PROJECT MALACHI

Final report - Project Malachi

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CEGE0029 Collaborative Projects

Executive summary

Project Malachi is led by The Salvation Army and aims to house rough sleepers in Redbridge, London. Homelessness is a global problem that has become increasingly visible in recent years as more of the world's population concentrate around urban centres. Over the past decades numerous legislative acts have been put in place to tackle homelessness in the UK, but rates continue to rise. The Salvation Army in Ilford have provided shelter to local rough sleepers during the colder months for several years, but the same individuals returning each year has spurred further action. The project involves constructing an apartment complex from disused shipping containers, and aims to be modular, inexpensive, and environmentally friendly. UCL's involvement began in 2017 with a team of students researching and proposing a range of green infrastructure for the project. Most of them were not realised, primarily due to costing. Our goals are to review the previous team's work and make improvements, and to research alternative green infrastructure while seeking to reduce expenses throughout.

Our research led us to four main proposals for the project involving a water system, insulation, energy efficiency, and waste management. Our main findings are as follows;

- **Water system**
  - A rainwater harvesting system can be installed to reduce water consumption for non-potable uses such as flushing.
  - The payback time for the proposed system is 1.5 years, which is in line with the proposed lifespan of the project.
- **Insulation**
  - An analysis was carried out comparing several commonly used insulation materials, giving cost priority.
  - Expanded polystyrene panel insulation can be installed to substantially improve the thermal efficiency of the building, in doing so reducing heating-related energy consumption and improving living conditions.
  - Insulation will not be cost-neutral over the 5-year lease but is a vital building service.
- **Energy efficiency**
  - Smart meters can be installed in each room to provide residents with feedback about their energy consumption, shown to influence behaviour
  - We provide a list of energy-efficient electrical appliances which will reduce overall electricity consumption, offering environmental and financial benefit
  - The option of combining Time-of-Use rates with energy storage is also propose, with a pay-off for the battery investment in 2.2 years.
- **Waste management**
  - We suggest an approach that adheres to the priorities of the waste hierarchy, addressing prevention, preparation for re-use and recycling, and energy recovery
  - Residents should be educated on how lifestyle and behaviour affect waste, with aims to reduce the volume of waste produced
  - The local municipal recycling program should be taken advantage of
  - An anaerobic digester can be installed, turning organic waste into biogas and digestate that can be used on site or sold

- Our cost analysis suggests that these proposals will be cost-neutral over the 5-year lease

These proposals have substantially reduced costs compared to the previous team's work, while retaining environmental benefit. Overall, they also require less maintenance – further reducing the burden on residents. We conclude that these are the most cost-effective green infrastructure solutions for Project Malachi.

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Introduction

Introduction

Project Malachi is a campaign led by the Salvation Army, which aims to house rough sleepers in Redbridge, London (The Salvation Army, 2018). Substantial progress has been made since it began in 2017; £1.9 million in funds allocated, land and planning permission obtained, and an initial design sent out to tender.

The construction will take place at 1A Chadwick Road, Ilford (IG1 1EQ), on a brownfield site (Figures 1 and 2). The current design proposes a three-storey complex consisting of 38 housing units, and 5 units reserved for The Salvation Army Ilford's bike workshop, ReCycles.

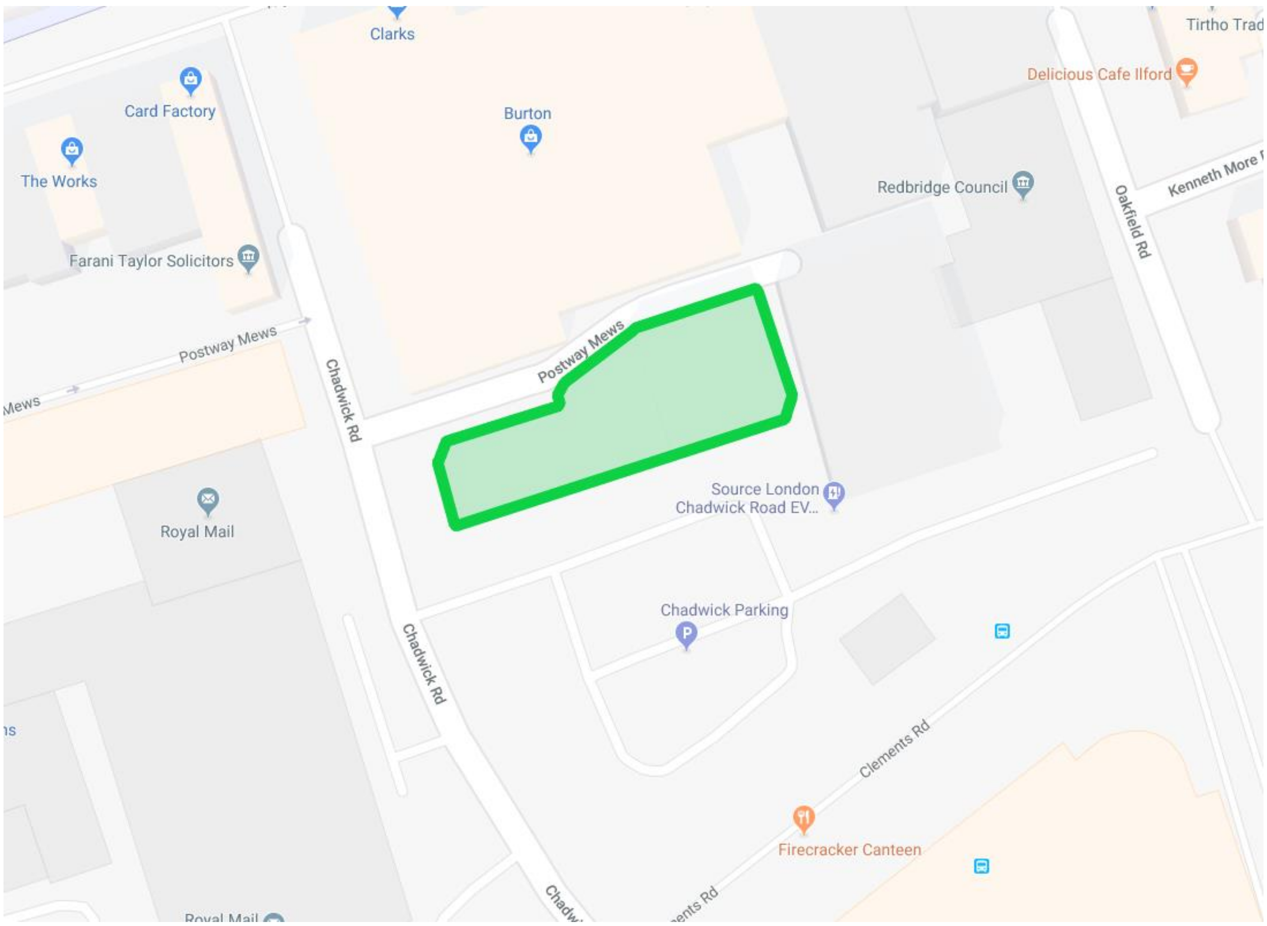

Figure 1: Google maps view of the location allocated for Project Malachi, 1A Chadwick Road, Ilford, IG1 1EQ. The area highlighted green is the ~350m^2 lot where construction will take place.

Figure 2: Ground view of the brownfield site allocated for Project Malachi, 1A Chadwick Road, Ilford, IG1 1EQ.

Background to problem

Homelessness is a global problem that has become increasingly visible in recent years as more of the world's population concentrate around urban centres. Estimates suggest that around 2 percent of the world's population (~150,000,000) are homeless, but figures are subject to large fluctuations based on the definition of 'homeless' used. Definitions range from simply lacking access to adequate living space to lacking access to permanent residence which provides security, identity, and emotional fulfilment (Chamie, 2017). 'Adequate living space' itself is then also subject to variation between countries based on living standards and cultural differences. Part VII of the UK Housing Act, 1996 defines homelessness as either having no available accommodation, or having accommodation but lacking access to it, including being part of a moveable structure or vehicle, or it being unreasonable for extended occupation (Parliament Publications, 2005). Rough sleeping is defined as people sleeping or intending to sleep in the open air (streets, tents, doorways, etc.), or people occupying buildings not intended for habitation (GOV.UK, 2018). These definitions will be adhered to for the remainder of this document.

Over the past decades, numerous legislative acts have been put in place to tackle rising rates of homelessness (GOV.UK, 2018). Among other imperatives, these place an obligation upon local authorities to conduct reviews and produce homelessness strategies for their districts (Parliament Publications, 2005). They also place statutory duties on local authorities to provide advice and assistance to those that apply for aid, giving priority to vulnerable groups; ages 16-17, ages 18-20, vulnerable due to time spent in care, in custody, in HM forces, or those having to flee their homes due to violence or threat thereof. If the applicants fit into these categories, the local authority must ensure that adequate accommodation is provided until an alternate solution is available. If the applicants do not fit into these categories or are deemed 'intentionally homeless', advice and assistance must be provided to help them seek accommodation for themselves (GOV.UK, 2018). In addition to this, numerous non-governmental organisations (NGOs) such as The Salvation Army and Crisis, Shelter provide aid to rough sleepers and homeless people.

Despite these efforts, homelessness rates in the UK continue to rise. Shelter, 2018 reported that 320,000 UK citizens were homeless, up from 307,000 in 2017. Rates of homelessness vary across the UK, the highest occurring in London and several regions of Southern England (Figure 3) (Shelter.org.uk, 2018). Causes of homelessness span a huge array of issues which vary on a regional and individual basis, contributing to the difficulty of diagnosing and treating the problem.

The Salvation Army have provided shelter to rough sleepers in Ilford during winter over the years, but the same individuals returning each year indicates that further action may be required. Herein lies the primary goal of Project Malachi: to provide more permanent shelter to rough sleepers in Ilford, as well as offer them a stable platform with which to be re-integrated into society. Disused shipping containers have been selected for the construction to form a relatively inexpensive and modular apartment complex. The containers are constructed from welded steel sheets and are designed to stack in columns and withstand adverse weather conditions. This combination of features makes them an excellent choice for constructing sturdy, modular housing. This is also considered environmentally friendly due to the re-use of containers, and substantially reduced raw material inputs in construction.

Incorporation of green technology into the design is also a consideration. Green technology has advanced significantly over the past decades; however, many technologies still pose substantial upfront investments of capital followed by long pay-off times. Given that Project Malachi has a 5-year lifespan and limited budget, many of the conventional options such as solar power may not be appropriate. Another key aspect of the project is ensuring that adequate building services are installed to ensure that the building meets the needs of the people living within and does so with minimal environmental impact (Cibse.org, 2018).

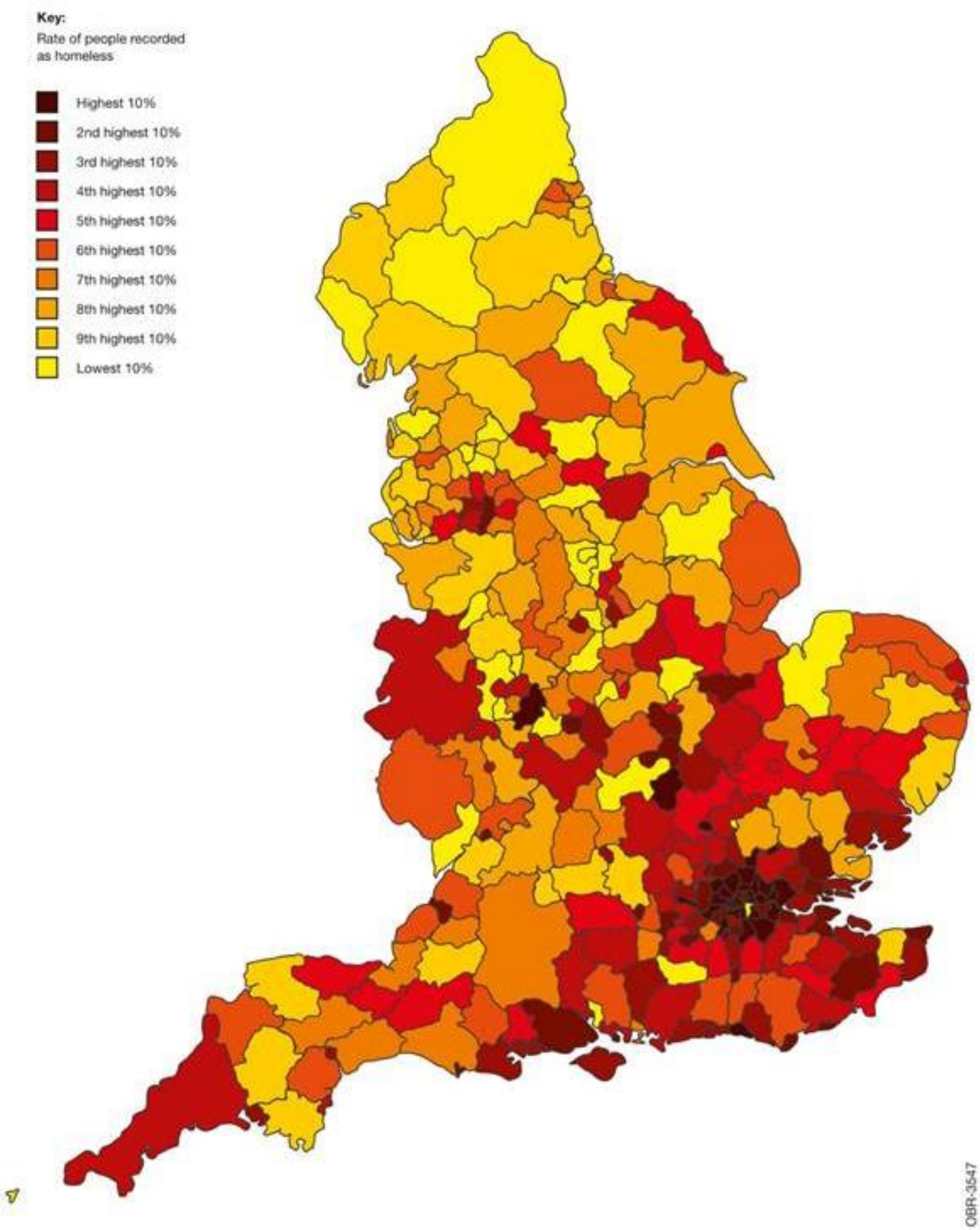

Figure 3: Heat map of homelessness in the UK, darker regions indicate higher rates. Taken from Shelter.org.uk, 2018.

Project aims & objectives

The team interviewed John Clifton, the Salvation Army representative in charge of Project Malachi to better understand his goals for the project. UCL's involvement began during 2017, with a different team researching and proposing a range of green infrastructure design options that could be included in the construction. While these were individually well-researched, a lack of cohesive design was apparent, and costs would have been too high. A preliminary assessment of building services was also carried out but lacked detailed comparisons of options for aspects such as energy efficiency and insulation. John Clifton stressed that the budget for Project Malachi was tight, and as such reducing costs is paramount, with environmental considerations coming afterwards. Given John Clifton's statements, the previous work, and other available information, our final objectives are as follows;

1. Study the previous work and make improvements
2. Identify ways to reduce expenses
3. Perform in-depth feasibility assessments for a range of green infrastructure designs
4. Incorporate the improved designs into the structures
5. Ensure that the improved designs integrate and function as a system

<u>Business plan</u>

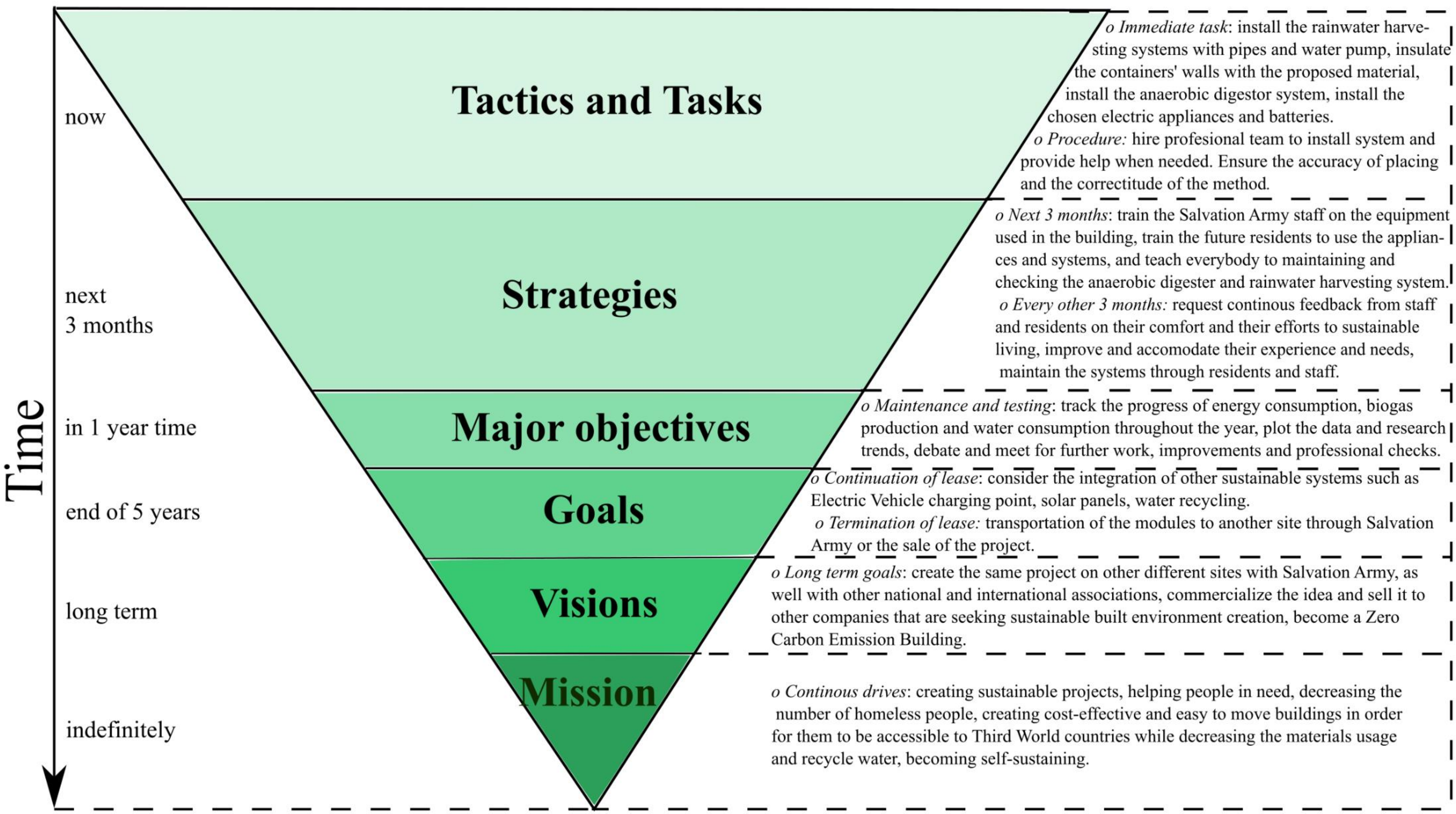

Figure 4: Business plan for Project Malachi, covering tasks and objectives as the project progresses.

A business plan is a set of documents that summarizes the operational objectives of a firm and the methods they will be achieved through (Business Dictionary, 2019). Figure 4 illustrates the business plan for Project Malachi. The initial cost of the systems chosen can be seen in Table 1.

Table 1: The total cost of each system and appliance, with the quantity assigned for Project Malachi.

Item	Cost (£)	Quantity	Item	Cost (£)	Quantity
Water Tank	1,170	1	Hob and oven	15,200	38
Water Pump	340	1	Light bulb	182.4	76
Water filtration system	290	1	Electric boiler	14,136	38
Pipes	328	200m	Computer	860	2
Insulation	33,000	1	Television	358	2
Electric showers	2660	38	Battery	23,300	3
Small fridges with freezer	11,362	38	Anaerobic digester	6,000	1
Washing machines	597	3		875	
Total			**109, 783.4£**		

Literature review

As previously mentioned, homelessness in the UK is a serious problem. The BBC reported 449 homeless deaths in 2018, although the actual figure is likely much higher as these frequently go unreported (BBC News, 2018). Many of these people resort to rough sleeping due to the unwillingness of families to provide shelter, loss of private housing, family breakdown, and several other reasons (UK Housing Review, 2008). The government and various NGOs have been attempting to tackle rising rates of homelessness (Eleanor, 2018), but the vast range of causes and nuance between individual cases makes it exceedingly difficult.

Providing shelters for rough sleepers and homeless people is one approach. Currently, there are many active hostels, night shelters, and winter shelters in the UK, such as Greenwich Winter Night Shelter and Croydon Churches Floating Shelter. These usually require rent payments, which can be covered by housing benefits. Some hostels also require fees for services such as meals, heating, and laundry, which are not covered by housing benefits and must be paid by the residents themselves (Shelter, 2018). Night and winter shelters are usually managed by non-profit organisations, some of which are free, while others cost between £2-5 per night to cover services and maintenance (Shelter, 2018). These shelters also tend to have cramped living conditions with up to a dozen small beds in a single room and a lack of personal space (Adam, 2016).

Project Malachi will provide rough sleepers in Redbridge with temporary housing built from shipping containers, both improving their living conditions and offering training in practical and employable skills. In 1987, Philip Clarke suggested that containers could be transformed into living spaces (Clark, 1987). Since then, others have proposed uses such as temporary solutions to housing shortages and office space (Smith, 2005). More recently, shipping containers have been used to construct shopping malls in New Zealand, Starbucks coffee houses, and student accommodation in Sweden (Giriunas et al., 2012).

Project Malachi chose shipping containers because of their modularity, the temporary nature of the project and concerns for sustainability.

Modularity

The shipping containers are designed to be stacked, and are constructed from heavy-gauge corten steel, which creates strong, impervious spaces (Fuller, 2006). Unlike shelters where several people share a space, shipping container units provide independent living spaces, greatly enhancing the comfort of living.

Temporary nature

Shipping containers are easy to disassemble and can be reused or recycled once Project Malachi has ended (Abrasheva et. al, 2012). The project currently has a 5-year lease, after which the shipping containers can be reused or transferred to other regions.

Sustainability

Compared to conventional buildings, shipping containers can reduce construction material input and waste. For example, Travelodge hotel built in Uxbridge, London produced 70% less on-site waste than a comparable conventional building.

