Net Zero Carbon for The Bartlett, UCL: An appraisal of options for reducing emissions caused by use of energy in buildings

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Introduction

This research paper will seek to provide recommendations to reducing carbon emissions and lowering energy consumption from buildings at University College London (UCL), more specifically, The Bartlett, through appraising current and potential technological developments which may help to bring UCL closer to net-zero carbon. With the effects of our change in climate becoming more vivid overtime, the matter is pressing and will require a prompt, effective and structured response to ameliorate the impacts of high emissions.

Net-zero carbon refers to the balance between the amount of carbon dioxide emitted and the amount removed or sequestrated from the atmosphere within defined system boundaries and within a specified period (National Grid, 2021). For this study we are focusing on UCL buildings and more specifically, The Bartlett, with a particular focus on the main Bartlett building, 22 Gordon Street.

A net-zero carbon building would be a highly energy efficient building that is fully powered from on-site and/or off-site renewable energy sources and offsets, according to the World Green Building Council and Building AGU (2021). System boundaries and the specified timeframe are an integral part of defining net zero as a building may achieve net-zero carbon in a specific year of its life cycle, but may have not achieved net-zero carbon throughout its entire lifecycle. The inverse may also occur, a building may have achieved net zero carbon up until a point of its life cycle but may not have done so in a specific year. Furthermore, system boundaries are important, as if a building is being extended or downsized we must take into consideration the new balance of emissions.

Currently, at UCL it is estimated that approximately £14 million is spent on energy per annum, from which approximately over 50% (Sustainable UCL, 2021) of this figure is from actively heating, cooling and ventilating our buildings, Not only does this represent a significant cost to the university, it resulted in emissions of over 49,800 tonnes of CO_2 in 2014 (Sustainable UCL, 2021) which is equivalent to the emissions resulting from fuelling 45 homes in the UK for a year.

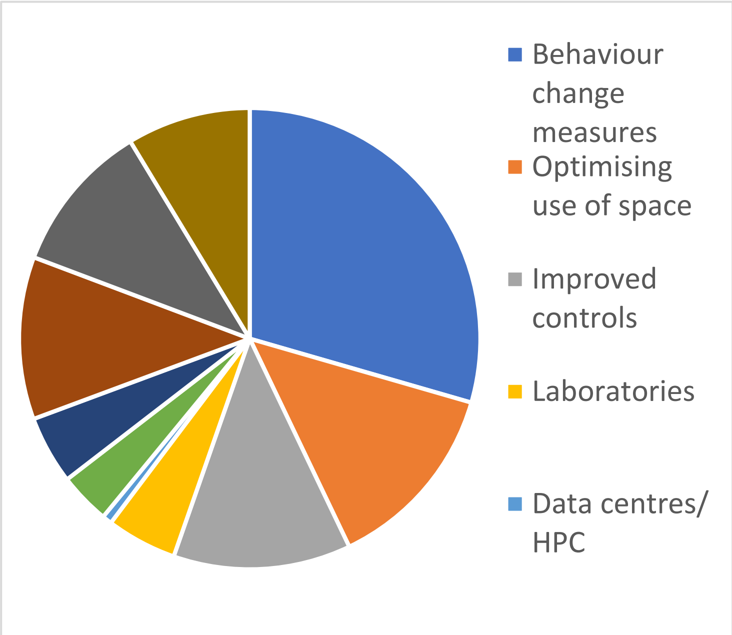
Different methods and approaches can be taken to reduce energy consumption and carbon emissions. We look at different solutions such as behavioural changes, the automation of HVAC systems, retrofitting existing buildings, and the potential of maximising the use of onsite renewable energy sources, as these have found to be the areas where change will have the most influential effects on UCL.

Methodology section

The method and approach taken for conducting this essay was to look at the data provided by Dr. Nick Hughes, and to identify relevant options through literature review, using google scholar, research gate, and UCL library, using key words and phrases such as “Net Zero Carbon for Existing Buildings”, “Institutional Buildings Net Zero Carbon”, “Renewable Energy for Institutional Buildings” and “Behavioural Changes in Institutional Buildings” to find relevant studies, in addition to the data provided by UCL colleagues. These have all contributed to the basis of arguments and evidence in this paper.

