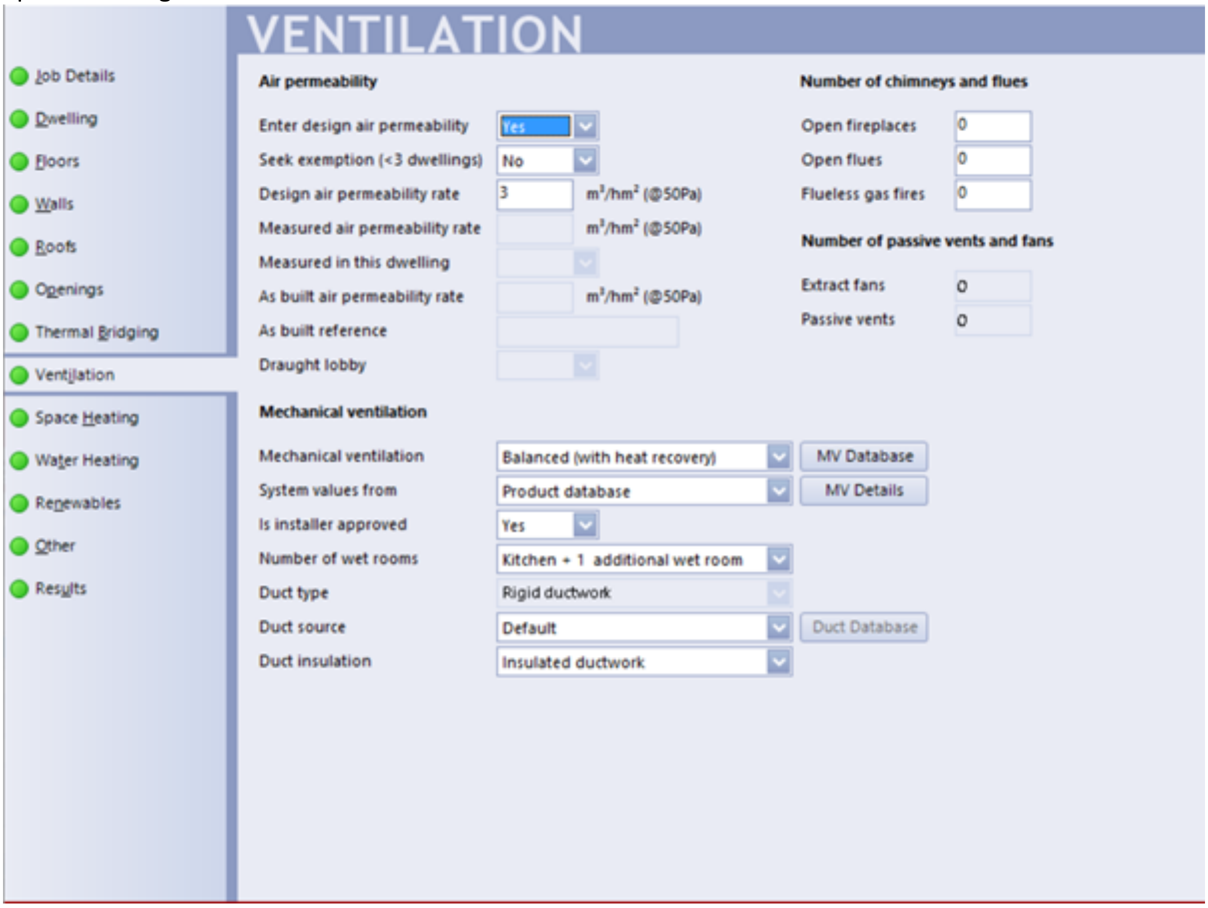
Openings



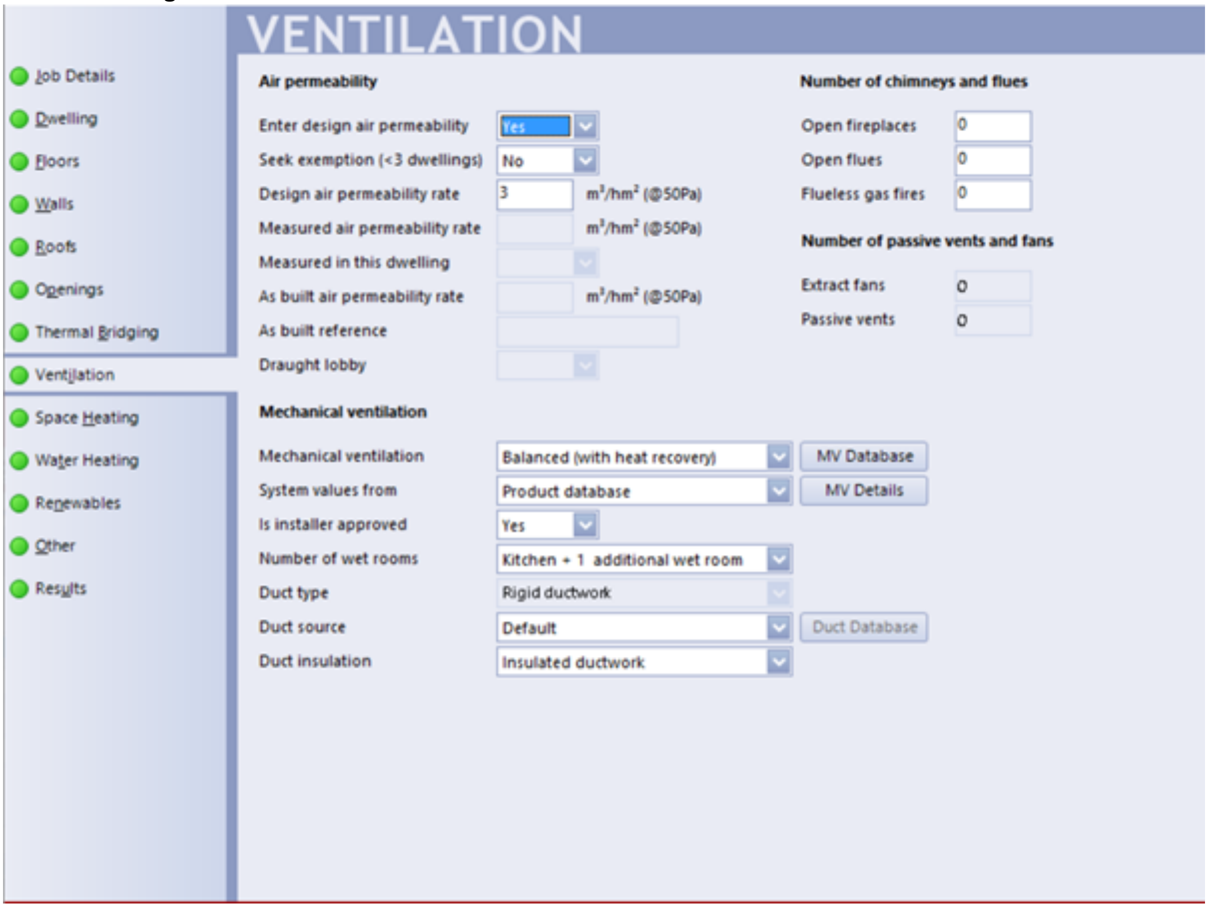
Ventilation



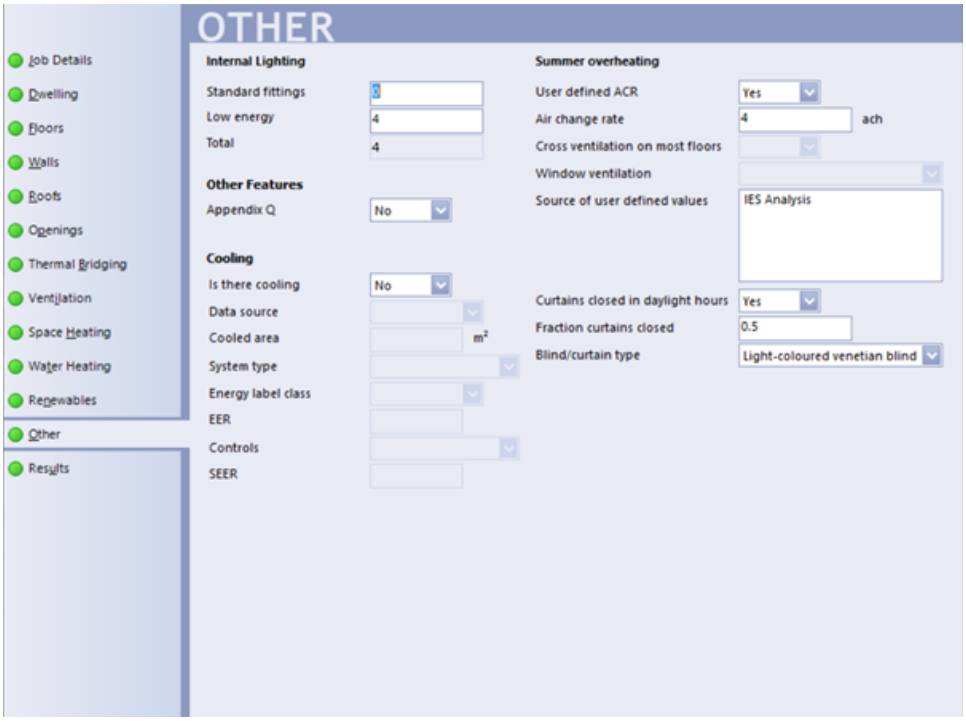
Space Heating



Water Heating



Other



Appendix E

Data required for calculations

London water Consumption (Lpd)	150
Annual Rainfall (mm)	755.5mm
Drainage Coefficient (flat roof)	0.8
Effective collection area (m^2)	270
Filter Efficiency	0.9

Required Volume Calculation

$$Size\ of\ storage\ tank\ required = Annual\ Rainfall\ (mm) \times effective\ collection\ area\ (m^2) \times drainage\ coeffcient\ (\%) \times filter\ efficiency \times 0.05$$

Cost savings calculated

Mains water and sewage (Essex & Suffolk Water)

Type	Fixed Cost	Cost per cubic metre
Mains water	42.10	1.50
Sewage Collection	68.02	0.78