Evaluating Combined Cooling, Heat and Power in Brent

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ABSTRACT

The Brent Council aims to further increase the energy-efficiency and cost-effectiveness of the CCHP biofuel engine powering the Brent Civic Centre. Under the supervision of the Council's Energy Manager, Anís Robinson, we, the WPI project team, have analysed the Council's existing data regarding the engine and the Civic Centre's energy consumption to determine best-use cases for the engine. We have developed deliverable tools for the Council to facilitate future cost-benefit and energy-saving analyses regarding the operation of the CCHP.

AUTHORSHIP

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EXECUTIVE SUMMARY

If the reduction of global anthropogenic greenhouse gas emissions is not taken seriously, the resulting long-term effects could impact our way of life in unfavorable and irremediable ways. The city of London has incorporated the United Kingdom's policies regarding sustainable energy-efficiency and greenhouse gas emission mitigation into their building development. The London Borough of Brent has demonstrated their commitment to renewable energy with the conception and planning of the Brent Civic Centre. The Brent Civic Centre is a Building Research Establishment Environmental Assessment Methodology (BREEAM) Outstanding accredited public building, and owes its merit to its Combined Cooling, Heat, and Power (CCHP) biofuel engine.

The operation of the CCHP is crucial to the Brent Civic Center's energy-efficiency and carbon emissions-reduction. The CCHP can provide both electrical and thermal energy from a single system, whereas conventional energy generation methods require separate plants for each. Most carbon emissions from conventional energy generation means stem from the energy lost through production. A CCHP scheme, however, captures the waste energy from power generation and converts it to either heating or cooling, depending on the building's thermal demands.

As a further means of emissions-reduction, the Brent Civic Centre's CCHP runs on a second generation biofuel, specifically pharmaceutical fish oil residue, which is a sustainable and eco-friendly alternative to diesel. Despite the environmental benefits of using fish oil, its continued use has become costly enough to justify further investigation into other fuel options which could be economically beneficial to the Council. Regardless of the fuel choice, the optimal operation of the CCHP requires that the engine runs at its maximum electrical and thermal

capacity, and that 100% of its energy output is being utilized. If the engine's energy output is not at 100%, the Council will not maximise the benefits from the energy-efficiency and cost-effectiveness of the CCHP.

During our tenure in the Brent Civic Centre, we were tasked with developing recommendations for the best economic and environmental use of the CCHP. Specifically, we compared the Brent Civic Centre's energy load to the CCHP's total output capacity, the best way to match the thermal load of the building to the capabilities of the CCHP, and performed a cost-benefit analysis of the possible fuel options for the CCHP. In conjunction with our analysis, we conducted a preliminary assessment of the Civic Centre's energy efficiency qualifications for BREEAM In-Use accreditation.

Using the Civic Centre's available energy consumption data and CCHP's energy output data, we analysed the feasibility of using the CCHP to its fullest potential. We also attempted to contact Fleetsolve, the company responsible for manufacturing, maintaining, and providing fuel for Brent Civic Centre's CCHP, for fuel data pertinent to the Civic Centre's specific biofuel engine. Additionally, we developed tools for further fuel- and energy-use analysis conducted by the Council. Based on recent trends in the Civic Centre's electrical usage data, we have determined that the building will have the electrical load for the CCHP to output 100% of its electrical energy within the building at all times.

Throughout our research, we discovered numerous additional areas for research and potential methods to utilize the CCHP's thermal energy to its fullest potential. Consequently, we developed the following five recommendations:

- ***Recommendation 1:*** *Establish the Civic Centre's thermal profile.* Without the building's thermal profile, the Council will not be able to assess the building's thermal usage nor the amount of excess thermal energy available from the CCHP. To build the thermal profile, the Council must remedy their metering and Building Management System (BMS) issues.

- ***Recommendation 2:*** *Overnight preconditioning of the building.* Bringing the Brent Civic Centre to an optimal temperature when the building is least occupied would be an easy means of using whatever excess thermal energy that is produced from the CCHP.

- ***Recommendation 3:*** *Increase the datacentre load.* A datacentre is a space where a company or borough keeps their servers and relevant data storage equipment. The Brent Council can offer to host the datacentres of other Councils in order to increase the occupancy of the datacentre, the Civic Centre's cooling load, and the Council's revenue.