With relation to the project goals, a detailed analysis will be carried out addressing four aspects of the design: water systems, insulation, electricity efficiency, and waste management. The implementation and integration of these four aspects aim to provide homeless people with good living conditions while reducing cost and environmental impact.

Water system

The water system is an important aspect of sustainable housing as people use it every day, and it is necessary to ensure that the water supply is adequate for the 38 residents. In the UK, the average person uses 150 litres of water each day (Ramulongo et al., 2017), thus we assume that 38 people will use approximately 5700 litres each day. Any reduction in this amount will result in monetary savings and reduced environmental impact. Hence, it is important to identify a water treatment or collection system that is both economical and environmentally friendly.

Cost-efficiency is a key requirement of Project Malachi. The water system will be designed to achieve the requirements of being eco-friendly, transportable as well as providing comfortable living conditions while reducing the cost of the project. Therefore, when designing the water system, we will consider cost (reduce), sustainability (reduce consumption), modularity (can be moved after 5 years), and living conditions (smell, noise, space).

Insulation

Insulation is a vital component in maintaining a comfortable living environment. An insulated wall generally consists of two walls with a cavity in between, known as a cavity wall. The insulating material sits within the cavity and reduces unwanted transmission of heat and sound, forming a building envelope which physically separates the conditioned indoor and unconditioned outdoor environment (Sadineni et al., 2011). Insulating materials tend to have low thermal conductivity values (W/(mK)) and are used to form a thin envelope around a building. This results in an insulating layer with low thermal transmittance (W/(m2K)) and high thermal resistance (Jelle, 2011). Increasing the width of an insulating layer leads to lower thermal transmittance but reduces the interior area of the living space – which is important to note when working with relatively small spaces such as shipping containers.

Insulating materials function by decreasing heat transfer via conduction, convection, and radiation, as well as reducing ventilation draughts. Gases have lower thermal conductivity values than solids and liquids because the molecules are spread further apart, hence collide and transfer energy less often (Kondepudi, 2009). Insulating materials take advantage of this by including many tiny gas pockets in their structure, thus reducing convective heat transfer by limiting the flow of air, and conductive heat transfer through incorporation of air in the wall cavity. A thin layer of foil can be included to limit heat transfer via radiation, as a portion of the infrared radiation is reflected by the foil (Pelanne, 1978).

Electricity efficiency

Electricity consumption plays a major part in the sustainability of a building. Electricity is the main source of energy for Project Malachi and therefore it is important to find the best solutions that are both environmentally friendly and economical while providing comfort for residents.

Energy efficiency has been defined as the reduction in the input of electricity to provide a given service for example, lighting by a bulb. Technical changes such as the use of efficient electrical appliances can contribute to reduction in energy consumption; however, consumption can also be reduced through social-behavioural changes of the residents or better organisation, and management of economic condition (Kohler, 2004).

The following factors contribute to the dynamics of electricity consumption: placing, design and construction of the house, efficiency of electric appliances, integration of heating systems, and the behaviour and demographics of residents. Barriers to implementing or improving these are investment costs, low awareness amongst consumers and inconsistent regulations and standards from councils and government (Bodach and Hamhaber, 2010).

Waste management

Waste management also plays a role in the sustainability of a building. Reducing and properly managing waste improves a building's sustainability by reducing its economic and environmental costs (DEFRA, 2012). Waste management is a cross-cutting issue with strong linkages to challenges such as climate change and public health as certain wastes produce harmful pollutants and can lead to infections and respiratory illness. Households in London produce 20 million tonnes of waste per year and the city has the lowest recycling rate in the UK. There is a need to move households towards more sustainable practices where waste is treated as a resource and maximized through re-use and recycling (DEFRA, 2018a). Rates of homelessness are rising, and consequently an increase in the number of shelters is expected. It is therefore important to ensure that feasible options for managing waste are available to these developments which play a critical role in society but are often crippled by limited capacity and resources.

The UK government has implemented the "polluter pays principle" which imposes recycling targets for waste from households (DEFRA, 2019). Managers of social housing developments are therefore pressed to seek cost-effective, simple and efficient ways to meet regulations (Warburton, 2013). Using the by-products of waste to create new resources, behaviour change initiatives and waste re-purposing programs have been highlighted as viable options for low-budget scenarios (Perrot and Subiantoro, 2018; Skoyles, Bulkeley and Askins, 2005). Their feasibility will be explored based on the proposed design and operation of Project Malachi.

Water system

The proposal of last year's students involved potable water treatment, grey water recycling, an aquaponics system and a rainwater harvesting system, however, installation and operation of these systems is costly. Additionally, the water consumption of 38 people (5700 L/day) is low compared to larger apartments. If all the above systems are used, the total cost and payback time would exceed the 5-year lease. Of the options proposed, the most cost-efficient was the grey water treatment system which costs £3000 in total and takes less than 5 years to payback. In order to meet the cost-efficient requirement of the project, the water system will be modified to cut the cost while retaining structural and environmental benefits.

With cost, operability, impact on residents, and recycling in mind, the rainwater harvesting system can be integrated with non-potable uses such as flushing and irrigation. This creates an economical, environmentally friendly, and highly viable system. In the UK, approximately 30% of drinking water supplied to households is used for toilet flushing (Fewkes, 1999), and the rainwater harvesting system can reduce this water consumption.

Rainwater harvesting involves collection and storage of rainwater from surfaces such as roofs and land (Khoury-Nolde, 2019) during rainfall. This is considered a safe supply of water (Villarreal and Dixon, 2005). Land-based and roof-based collection are the two main forms of rainwater harvesting (Khoury-Nolde, 2019). Rooftop rainwater harvesting is suitable for domestic purposes, for its simple maintenance and control. The roof-based rainwater harvesting system has been chosen in this design.

There are three main types of roof-based rainwater collecting systems at present (Innovative Water Solution, 2019):

- Rain barrels

Rain barrels involve installing a barrel (which can be recycled barrels or new commercial rain barrels) at a gutter downspout to collect rainwater, which is the most common and familiar method.

- “Dry” system

The "Dry" system is drained directly to the top of the tank and the collection pipe is dry after each rainy day. It has a larger capacity than rain barrels.

- “Wet” system

The "Wet" system uses collection pipes underground to connect multiple downpipes of different drains in order to transfer rainwater. When the rainwater fills the underground pipeline, the water level will rise, and the rainwater will overflow into the water tank.

(a) (b) (c)

Figure 5: Pictures of three types of rainwater collection (a) Rain barrels (b) “Dry” system (c) “Wet” system (Innovative Water Solution).

After considering the advantages and disadvantages of the three methods summarised in Table 2, we find that the capacity of standard rain barrels is not enough for 38 people. The "wet" system is buried in the ground and cannot be transported after 5 years which violates the requirement of modularity and transportability. Thus the "Dry" system is the most suitable method for its large capacity and cost-effectiveness.

Table 2: Comparison of the pros and cons of the three types of rainwater collection.

	Pros	**Cons**
Rain barrels	• Easily implemented • Barrels are easy to obtain • Barrels do not take up much space that can fit into any situation	• Capacity is only 50 to 100 gallons • Easily overflows and wastes collection opportunities
“Dry” system	• Can store a large amount of rainwater • Can be inexpensive to implement • Easier maintenance for less complicated system	• The storage tank must be located next to the house
“Wet” system	• Collect from the entire surface • The ability to collect from multiple gutters and downspouts • Can be located away from your house	• More expensive to implement • Located underground which is non-transportable • Needs sufficient difference between gutters and tank inlet

In order to derive the capacity of the rainwater harvesting system, the Rainwater Collection Calculation Formulas and Equations provided by Innovative Water Solution (2019) has been used:

*Roof Area (m2) * drainage varies * Precipitation Amount (mm) = Amount Collected (liters)*

Roof Area: According to the design of the students last year, the total roof area is 270m^2.

Drainage: varies from 0.9 on a steep pitched roof, to 0.4 on a flat roof with gravel, 0.7 is used in this design.

Precipitation Amount: The rainwater information was sourced from the Met Office (Data.gov.uk, 2019), which was 60.6 mm in 2018.

The amount to be collected is 11,453 liters. Considering rainwater loss, such as incomplete collection and evaporation, this design will use a 10,000 litre water tank. The cost of a rainwater harvesting system that has been put into commercial production will be relatively low compared to one tailored to a specific size. After comparing products from different manufacturers, Ecosure 10,000 Litre Water Tank (Figure 6. a) (Ecosure, 2019) with a Rain Water Harvesting 3P Volume Filter VF1 (Figure 6. c) is a suitable rainwater collecting device. In order to transport water from the tank to the toilets, a 1100w Evolution X-AJE 80 Steel Pump (Figure 6. b) from Rain Water Harvesting can be used. This pump is automatic, and suitable for toilet flushing (Rain Water Harvesting, 2019a).

(a) (b) (c)

Figure 6: a. Appearance and price of Ecosure Water Tank 10000 Litre (Ecosure, 2019) b. Appearance of 1100w Evolution X-AJE 80 Steel Pump (Rain Water Harvesting, 2019b) c. Appearance of 3P Volume Filter VF1 (Rain Water Harvesting, 2019c).

According to the Met Office Climate data (2019), there were 106.5 days of rainfall per year on average over the past 30 years. If the water tank collects the maximum amount of rainwater every rainfall, it can save about 0.6 million litres of water each year, resulting in savings of approximately £2000/year (United Utilities, 2019). The cost of running the pump is around £520/year (YouGen, 2019), hence it can save £1480/year, resulting in a payback time of 1.5 years.

Conclusion

Having compared the potable water treatment, grey water recycling, aquaponics system and rainwater harvesting system; the rainwater harvesting system is the most suitable. The rainwater harvesting system is inexpensive, has a short payback time (1.5 years), and reduces water consumption thus providing environmental benefit. The equipment is designed to be on land instead of underground, so it can be transported after five years according to the needs of project.

Insulation

The previous year's team carried out a heat load calculation of a shipping container using Passive Design Assistant software. They concluded that adding an insulating layer to the steel walls resulted in significantly lower heat loss, however a detailed comparison of different materials was not carried out. In keeping with project objectives, research on insulation will be aimed at identifying the most cost-effective material. Adequate insulation is very important in shipping container homes due to the high thermal conductivity of standard corten steel (21,000-31,000 mW/mK) (Engineering ToolBox, 2003). Total lack of, or inadequate insulation would result in substantial unwanted heat transfers, consequently increasing electricity consumption to generate heat (Sadineni et al., 2011).

Materials comparison

Several natural and synthetic materials were considered by comparing their thermal conductivity values and cost per metre squared, summarised in Table 3. Commonly used, but more expensive materials such as spray-applied foams and polyurethane (PUR) or polyisocyanurate (PIR) panels were excluded from comparisons based on cost. Environmental impact was also considered, but cost was given priority. The most cost-effective material was expanded polystyrene (EPS) panelling (~35 mW/mK), followed by extruded polystyrene (XPS) panelling (~35 mW/mK) (Jelle, 2011). Though both are obtained from petrochemicals, the reduction in energy consumption is an environmental benefit, which will also reduce the running costs for the shelter.

Table 3: The most applicable insulation materials for Project Malachi. Thermal conductivity values are averages taken from Engineering ToolBox, 2003, Jelle, 2011, Korjenic et al., 2011, Pennacchio et al., 2017. Costs are averages taken from Insulation-info.co.uk, 2018.

Type of insulation	***Cost (£/m^2)***	***Thermal conductivity (mW/mK)***
EPS	10.00	35
XPS	12.50	35
Cellulose	15.00	45
Rock wool	15.25	35
Hemp	15.50	45

Insulating a 6.1x2.9m shipping container with EPS panelling costs approximately £875, not accounting for doors, windows, or other appliances that obstruct the panels. This yields a total material cost of approximately £33,000 for 38 shipping containers. This will substantially improve energy efficiency and comfort while decreasing running costs and energy consumption. The panels will outlast the project and can be recycled at the end of their life at several UK sites (eps.co.uk, 2019). While this is not cost-neutral, adequate insulation of living space is a necessity, and the team concludes that this is the most cost-effective approach.

Heating load calculation

To estimate how much money this would save, a heating load calculation was carried out using Passive Design Assistant (PDA) by ARUP. The heating load of a room represents the amount of heat energy required to maintain the indoor temperature around a set point. This calculation makes several assumptions as an updated design schematic has not been made available, hence should only be referred to as an indicator of the difference between an EPS insulation and no insulation.

The simulated heating load assumes an uninsulated 6.1x2.9m shipping container with 27mm thick steel walls, and no doors, windows, or furnishings, while the insulated container has an additional layer of 12.5mm thick plasterboard wall, and a 50mm cavity filled with EPS panelling on the interior. These measurements were taken from the previous team's work. The simulation assumes a desired internal temperature of 20C, defined as comfortable by the IAQ Rating Index (Riggs, 2015), and takes place in London in December, using the climate data within PDA. Full details of the PDA settings and assumptions can be found in Appendix 1a-c. Statistics were calculated using the programming language R.

Results show that EPS panelling had a significant effect on heating load of the container (mean heating load ± SE (W): steel = 1384 ± 15, insulated = 596 ± 11) (two-sample t-test: t=-41.53, df=43.435, p<0.001, n=48) (Appendix 1d-f).

Using the average UK electricity tariff of 14.33p/kWh (Energy Saving Trust, 2018), this reduction in heating load corresponds to savings of £2.75/day in December when heating a single container with an appropriately rated electric heater for 24 hours. As previously mentioned, this figure is not representative of actual savings – but does demonstrate the substantial reduction in required heating with the addition of EPS panelling insulation.

Conclusion

To conclude, insulation is a vital building service for Project Malachi and will aid in providing a more comfortable living environment and reducing energy expenditure on heating, making the construction more electricity efficient. Our research suggests that EPS panelling is the most cost-effective insulator. While EPS is made from petrochemicals, unlike alternatives such as wool or hemp; it carries a lower cost, offers environmental benefit in terms of reduced electricity consumption, and can be recycled at the end of the project's life.

Electricity efficiency

Considering the literature review, the solutions chosen for Project Malachi are training and constant interactive feedback for a higher awareness of environmental problems; choosing the best balance between energy efficiency and price for electric appliances; applying to a utility company that offers time-of-use rates and 'green' electricity (sourced from renewable energy); and installing a household battery to accommodate the utilities requirements.

Offering training and feedback for a complete environmental attitude

As future residents and staff may not have had prior exposure to sustainable housing, training will be provided to familiarise them with the endeavours and technologies they will be exposed to.

Feedback is necessary to inform future developments of this project as the contribution of environmental attitudes to sustainable housing has not been studied before. The most relevant studies such as Brandon and Lewis (1999) have shown that energy conservation can be encouraged through feedback on consumption. Armel et al. (2012) and Fischer (2008) have shown that the most effective feedback is frequent, takes place over a long period, includes a breakdown for specific appliances, is clear with an appealing presentation, and involves interactive tools that provide future recommendations. Armel et al. (2012) suggests that consumption feedback can result in reductions of over 12% in domestic energy consumption (Figure 7). Utility companies often provide a smart meter, at request. The provider chosen for Project Malachi offers a smart meter at the start of the contract, and we recommend that each individual occupant receives one.

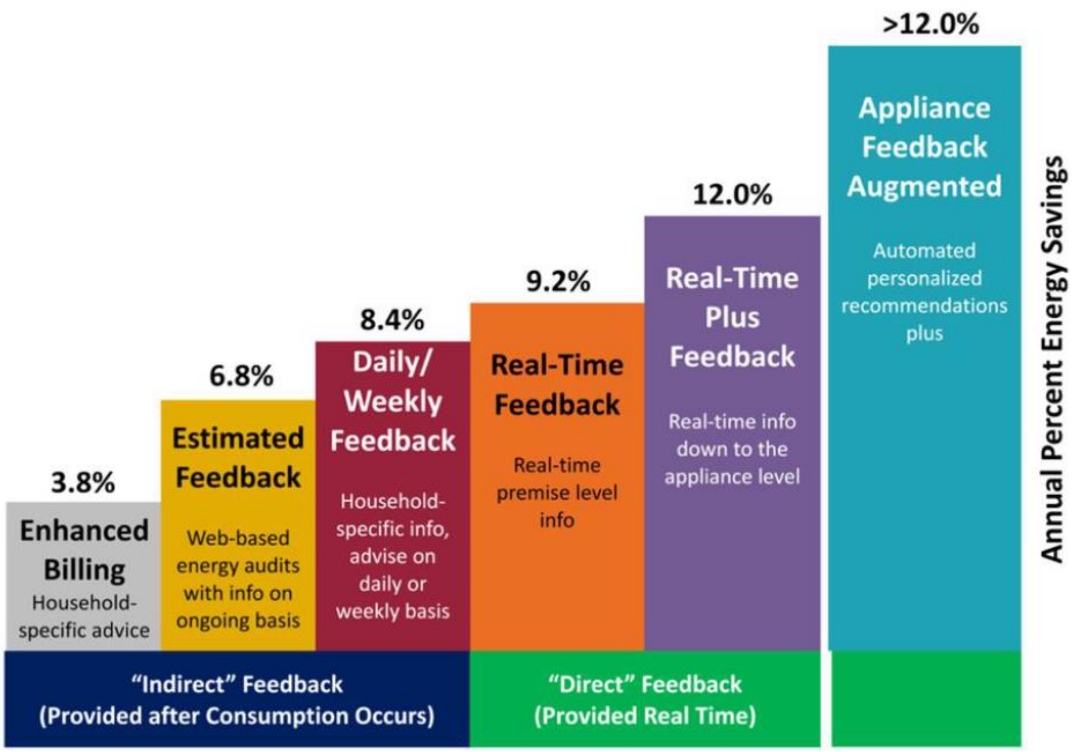

Figure 7: Residential saving percentage due to energy consumption feedback (Armel et al., 2012).

Feedback provided to residents has to be simple and clear – therefore a negotiation with the future provider over the type of smart meters is recommended. During the training the residents will learn how to read the smart meters and be informed on how they can reduce their consumption. However, ethical considerations must be made to ensure that the residents are not participating in an experiment, rather that they are given the opportunity to give back to The Salvation Army.

Questionnaires regarding environmental attitudes are useful in reducing electricity consumption (Kaiser et al., 2007). In order to monitor the experience and the consumption of the residents of Project Malachi, three short questionnaires have been created: a training feedback provided upon their arrival to the shelter, an interim questionnaire halfway through their residency, and a final questionnaire at the end of stay. The questionnaire will also capture feedback on their attitude towards waste management. These can be found in Appendix 3.

Electrical appliances

Electrical appliances are one of the most significant contributors to domestic energy consumption. They account for over 50% of total domestic energy consumption (DOE, 2018). Using eco-friendly electrical appliances has been shown to reduce electricity consumption by ~11% (Intertek, 2012). Considering that households constitute 17% of carbon emissions (Nejat et al, 2014), it is vital to make positive changes by replacing old equipment with newer eco-friendly models. This will aid in achieving future government targets of cutting emissions by at least 80% of 1990 levels (Committee on Climate Change, 2015).

The distribution of electricity use in British households can be seen in Figure 8.

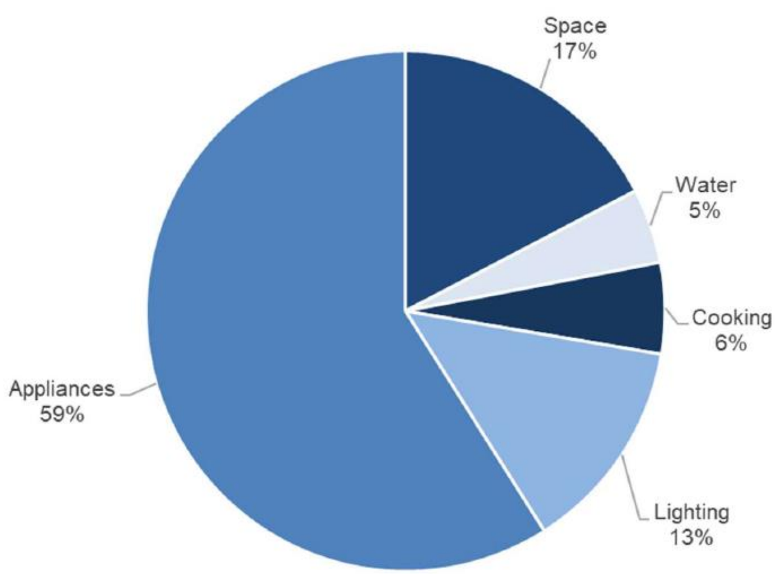

Figure 8: Domestic electricity consumption division by end-use. (DOE, 2018).

A report issued by Intertek (2012), has shown that energy savings in the United Kingdom are obtained through different methods such as: replacing all cold appliances with class A+ and A++ equipment, replacing incandescent and halogen light bulbs with CFL and LEDs, changing washing machines for more efficient alternatives and reducing standby power for televisions and computers (Intertek, 2012). The annual energy savings are shown in Table 4.

Table 4: Potential average savings by type of appliance (Intertek, 2012).

Appliance	Average annual saving (kWh)
Fridge-freezer	271
Lighting	58
Washing machine	9
Television	100
Computer	117

To find the best suitable electric appliances for Project Malachi, options for each appliance have been proposed considering the kW (kilo-Watt) consumption, energy efficiency and cost. As the project is still developing and the type and number of appliances has not been confirmed, the following assumptions have been made:

- Type of electric appliances
- Number of electric appliances

The catalogue for electric appliances can be found in Appendix 4. Calculations for electric usage can be found in Appendix 5.

1. Electric shower (each unit)

Generally, electric showers consume between 7 kW and 10.5 kW (Expert Reviews, 2018a). They are quick and easy to install, and considered 99.7% energy efficient (Triton Showers, 2019). A higher voltage could achieve higher pressure and give a better flow performance but demands higher energy consumption. Electric showers have become more popular and as Project Malachi will use electricity as its main source of heating, the showers will draw on a cold water supply with electricity heating the water on demand. The best option has been found to be Triton Seville of a rating of 7.5kW with the price of £70, with an assumed use of 10 mins/day/unit.

2. Mini fridge (each unit)

Fridges have a wide electricity use range, depending on size and efficiency. According to OVO Energy (2019a), the range averages from 162 kWh/year for a fridge to 427 kWh/year for a fridge freezer. The most appropriate type of fridge for Project Malachi would be an individual mini fridge with freezer for each room. The range of electricity usage for the products proposed is from 117 kWh to 188 kWh, low on the average range. The most suitable option is the Liebherr IKS1614 with an annual consumption of 148 kWh and a cost of £299. It has an energy efficiency of 85%.