Behavioural Changes

According to Sustainable UCL (2021), changing behaviour will have the largest impact in reducing climate change impacts, by reducing energy consumption. The pie chart in Figure 1 displays the potential impact each sector can have in reducing emissions. Behavioural change is the largest initiative occupying approximately 33% of the total chart. Behavioural changes in this context would refer to the intentional changes in actions or operations from the occupants of our defined system, UCL and more so specifically the Bartlett.



(Figure 1, Sustainable UCL, 2021)

Figure 2 shows the energy usage of 22 Gordon Street from Jan 2019 till Jan 2020. The blue bars represent total electricity consumption on a weekly basis and the green bars represent heating deand. 2019 is the most recent year without the full impact of Covid, which will briefly be addressed later on. From the graph we see that off term times such as 31/12/2018 (Christmas break) and 22/04/2019 (Easter Break) have the lowest energy usages. This is what we expect as less people occupy the building. However, this also may suggest that that the way we use the building can be a large factor in reducing consumption as the consumption rates drop by approximately 50% in both weeks.

(Figure 2, Sustainable UCL, 2021)

First and foremost it is important to address the importance of all users in making such change. The idea of making considerable reductions to carbon emissions & consumption vis-a-vis behavioural changes require a holistic approach and support from all levels of the institution (Klein et al., 2012). That is a top-down approach which requires participation from all occupants from lecturers, students and building staff. Alongside all occupiers participating, a specifically allocated management committee would be responsible for initiating, managing and enforcing the scheme on behavioural changes.

In terms of initiatives, studies in universities have suggested that giving users access to their energy usage in real time can help influence their actions in decision making. In the halls of residence at the University of Kent (Emeakaroha et. al, 2012) real time electricity data was captured using smart sensors, and relayed on visual web interfaces and energy delegates (acting as motivators). This created a system that induced information strategies to simplify complex data on energy usage, encourage dialogue, distinguish facts from opinions, and most importantly to personalise the matter of energy consumption. Since all or at least most of the students possessed a PC, they were all able to receive feedback, the result was that they found a 32% reduction throughout all halls.

Another similar study by Fabi, et al in 2017 showed how the awareness of measurable benefits such as reduction in energy consumption influenced behavioural change within the University of Cambridge by providing real time feedback loops. Unlike the previous stated study which was limited to students in student accommodation, this study was expanded to all staff members and students within the university. In this study, the University of Turin conducted research in the University of Cambridge by adopting a real time system of both building sensors and wearable sensors categorised as Direct Virtual Sensors (DVS) and gathering comfort-related feedback by the users. Building energy simulation, a software known as (IDA ICE, v.4.6) was used to connect the energy outcomes to the desired comfort levels, alongside a phone app to display real time energy consumption of each user's action. Users were divided into informed users and uninformed users. Well informed users were able to adopt a pro-active behaviour in campuses, which ultimately showed a 29% reduction in usage.

Beyond the scope of this study, UCL can consider using Building Information Modelling or Internet of Things to record most optimal timings of energy use with optimal thermal comfort to then automate and programme the HVAC systems.

UCL may seek to conduct similar initiatives where prizes are won, providing factual information distinguishing from opinions to display how actions contribute to overall energy consumption, and to provide confidence in changes of behaviours. Individuals may further be put into groups for whom they are accountable to. With the objective of reducing individual consumption and thus overall user consumption, the following questions can be considered when implementing such a grand schemed idea:

- "How are we going to achieve improved energy performance?"
- "Who will be responsible for ensuring strategies are implemented?"
- "What resources in terms of personnel and finance are required to implement the proposed management system?"
- "What additional training is required for staff?"
- "What savings are likely to be achieved?"
- "What enhanced reputation and other non-financial benefits might the UCL achieve through the proposed initiatives?"

At the minimum UCL can at least consider raising awareness, especially in buildings where the consumption levels are exceedingly high. Another study (Tovey and Turner, 2006) showed that 25% reduction in electricity consumption can be achieved through encouraging occupants to switch off unnecessary appliances when not in use, and through creating "Energy Champions". However, though East Anglia achieved this in 2006, results may vary depending on several factors, such as institutions' environmental goals, policies, and available budget.

Retrofitting

Retrofitting is the process of adding a component to a building that it did not have when it was initially manufactured. It is said that retrofitting an existing building can oftentimes be more economical than building a new facility, as over time, occupational use will create wear and tear which may lead to a reduction in energy efficiency. In the lens of energy consumption, existing buildings constitute the largest fraction of the built environment, so the idea of retrofitting has become more popular as it is generally more cost effective and convenient than demolition and reconstructing the whole building. Practically, initiating a retrofit involves the evaluation of the use of the building by the occupants and redesigning building elements which might offer an opportunity to maximize space efficiency, reduce energy consumption and lower the operating costs of the building.