- ***Recommendation 4:*** *Decentralised Energy Network.* Whatever thermal energy the Brent Civic Centre is not using at any given time could be distributed throughout a decentralised network. This approach to the CCHP could allow for continuous use of the CCHP's maximum energy output.

- **Recommendation 5:** *Contact Fleetsolve for fuel data.* Fleetsolve, as the CCHP and biofuel provider for the Council, has the only accurate fuel data for the Civic Centre's CCHP. Since we could not get a hold of Fleetsolve ourselves, it is imperative for the Council to retrieve the fuel data in order to compare the available fuel options.

Once the the Council creates the Civic Centre's thermal profile for the Civic Centre retrieves Fleetsolve's fuel data, the Council can then use the tools we have created in order to determine which fuel would best suit the Council's interests, and how much excess thermal energy is available for preconditioning, datacentre expansion, or decentralisation. Using some permutation of these methods, the Council could maximise their profits while minimizing their impact on the environment.

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ACRONYM SHEET

ADE .... Association of Decentralised Energy
BMS .... Building Management System
BRE .... Building Research Establishment
BREEAM ...... Building Research Establishment Environmental Assessment Methodology
CEB .... Council of Europe Development Bank
CCHP .... Combined Cooling Heat and Power
CCL .... Climate Change Levy
CHP .... Combined Heat and Power
CHPQA .... Combined Heat Power Quality Assessment
CO_2 .... Carbon Dioxide
CRC .... Carbon Reduction Commitment
DECC .... UK Department of Energy and Climate Change
EC .... European Commission
EEVS .... Energy-Efficiency Verification Specialists
EIB .... European Investment Bank
EUA .... European Union Allowance
EU ETS .... European Union Emissions Trading System
EU .... European Union
FMD .... Fuel Mix Disclosure
GLA .... Greater London Authority
$GtCO_2$ .... Gigatonne Carbon Dioxide
IEA .... International Energy Agency
IPCC .... Intergovernmental Panel on Climate Change
JESSICA .... Joint European Support for Sustainable Investment in City Areas
Kg .... Kilogram
kW .... Kilowatt
kWe .... Kilowatt Electric
kWth .... Kilowatt Thermal
LEC .... Levy Exemption Certificate
LEEF .... London Energy Efficiency Fund
LWARB .... London Waste and Recycling Board
NAMAs .... Nationally Appropriate Mitigation Actions
Ofgem .... Office of Gas and Electricity Markets
REGO .... Renewable Energy Guarantees of Origin
RFFGS .... Relevant Fossil Fuel Generating Station
RHI .... Renewable Heat Incentive
RO .... Renewable Obligation
ROC .... Renewables Obligation Certificates
UDFs .... Urban Development Funds
UNFCCC .... United Nations Framework - Convention on Climate Change
UK .... United Kingdom
US .... United States
US EPA .... US Environmental Protection Agency

1.0 INTRODUCTION

A 2013 report by the United States Environmental Protection Agency (US EPA) concluded that 31% of all greenhouse gases come from the production of electricity (US EPA, 2013). The consequences of these emissions are too drastic to ignore, from heat waves and lack of rainfall to flooding and fluctuating temperatures, greenhouse gas emissions and their resulting impact on the climate have become a global concern. Since greenhouse gas emissions trap heat in the atmosphere, climate change mitigation policies have been centered on the reduction of carbon dioxide emissions, which constitute most of greenhouse gases from human activity (Id).

London Mayor Ken Livingstone, and every subsequent mayor since 2004, addressed the issue of climate change in the spatial development strategy known as the *London Plan.* As part of this continually updated plan, the mayors hope to reduce London's carbon dioxide emissions by 60% by 2025 (London Plan, 2015). This can only be achieved through the cooperation of the London boroughs, and through practices consistent with the sustainable energy portion of the *London Plan*. Subsequent local plans are in continual development by the individual boroughs in order to contribute to the meeting of the plan's reduction goals.

Our project has been shaped around the reduction goals of the London borough of Brent. The policies in place in Brent are influenced by the regional goals of London, the national goals of the United Kingdom (UK), the framework provided by international treaties, and relevant incentive programs promoting the use of low-carbon technologies and practices. The Brent Council has shown their commitment to environmentally friendly energy production and the Brent community through the establishment and design of the Brent Civic Centre (Brent Council, 2013).