3.	Washing machine (laundry room)
In the UK the average annual electricity use of washing machines is 166 kWh/year (OVO energy, 2019a). This depends on the amount of cycles used and the average cycle clock. As Project Malachi has a laundry room instead of individual washing machines, three machines will suffice based on the level of occupancy. The most suitable option is a Logik L814WM16, costing £199, and achieving 79% energy efficiency. The electricity usage range for the chosen products is 162.5 kWh/year in total.	

4.	Hob & Oven (each unit)
Electric cookers are generally quite efficient, but have a very high electricity consumption (Houzz, 2015), as remarked in Appendix 4. Therefore, the products proposed are dual-fuelled. The anaerobic digester proposed will produce biogas that can be fed into the hob and oven in the 38 units. The amount of biogas provided by the proposed digester is: 2 m^3/week and therefore each room will be provided with 0.05 m^3/day, which is sufficient for cooking. The most suitable choice is a Newworld NW601DFDOL cooker with an A rating, an energy consumption of 1.46 kWh and a cost of £400. We estimate that the cookers will be used for 30 mins/day/unit. If an electric hob and oven are preferable; we recommend the Miele option given in the catalogue in Appendix 4.	

5.	Computer (office)
Intertek (2012) has shown that laptops are more energy efficient than desktop computers due to their battery dependency. However, due to the fact the building has an office, the computers proposed are desktops. They use roughly 150 kWh/year (OVO Energy, 2019a). The choices are only the desktop computers, with a high energy efficiency and the best option is the HP 260 G2 Mini Desktop, with an energy efficiency of 99% and a cost of £430.	

6.	TVs (common room)
The electricity consumption of a TV depends heavily on the amount of use. LED technology has decreased TV electricity consumption drastically; from approximately 600 kWh to 200 kWh (OVO Energy, 2019a). Two TVs are being proposed for the possible common room for the residents. They can be 100% energy efficient, with the most suitable option being the Linsar 24LED1700 with an annual consumption of 27 kWh and a cost of £179.	

7.	Light bulbs (each room)
There are four main types of light bulbs: standard, halogen, CFL and LED (OVO Energy, 2019b). Halogen light bulbs have been banned in United Kingdom and standard ones are obsolete. Therefore, the types of light bulbs proposed for Project Malachi are either CFL or LED. We recommend LED light bulbs due to their high efficiency - 90% energy reduction per bulb compared to halogen bulbs (OVO Energy, 2019b). They are slightly more expensive (20%), however their efficiency makes them last much longer than the CFL bulb. Therefore, with the assumption each unit has two light bulbs and that each is used for 4 hours per day, the energy consumption has been calculated in Appendix 5.	

8.		Electric boiler (each unit)
The heating load has been calculated as approximately 600W per residential unit. The electric boiler proposed should accommodate this need. Therefore, the choices of boilers are between 2 to 5 kWh. Electric boilers are generally more costly due to the price difference between electricity - 14.33p/kWh (Energy Saving Trust, 2018) and gas – 3.63p/kWh (Energy Saving Trust, 2018). However, Project Malachi will not have a gas connection. The electric boiler chosen is a Trianco Inca of an energy rating of 2 kW and a cost of £372.		

9.		Others
Other equipment and appliances to be used in Project Malachi include; lamps, kettles, electrical equipment for the ReCycles workshop, sensors for the anaerobic digester and water pump for the rainwater harvesting system. We assume, based on an average consumption (OVO Energy, 2019a), that an amount of 0.5 kWh/day would cover their electricity usage.		

Utilities and Time-of-Use/Economic 7 and 10 rates

Electricity utility companies have different offers in order to meet the needs of the client to reduce consumption. These include feed in tariffs, time of use and Economic 7 and 10. The most applicable to Project Malachi are time of use and economic rates. With both offers, lower rates are paid if electricity is consumed during off-peak hours. Yohanis et al. (2008) suggests there is a significant impact on the network capacity during peak hours (16:00-20:00) (Figure 9). Therefore, using electricity during off-peak hours saves Project Malachi money and contributes to sustainability.

The Economy 7 and Economy 10 schemes are well known in the United Kingdom. These offer two different prices for different times: Economy 7 has 7 hours during the night when the price of electricity is lower, while Economy 10 has 10 hours. Economy 7 is offered by most suppliers, and Economy 10 is offered by certain suppliers (Economy 10, 2019).

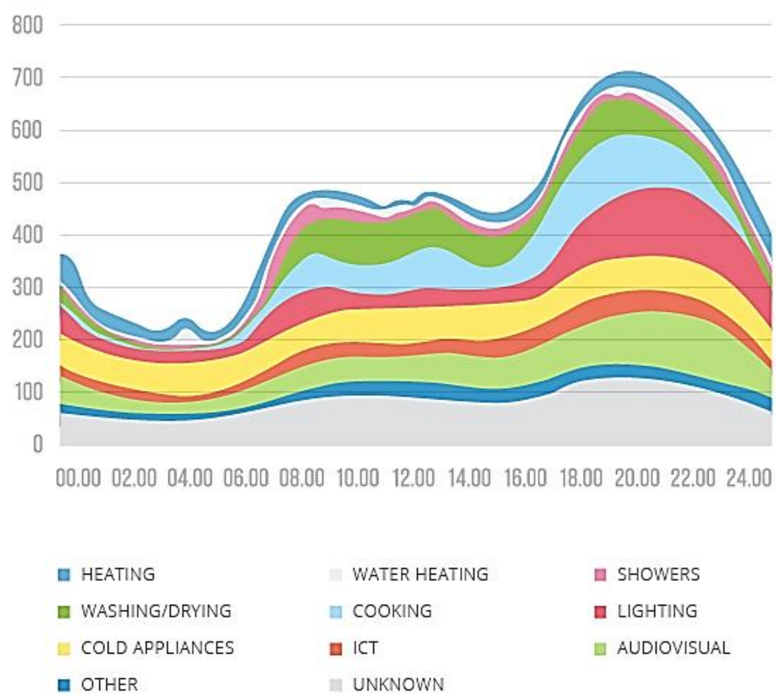

Figure 9: Average 24-hour electricity use profile for a typical UK home and the end-use products (Watts) (OVO Energy, 2019a).

Time-of-use rates offer a more thorough breakdown of the hours with cheaper tariffs. This is popular in the United States, however in the United Kingdom there is only one utility company (Green Energy) that offers this through the programme called TIDE (Green Energy, 2019). Their tariffs are shown Figure 10. These offers are particularly beneficial to households that use electric heating, electric car charging, or energy storage (Citizens Advice, 2017). This offers a potential saving of £272 million for the United Kingdom electricity sector (Citizens Advice, 2017).

TIDE 2020 — Fixed Until 31st March 2020 No Exit Fees

Electricity (including VAT)	
Daily Fixed Charge	29.70p
WEEKDAY	
00:00 – 07:00 unit/kWh	7.91p
07:00 – 16:00 unit/kWh	16.27p
16:00 – 20:00 unit/kWh	32.55p
20:00 – 00:00 unit/kWh	16.27p
WEEKEND	
00:00 – 07:00 unit/kWh	7.91p
07:00 – 00:00 unit/kWh	16.27p

Figure 10: Green Energy - TIDE 2020 tariffs depending on hour (Green Energy, 2019).

Also, Green Energy offers 100% renewable energy sourced electricity, which decreases the net CO^2 emissions Project Malachi would be responsible for.

Using normal rates of 14.33 pence/kWh (Energy Saving Trust, 2018), the total daily expenditure for the building would be 14.33 p/kWh x 479.44 kWh = £68.7/day, resulting in a total of £25,094/year. However, if using TIDE rates in combination with energy storage, being charged the lowest rate, the annual cost of electricity would be a maximum of £13,852.

Household battery

Demand smoothing is a process through which consumers can store electricity during non-peak demand hours and discharge during peak demand hours (Purvins et al., 2002). The technical advantages of this process are decreased peak demand, a more stable grid (Aneke and Wang, 2016), increased energy security (Purvins et al., 2002), conservation of fossil fuel resources and reduced environmental impact of energy generation (Aneke and Wang, 2016), while decreasing 30-45% the initial demand profile (Purvins et al. 2002).

The options suitable for Project Malachi are purchasing multiple small batteries to accommodate the peak hour demand, or one high capacity battery. There are currently multiple types of batteries on the market that can accommodate a range of demands. Usually a tenth of the normal consumption is chosen for the capacity of the battery in order to accommodate a minimum demand for the peak hours. The capacity needed for Project Malachi is one tenth of the maximum energy demand, which is approximately 500kWh (calculated in Appendix 5).

Reliability is important in choosing batteries hence we recommend multiple batteries to prevent a single failure from forcing the building to draw from the grid. The decision process and the types of batteries chosen to accommodate the energy need can be found in Appendix 6.

Investing in a household battery can reduce energy consumption, however the initial cost can be significant. For example, for 3 Tesla Powerwalls, the customer will have to pay £20,300 with the installation costs which can be up to £3000 (Tesla, 2019). An ElectrIQ battery costs £6750, and the YIY battery of 50 kWh costs £8800. However, the most accurate prices can be obtained by contacting the companies and asking for a quote.

The best option with the information available is three Tesla Powerwalls mounted together inside the building where the temperature is maintained at a normal level. Considering the high initial cost of this, it is taken as an optional solution and possible investment. Calculated in the previous section, the savings with energy storage are of approximately £11,000, therefore the payback time is ~2.2 years.

Other considerations

As the batteries should be able to provide the electricity needed during the peak hours, there is the possibility of installing an Electric-Vehicle charge point and charging customers a small fee when they refill. Additionally, instant electric taps could be installed instead of kettles as a more sustainable choice.

Conclusion

Electricity is a very important tool in the running of Project Malachi. Solutions to decrease the electricity consumption and price of running appliances, as well as helping to stabilize the grid and consume 'green' electricity have been proposed. Multiple choices have been offered for each solution to allow flexibility, however the best combination of cost-effective and energy-efficient are highlighted throughout. We also recommend training programmes and feedback to inform the residents on sustainability, with hopes of reducing their consumption. The biggest investment would be the battery, however it is possible for it to become a source of income.

Waste Management

Background

Waste management is the collection, transportation, recycling, disposal and monitoring of waste (Cheyne, 2002). Traditional waste management focuses on transportation, and disposal by landfilling and incineration, however this has severe consequences. Decomposition of waste in landfills produces leachate which pollutes soil and water and generates methane which contributes significantly to the greenhouse effect. Incineration produces toxic substances causing air pollution and acid rain (DEFRA, 2013). Storage of non-biodegradable waste is costly as landfill space in urban areas is limited, and energy prices make transportation and incineration expensive. Projects such as Malachi are burdened by this cost which is passed on by municipalities through taxation. Traditional waste management is not environmentally or financially sustainable. Prevention of waste is therefore paramount, and where waste is inevitable the focus should be on more sustainable waste management practices such as recycling (Environment Agency, 2011).

Food is anticipated to constitute 55% of the total waste generated from Project Malachi and will therefore be targeted. This reflects the typical constitution of household waste in London (DEFRA, 2018). The Borough of Redbridge has set a target to recycle 50% of household waste by 2020 (Borough of Redbridge, 2013) and targeting food waste provides the opportunity to be compliant with the directive. Paper and plastics which each constitute 12% of typical household waste will also be addressed.

Feasibility Assessment

The objectives of the project target three areas: cost (including maintenance), eco-friendliness and overall resource efficiency. The waste management hierarchy (Figure 11), the UKs guide for sustainable waste management has been used to base the fesibility assessment conducted in Appendix 7, and the main findings have been detailed below.

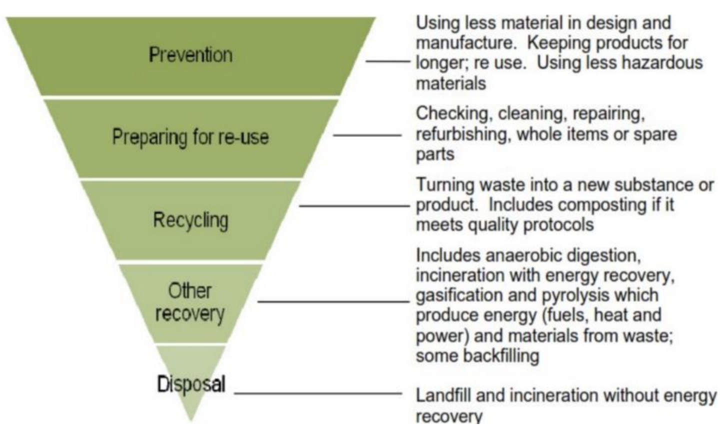

Figure 11: Waste Management Hierarchy from most to least desirable (European Commission, 2012)

Prevention

A lifestyle/behaviour change program is the most economical and effective option. The program, linked to energy efficiency, will include an ongoing questionnaire (Appendix 3), and easy to read signs about preventing waste e.g. discouraging single use plastics (waste), unplugging appliances when not in use (energy) and not running taps continually during showers (water) (Appendix 8).

Preparing for re-use and recycling

The option which integrates seamlessly with the running of the shelter is tapping into the municipal recycling program. The Redbridge Council provides coloured bins for separating garbage and recycling collection free of cost. Residents will be briefed on simple measures to prepare waste to increase the quantity that can be recycled (Appendix 9). The second most feasible option, creating products for resale, has high logistic requirements and relies on markets which cannot be guaranteed.

Food waste compliments the solution determined most feasible for energy recovery and will be addressed in the next section.

Other recovery

Incineration, gasification and pyrolysis are very expensive. Anaerobic digestion is scalable and cost benefits are increasing as more digesters are being developed for small-scale urban applications. The process is also an established and reliable method for energy recovery and transforms food waste into value-added resources.

Disposal

Municipal bins and collection services are recommended.

<u>Anaerobic Digestion</u>

Anaerobic Digestion (AD) is the process by which microorganisms break down organic matter in the absence of oxygen to produce biogas (a renewable energy source) and bio-fertiliser using an anaerobic digester (Polprasert, 1996) as illustrated below:

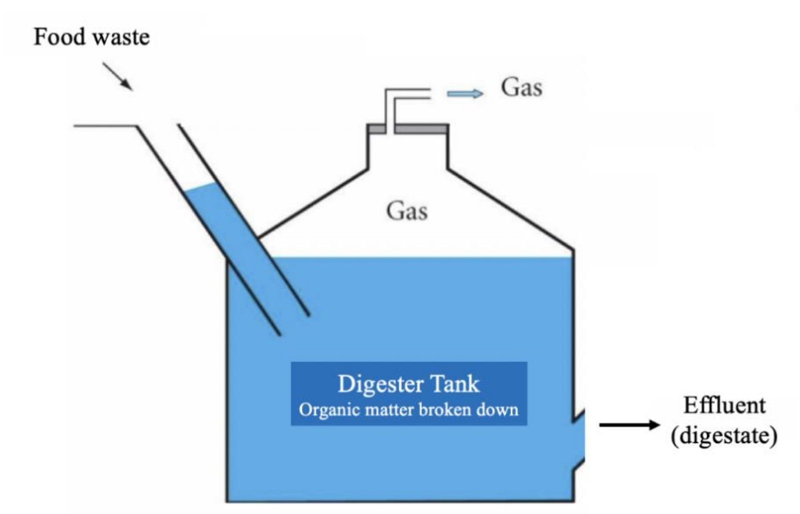

Figure 12: Generalised scheme of anaerobic digestion (Environmental and Energy Study Institute, 2017)

Strategies to increase its feasibility for Project Malachi are as follows:

Table 5: Strategies for advantages and disadvantages of anaerobic digestion for Project Malachi (Polprasert, 1996; Kindred Association, 1994; Lund, 2000).

Advantages	Disadvantages	Strategy
Biogas is a renewable form of energy with a low carbon footprint and can be stored at ambient temperatures	Biogas has an unpleasant smell	Sensitize residents about the smell, use biogas scrubber to reduce smell
Biogas increases energy savings and attracts feed in tariffs	The gas can feed directly into gas-run appliances but needs additional equipment to convert the gas to electricity for electrical appliances.	Make biogas storage tank 1.5 times larger to keep it compact but increase storage area to maximize its use for gas stoves.
Anaerobic digestion is a widely applicable renewable energy technology	Functions best in warm climates. Heating the digester in colder climates may be costly	Place digester in an already insulated closed space
Digestate is a rich fertiliser which can be used onsite and has identified resale markets. Pathogen inactivation in digestate achieved by anaerobic digestion	Digestate is difficult to handle and heavy.	Design digestate tank modularly so ease of moving and pouring is increased. Low cost monitoring system to ensure digestate is safe/pathogen free
Diverts organic waste from landfill	Organic waste stored onsite needs additional precautions in place for handling potentially hazardous waste	Use bins and buckets that require limited human contact with waste (e.g. small, sealable covers, handle for pouring). Implement basic safety protocol (debriefing, gloves)
Rise in small-scale anaerobic digestion makes application in urban settings more cost-effective	Small scale digesters are not as widely used as medium to large scale and the technology still has some ways to go to optimize cost-effectiveness	Use a wide selection of case studies and adapt most cost-effective method of implementation
The process of anaerobic digestion is relatively self-automated	Need to maintain a constant feedstock and good operating conditions to avoid failures or shortcomings in biogas and digestate	Marks and Spencer who is already a partner can supplement feedstock from their waste if needed. Employ use of low-cost online monitoring technology.

Achinas and Euverink (2017) found that a tonne of food waste can produce approximately 110 m^3 of biogas (equivalent to 220 kWh electricity) and 0.9 tonnes of digestate. WRAP, 2013 estimates that a studio flat produces 1kg (0.001 tonnes) of food waste per week. Assuming full occupancy throughout the year for 8 hours per day as the shelter will operate at night, it is estimated that the 38 units will produce 19kg (0.019 tonnes) per week. This equates to $2m^3$ biogas, 4kwh electricity and 17kg (0.017 tonnes) of digestate. At this scale much profit cannot be made from renewable heat incentive and recycling credits which are £0.04 per kwh and £70 per tonne respectively however, the gas is compatible with the hob ovens proposed in the energy efficiency section which requires 1.46kwh. Digestate, which costs approximately £1 per kilogram can be sold to project partner Redbridge Borough to garden neighbourhood parks, to the community or be used to develop a crop farming program for the project.

Case studies

The Calthorpe Project, a non-profit community garden and café uses a custom built anaerobic digestor. The main components are a $2m^3$ digester tank, $1m^3$ biogas tank, $0.46m^3$ digestate tank, automated mixer, boiler and online data logging system. For Project Malachi variations to these components will be used with a $1m^3$ digester tank chosen based on a proration from social housing projects (Appendix 10). The cost of the Calthorpe digester was higher than expected due to an expensive control system and boiler (Walker et al., 2017). Since the digester was built, lower cost technologies have become available which will be taken advantage of for Malachi (Appendix 11). At this scale, a manual mixer can be substituted for the automated one and the digester will be housed indoors so passive heating can be used. Anaerobic digestors with the same components are also used for similar applications in Camley Street Natural Park, Alara Wholefoods and Loop Recycling Limited. Based on these projects, WRAP, 2013 has developed a price index where a $1m^3$ system costs approximately £6,000 (Appendix 12). If biogas production is optimal over the period, energy savings from using biogas for cooking could make the digester cost-neutral over five years. Methanogen, a company that custom builds digesters is recommended. Anaerobic digestors sold commercially were also examined as they offer ready-made solutions which could increase feasibility. The most suitable is the Home Biogas Digester which costs £550 but it requires added insulation which may be difficult to retrofit (Appendix 13). Shipping container anaerobic digestors exist but are expensive at £20-30,000 (SEAB Energy, 2014). The adaptation of shipping containers using smaller equipment will be explored.

Process and design

The biochemical reactions which occur in a biodigester are illustrated below:

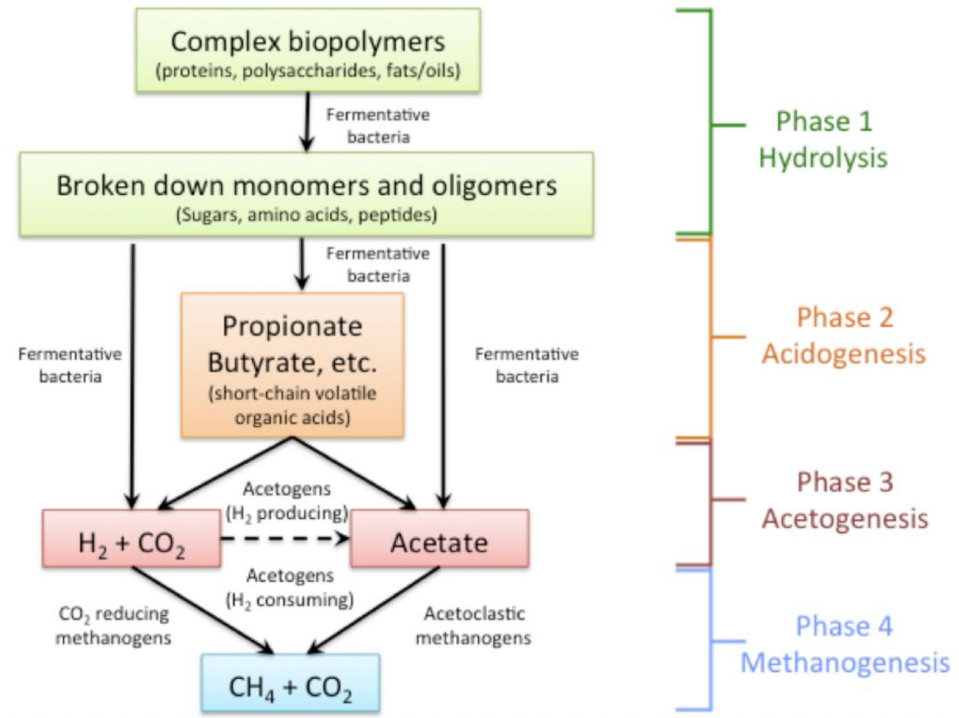

Figure 13: Anaerobic Digestion Biochemical Process (Penn State University, 2019)

Factors affecting the process and how they will be addressed are as follows:

Micro-organisms – Hydrolysis is slowed by foods high in cellulose. This in turns slows down the overall operation of the digester. Foods conducive to the optimum operation of the digester will be suggested in the section on sorting. The growth of acidogenic and acetogenic bacteria are sensitive to pressure above 0.0001 atmosphere which minimises the production of acetate (McInerney and Bryant, 1981). About 70% of methane (CH_4) is formed as a direct by product of this process and researchers recommend monitoring pressure using an electronic instrument (Mosey, 1983). This will be done for Project Malachi. Methanogenic bacteria growth is inhibited by even small amounts of oxygen thus, it is essential that anaerobic conditions are maintained by limiting oxygen entering the digester. The mechanism for feeding the digester will be developed to limit oxygen.