Considering 22 Gordon Street has recently been retrofitted, we would expect it to perform better than non-retrofitted/refurbished buildings. So in this example we look at the consumption rates of 22 Gordon St per square meter in comparison to Central House which has not been refurbished. For the period 01/01/2019-01/01/2020, 22 Gordon Street which has an area of 8,454m2 consumed 1,219,298.2 kWh of electrical energy and Central House which has an area of 5052m2 consumed 713,650 kWh of electrical energy.

This means that annually for total electrics:
- for 22 Gordon Street, 144.00kWh of energy per m2 is consumed
-for Central House, 142.02 kWh of energy per m2 is consumed.

In other words, the electricity consumption of both buildings per square metre is relatively similar.

For the same period the consumption for heating was 423,282.9 kWh for 22 Gordon Street and 190,890.75 kWh for Central House

This means that annually for total heating:
-for 22 Gordon Street, 50kWh of energy per m2 is consumed
-for Central House, 37kWh of energy per m2 is consumed

In other words, it appears that 22 Gordon Street has a higher consumption of heating energy per square metre than Central House, in spite of the recent retrofit of 22 Gordon Street. Our results may not match our hypothesis for several reasons:

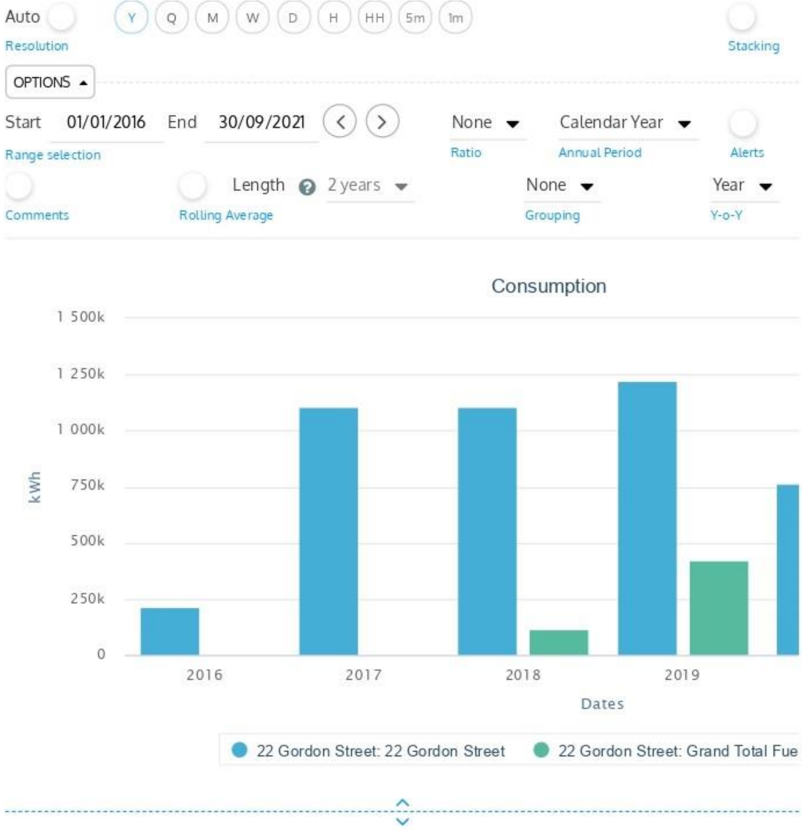
-The building use of Central House may require less energy. Gordon Street has lectures for 1st-4th years taking place and work spaces for architecture students carrying out projects.

-Times in which the building is occupied – it may be that Gordon Street's out-of-hours period is less than that of Central House

-Control of the building – Central House may have a better management system of energy use or well-informed occupants in comparison to Gordon Street

Though these factors could be contributing factors, it also may be that the refurbishment or retrofits were not conducted in ways that would not reduce occupiers' energy consumption. Or, since we are unaware of the date the refurbishments/retrofits were carried out, it may be that retrofits were conducted so long ago that the overall building energy efficiency has declined so much over years that a new retrofit is required.