PH - The ideal operational range is pH 6.6-7.2. While hydrolytic and acetogenic bacteria can tolerate a PH as low as 5.5, the methanogenic bacteria are inhibited at low PH values. Sensors are the most effective measure for monitoring PH in a digester (Capri and Marais, 1975).

Temperature - Temperatures in Ilford range from 1-18°C throughout the year. Rates of anaerobic digestion are highest at 50-65°C, decreasing as temperature drops. At 10-15°C gas production decreases drastically. Maintaining temperatures of 35+°C would require substantial energy which is costly. As such, a temperature range of 25-30°C is optimal for colder climates and insulation can increase temperature in the digester 5-10°C higher than the ambient temperature (Kim, Kim and Yun, 2017). Based on the analysis in the insulation section, a temperature of 20°C will be maintained indoors and as such insulation will be used to maintain 30°C.

Retention Time – This is the average time the feedstock should remain in the digester. Incorrect retention time results in excessive volatile fatty acid production which will decrease PH and adversely affect microorganisms. Based on an operating temperature of 30°C and digester volume of 1m^3, a retention time of 15-20 days is recommended (Mir, Hussain and Verma, 2016).

Feedstock- To guarantee normal biogas production, it is important to consider the carbon to nitrogen (C/N) ratio of food. Bacteria use up C 25-30 times faster than they use N. Therefore, the ideal ratio of C/N is 25-30/1 (Polprasert, 1996). Foods conducive to the optimum operation of the digester will be suggested in the section on sorting.

Loading Rate - The anticipated 19kg food waste per week which breaks down to a loading rate of 2kg per day has been found suitable for a 1m^3 digester.

Based on the analysis conducted, the following solutions are being proposed:

1. Custom built digester by Methanogen (with possible maintenance support from Calthorpe project and UCL Energy centre)- approximately £6000 (Figure 14)
2. Pre-packaged digester - £550 (Appendix 13)

a. 1m3 digester tank
b. Manual mixer
c. 1m3 pre-digestion tank with manual chopper (larger than case study to maximise holding, limiting storage time for waste outside system, conical to limit oxygen entering
d. Manual pre-feed weight set to release 2kg/day
e. Removable 1m3 digestate tank. Slides out of compartment with pouring nozzle for easy handling
f. Biogas pipe with gas scrubber to reduce smell of biogas
g. 2m3 biogas tank
h. Digestate gravity overflow feed so no pump needed
i. Food sorting bins

*all tanks lined with 50mm EPS

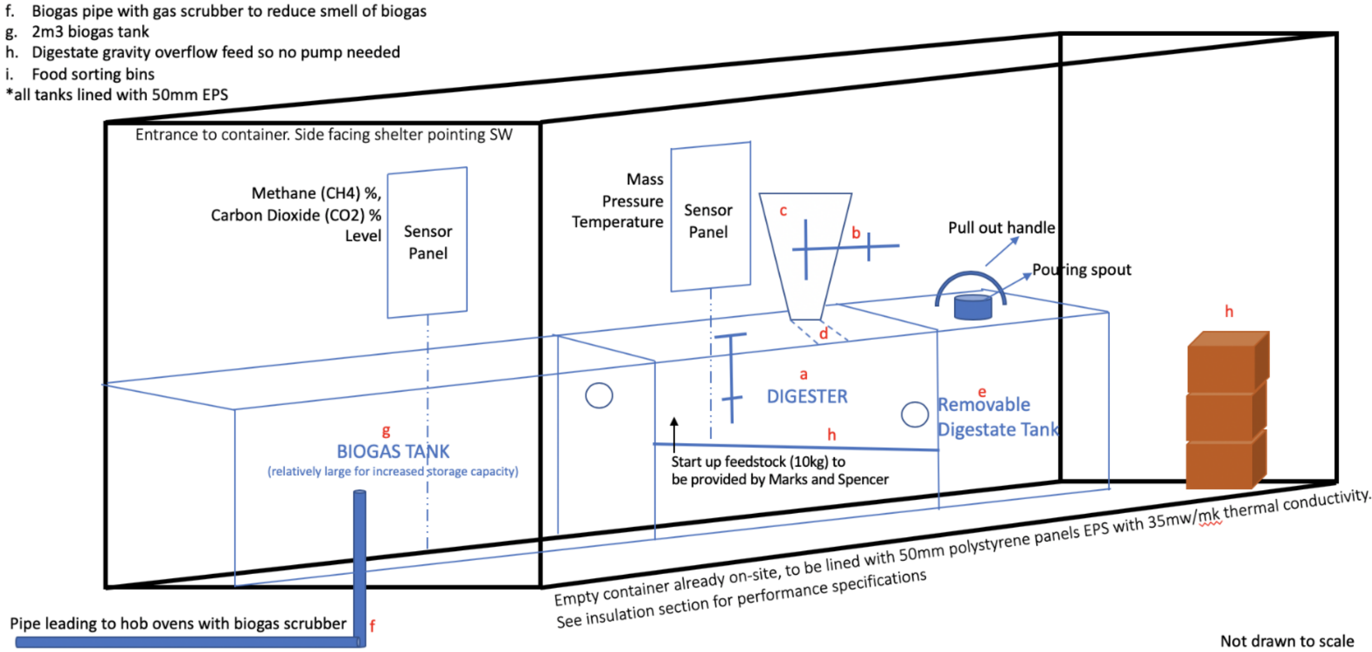

Figure 14: Schematic design for custom built anaerobic digester.

Sorting

Sorting waste is an important step for optimal digester performance. Figure 15 below shows how biogas yield is affected by feedstock (Figure 15).

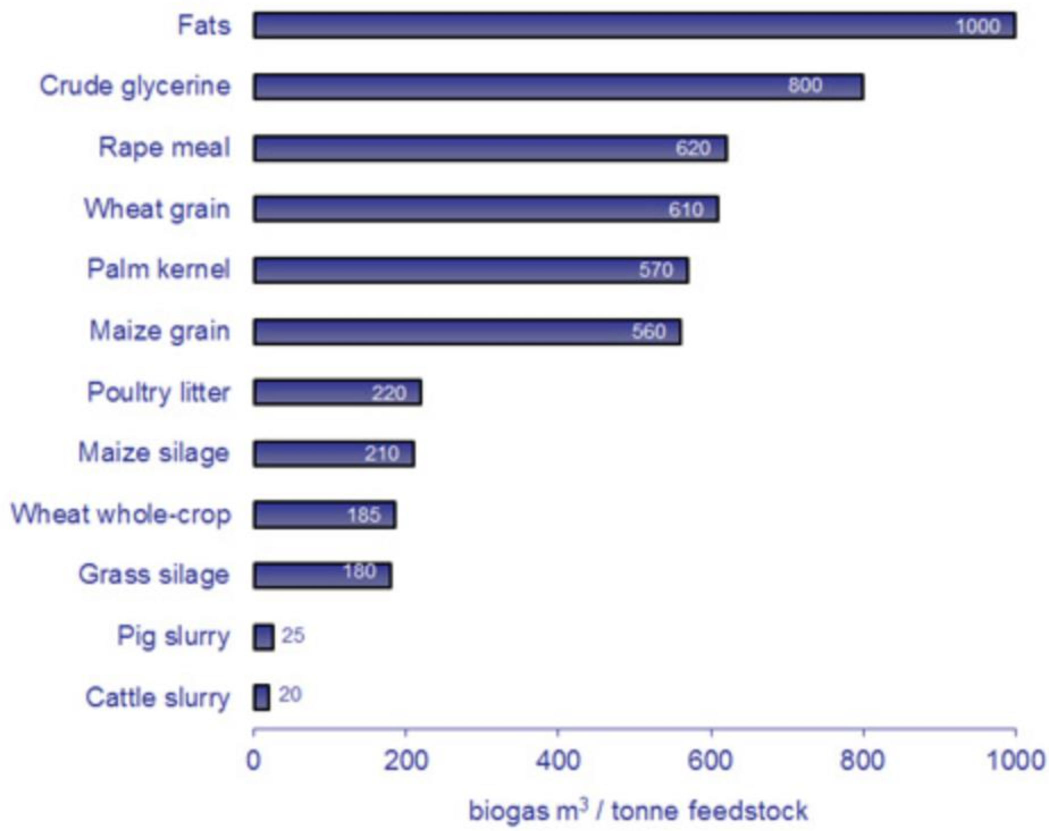

Figure 15: Typical biogas yield of various feedstock (abstracted from Penn State University, 2019)

Additionally foods like plants, meat, dairy and breads decompose readily while bones and shells will take a long time to break down and should be avoided. To guide staff and residents, a sorting guide has been developed (Appendix 14).

Conclusion

Waste management is an essential consideration if Project Malachi is to be considered environmentally friendly. The most feasible solutions for the project are:

- Prevention: lifestyle and behaviour program
- Preparation for re-use and recycling: Municipal recycling program
- Energy recovery: Anaerobic digestion
- Disposal: Municipal system

The feasibility of anaerobic digestion has been enhanced by proposing strengthened partnerships with Redbridge Municipality and Marks and Spencer, new partnerships with Calthorpe Project and UCL energy, and design considerations that are cost effective and easy to maintain.

Systems integration

A systems approach has been used to develop the collaborative proposals for Project Malachi. To this end, a situational analysis was conducted. From this, key stakeholders and elements such as environmental conditions and utilities which will affect the project and most importantly have high cost implications were identified. Proposals were then developed to address these areas based on their positive impact on the environmental friendliness and feasibility. Figure 16 shows the system view of Project Malachi and how the proposals work within the overall system in which the project will operate to achieve the stated objectives. The arrows show relationship between variables and lead from cause to effect.

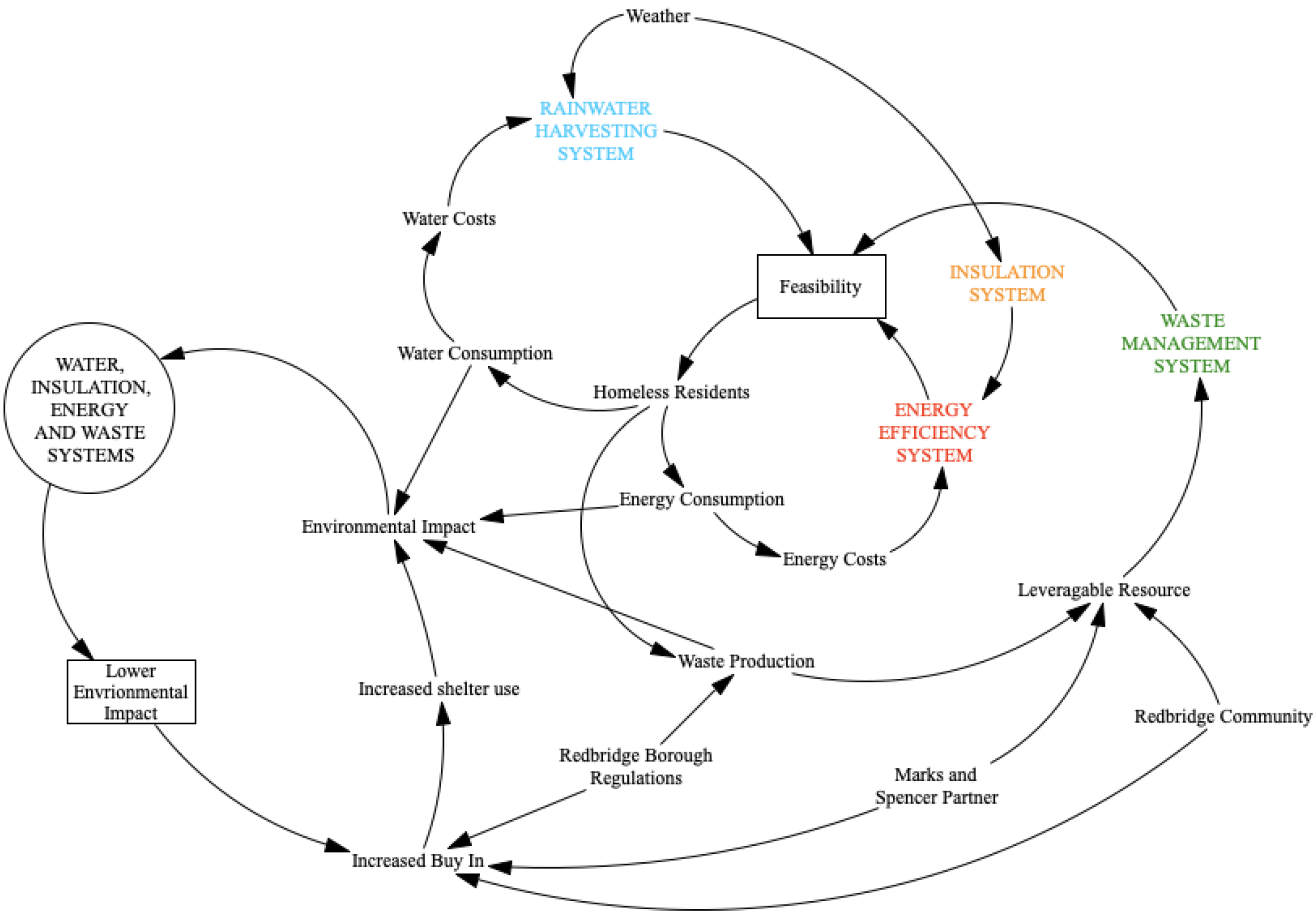

Figure 16: System Diagram showing interaction of proposed systems with context.

Efficient and seamless integration of the proposed systems with each other and with the infrastructure that will be built by the contractors is essential especially given the cost and time constraints of the project. Within Project Malachi's physical system, Figures 17a-b show each proposal, their specifications and how they work together to increase the benefits of partner systems.

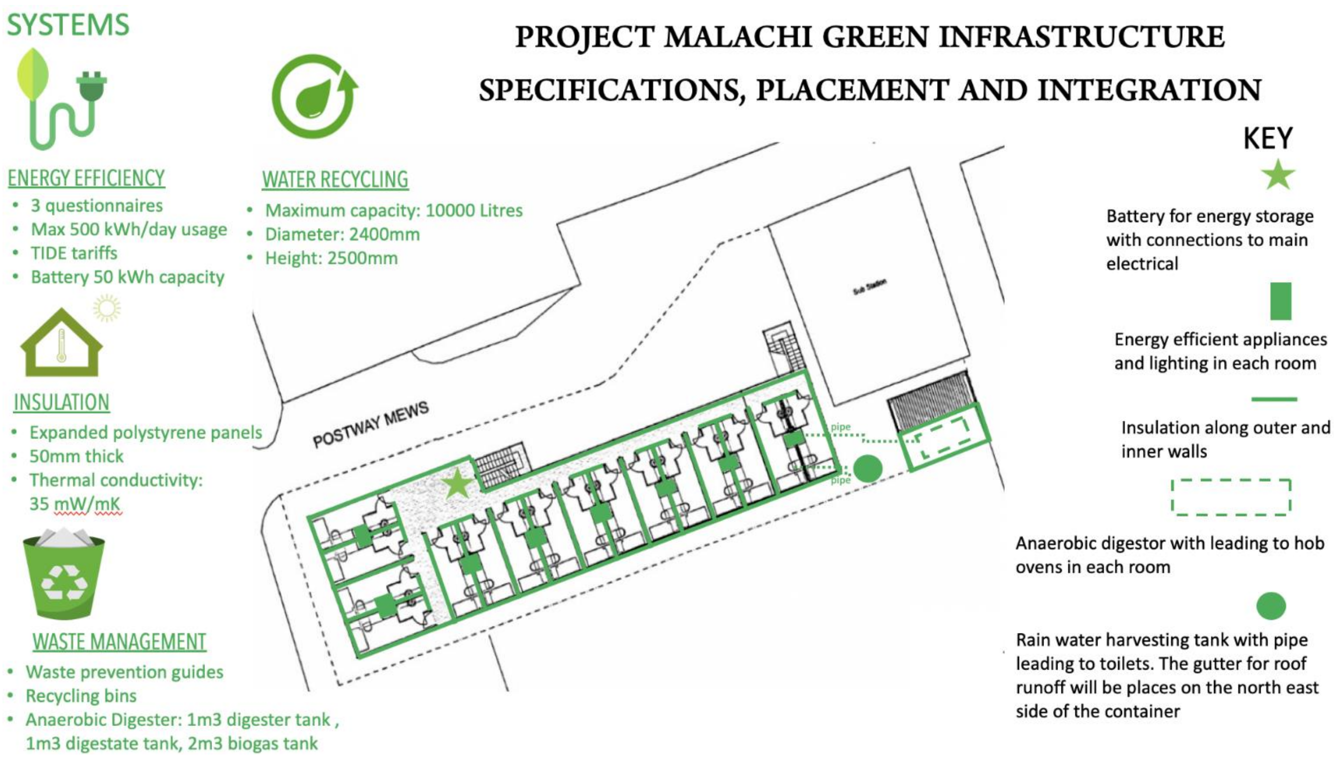

Figure 17a: Placement and integration of systems within Project Malachi.

- **Insulation - Expanded polystyrene (EPS) panel insulation substantially decreases heat loss in colder seasons, and heat gain in warmer seasons**

maintains ambient temperature of 20°C for anaerobic digestor
minimizes heat needs increasing energy efficiency

- **Water harvesting – Storage tank reduces water bill and increases efficiency of water use prioritizing fresh water for drinking and cooking and grey water for flushing**

Excess used for anaerobic digestor feed
Water pump needs electricity to function which is balanced out by energy savings from efficient appliances and battery

- **Waste Management – Recycling bins improves eco friendliness, complies with municipal standards and anaerobic digester produces renewable energy and fertilizer for resale or onsite use**

Biogas from anaerobic digestor used for hob ovens selected for energy efficiency

- **Energy efficiency– Provides best cost/highest efficiency solutions and energy storage to to take advantage of peak tariffs**

50kwh battery supports water pumps and heating device if weather drops below anticipated minimum which was used to determine insulation for the anaerobic digester

- **Container and Infrastructure– Provides the basic physical components for quality standard of living**

Insulation analyzed to provide best performance and cost
Pipe connections for rain water harvesting and anaerobic digestion surface, easy to install, cheap pvc pipes

*Behavior training and questionnaire integrates water, energy (consumption) and waste (production)

Figure 17b: System specifications for Project Malachi

Recommendations

Water system
Due to the irregular intervals between rainfall, there will not always be water in the tank. Regulators are needed to apportion use of water from the tank, and the water from the mains, which poses another cost. Additionally, drainage varies in the equation used to calculate capacity depending on the surface material of the roof. It is not possible to determine the roof condition at this stage, so the value is not certain, and the result will be slightly different.

Insulation
Access to the updated schematic for the containers would have aided in providing a more accurate heating load calculation, which could be applied to the entire building. This would enable future teams to more accurately assess how much heating is required to maintain the desired internal temperature.

Electricity efficiency
The breakdown of the budget and the actual list of appliances to be used for the units would have made the calculations more accurate. 'Chasing' the companies that make the products suggested would also have been useful, in order to get discounts and better quotes for the items.

Waste Management
A site visit to the anaerobic digestor at the Calthorpe project was made however, more site visits to see other designs in person could have improved the design of the digester. Additionally, a simulation of the digestor could have been undertaken, however due to time and capacity constraints, this was not possible. A small digester has been proposed due to cost and logistics constraints, but the project could yield greater cost benefit from a larger digester. Scaling up can be discussed with the proposed contractor Methanogen.

Future work

Water system

When an updated schematic of the building becomes available, the arrangement of pipes can be designed accordingly. The roof can also be designed so that rainwater can be better collected by the pipes.

Insulation

Once the building is complete, occupancy and heating information can be logged, which will help inform insulation- and energy-related decision making in future projects involving shipping containers. Future projects must also consider the changing price of panels, and innovation within the field. Several state-of-the-art panels such as vacuum panels could disrupt the market when they enter mass production, which may affect the cost of other insulation materials.

Electricity efficiency

An energy systems model could observe the trends of the energy consumption and costs, especially after the residents have occupied the units for a certain amount of time, e.g. 3 months. Constant data collection from questionnaires will also be used to improve future iterations of the project. Additionally, investment in solar panels or solar water heating could be considered when funds become available. They will improve the self-sufficiency of the building and decrease the costs of electricity.

Waste Management

A waste management feasibility planning tool for social housing projects which requires inputs such as anticipated waste streams and budget to calculate feasibility of solutions and return on investment would be useful to the project. With this, any change in the assumptions used to develop the solutions presented could be put in the system to generate an updated solution. For the anaerobic digester, the solution is one that can be moved to another project and plugged in to infrastructure easily. To make the system more modular however, especially since the scale of the new project might vary, future work can look at making the components within the digestor scalable e.g. being able to retrofit a tank to increase its capacity by screwing on an extender for example.

Commercialisation

The project can be replicated on different sites with The Salvation Army, as they have offices in over 130 countries (Salvation Army International, 2019). The project can also be commercialized, transforming the sustainable shipping containers into a product and advertising it. Companies and organisations that are interested in temporary and environmentally-friendly buildings, including consultancies, NGOs, and building service industries will be able to purchase or use the idea and principles for future projects.

Conclusion

To conclude, our main proposals regarding Project Malachi's water system, insulation, electricity efficiency, and waste management offer utility, environmental benefit, and in some cases monetary savings. Our solutions are cost-effective, and our findings can be used by researchers of low-cost sustainable housing in the future. More broadly, we have shown that there are a variety of low-cost green infrastructure solutions that can be implemented in social housing.

References & acknowledgements

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References

Abrasheva, G, Senk, D., Habussling, R. (2012). *Shipping containers for a sustainable habitat perspective*, Revue de Metallurgie, 109, pp.381-389.

Achinas, S., Achinas, V. and Euverink, G. J. W. (2017). *A Technological Overview of Biogas Production from Biowaste*, Engineering, Elsevier, 3(3), pp. 299–307. doi: 10.1016/J.ENG.2017.03.002.

Adam Forrest. (2016). *The problem with homeless hostels. And why they need fixed*, The Big Issue. [online] Available at: https://www.bigissue.com/latest/problem-homeless-hostels-need-fixed/ [Accessed 03 Mar. 2019].