It is for this reason, we look at figure 3 below to show the consumption over the years, the blue bar notates total electricity, the green notates total energy used for heating.



(Figure 3, Sustainable UCL, 2021)

This graph shows a drastic increase in consumption from 2016 to 2017, this maybe due to the period in which energy consumption calculations were initiated, if they started at the latter quarters of 2016 this would make sense. This strongly may be the case as there are no recordings prior to 2016. The same applies for the green bar in 2018. There is stability between 2017-2019, however, there is a gradual increase from 2018-2019 and this may suggest more use, more students admitted, or even a wear and tear of equipment such as heaters, boilers or cooling systems. 2020 is lower than 2019 as we would expect with the pandemic enforcing user to work at home and therefore less use of the building.

However, the idea that retrofitting should be conducted to decrease consumption levels and emissions, should still be thought of as efficient. The following results show that retrofitting can significantly reduce energy consumption. An energy efficiency retrofit study by El-Darwish and Gomaa suggested that simple retrofit strategies including solar shading, window glazing, air tightness followed by insulation, can decrease energy consumption by 33%. More specifically, a study conducted by Ardente. et al (2011) suggested that most significant benefit reductions derived from the improvement of envelope thermal insulations, lighting and glazing. However, for this study, we will consider window glazing, insulation and thermal bridging.

Window Glazing

Windows have several functions including providing exit and entry points, and the transmission of natural light; but they also play a key role in heat transfer. Ordinarily, 11-20% of heat is lost through windows (El Darwish and Gomaa, 2017)

3 main factors that influence heat transfer are season, building type and operation of the building. Windows should maintain low U values, that is, a measure of thermal transmission. In seasons where the external temperature is higher than the internal, it means that the material can resist thermal energy and reduce heat transfer reducing the need for an air conditioner. The opposite also applies, in cooler seasons, high thermal resistance means less heat loss to cooler external environment and therefore less applications of heaters. Most buildings have moved away from single glazing windows which provide U values of around 4.5-5.6 W/m2K to double glazing windows 2.8-3.0 W/m2K (El Darwish and Gomaa, 2017) which is the likely utilisation of the Bartlett. However, there are other options such as modern double-glazed units with argon gas and low-E coating that have U values of around 1.2 W/m2K, and for a greater expense triple glazed units, which are used in highly sustainable buildings in London such as The Shard, which uses low iron glass, or The Gherkin, which uses tempered and tinted glass. Many of these state-of-the-art structures generally use a triple-glazed window system with two layers of low-e glass, high solar heat gain, and a low conductive frame. Exterior shading is used for best results in a moderate European climate (Aspire Bigolds, 2018).

Insulation and thermal bridge

Many of the UCL structures are mass structures, such as concrete or masonry. Many of such materials contain structural cavities that act as thermal bridges. This elicits the consideration for insulation. Cellulose, fiberglass, and mineral (rock or slag) wool, tend to be the most common materials used, and so it is likely that the most recent refurbishment of the Bartlett contains this material. Alternatively, Structural Insulation Panels (SIP) as demonstrated in figure 4 is a more recent approach to insulation. This is a prefabricated building panel with strand board or plywood outer face and an insulated interior such as an Expanded Polystyrene System. The energy savings potential with such insulation is 50% of each room that is insulated.

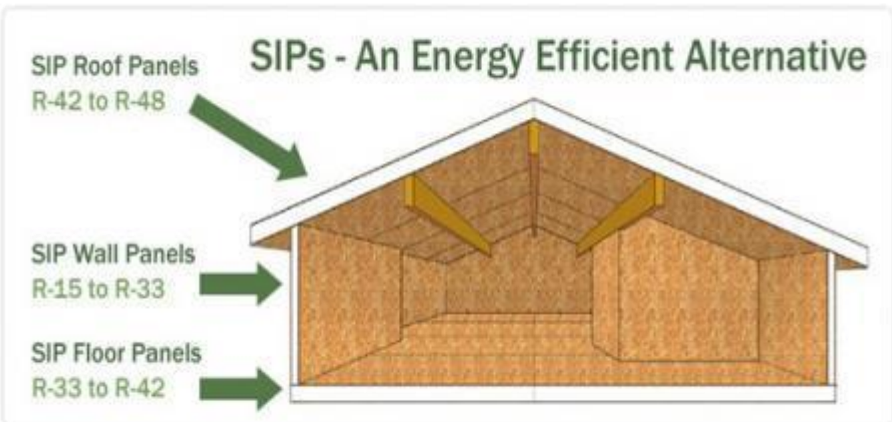
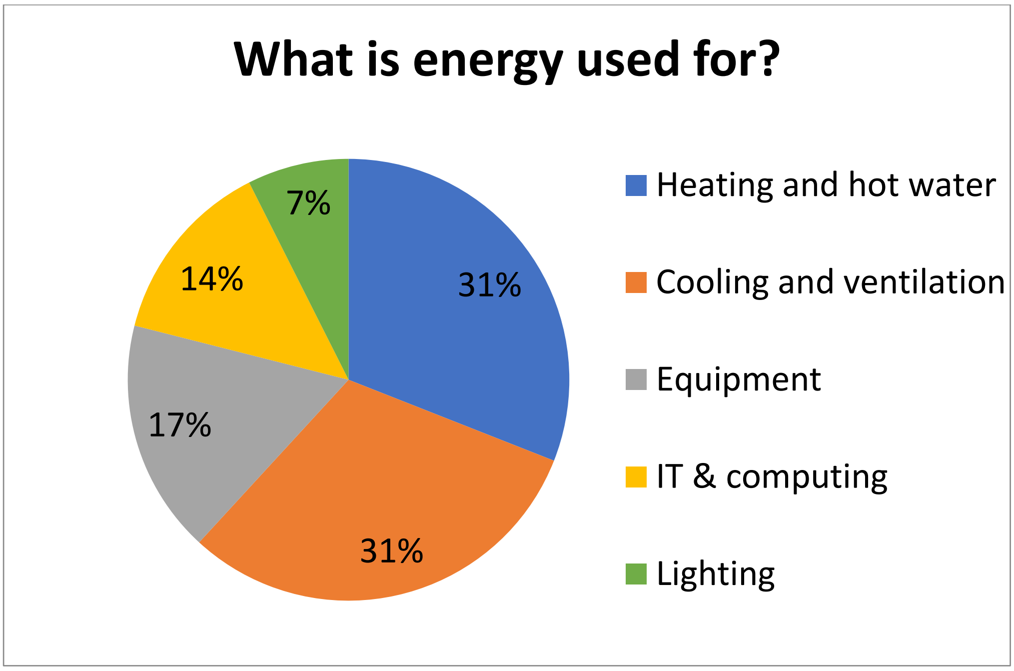


Figure 4 (About Saving Heat, 2018- https://www.aboutsavingheat.com/blog/structural-insulated-panels)



(Figure 5, Sustainable UCL 2021)

HVAC/ Alternative

Heating, ventilation and air conditioning (HVAC) systems are said to be the largest end use in both the residential and non-residential sectors, now considered essential when considered a luxury several decades back. Perez-Lombard, Ortiz and Pout estimate HVAC energy consumption of a standard HVAC system to be 50% of the overall usage. The pie chart in Figure 5 shows that heating, cooling and ventilation accounts for 66% of the energy usage in UCL. The fact that this above the average of 48%, may suggest an excess usage in electrical use to maintain thermal comfort, or maybe that the systems used in UCL may require updating or changing to more energy efficient systems.

A way the Bartlett may improve the energy efficiency of the HVAC systems is through zone control. This is where similar sized rooms, utilised for similar purposes are programmed and controlled unanimously to be at the same temperatures at the same times during the day regulated by a single thermostat sensor. This way end users are able to individually and only slightly adjust temperatures to match thermal comfort levels. In 2009, DLS found that zonal systems decreased energy consumption by approximately 25%.

Another consideration for the current HVAC system is to reconfigure the positionality, specifically the location of the fresh air intake. An area with contaminated air can alter the freshness of the air released, especially in warmer seasons. Lastly, we may consider incorporating a renewable energy source to power them during the daytime such as solar panels since they consume a large amount of energy. In turn, the maximum load can be moved to cooling devices at night through off peak power so thermal energy is retained and then utilised in most utilised hours for heating or cooling and therefore lowering peak demand.