Alibaba. (2019). *YIY lithium battery*. [online] Available at: https://www.alibaba.com/product-detail/48v1000ah-50kwh-lithium-battery-48v 500ah_60725017159.html?spm=a2700.7724857.normalList.2.2afd1e3fyGDxJv&s=p [Accessed 03 Mar. 2019].

Apple. (2018). *Apple Mac mini – technical specifications*. [online] Available at: https://support.apple.com/kb/SP710?locale=en_GB [Accessed 18 Feb. 2019].

Aneke, M. and Wang, M. (2016). *Energy storage technologies and real life applications – A state of the art review*, Applied Energy, 179, pp. 350-377, http://dx.doi.org/10.1016/j.apenergy.2016.06.097.

Ao. (2019a). *Newworld NW601DFDOL 60cm Dual Fuel Cooker - Black - A/A Rated*. [online] Available at: https://ao.com/product/nw601dfdol-newworld-dual-fuel-cooker-black-26432-12.aspx?WT.srch=1&WT.z_MT=skimlinks_phg&WT.z_RTM=PHG&WT.z_CN=305950&WT.z_AG=True+Content&WT.z_AT=Dennis&WT.z_KW=skimlinks_phg [Accessed 16 Feb. 2019].

Ao. (2019b). *Philips 24PFT5303/05 24" TV*. [online] Available at: https://ao.com/product/24pft530305-philips-5300-tv-black-57641-

108.aspx?WT.z_PT=AV&WT.z_AT=Led+Tvs&WT.z_AT=&WT.z_BR=Philips+TV&WT.z_FT=Free+Standing&WT.z_PC=24PFT5303/05&WT.srch=1&WT.srch=1&WT.z_MT=Affiliate&WT.z_MT=pricerunner_uk&WT.z_RTM=PHG&WT.z_RTM=PHG&WT.z_CN=11l131&WT.z_AG=Comparison&WT.z_KW=pricerunner_uk [Accessed 19 Feb. 2019].

Appliance City. (2017). *Liebherr IKS1614 88cm Integrated In Column Fridge With Ice Box.* [online] Available at: https://www.appliancecity.co.uk/refrigeration/fridges/integrated-fridges/liebherr-iks1614-88cm-integrated-in-column-fridge-with-ice-box/ [Accessed 10 Feb. 2019].

Armel, K.C., Gupta, A., Shrimali, G., Albert, A. (2012). *Is disaggregation the holy grail of energy efficiency? The case of electricity*, Energy Policy, 52, pp.213-234. http://dx.doi.org/10.1016/j.enpol.2012.08.062

BBC News. (2018). *Homeless deaths: At least 449 reported in the past year*. [online] Available at: https://www.bbc.co.uk/news/uk-45797223 [Accessed 8 Dec. 2018].

Beko. (2019). *Freestanding A 6kg 1200rpm Washing Machine WTG620M1*. [online] Available at: https://www.beko.co.uk/a-6kg-1200rpm-washing-machine-wtg620m1-white [Accessed 15 Feb. 2019].

Best Electric Shower. (2019). *Top 5 Best Electric Showers for 2018*. [online] Available at: https://www.bestelectricshower.com/ [Accessed 11 Feb. 2019].

Biogas Info. (2017a). *Digestate | Anaerobic Digestion*. [online] Available at: http://www.biogas-info.co.uk/about/digestate/ [Accessed 4 Mar. 2019].

Biogas Info. (2017b). *Feedstock | Anaerobic Digestion*. [online] Available at: http://www.biogas-info.co.uk/about/digestate/ [Accessed 4 Mar. 2019].

Bodach, S. and Hamhaber, J. (2010). *Energy efficiency in social housing: Opportunities and barriers from a case study in Brazil*, Energy Policy, 38, pp.7898-7910.

Borough of Redbridge. (2013). *Redbridge Environmental Action Plan (REAct) 2010 to 2018 (Revised 2013)*. [online] Available at: https://www.redbridge.gov.uk/media/2990/lbr-264-react-part-a-april-2013.pdf [Accessed 22 Jan. 2019].

Borough of Redbridge. (2019). *Redbridge - Bins, waste and recycling*. Available at: https://www.redbridge.gov.uk/bins-waste-and-recycling/ [Accessed: 1 Feb 2019].

Brandon, G. and Lewis, A. (1999). *Reducing household energy consumption: a qualitative and quantative field study*, Journal of Environmental Psychology, 19, pp. 75-85.

Business Dictionary (2019). *Business Plan*. [online] Available at: http://www.businessdictionary.com/definition/business-plan.html [Accessed 17 Mar. 2019].

Buywise. (2019a). *Zanussi ZRG14800WA Free-Standing Fridge in White*. [online] Available at: https://buywiseappliances.co.uk/zanussi-zrg14800wa-free-standing-fridge-in-white.html?utm_source=pricerunner&utm_medium=cpc&utm_campaign=pricerunner&sid=62758d74393af085c0e9d39185113b18 [Accessed 10 Feb. 2019].

Buywise. (2019b). *Liebherr Tsl 1414 under counter fridge Comfort*. [online] Available at: https://buywiseappliances.co.uk/liebherr-tsl-1414-under-counter-fridge-comfort.html?utm_source=pricerunner&utm_medium=cpc&utm_campaign=pricerunner&sid=62758d74393af085c0e9d39185113b18 [Accessed 10 Feb. 2019].

Capri, M. G. and Marais, G. v. R. (1975). *pH adjustment in anaerobic digestion*, Water Research, 9(3), pp. 307–313. doi: 10.1016/0043-1354(75)90052-4.

Carlile, C. (2018). *Washing Machines*. [online] Available at: https://www.ethicalconsumer.org/home-garden/shopping-guide/washing-machines [Accessed 14 Feb. 2019].

Chamie, J. (2017). *As Cities Grow Worldwide, So Do the Numbers of Homeless | YaleGlobal Online*. [online] Available at: https://yaleglobal.yale.edu/content/cities-grow-worldwide-so-do-numbers-homeless [Accessed 8 Feb. 2019].

Cheyne, I. (2002). *The definition of waste in EC Law*, Journal of Environmental Law, Oxford University Press, pp. 61–73. doi: 10.2307/44248349.

Cibse.org. (2018). *CIBSE - What is Building Services?*. [online] Available at: https://www.cibse.org/building-services/what-is-building-services [Accessed 3 Mar. 2019].

Citizens Advice. (2017). *The Value of Time-Of-Use tariffs in United Kingdom*. [online] Available at: https://www.citizensadvice.org.uk/about-us/policy/policy-research-topics/energy-policy-research-and-consultation-responses/energy-policy-research/the-value-of-time-of-use-tariffs-in-great-britain/ [Accessed 01 Dec. 2018].

City of London. (2010). *Residential Household Recycling*. Available at: https://www.cityoflondon.gov.uk/services/environment-and-planning/waste-and-recycling/household-waste-and-recycling/Pages/default.aspx [Accessed 4 Dec. 2018].

Clark, P.C. (1987). *Method for converting one or more steel shipping containers into a habitable building at a building side and the product thereof*, Patent US4854094. [online] Available at https://patents.google.com/patent/US4854094 [Accessed 04 Dec. 2018].

Committee on Climate Change. (2015). *How the UK is progressing* [online] Available at: https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/how-the-uk-is-progressing/ [Accessed 20 Dec. 2018].

Corbetts Electrical. (2019). *Liebherr TPesf 1714 under counter fridge Comfort*. [online] Available at:https://corbettselectrical.co.uk/liebherr-tpesf-1714-under-counter-fridge-comfort.html?___store%5b_data%5d%5bstore_id%5d=1&___store%5b_data%5d%5bcode%5d=default&___store%5b_data%5d%5bwebsite_id%5d=1&___store%5b_data%5d%5bgroup_id%5d=1&___store%5b_data%5d%5bname%5d=Default+Store+View&___store%5b_data%5d%5bsort_order%5d=0&___store%5b_data%5d%5bis_active%5d=1/ID=pricerunner&utm_source=pricerunner&utm_medium=cpc&utm_campaign=pricerunner [Accessed 10 Feb. 2019].

Currys. (2019a). *LOGIK L814WM16 Washing Machine – White*. [online] Available at: https://www.currys.co.uk/gbuk/household-appliances/laundry/washing-machines/logik-l814wm16-washing-machine-white-10140689-pdt.html?srcid=3&cmpid=comp~Pricerunner [Accessed 14 Feb. 2019].

Currys. (2019b). *BEKO WTB820E1W 8 kg 1200 Spin Washing Machine – White*. [online] Available at: https://www.currys.co.uk/gbuk/household-appliances/laundry/washing-machines/beko-wtb820e1w-8-kg-1200-spin-washing-machine-white-10163994-pdt.html [Accessed 15 Feb. 2019].

Data.gov.uk. (2019). [online] Available at: https://data.gov.uk/dataset/17ba3bbe-0e98-4a8c-9937-bd1d50fdc3c5/historical-monthly-data-for-meteorological-stations [Accessed 22 Feb. 2019].

Dahlén, L. (2005). *To Evaluate Source Sorting Programs in Household Waste Collection Systems*. [online] Available at: http://epubl.luth.se/1402-1757/2005/71 [Accessed 11 Dec. 2018].

Debenhams PLUS. (2019). *Hisense WFBJ7012 7kg 1200rpm Freestanding Washing Machine*. [online] Available at: https://www.debenhamsplus.com/p/1190479/hisense-wfbj7012-7kg-1200rpm-freestanding-washing-machine-white?tduid=62758d74393af085c0e9d39185113b18&utm_source=pricerunner.com_297850&utm_medium=tradedoubler [Accessed 14 Feb. 2019].

DEFRA. (2012). *Guidance on the legal definition of waste and its application.* [online] Available at: www.defra.gov.ukhttp://www.defra.gov.uk/environment/waste/legislation/eu-framework-directive/http://wales.gov.uk/consultations/environmentandcountryside/wastedefinition/?lang=en http://www.doeni.gov.uk/index/protect_the_environment/waste.htm [Accessed 22 Jan. 2019].

DEFRA. (2013). *Waste Prevention Programme for England Evaluation of Annex IV measures*. [online] Available at: www.gov.uk/defrawww.gov.uk./defra [Accessed 27 Feb. 2019].

DEFRA. (2018a). *Our waste our resources: A strategy for england*. [online] Available at: www.nationalarchives.gov.uk/doc/open-government-licence/version/3/oremailPSI@nationalarchives.gsi.gov.uk [Accessed 2 Feb. 2019].

DEFRA. (2018b). *UK Statistics on Waste 09-10-2018 update*.

DEFRA. (2019). Environmental Permitting Guidance. [online] Available at: www.defra.gov.uk [Accessed 9 Mar. 2019].

Denyer, M. (2018). *Gas & Electric Cookers*. [online] Available at: https://www.ethicalconsumer.org/home-garden/shopping-guide/gas-electric-cookers [Accessed 15 Feb. 2019].

DOE. (2018). *Energy Consumption in the UK*. [online] Available at: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk [Accessed 02 Feb. 2019].

Ebay. (2019). *Mini Spiral Low Energy Power Saving CFL Lamps B22 E27 E14 B15d Light Bulbs*. [online] Available at: https://www.ebay.co.uk/itm/Mini-Spiral-Low-Energy-Power-Saving-CFL-Lamps-B22-E27-E14-B15d-Light-Bulbs-UK/222304660703 [Accessed 17 Feb. 2019].

Economy 10. (2019). *List of suppliers*. [online] Available at: https://economy10.com/overview/list-of-suppliers/ [Accessed 22 Jan. 2019].

Ecosure. (2019). [online] Available at: https://www.ecosure.co.uk/acatalog/15_000_Litre_Water_Tank.html [Accessed 22 Feb. 2019].

EHC. (2019). *SlimJim Electric Boiler*. [online] Available at: https://www.electric-heatingcompany.co.uk/shop/slimjim-electric-boiler/ [Accessed 25 Feb. 2019].

Eleanor Busby. (2018). *Homelessness crisis: Thousands left living in cars and tents across UK, figures reveal*. [online] Available at: https://www.independent.co.uk/news/uk/home-news/homelessness-crisis-uk-rough-sleeping-cars-tents-streets-crisis-charity-report-a8696791.html[Accessed 01 Mar. 2019].

ElectrIQ Power. (2018). *ElectrIQ PowerPod: Clean, Reliable and Inteligent Backup Power*. [online] Available at: https://electriqpower.com/powerpod-info/ [Accessed 05 Mar. 2019].

Elnur. (2019). *Mattira Wall Mounted Electric Combi Boiler*. [online] Available at: https://www.elnur.co.uk/products/electric-combi-boilers/mattira-wall-mounted-electric-combi-boiler/ [Accessed 26 Feb. 2019].

Energy Sage. (2019). *How to choose the best battery for a solar energy system*. [online] Available at: https://www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/ [Accessed 07 Mar. 2019].

Energy Saving Trust. (2018). *Our calculations*. [online] Available at: https://www.energysavingtrust.org.uk/about-us/our-calculations [Accessed 22 Feb. 2019].

Energy Use Calculator. (2019). *Electricity usage of a LED Light Bulb*. [online] Available at: http://energyusecalculator.com/electricity_ledlightbulb.htm [Accessed 17 Feb. 2019].

Engineering ToolBox. (2003). *Thermal Conductivity of common Materials and Gases.* [online] Available at: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html [Accessed 29 Jan. 2019].

Environment Agency. (2011). *London's Environmental Infrastructure Needs: A Strategic Study*. [online] Available at: www.environment-agency.gov.uk [Accessed 10 Mar. 2019].

Environmental and Energy Study Institute (2017) *Converting Waste to Energy White Paper*. Available at: https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy (Accessed: 1 Mar 2019).

Eps.co.uk. (2019). *The BPF Expanded Polystyrene Group | Airpop*. [online] Available at: http://www.eps.co.uk/sustainability/recycling_post_construction.html [Accessed 10 Mar. 2019].

European Commission. (2012). Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste. Available at: http://eur-lex.europa.eu/RECH_consolidated.do. (Accessed: 01 Mar. 2019).

Expert Reviews. (2018a). *Best electric shower: The showers that will leave you feeling warm, clean and refreshed from £57 to £280*. [online] Available at: https://www.expertreviews.co.uk/home-appliances/1405956/best-electric-showers [Accessed 12 Feb. 2019].

Expert Reviews. (2018b). *Best oven: The best ovens, hobs and cookers from £380*. [online] Available at: https://www.expertreviews.co.uk/home-appliances/1405946/best-oven-the-best-ovens-hobs-and-cookers-from-350 [Accessed 16 Feb. 2019].

Fewkes, A. (1999). *The use of rainwater for WC flushing: the field testing of a collection system.* Building and Environment, 34 pp. 765-772.

Fischer, C. (2008). *Feedback on household electricity consumption: a tool for saving energy?*, Energy Efficiency, 1, pp.79-104, doi 10.1007/s12053-008-9009-7.

Fuller, M. (2006). *Building with Steel Shipping Containers and Super Therm, Gainsborough Showers*, SE shower. [online] Available at: https://www.gainsboroughshowers.co.uk/shower-store/electric-shower/Gainsborough-85-se/ [Accessed 12 Feb. 2019].

Giriunas, K, Sezen, H., Dupaix, R.B. (2012), *Evaluation, modeling, and analysis of shipping container-building structures*, Eng. Struct, 43, 48–57.

Green Energy. (2019). *TIDE tariffs*. [online] Available at: https://www.greenenergyuk.com/tide [Accessed 03 Jan. 2019].

GROHE Professional. (2016). *GROHE Tempesta 100*. [online] Available at: https://pro.grohe.com/uk/31597/showers/electric-showers/grohe-tempesta-100-electric-showers/ [Accessed 12 Feb. 2019].

GOV.UK. (2018). *Homelessness data: notes and definitions*. [online] Available at: https://www.gov.uk/guidance/homelessness-data-notes-and-definitions [Accessed 8 Feb. 2019].

Houzz. (2015). *Kitchen planning: Is a Gas or Electric Hob Right for you?* [online] Available at: https://www.houzz.co.uk/magazine/kitchen-planning-is-a-gas-or-electric-hob-right-for-you-stsetivw-vs~49429208 [Accessed 14 Feb. 2019].

Home Biogas. (2017). *Homebiogas | Household Biogas Digester System.* [online] Available at: https://www.homebiogas.com/ [Accessed 2 Jan. 2019].

HP. (2017). *HP G2 Mini Desktop*. [online] Available at: https://store.hp.com/UKStore/Merch/Product.aspx?id=2KL47EA&opt=ABU&sel=DEF [Accessed 18 Feb. 2019].

Hughes. (2019). *Linsar LED1700*. [online] Available at: https://www.hughes.co.uk/tv-and-entertainment/televisions/all-televisions/?p=1 [Accessed 19 Feb. 2019].

Innovative Water Solution. (2019). *Rainwater Harvesting 101*. [online] Available at: https://www.watercache.com/education/rainwater-harvesting-101 [Accessed 21 Feb. 2019].

Insulation-info.co.uk. (2018). *Insulation: Price guidance and Tips | Insulation-info.co.uk.* [online] Available at: https://www.insulation-info.co.uk/ [Accessed 1 Dec. 2018].

Intertek. (2012). *Household Electricity Survey: A study of domestic electrical product usage*. [online] Available at: https://www.gov.uk/government/publications/household-electricity-survey--2 [Accessed 02 Feb. 2019].

Jelle, B. (2011). *Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities*, Energy and Buildings, 43(10), pp.2549-2563.

John Lewis. (2019a). *John Lewis & Partners JLFSMC613 Dual Fuel Cooker, Stainless Steel*. [online] Available at: https://www.johnlewis.com/john-lewis-partners-jlfsmc613-dual-fuel-cooker-stainless-steel/p1445222 [Accessed 16 Feb. 2019].

John Lewis. (2019b). *Miele H2265B Discovery Built-In Single Oven, Clean Steel*. [online] Available at: https://www.johnlewis.com/miele-h2265b-discovery-built-in-single-oven-clean-steel/p3228052?s_afcid=af_78888&tmad=c&awc=1203_1550694201_704afb6ff3e8f59344646fcfe6063ff3&tmcampid=48 [Accessed 16 Feb. 2019].

John Lewis. (2019c). *Miele KM6115 Induction Hob, Black*. [online] Available at: https://www.johnlewis.com/miele-km6115-induction-hob-black/p231048987?s_afcid=af_78888&tmad=c&awc=1203_1550694203_592bf6b030211a358ab9358be28d0f1f&tmcampid=48 [Accessed 16 Feb. 2019].

John Lewis. (2019d). *Linsar 24LED4000 LED HD Ready 720p Smart TV/DVD Combi, 24" with Built-In Wi-Fi, Freeview HD & Freeview Play*. [online] Available at: https://www.johnlewis.com/linsar-24led4000-led-hd-ready-720p-smart-tv-dvd-combi-24-with-built-in-wi-fi-freeview-hd-freeview-play/p3089364 [Accessed 19 Feb. 2019].

Kaiser, F.G., Oerke, B., Bogner, F.X. (2007). *Behaviour-based environmental attitude: Development of an instrument for adolescents*, Journal of Environmental Psychology, 27, 242-251, doi:10.1016/j.jenvp.2007.06.004.

Khoury-Nolde, N. (2019). *Rainwater Harvesting. Germany: Zero-M & Fachvereinigung Betriebs- und Regenwassernutzung e.V.* [online] Available at: http://www.ercsa.eu/uploads/media/Rainwater_Harvesting_-_an_overview_.pdf [Accessed 22 Feb. 2019].

Kim, Y., Kim, S., Shin, S. and Sohn, J. (2009). Contribution of natural ventilation in a double skin envelope to heating load reduction in winter. *Building and Environment*, 44(11), pp.2236-2244.

Kim, M.-S., Kim, D.-H. and Yun, Y.-M. (2017). *Effect of operation temperature on anaerobic digestion of food waste: Performance and microbial analysis*, Fuel, 209, pp. 598–605. doi: 10.1016/J.FUEL.2017.08.033.

Kindred Association. (1994). *A practical recycling handbook*, T. Telford.

Kohler, M. (2014). *Differential electricity pricing and energy efficiency in South Africa*, Energy, 64, pp. 524-532, http://dx.doi.org/10.1016/j.energy.2013.11.047.

Kondepudi, D. (2009). Introduction to modern thermodynamics. Vancouver, B.C.: Langara College.

Korjenic, A., Petránek, V., Zach, J. and Hroudová, J. (2011). *Development and performance evaluation of natural thermal-insulation materials composed of renewable resources.* Energy and Buildings, 43(9), pp.2518-2523.

Lund, H. F. (2000). *The McGraw-Hill recycling handbook,* McGraw Hill.

McInerney, M. J. and Bryant, M. P. (1981). *Basic Principles of Bioconversions in Anaerobic Digestion and Methanogenesis*, Biomass Conversion Processes for Energy and Fuels. Boston, MA: Springer US, pp. 277–296. doi: 10.1007/978-1-4757-0301-6_15.

Met Office. (2019). [online] Available at: https://www.metoffice.gov.uk/public/weather/climate/gcpvj0dup[Accessed 21 Feb. 2019].

Mir, M. A., Hussain, A. and Verma, C. (2016). *Design considerations and operational performance of anaerobic digester: A review,* Cogent Engineering. Edited by S. Dubey. Cogent, 3(1). doi: 10.1080/23311916.2016.1181696.

Mira Showers. (2019). *Mira Jump Multi-Fit Shower*. [online] Available at: https://www.mirashowers.co.uk/showers/electric-showers/mira-jump-multi-fit-75kw/ [Accessed 12 Feb. 2019].

Mosey, F. E. (1983). *Mathematical Modelling of the Anaerobic Digestion Process: Regulatory Mechanisms for the Formation of Short-Chain Volatile Acids from Glucose,* Water Science and Technology, 15(8–9), pp. 209–232. doi: 10.2166/wst.1983.0168.

Nejat, P., Jomehzadeh, F., Taheri, M.M, Gohari, M., Abd. Majid, M.Z. (2014). *A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries),* Renewable and Sustainable Energy Reviews, 43, 843-863, doi: http://dx.doi.org/10.1016/j.rser.2014.11.066

Next. (2019). *Indesit My Time EWSD61252W Washing Machine – White*. [online] Available at: https://www.nextdomesticappliances.co.uk/product/ewsd61252w-indesit-my-time-washing-machine-white-37178-1.aspx?WT.z_PT=MDA&WT.z_AT=Washing+Machines&WT.z_AT=&WT.z_BR=Indesit&WT.z_FT=Free+Standing&WT.z_PC=EWSD61252W_WH&WT.srch=1&WT.srch=1&WT.z_MT=Affiliate&WT.z_MT=pricerunner_uk&WT.z_RTM=PHG&WT.z_RTM=PHG&WT.z_CN=%3dprsp_uk_sustit&WT.z_CN=11l131&WT.z_AG=Comparison&WT.z_KW=pricerunner_uk [Accessed 14 Feb. 2019].

Nissan. (2018). *Nissan Energy Solar*. [online] Available at: https://www.nissan.co.uk/experience-nissan/electric-vehicle-leadership/storage-solutions.html [Accessed 03 Mar. 2019].

Opten. (2019*). 5kw High Efficiency Domestic Electric Wet Central Heating Hot Water Boilers for Home Heating*. [online] Available at: http://www.electricboilerschina.com/electric-boilers/electric-central-heating-boiler/5kw-high-efficiency-domestic-electric-wet.html [Accessed 25 Feb. 2019].

OVO Energy. (2019a). *How much electricity does a home use?* [online] Available at: https://www.ovoenergy.com/guides/energy-guides/how-much-electricity-does-a-home-use.html [Accessed 14 Feb. 2019].

OVO Energy. (2019b). *The ultimate beginner's guide to energy saving light bulb.* [online] Available at: https://www.ovoenergy.com/guides/energy-guides/energy-saving-light-bulbs.html [Accessed 16 Feb. 2019].

Parliament Publications. (2005). *Homelessness*. [online] Available at: https://publications.parliament.uk/pa/cm200405/cmselect/cmodpm/61/61i.pdf [Accessed 8 Feb. 2019].

Pelanne, C. (1978). Thermal Insulation: what it is and how it Works. *Journal of Thermal Insulation*, 1(4), pp.223-236.

Pennacchio, R., Savio, L., Bosia, D., Thiebat, F., Piccablotto, G., Patrucco, A. and Fantucci, S. (2017). *Fitness: Sheep-wool and Hemp Sustainable Insulation Panels*, Energy Procedia, 111, pp.287-297.

Penn State University (2019) *Anaerobic Digestion*. Available at: https://www.e-education.psu.edu/egee439/node/727 [Accessed: 1 Mar 2019).

Perrot, J. F. and Subiantoro, A. (2018). *Municipal waste management strategy review and waste-to-energy potentials in New Zealand*, Sustainability (Switzerland), 10(9). doi: 10.3390/su10093114.

Polprasert, C. (1996). *Organic waste recycling*, J. Wiley.

Powervault. (2019). *Technical specifications*. [online] Available at: https://www.powervault.co.uk/technical/technical-specifications/ [Accessed 06 Mar. 2019].

Purvins, A., Papaioannou, I.T., Debarberis, L. (2013). *Application of battery-based storage systems in household-demand in smoothening in electricity-distribution grids*, Energy Conversion and management, 65, pp.272-284, http://dx.doi.org/10.1016/j.enconman.2012.07.018.

Rain Water Harvesting. (2019a). [online] Available at: https://www.rainwaterharvesting.co.uk/pipes-hose/rainwater-pipe-32mm-50m-70 [Accessed 15 Mar. 2019].

Rain Water Harvesting. (2019b). [online] Available at: https://www.rainwaterharvesting.co.uk/rainwater-pumps/1100w-evolution-x-aje-80-steel-pump-37 [Accessed 28 Feb. 2019].

Rain Water Harvesting. (2019c). [online] Available at: https://www.rainwaterharvesting.co.uk/filtration/3p-volume-filter-vf1-55 [Accessed 15 Mar. 2019].

Ramulongo, L., Nethengwe, N.S. and Musyoki, A. (2017). *The Nature of Urban Household Water Demand and Consumption in Makhado Local Municipality: A Case Study of Makhado.*

Recycle Reminders. (2019). *Conservation Signs*. Available at: https://www.recyclereminders.com/conservation-signs [Accessed: 1 Jan 2019].

Refsgaard, K. and Magnussen, K. (2009). *Household behaviour and attitudes with respect to recycling food waste - experiences from focus groups*, Journal of Environmental Management, Elsevier Ltd, 90(2), pp. 760–771. doi: 10.1016/j.jenvman.2008.01.018.

Riggs, J. (2015). *IAQUK Rating Index.* [online] Available at: http://www.iaquk.org.uk/ESW/Files/IAQ_Rating_Index.pdf [Accessed 19 Feb. 2019].

Sadineni, S., Madala, S. and Boehm, R. (2011). *Passive building energy savings: A review of building envelope components,* Renewable and Sustainable Energy Reviews, 15(8), pp.3617-3631.

Salvationarmy.org.uk. (2018). *About us | The Salvation Army.* [online] Available at: https://www.salvationarmy.org.uk/about-us [Accessed 7 Dec. 2018].

Salvation Army International. (2019). *Worldwide*. [online] Available at: https://www.salvationarmy.org/ihq/zones [Accessed 13 Mar. 2019].

Screwfix. (2019). *Lap ES GLS LED Light Bulb 806lm 9W 5 Pack*. [online] Available at: https://www.screwfix.com/p/lap-es-gls-led-light-bulb-806lm-9w-5-pack/1873t [Accessed 17 Feb. 2019].

SEAB Energy. (2014). *MUCKBUSTER® Anaerobic Digester*. [online] Available at: https://seabenergy.com/products/anaerobic-digesters/ [Accessed 4 Feb. 2019].

Shelter. (2018). *Temporary housing if you're homeless: hostels.* [online] Available at: https://england.shelter.org.uk/housing_advice/homelessness/temporary_housing_if_youre_homeless/hostels [Accessed 3 Mar. 2019].

Shelter.org.uk. (2018). *320,000 people in Britain are now homeless, as numbers keep rising - Shelter Media England*. [online] Available at: http://media.shelter.org.uk/press_releases/articles/320,000_people_in_britain_are_now_homeless,_as_numbers_keep_rising [Accessed 8 Feb. 2019].

Skoyles, R., Bulkeley, H. and Askins, K. (2005). *Governing Sustainable Waste Management Designing sustainable waste management into the housing sector.* [online] Available at: www.dur.ac.uk/geography/research/researchprojects/ [Accessed 5 Mar. 2019].

SimpliPhi. (2018). *Phi High-Voltage*. [online] Available at: https://simpliphipower.com/product/phi-high-voltage/ [Accessed 06 Mar. 2019].

Sonnen. (2018). *SonnenBatterie*. [online] Available at: https://sonnengroup.com/sonnenbatterie/ [Accessed 05 Mar. 2019].

Smartteck. (2019). *Asus Chromebox SN62 G008U*. [online] Available at: https://www.smartteck.co.uk/asus-chromebox-sn62-g008u-2-1-ghz-5th-gen-intelr-coretm-i3-i3-5010u-black-usff-mini-pc.html [Accessed 18 Feb. 2019].

Smith. J. D. (2005). *Shipping containers as building components,* University of Brighton.

Steam Shower Parts. (2019). *Top 10 best Electric Showers Revealed: Ultimate UK Review Guide 2019*. [online] Available at: https://www.steamshowerparts.co.uk/buyers-guides/top-10-best-electric-showers/ [Accessed 12 Feb. 2019].

Sunverge. (2016). *AC Coupled System*. [online] Available at: http://www.sunverge.com/energy-management/ [Accessed 06 Mar. 2019].

Sust-It. (2018a). *Upright Fridges (Small)*. [online] Available at: https://www.sust-it.net/energy-saving/upright-fridge-small&sort=1 [Accessed 09 Feb. 2019].

Sust-It. (2018b). *Washing Machines*. [online] Available at: https://www.sust-it.net/energy-saving/washing-machines&cl=0&sort=1&start=0 [Accessed 13 Feb. 2019].

Sust-It. (2018c). *Cookers*. [online] Available at: https://www.sust-it.net/energy-saving/cookers [Accessed 15 Feb. 2019].

Sust-It. (2018d). *Desktop Computers*. [online] Available at: https://www.sust-it.net/energy-saving/desktop-computers [Accessed 18 Feb. 2019].

Sust-It. (2018e). *Televisions*. [online] Available at: https://www.sust-it.net/energy-saving/televisions [Accessed 19 Feb. 2019].

TDL. (2019). *Polypipe Single Zone 3kw Electric Boiler for Underfloor Heating*. [online] Available at: https://www.tdlonline.co.uk/Heating/Polypipe-Underfloor-Heating/Polypipe-Water-Temperature-Control/57592-/Polypipe-Single-Zone-3kw-Electric-Boiler-for-Underfloor-Heating [Accessed 25 Feb. 2019].

Tesla. (2019). *Powerwall*. [online] Available at: https://www.tesla.com/en_GB/powerwall?redirect=no [Accessed 06 Mar. 2019].

Tesvolt. (2019). *Tesvolt Lithium Battery Storage 500 kWh*. [online] Available at: https://zerohomebills.com/product/tesvolt-lithium-battery-storage-500-kwh-tlc500/ [Accessed 02 Mar. 2019].

The Appliance Depot. (2019). *Graded Smeg UKS3C090P 54cm Integrated In Column Upright Fridge (JUB-24084)*. [online] Available at: https://www.theappliancedepot.co.uk/graded-smeg-uks3c090p-55cm-integrated-in-column-fridge-with-ice-box-jub-24084?gclid=Cj0KCQiA-onjBRDSARIsAEZXcKbXoOl4LNO2HXK3dKjSQbi5Pk1tDg6AJHi3Em9z6Iri9Sk8udoJoI8aApcTEALw_wcB [Accessed 10 Feb. 2019].

Trianco. (2019). *Inca Electric Boiler*. [online] Available at: https://shop.trianco.co.uk/product/inca-electric-boiler/ [Accessed 25 Feb. 2019].

Triton Showers. (2019a). *Shower types explained*. [online] Available at: https://www.tritonshowers.co.uk/shower-types-explained [Accessed 14 Feb. 2019].

Triton Showers. (2019b). *Seville Shower*. [online] Available at: https://www.tritonshowers.co.uk/electric-showers/seville-electric-shower.html [Accessed 12 Feb. 2019].

Triton Showers. (2019c). *T80si*. [online] Available at: https://www.tritonshowers.co.uk/clearance-deals/electric-showers/t80si-electric-shower.html [Accessed 12 Feb. 2019].

Turner, J. (2016a). *Desktop Computers*. [online] Available at: https://www.ethicalconsumer.org/technology/shopping-guide/desktop-computers [Accessed 17 Feb. 2019].

Turner, J. (2016b). *Televisions*. [online] Available at: https://www.ethicalconsumer.org/technology/shopping-guide/televisions [Accessed 19 Feb. 2019].

UK Housing Review. (2008). [online] Available at: https://www.ukhousingreview.org.uk/ukhr0708/compendium.html#economy [Accessed 28 Feb. 2019].

United Utilities. (2019). [online] Available at: https://www.unitedutilities.com/faq/bills-payments/what-does-a-litre-or-cubic-metre-of-water-cost/ [Accessed 22 Feb. 2019].

Villarreal, E and Dixon, A. (2005). *Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden*, Building and Environment, 40(9) pp. 1174-1184.

Walker, M. *et al.* (2017). *Assessment of Micro-Scale Anaerobic Digestion for Management of Urban Organic Waste: A Case Study in London, UK*, Waste Management (Preprint), pp. 756–756. doi: 10.1007/978-1-4419-6247-8_11977.

Warburton, N. (2013). *Social housing landlords to benefit from waste exchange service*. [online] Available at: https://www.edie.net/news/5/Social-housing-landlords-to-benefit-from-waste-exchange-service-/ [Accessed 5 Mar. 2019].

Webb, H. (2017). *Light Bulbs*. [online] Available at: https://www.ethicalconsumer.org/energy/shopping-guide/light-bulbs [Accessed 17 Feb. 2019].

Wexler, J. (2018). *Fridge & Freezers*. [online] Available at: https://www.ethicalconsumer.org/home-garden/shopping-guide/fridge-freezers [Accessed 09 Feb. 2019].

WRAP. (2013). *Optimising Urban Micro AD Networks.* [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Community%20by%20Design%20-%20DIAD%202%20feasibility%20study.pdf [Accessed 12 Feb. 2019].

Yaman, R. (info@communitybydesign.co.uk). *"Anaerobic Digester – Calthorpe Project*." e-mail to Salina Solomon (ucessjs@ucl.ac.uk). [Accessed 07 Feb. 2019].

Yohanis, Y.G, Mondol, J.D., Wright, A., Norton, B. (2008). *Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use*, Energy and Buildings, 40, pp.1053-1059. doi:10.1016/j.enbuild.2007.09.001.

YouGen. (2019). [online] Available at: http://www.yougen.co.uk/energy-saving/Rain+Harvesting/ [Accessed 28 Feb. 2019].

APPENDICES

<u>Appendix 1</u> – Passive Design Assistant settings

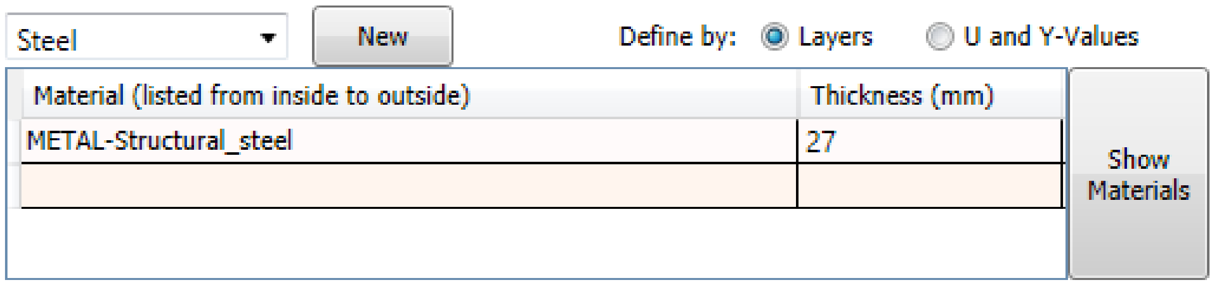


Figure 18: Material settings for the insulated container wall in Passive Design Assistant by ARUP.

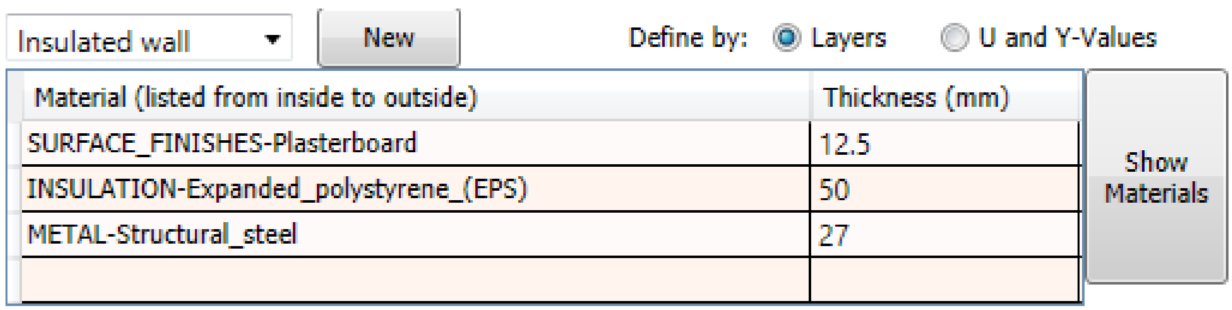
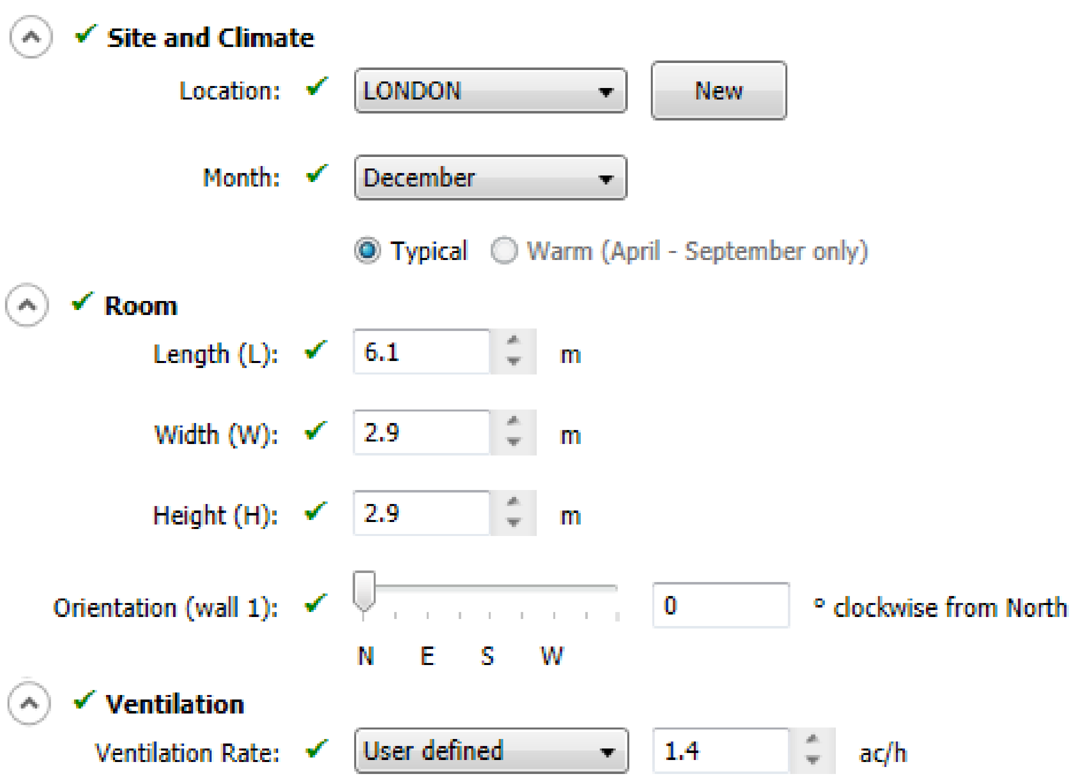


Figure 19: Material settings for the insulated shipping container wall in Passive Design Assistant by ARUP.



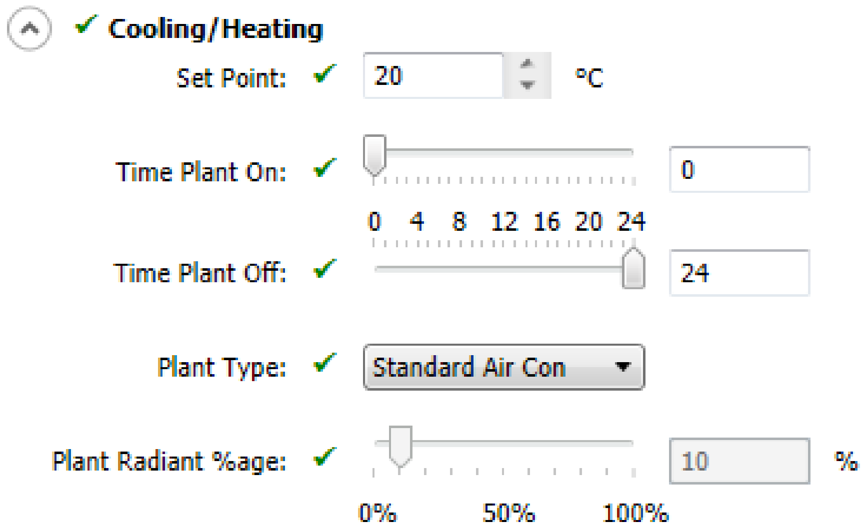


Figure 20: Passive Design Assistant settings for the heating load simulations.

<u>Appendix 2</u> – Heating load calculation results

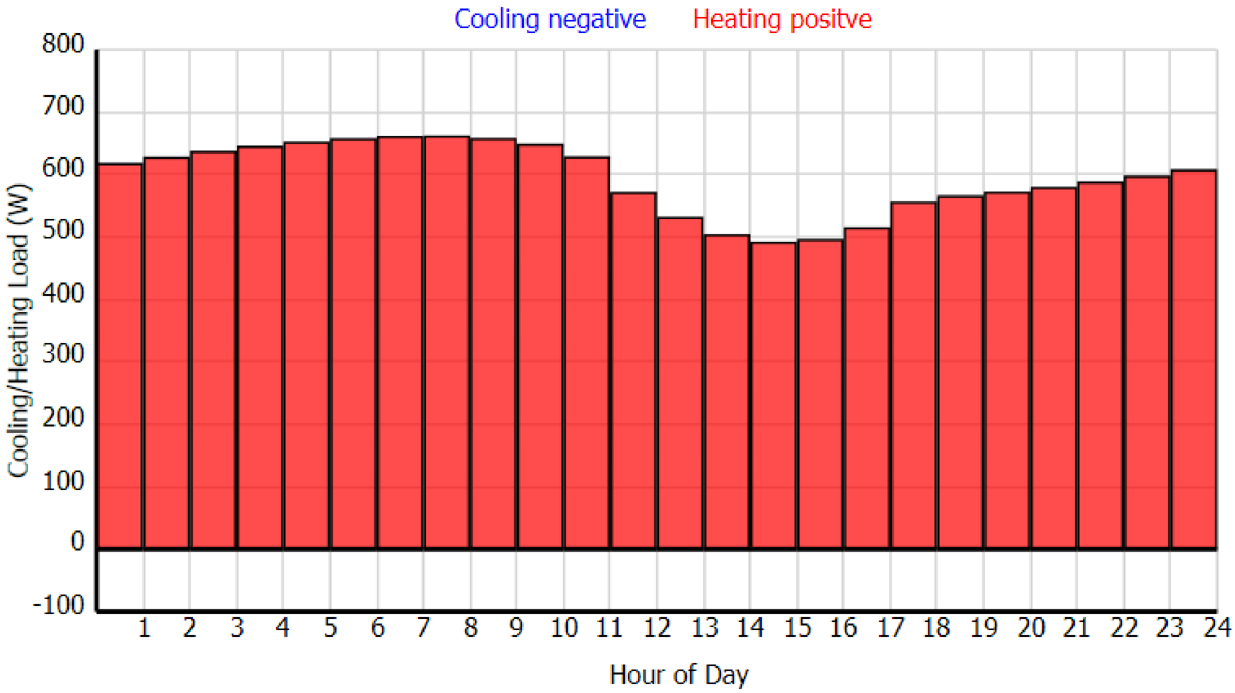


Figure 21: Simulated mean heating load over 24 hours for an insulated shipping container, and an un-insulated shipping container.