The pie chart in figure 5 shows that 31% of the energy at UCL is used for cooling and ventilation, which is equal to the heating and hot water. Given the temperate maritime climate of the UK and the more abundant cooler seasons we may have expected this figure to be lower. So, this may suggest an excessive use of cooling systems in warmer seasons or the usage of non-optimal cooling systems. Conventional HVAC systems use vapour compression systems (VCR) for cooling which have an electricity demand of around 2110 kWh/a. If UCL was using conventional systems, much energy consumption can be decreased by incorporating a HVAC system with a desiccant system of reasonable dimension. Such a system has an energy demand of 850 kWh/a , that is 2.6x less energy demand than a standard system. Furthermore the green-house gas saving potential is calculated to be approximately 60% (Erhat. et al., 2016).

Renewable Energy

The use of renewable energy sources is a vital consideration in the pursuit to reducing emissions. Natural sources that do not deplete the Earth's resources should be maximised in order to attain fuel security, diversification and to minimise greenhouse emissions. In this report we'll marginally address attaining renewable energy onsite. From an institutional perspective, it may initially seem farfetched to run UCL buildings all on renewable energy. However, with 35% of onsite energy use sourcing from the district network and Gower Streets Heating Network contributing 28% of UCL's total emissions (Sustainable UCL, 2021), a switch in energy source reducing dependency on local network sources could show a dramatic decrease in carbon emissions.

Solar energy

Currently the Bartlett UCL, 2021) building has 16 kWp of solar PVs installed on roof to generate electricity from sunlight which has a predicted energy generation of 14,674 kWh/year (Sustainable UCL, 2021). Across UCL, currently there is 600m2 of solar panels producing 120,000kWh pa and it has been estimated that there is space for 2400m2 more to be added. Excluding factors such as position and efficiency, we may be able to generate 480,000kWh pa which is approximately 40% of the Bartlett's energy use in 2019. An example where this has been successful is the PEARL building (Person-Environment-Activity Research Laboratory), which has a CO_2 rating of -9|A. This is said to be partially as a result UCL's largest installation of photovoltaic solar panels covering the entire roof. Perhaps examples for implementing this on current UCL buildings can be taken from the same contractors or sub-contractors that achieved this design and construction.

In application we would need to consider factors such as maintenance, wear and tear as well as what machines, rooms or systems we need these solar panels to channel. As found earlier, channelling renewable energy equipment to power high energy consuming units was stated to be the most beneficial. Further notes to account for are whether the space in question may be more appropriately used as a green garden, absorbing CO_2 and increasing biodiversity.

Wind Turbines

The function of a wind turbine is to convert a steady flow of wind to electrical energy. The amount of generated electricity depends on the wind's strength and the calibre of turbine attained. We generally have the idea of large turbines, which may be complicated when considering planning permission for the installation and running of such system or risk assessments especially when browsing the idea of an on campus one and visibility interferences. Alternatively, incorporating turbines to our taller buildings or building in turbines to future UCL buildings may overcome some of the mentioned challenges. A local example of this design is the Strata located in Southeast London displayed in figure 4 which generates 8% of its own electricity usage across the year. A further example of a similar design is The Bahrain World Trade Centre. These designs may appear sophisticated however, the option of installing small units of turbines may be a viable option for the currently built buildings.

(Figure 4)

Conclusions

From the data obtained, there is clear scope for improvements in reducing consumption and emissions at UCL, or specifically the Bartlett. This includes the occupational perspective where behaviours are influenced, and the structure of the building, including retrofitting through altering or improving the current HVAC systems as well as the façade and insulation. Then overall energy building efficiency can be improved through the lens of exploring onsite renewable options on existing or new UCL buildings. The results of this study can be supported by a recent study undertaken by Chen et al. (2020) which revealed that the efficiency of a building pertaining to energy can be divided into 3 categories (1) improvement of building features to decrease the building energy demand; (2) use of energy efficient equipment and technologies, and (3) occupant's behaviours. This is further supported by the work of Ruparathna et al. (2016), where three contextual elements for energy performance improvement in buildings were found, namely technological changes, organisational/managerial change and behavioural change. The track to obtaining net zero first starts from seeing how we can locally reduce emissions and consumption and finding a measurable means to track this.

For future buildings it may be beneficial to take designs from highly energy efficient buildings such as One Angel Square, Manchester, The Walkie Talkie Building, London (for its solar panel and roof garden space), The Gherkin, London (design in heat retention abilities). On the other hand, looking at what other universities have done in the UK or around the world may inspire ideas, for example the University of Sheffield who are using renewable sources to cut emissions (University of Sheffield, 2021). Further considerations may lie in creating more green spaces which will also provide spaces for amenities.

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