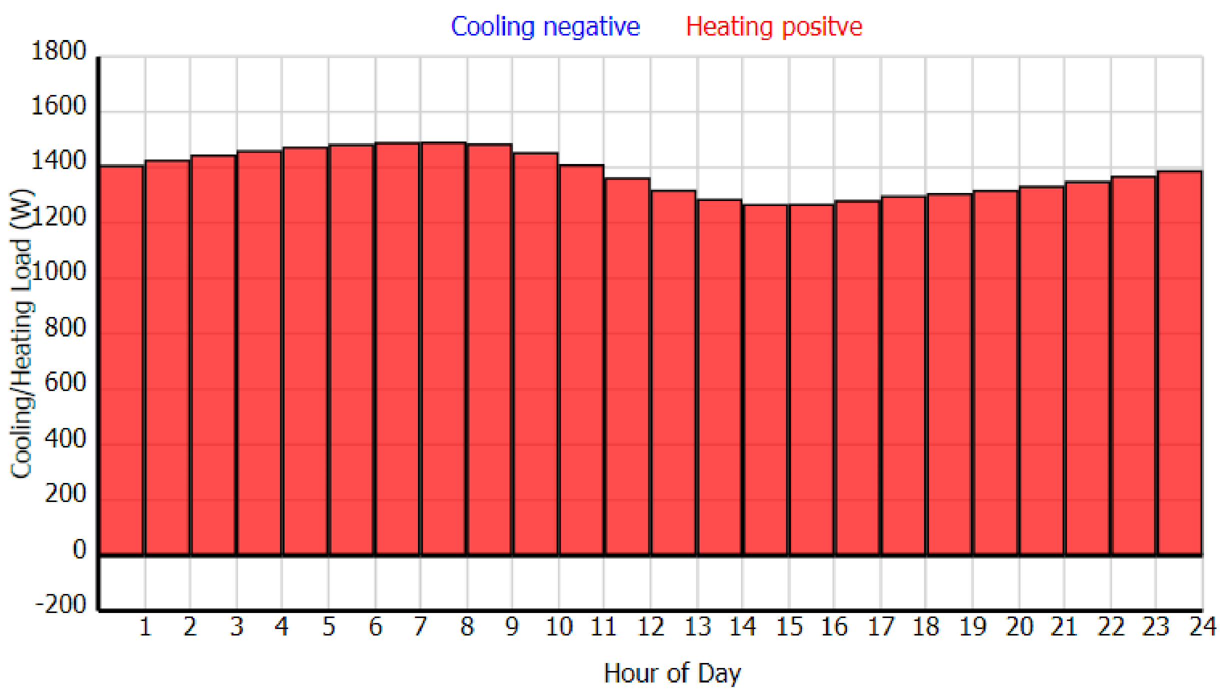


Figure 22: Simulated heating load over 24 hours for the un-insulated shipping container in Passive Design Assistant by ARUP.

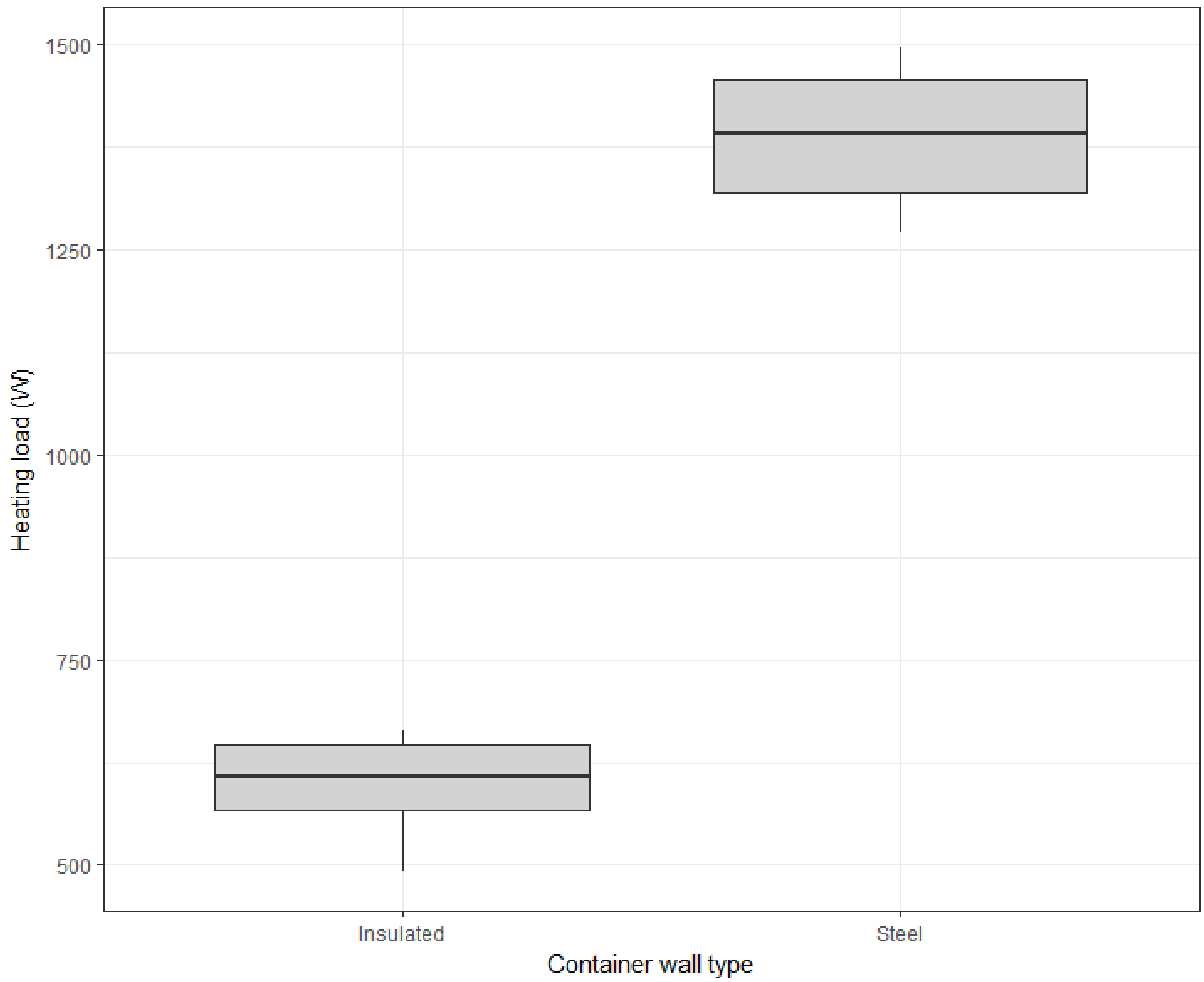


Figure 23: Box plot of mean heating load over 24h for the insulated and un-insulated shipping containers.

APPENDIX 3 – Training brief and questionnaires

- It has been decided to make own questionnaires as the literature on environmental attitude of residents that were previously homeless people is non-existent.
- It is vital to keep track of the progress so future work will be improved.
- It is important to see if training, energy feedback and praising on managing waste has any effects on this category of renters.
- In the possibility that the residents will not be able to read, a member of staff should run the questionnaires with them.
- Future ethical work must be done – is it correct for us to ask people that did not have access to clean water/heat to use it moderately when rich people are not asked to/obliged to?

Training programme

The training programme will last for 3 hours and it will cover the following topics:

- Acknowledgement of UK's household electricity consumption
- Fossil fuels and their impact on climate
- Improvements on the shelter's electricity demand:
    - Electric appliances
    - TOU rates
    - Battery
- Improvements on the shelter's insulation: the insulation chosen
- Improvements on water consumption: rainwater harvesting system
- Improvements on waste management:
    - Anaerobic digestion
    - Sorting
- They will be directly involved in their electricity consumption and waste management
- What their role is and how they can contribute, for example:
    - When boiling a kettle, only use as much water as needed
    - Do not leave appliances on stand-by
    - Defrost your freezer regularly
    - When using the washing machine, never set it higher than 30˚
    - Do own laundry every other week or rarer, and after midnight
    - Hang out in the common room with the rest of residents instead of using own appliances (electricity & heating) at all times
    - Use the electricity feedback given in a constructive way and understand which appliance uses more/less energy
- The residents will complete a questionnaire just after training as it is important to see if the programme had any immediate impact and if it has been lost
- The questionnaires will be divided in 3:
    - First – training feedback – likeliness for future change (immediate effect)
    - Second – data collection of current environmental attitudes (Kaiser et al., 2007); including energy conservation, waste avoidance and recycling.
    - Third – data collection of possible future outcomes.
- Trying to make all questionnaires having the same balance e.g. 4 options in option choice – 1st the worst – 4th the best impact/result

QUESTIONNAIRE 1 – training feedback

1. How do you feel about the environmental problems United Kingdom's households are having?
    a. I don't want to contribute in any way.
    b. I am neutral
    c. I could help, but I don't feel I could be involved.
    d. I could help.
2. Do you feel this training will change your future habits on subjects covered (eg energy conservation, waste avoidance)?
    a. Mostly unlikely
    b. Probably unlikely
    c. Probably likely
    d. Mostly likely
3. Would you help somebody to change their environmental attitude towards better? (e.g. if you see them throwing trash on the floor).
    a. Mostly unlikely
    b. Probably unlikely
    c. Probably likely
    d. Mostly likely
4. (open-ended) Do you know how would you be able to contribute?
5. (open-ended) How would you improve the training? Is there something you consider it has not been included?

QUESTIONNAIRE 2 – midway throughout the contract

Energy conservation

1. I do laundry:
    a. More than once a week
    b. Once a week
    c. Every other week
    d. Less than 2 times a month

2. I switch lights off:
    a. Almost never
    b. Every time I have natural light in the room
    c. Every time I could use the lamp
    d. Every time I am the last in the room and there is absolutely no need for extra light

3. I use the electric appliances, and then:
    a. I leave them
    b. I make sure they are turned off
    c. I make sure they are turned off and switched-on
    d. I make sure they are turned off and switched-off

4. I use the electric heater:

    a. More than 6 hours per day.

b. More than 4 hours per day.
c. Around 2 hours per day.
d. Less than 2 hours per day.

5. I check the electricity feedback:
a. Never
b. Once a month
c. Every other week
d. Every week

6. (open-ended) Have you changed your consumption since the beginning of your stay? If so, how? How have you contributed toward this?

7. I stay…
a. Alone in the room and have my lights on
b. At least once a week with the other residents in the common room
c. More than twice a week with the other residents in the common room and at times have meals together
d. Almost every day with the other residents in the common room and often (2-3 times a week) have meals together

Waste avoidance and recycling

1. I buy…
a. Beverages in cans
b. Products in plastic wrapping
c. Products in semi recyclable packing
d. Mostly products that their packing could be recycled.

2. When I shop…
a. I buy a plastic bag every time
b. I reuse some of the plastic bags I bought, but buy extra at times
c. I reuse plastic bags
d. I have my own bags

3. When I throw away my waste..
a. I throw it wherever I finish consuming
b. I throw it in the nearest bin
c. I throw it close to me, trying to make the difference between recyclable and non-recyclable
d. I make sure I sort all of my waste as instructed in the training.

4. Regarding the anaerobic digester…
a. It is not in my interest
b. I help maintain it and take waste to it once a month
c. I help maintain it and take waste to it once every two weeks
d. I help maintain it and take waste to it every week

QUESTIONNAIRE 3 – at the end of the contract

1. How do you feel about the environmental attributes of Project Malachi?
    a. I did not contribute in any way
    b. I helped when I wanted
    c. I helped every other week
    d. I helped every week

2. Do you feel this stay will change your future habits on subjects covered (eg energy conservation, waste avoidance)?
    a. Mostly unlikely
    b. Probably unlikely
    c. Probably likely
    d. Mostly likely

3. Would you help somebody to change their environmental attitude towards better? (e.g. if you see them throwing trash on the floor).
    e. Mostly unlikely
    f. Probably unlikely
    g. Probably likely
    h. Mostly likely

4. (open-ended) Do you know how will you be able to contribute in the future?

5. (open-ended) How would you improve your experience? Is there something you consider it has not been included?

Appendix 4 - Catalogue for electric appliances

- Electric shower

Table 6: Range of showers that could be chosen for Project Malachi. They have been selected due to their electric usage and cost. Inspired from Expert Reviews (2018a), Best Electric Shower (2019) and Steam Shower Parts (2019).

	Option	Usage	Cost	Image	Source
1.	Triton Seville	7.5 kWh	70£		Triton Showers (2019b)
2.	Triton T80si	7.5 kWh	80£		Triton Showers (2019c)
3.	Gainsborough SE	8.5 kWh	78£		Gainsborough Showers (2010)
4.	GROHE Tempesta 100	9 kWh	90£		GROHE Professional (2016)
5.	Mira Jump Multi-Fit	7.5 kWh	139£		Mira Showers (2019)

- Small Fridge with Freezer

Table 7: Range of small fridge freezer that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Sust-It (2018a) and Wexler (2018).

	Option	Annual consumption	Cost	Image	Source
1.	Liebherr IKS1614 (85 % energy efficient)	148 kWh	299£		Appliance City (2017)
2.	Zanussi ZRG14800WA (58% energy efficient)	188 kWh	244£		Buywise (2019a)
3.	Liebherr Tsl 1414 (39% energy efficient)	117 kWh	289£		Buywise (2019b)
4.	Smeg UKS3C090P (33% energy efficient)	189 kWh	289£		The Appliance Depot (2019)
5.	Liebherr TPesf 1714 (91% energy efficient)	146 kWh	459£		Corbetts Electrical (2019)

- Washing machine

Table 8: Range of washing machines that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Sust-It (2018b) and Carlile (2018).

	Option	Annual consumption	Cost	Image	Source
1.	Logik L814WM16 (79 % energy efficient)	195 kWh	199£		Currys (2019a)
2.	Beko WTG620M1 (69% energy efficient)	152 kWh	249.9£		Beko (2019a)
3.	Beko WTB820E1W (74% energy efficient)	195 kWh	209£		Currys (2019b)
4.	Indesit My Time EWSD61252W (53% energy efficient)	172 kWh	199£		Next (2019)
5.	Hisense WFBJ7012 (85% energy efficient)	174 kWh	245£		Debenhams PLUS (2019)

- Hob & Oven

Table 9: Range of cookers that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Expert Reviews (2018b), Denyer (2018) and Sust-It (2018c).

	Option	Energy consumption	Cost	Image	Source
1.	Newworld NW601DFDOL (A rating) *Dual fuel*	1.46 kWh	400£		ao (2019a)
2.	John Lewis JLFSMC613 (A rating) *Dual fuel*	10.48 kWh	629£		John Lewis (2019a)
3.	Miele H2265B & KM6115 (A+ rating)	1.8 kWh & 11.9 kWh	549£ & 757£		John Lewis (2019b), John Lewis (2019c)

- Light bulb

Table 10: Types of light bulbs that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Energy Use Calculatior (2019), Webb (2017) and OVO Energy (2019b).

	Option	Energy consumption	Cost	Image	Source
1.	LED Light Bulb	9 W	2.4£		Screwfix (2019)
2.	CFL Light Bulb	14 W	2£		ebay (2019)

- Desktop computer

Table 11: Range of desktop computers that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Sust-It (2018d) and Turner (2016a) .

	Option	Annual consumption	Cost	Image	Source
1.	HP G2 (99 % energy efficient)	19.5 kWh	429.6£		HP (2017)
2.	Apple Mac mini – late 2014 (98% energy efficient)	20 kWh	474£		Apple (2018)
3.	ASUS Chromebox (96% energy efficient)	28.2 kWh	405£		Smartteck (2019)

- Television

Table 12. Range of TVs that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost. Inspired from Sust-It (2018e) and Turner (2016b).

	Option	Annual consumption	Cost	Image	Source
1.	Linsar 24LED1700 (100 % energy efficient)	27 kWh	179£		Hughes (2019)
2.	Linsar 24LED4000 (99% energy efficient)	36 kWh	199£		John Lewis (2019d)
3.	Philips 24PFT5303/05 (99% energy efficient)	30 kWh	139£		ao (2019b)

- Electric boiler

Table 13: Range of electric boilers that could be chosen for Project Malachi. They have been selected due to their electric usage, eco-friendliness and cost.

	Option	Energy rating	Cost	Image	Source
1.	Trianco Inca	2 kW	372£		Trianco (2019)
2.	EHC SlimJim	4 kW	649£		EHC (2019)
3.	Mattira Electric Combi	3 kW	1007£		Elnur (2019)
4.	Polypipe Single Zone	3 kW	720£		TDL (2019)
5.	Zhong Shan Opten	5 kW	Inquired		Opten (2019)

Appendix 5 - Electric consumption and costs

Table 14: Calculations for the amount of electricity consumed per day and per month and initial costs for all electric appliances based on the choices from Appendix 4.

Source	Rating	Cost (£) for all units	Time used/day for a single unit	All units usage/day	Monthly usage
Electric showers	7.5 kWh	$70£ \times 38\,units = 2660£$	10 mins	$\frac{7.5\,kW \times 10\,mins}{60\,mins} \times 38\,units = 47.5\,kWh/day$	$\frac{47.5\frac{kWh}{day} \times 365.25\,days}{12\,months} = 1445.8$ kWh
Small fridges with freezer	148 kWh/year	$299£ \times 38\,units = 11362£$	-	$\frac{148\frac{kWh}{year} \times 38\,units}{365.25\,days} = 15.4$ kWh/day	$\frac{148\frac{kWh}{year} \times 38\,units}{12\,months} = 468.7$ kWh
Washing machines	195 kWh/year	$199£ \times 3\,machines = 597£$	-	$\frac{195\frac{kWh}{year} \times 3\,machines}{365.25\,days} = 1.6$ kWh/day	$\frac{195\frac{kWh}{year} \times 3\,machines}{12\,months} = 48.75$ kWh
Hob and oven	1.46 kWh	$400£ \times 38\,units = 15200£$	30 mins	$\frac{1.46\,kW \times 30\,mins}{60\,mins} \times 38\,units = 27.74\,kWh/day$	$\frac{27.74\frac{kWh}{day} \times 365.25\,days}{12\,months} = 844.3$ kWh
Light bulb	9 W	$2.4£ \times 38\,units \times 2\,bulbs = 182.4£$	4 hours	$2\,bulbs \times 9\,W \times 4\,hours \times 38\,units = 2.74\,kWh/day$	$\frac{2.74\frac{kWh}{day} \times 365.25\,days}{12\,months} = 83.4$ kWh
Electric boiler	2 kW	$372£ \times 38\,unit = 14136£$	5 hours	$2\,kW \times 5\,hours \times 38\,units = 380\,kWh/day$	$\frac{380\frac{kWh}{day} \times 365.25\,days}{12\,months} = 11566.25$ kWh
Computer	19.5 kWh/year	$429.6£ \times 2\,computers = 859.2£$	-	$\frac{19.5\frac{kWh}{year} \times 2\,computers}{365.25\,days} = 0.11$ kWh/day	$\frac{19.5\frac{kWh}{year} \times 2\,computers}{12\,months} = 3.25$ kWh
Television	27 kWh/year	$179£ \times 2\,TVs = 358£$	-	$\frac{27\frac{kWh}{year} \times 2\,TVs}{365.25\,days} = 0.15$ kWh/day	$\frac{27\frac{kWh}{year} \times 2\,TVs}{12\,months} = 4.5$ kWh
Other	-	-	-	0.5 kWh/day	$\frac{0.5\frac{kWh}{day} \times 365.25\,days}{12\,months} = 15.22$ kWh
TOTAL		**45356.4£**		**475.74 kWh/day**	**14490.17 kWh/month**

APPENDIX 6 – The decision pathway for household battery

When choosing a household battery there are certain specifications that could be verified in order to have the most efficient system:

1. *Battery capacity*

The battery capacity is amount of electricity that a battery can store, measured in kWh. The electricity demand of the building has been calculated to be approximately ~500 kWh/day therefore the capacity of the battery should be at least 10% of this (50 kWh) as this would meet the power demand during peak hours. However, the capacity does not include the amount of electricity the battery can provide at any moment – this is consider through the power rating which should still accommodate the 50 kWh as in the case of a low power rating, the battery will provide the electricity but in a long time at a low rate (Energy Sage, 2019).

2. *Depth of discharge (DoD)*

DoD is a common measure of the battery efficiency. It is applicable to any type of battery and it represents the amount of the battery's capacity that has been used. Therefore, the battery must retain some charge due to their chemical composition (Energy Sage, 2019). For example, in smartphones, even if the screen is showing 0% battery, the battery still has some charge in order to function for the next charge.

3. *Round-trip efficiency*

The round-trip efficiency is the percentage amount of energy that can be used from the energy that has been stored (Energy Sage, 2019). A higher efficiency is equivalent for a better economic value.

4. *Lifespan*

The useful lifespan is generally between 5 to 15 years – however proper maintenance can have an effect towards the battery – for example protecting the battery from freezing (Energy Sage, 2019).

Comparison

Household batteries are mainly made with one of the next chemical compositions: lead acid, lithium ion and salt water.

Table 15: Types of household batteries and their advantages and disadvantages (Energy Sage, 2019).

Battery	Advantages	Disadvantages
Lead acid	-known technology -least expensive	-low DoD -short life
Lithium ion	-majority of household batteries -light -compact -long lifespan -high DoD	-expensive
Saltwater	-new technology -do not contain heavy metals -no need for special process during disposal -easily recyclable	-untested

The recommendation is to have a lithium ion battery due to their multiple advantages, despite its' disadvantage of high upfront cost.

Products example

On the market the household battery capacity range from 3 kWh to 13 kWh. However, higher capacity batteries exist and can be designed. Here are a few examples of diverse household batteries:

Table 16: Household batteries on the market with their specifications.

Battery	Capacity	DoD	Efficiency	Reference
Tesla Powerwall	13.5 kWh	100%	90%	Tesla (2019)
ElectrIQ PowerPod	11 kWh	-	96%	ElectrIQ Power (2018)
Powervault	4.1 – 20.5 kWh	100%	-	Powervault (2019)
Sunverge	7.7-19.4 kWh	-	93%	Sunverge (2016)
SimpliPhi	3.2 kWh	100%	98%	SimpliPhi (2018)

Sonnen (Sonnen, 2018) and Nissan (Nissan, 2018) have also their types of batteries as well. Other types of batteries are the ones of higher capacity such as Tesvolt with a battery of 500 kWh which would cover the whole demand of the building at maximum capacity, however usually such high capacity is used for wind farms and a group of solar panels (Tesvolt, 2019). As mentioned, there are plenty of batteries on the market, therefore one with the exact capacity needed in this case exists: YIY, a Chinese company makes such battery on a DoD of at least 80% (Alibaba, 2019).

APPENDIX 7 - Waste Management Plan Feasibility Assessment

Table 17: Waste Management Plan Feasibility Assessment from a study of Dahlen (2005); Skoyles, R., Bulkeley, H. and Askins, K. (2005); City of London (2010); Defra (2018a).

Waste Hierarchy	**Feasibility:** *C: Cost; EF: Environmental Friendliness; I: Integration*	
Prevention	C	Prevention programs, awareness campaigns and training programs are the most cost-effective options. Incentives to influence behavior is also a tactic used but can become costly and add obligations which become difficult to fulfill.
	EF	Very low environmental impact which is enhanced by increasing the value of waste that is prevented e.g. storing energy saved in off peak hours for use in high peak times when energy is more expensive.
	I	Easy integration into day to day operations. Reducing volume of waste increases the capacity of the other systems.
Preparing for re-use	C	Can be costly depending on labor and training costs and also involves implementing provisions for handling hazardous waste. Cost can be improved by voluntary labor as preparing for re-use generally involves quick, simple steps such as rinsing and crushing containers.
	EF	No or low environmental impact once sustainable practices are used e.g. rinsing items with grey water then fresh water rather than fresh water only.
	I	May be difficult to integrate into day to day operations as staff will be required to monitor this step.
Recycling	C	This involves sorting, cleaning, repackaging, transporting and marketing and is almost always more expensive than landfilling. Resale markets generate profit on volume and at small scales onsite recycling to repurpose waste may not be viable. Outsourcing this activity is more cost effective. Food waste is cheaper to recycle than other wastes.
	EF	Recycling has medium environmental impact because of the resources (e.g. energy and water) that are inputs to the process. Outsourcing will be more environmentally friendly as the incremental increase in environmental impact to a plant that is already operations will be minimal at the scale of operation. Composting is the most environmentally friendly recycling option for food waste.
	I	May be difficult to integrate into day to day operations because of logistics and staffing required. Reduces resource efficiency as additional funds will need to be spent
Other recovery	C	Gasification, incineration and pyrolysis are very expensive and only produce return on investment at large scales. Anaerobic digestion is the most cost-effective option
	EF	Anaerobic digestion is more environmentally friendly than composting despite placement on the hierarchy as its has lower overall environmental impact when energy generation is considered.
	I	Requires more resources and integration effort than the other options but the cost benefit of generating energy significantly increases its viability.
Disposal	C	No direct cost. Shelter may be exempt from municipal taxes which indirectly pay for disposal as a social enterprise.
	EF	High environmental impact, last resort
	I	Easy integration into day to day operations as bin will provided by municipality and can be easily placed.

APPENDIX 8 - Waste Prevention Signs

Upon arrival to the shelter, residents should be verbally informed that there are three important areas where persons must make an effort to save that keeps the shelter running free of cost, that is, energy, water and waste. The following signs which will be placed in each room should be then be explained by a member of staff before they ae allocated a place to sleep.

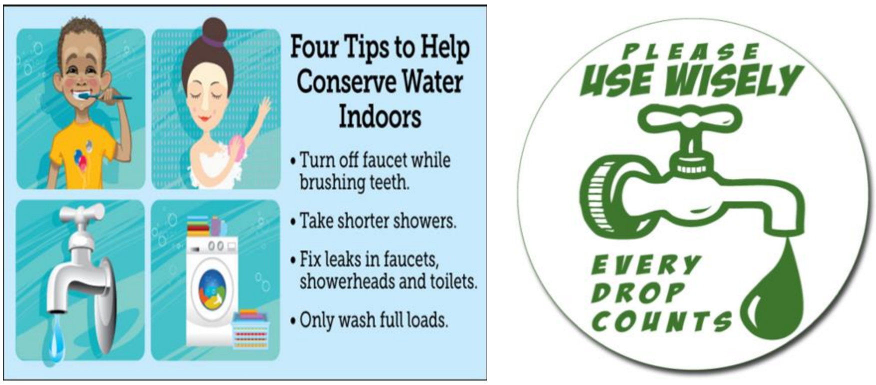


Figure 24: Water Conservation Signs - to be placed by faucets (Recycle Reminders, 2019)

Figure 25: Water Conservation Signs - to be placed by faucets (Recycle Reminders, 2019)

Figure 26: Waste Prevention Signs - to be placed by bins (Recycle Reminders, 2019)

APPENDIX 9 – Preparation for re-use and recycling guidelines

With the briefing in Appendix 8, the following guidelines from Borough of Redbridge, 2019 should also be outlined. Residents should be given a sample of 3 containers to carry out preparation themselves.

Most items can be thrown in the recycling but taking these steps increases the benefits:

- Squash or crush items like plastic bottles, cartons, and jugs, and aluminum cans to make more room in your recycle bin.
- Make sure you thoroughly rinse out all bottles and cans.
- Always remove lids from bottles and jars — those can't usually be recycled.
- Place paper items and other things that may blow away at the bottom of your recycling bin, or see if the garbage and recycling pick-up service in your area allows items to be set out in a paper bag.
- Remove all metal rims or parts from all materials you're recycling.
- Make sure no food or sticky liquid is stuck to any of your recyclables.

These bin explanations and pictures should be placed at each recycling point.

Your 3 coloured bins take different waste:

- your **blue** bin is for recyclable waste
- your **brown** bin is for kitchen and garden waste
- your **green** or **grey** bin is for non-recyclable waste

Putting the right rubbish in the right bin helps us to recycle properly. We won't collect bins with the wrong types of rubbish in them.

What to put in your 3 bins

Blue	Brown	Green or Grey
• paper - newspapers, magazines, junk mail, envelopes • phone directories and catalogues • cardboard • aerosols • food tins • drink cans and cartons • glass bottles and jars, but **no other types of glass** • plastic bottles • plastic food trays and yoghurt pots • Tetra Pak packaging	• plate scrapings • vegetable peelings • meat and bones • egg shells • cooked and uncooked food • teabags and coffee grounds • cut flowers • garden waste such as grass cuttings, prunings and leaves • **food waste may be wrapped in newspaper or kitchen paper towels**	• general refuse and pet waste • plastic bags • polystyrene • light bulbs, but not fluorescent bulbs • glassware such as Pyrex and mirrors • sanitary products • nappies

Figure 27: Recycling Bins and specified waste (Borough of Redbridge, 2019)

Brown bin or container

Things that can go in your brown bin include: glass bottles and jars, plastic bottles (but not the lids), tins, cans, tin foil and foil containers, aerosols.

Things that can't go in include: plastic bags, cling film, plant pots, yoghurt pots, plastic toys, bottle tops, plastic food trays.

Figure 28: Brown Recycling Bin Pictorial Guide (Borough of Redbridge, 2019)

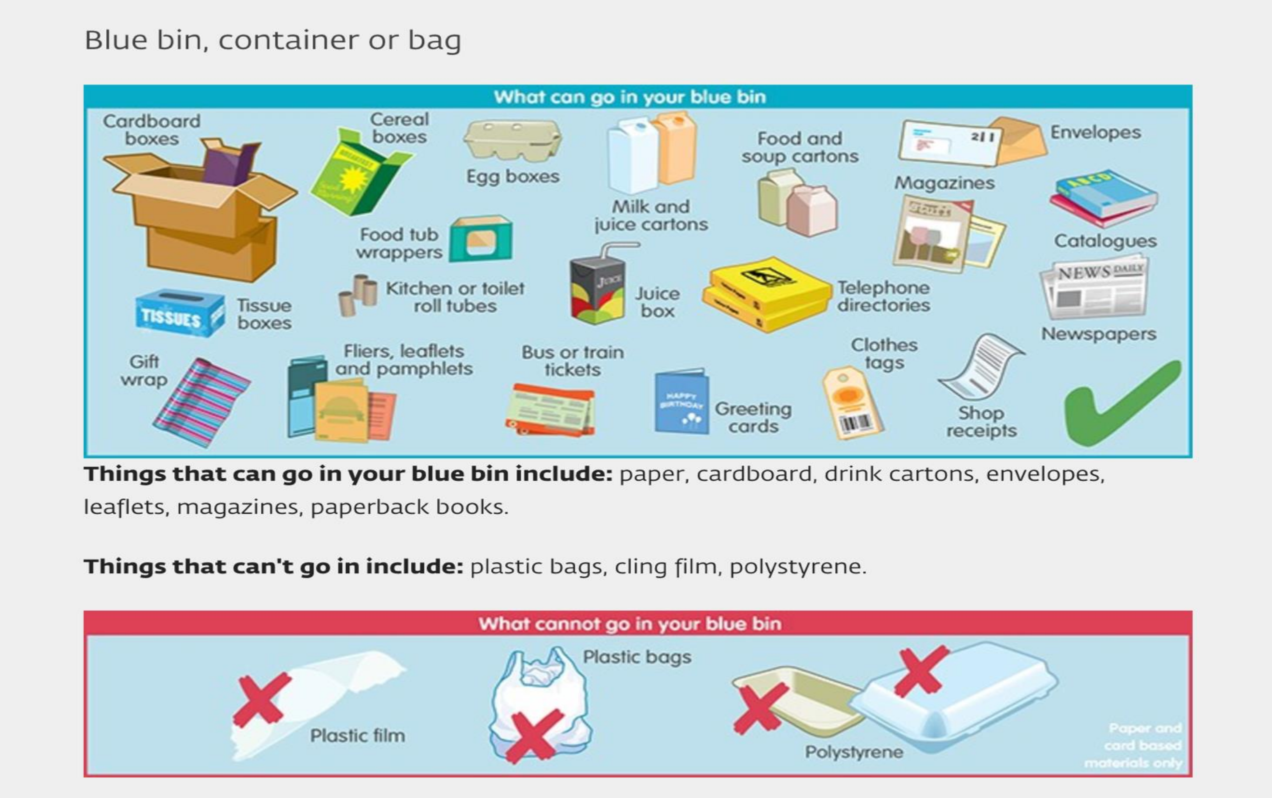


Figure 29: Blue Recycling Bin Pictorial Guide (Borough of Redbridge, 2019)

Figure 30: Green Recycling Bin Pictorial Guide (Borough of Redbridge, 2019)

Hazardous substances such as cleaning chemicals should be locked away by the staff and appropriately labelled.

APPENDIX 10 – Anaerobic Digestion in social housing projects

Table 18: Details and performance of anaerobic digesters used in social housing projects in London (Yaman, 2019)

ESTATES	Flats	Food waste		Staff cost	Digester	Biogas	Digestate	Energy generation					Income		
	total	per week	per annum	£ p/a	volume m^3	m^3/day	kgs/day	Electricity kWh_e/day	Heat kWh_{th}/day	Electricity kWh_e/year	Heat kWh_{th}/year	Equivalent	FiT & RHI income	Residual waste savings £ p/a	Totals p/a
Alexandra Place	700	1.56	80.91	£11,440	15.9	39.7	200.1	49.6	99.2	18,110.3	36,220.7	2.5 flats	£2,943	£5,667.89	£8,611
Kiln Place	164	0.41	21.32	£4,160	4.2	10.5	52.7	10.5	62.8	3,817.6	22,905.6	1-2 flats	£1,297	£1,493.47	£2,790
Broadfields	108	0.25	13.10	£2,340	2.6	6.4	32.4	6.4	38.6	2,346.4	14,078.6	1 flat	£797	£917.94	£1,715
Abbey Road	102	0.19	9.72	£1,820	1.9	4.8	24.0		29.6		10,812.8	<1 flat	£479	£681.17	£1,160
Branch Hill	42	0.14	7.23	£1,820	1.4	3.5	17.9		22.0		8,037.4	<1 flat	£356	£506.32	£862

Note: Staff costs on avergae are £8.20 per hour. All flats calculated as 1 bed studios. Energy generation from heat for Abbey Road and Branch Hill are directly from biogas

APPENDIX 11 – Control System Specifications

Table 19: Sensor specification for anaerobic digester control panels (Wrap, 2013)

Variable	Range	Sensing Principle	Input	Output signal	Operation & Maintenance	Notes	Manufacturer	Model	Cost £ (Excluding VAT)
Methane and (Carbon Dioxide) Conc.	0-100% (0-70%)	Non-Dispersive Infrared (NDIR)	12 VDC 1.8W	RS232C asynchronous serial 4-20 mA USB	Calibration: 2 yrs. Maintenance: 2 yrs. Cleaning of the optical path and eventual substitution of light source. Periodic cleaning of filter in sampling system.	Independent measure of both CH_4 and CO_2 volume fraction; internal compensation for cross-sensitivity. Temperature and pressure compensation. H_2S resistant. *Pneumatic sampling system included; with water and particulate removal system.	LumaSense technologies	ANDROS 5111	666.00 *990.00
Carbon Dioxide Conc.	0-100%	Non-Dispersive Infrared (NDIR)	3-5 VDC	0.4-2V Digital UART format	Calibration: 1 yr.	Electronics embedded in the sensor provides linearized, temperature-compensated output. Output is set to 0V under fault conditions.	Dynament	TDS0054	120.00
H_2S Conc.	0-10,000 ppm	Electrochemical 3 electrode cell with potentiostat	Buffering battery on-board	0.2 to 2 mA/ppm	Sensor lifetime: 2 yr. Drift: < 10 % yr^{-1}	Discontinuous measuring. Sensor housing, battery and voltage protection included. Humidity range: 30-98%.	IT Dr. Gambert Gmbh	I-42	202.00
Biogas Flow	0.2–20 l min^{-1}	Thermal dispersion (Mass flow)	24 Vdc @ 3.6W	4–20 mA 0 -5 V	Maintenance free.	Required: non condensing gas	Omega	FMA2812	496.00
	0-6 m^3 hr^{-1}	Diaphragm - positive displacement (Volumetric flow)	N/A	Pulse (every cf)	Maintenance free. Calibration : 1 yr.	Required: non condensing gas	EK Metering	PGM.75	77.95
pH	0 -14	Analogue differential pH sensor. Glass Electrode. Body material: PEEK	-	0 - 0.8 V	Cleaning and calibration: 1 month Maintenance: substitution salt bridge and buffer solution every 6-12 months.	Mounting: immersion into tank. Automatic temperature compensation. Built-in preamplifier. To be connected to STAMP before controller.	Hach Lange	PD1P1.99	501.00
Temp.	-20-70 C	Thermistor probe (10K)			Maintenance free.	General purpose stainless steel probe for air and liquid	QTI	QT06001C	20.00
Biogas Storage Level	0-2100 mm	Draw-wire displacement sensor	14-27 VDC	4-20 mA	Maintenance free.	IP54 protection class	Micro-epsilon	WPS-2100-MK77	187.00
	60-2000 mm	Ultrasonic	10 -30 VDC	4-20 mA	Maintenance free.	IP54 protection class	Pepperl-Fuchs	UB2000-F42S-I-V15	163.51
Digestate Tank High Level		Level Switch							
Power to electrical motors	Primary nominal current: 5-50 A	Split-core transducer	20-30 VDC	4-20mA (RMS output)	Maintenance free.	-	LEM	AT-B420L	43.86
H_2S in air	0-20 ppm	Conductometric - metal oxide semiconductor	5 VDC	N/A	Maintenance free. Lifetime: 3-5 yrs. Field calibration available with Field Calibrator and Ampoules.	-	General Monitors	50445-9	50.00
CH_4 in air	500-10,000 ppm	Conductometric - metal oxide semiconductor	5 VDC	N/A	Maintenance free.	-	Figaro	TGS 2611	30.00

Appendix 12 – WRAP Cost Model

Tables 20 and 20a: Cost breakdown for anaerobic digester based on model developed by Wrap, 2013 from case studies of micro digesters in operation in London

Item	Budget base price excluding VAT
Base Digester Systems	
1m3	£1,324
2m3	£5,800
6m3	£12,000
20m3	£18,000
Ancillaries	
Control systems	Variable £1,270 to £2,700
Pre-feed system: mill, pump & 650l pre-digester	£5,300
Pasteuriser - 1m3	£5,000
Biogas boiler	£1,150
Water press separator	Variable: £2,500-£3,500
Gas holders - .15m3 to 5m3	Variable: £200 -£3,500
Biomethane upgrading	£2,500 - £30,000 (plus fill equipment)

1m^3 system

Total capital cost	**5,984**
Annualised capital cost	239
Total operational costs (£/yr)	967
Total electrical cost	-
TOTAL OPERATING COSTS (Waste handling, parts, digestate, maint, electricity)	967
TOTAL ANNUALISED COST	**1,206**

No pasteuriser will be used for this size. Pre-feed will be manual and estimated to cost £1000 to build. Gas boiler will not be used, if temperature drops below anticipated with insulation a small electric heater which has a low electrical demand (which costs about £30) will be placed in the container to maintain the ambient temperature (see schematic design Fig. 13). Biomethane upgrading is optional as hobs can utilise the output. We hope that a partnership with UCL energy and/the Calthorpe project can offset operational costs per year which is mainly maintenance.

APPENDIX 13 - Home Biogas Specifications

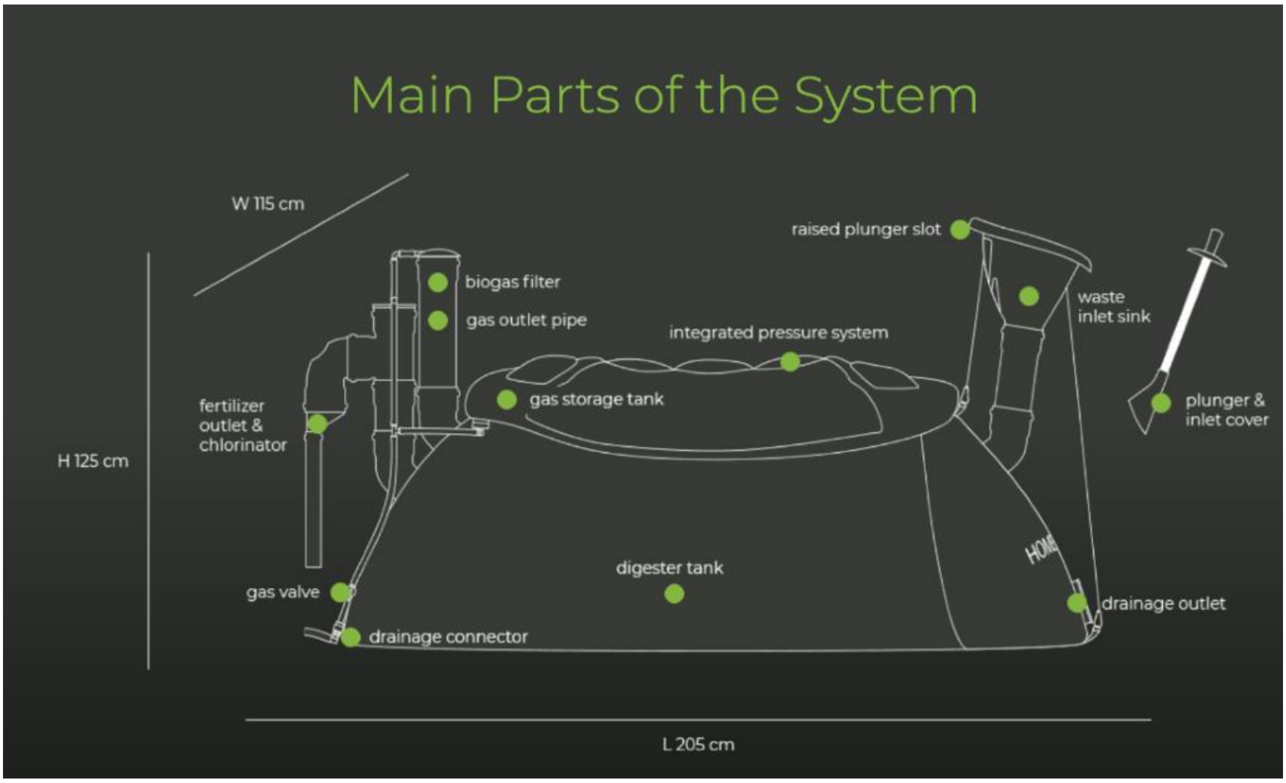


Figure 31: Homebiogas digester and specifications (Homebiogas, 2017)

Dimensions: 210x115x125cm/83x45x49
Gas tank volume: 700 litres
Digester Tank Volume: 1200 litres
Maximum daily quantity of kitchen waste: Up to 6 kg
Stove cooking time: Up to 2 hours daily
Accessories: Biogas stovetop and connection, 700L gas tank with a mechanical pressure release mechanism, 7m/23ft pipe from the system to the kitchen stove, Gas filter to remove odor, 1300L flexible digester tank, Assembly manual, Warranty, 3m/10ft indoor gas tube with connectors and gas valves, user friendly fertiliser outlet
Maintenance guide: Included
Homebiogas, 2017

Proposed retrofit: insulated box 230x135x145cm

APPENDIX 14 - Food Sorting Guide

Food waste will be taken from the green recycling bin. Food waste that can be put in the digester include meat, dairy, breads, tea, coffee, fruits and vegetables and can be supplanted by other organic waste such as garden clippings. Any food can be put into the digester, however, to reduce the likelihood of imbalances such as an increase in PH that can result from higher C/N, the following is a guide to foods closest to the recommended 25-30:1.

Food scraps (17:1)
Vegetable Scraps (25:1)
Coffee (25:1)
Fruit waste (30:1)
General garden waste - nothing too fibrous like small branch clippings (30:1)

When the food is put into the digester's pre-feeder, the manual mixer will need to be turned to shred/chop the food. This will be done to increase the surface area so food will be broken down more efficiently. As the microorganisms will break down the waste even if it is not chopped, the manual mixer can be turned for about one minute each time food is put in.

The following foods should NOT be put into the digester:

Excreta (hazardous and should not be handled)
Wastewater (potentially hazardous and should not be handled)
Paper, plastics and textiles
Woods and other high/dense cellulose material

Fats and breads yield higher biogas production (Figure 14), while fruits and vegetables have a good C/N ratio and this should be minded when procuring the shelters food.