In 2013, the Civic Centre was recognized as one of the greenest public buildings in the UK (Building Research Establishment Environmental Assessment Methodology [BREEAM], n.d.). The Civic Centre earned an 'Outstanding' score, the highest available rank from the BREEAM accreditation (BREEAM, n.d.). The BREEAM accreditation is a globally recognized rating system for buildings based on sustainable building design. Among the key features that earned this building its environmental merit was its CCHP liquid biofuel engine.

The CCHP engine was originally designed to power a large, on-site, datacentre. However, due to advances in cloud technology, the datacentre has been filled to less than its intended capacity. The actual load of the datacentre has left, what we believe to be, an excess in engine capacity that the Council would like to use in an effective manner. The engine currently runs on waste fish oil residue, which is becoming increasingly expensive, but the engine can run on 15 other types of fuels. Fourteen of these 16 different fuels that the CCHP can operate on are types of biofuel.

Biofuels, or fuels produced from living matter, produce less greenhouse gas emissions than their petroleum and nonrenewable counterparts but, because of their higher cost, biofuels do not enjoy widespread-use (Biofuel, 2010). However, due to pressing environmental factors, the world has been more amenable to the transition to biofuels, despite the monetary cost, because of their environmental benefits (Id). For those looking for a middle ground between biofuels and petroleum, it is possible to blend the two when the technology permits, and the blends will still produce lower emissions than pure petroleum (Mrad, 2012). One of the main goals of our project was to analyse the different fuel options for the CCHP and determine which one would be the most economical, environmentally beneficial and accessible for use in the Brent Civic Centre CCHP.

We have assessed the feasibility of increasing the thermal load of the Brent Civic Centre. In doing so, we have recommended three ways to increase the building's thermal load, which are building preconditioning, increasing the datacentre's cooling load, and establishing a decentralised energy network with the CCHP as the energy source. We also created Excel tools to facilitate future analysis of the building and CCHP data.

Lastly, we completed the energy category of the BREEAM In-Use questionnaire. The CCHP was the main contributor to the building's original BREEAM 'Outstanding' accreditation, as such it plays a key role in the Civic Centre's eligibility for BREEAM In-Use certification. In order to qualify for an 'Outstanding' BREEAM In-Use accreditation, the Civic Centre must achieve a score of 85% or higher throughout all ten of the different environmental categories. Although we did not have access to the scoring rubric, we completed the energy portion of the BREEAM In-Use questionnaire, which accounts for 31.5% of the certification's overall scoring.

In chapter 2, we discuss the global impact of climate change, energy-saving options, laws and policies regarding climate change, incentive programs for renewable energy, and the London borough of Brent. In chapter 3, we describe the methodology we followed in order to achieve our project goals. In chapter 4, we discuss the findings we uncovered during our tenure at the Civic Centre and our recommendations on how to proceed in the future.

2.0 BACKGROUND

If the reduction of global anthropogenic greenhouse gas (GHG) emissions is not taken seriously, the resulting long-term effects could impact our way of life in unfavorable and irremediable ways. The International community has already developed laws and policies in an effort to mitigate these emissions, with a focus on energy-saving practices and low-carbon technologies. Specifically, the United Kingdom (UK) has taken interest in energy-efficiency and emissions-reduction schemes. London has incorporated UK policies regarding sustainable energy-efficiency and GHG emissions mitigation into their regeneration efforts. The London Borough of Brent has demonstrated their commitment to renewable energy with the conception of the Brent Civic Centre. The Brent Civic Centre is a Building Research Establishment Environmental Assessment Methodology (BREEAM) Outstanding accredited public building, and owes its merit to its Combined Cooling, Heat, and Power (CCHP) biofuel engine.

In section one of this chapter, we focus on the significance and impact of climate change on a global, regional, and local scale. In section two, we review the laws and policies surrounding GHG emissions reduction. In the third section, we examine existing energy-saving options. In the fourth section, we introduce incentive programs for using renewable, energy-efficient, and low carbon technologies. In section five, we review the infrastructure of the Brent Council. Finally, in section six, we discuss the Brent Civic Centre and the potential to optimise the use of its CCHP.

2.1 Climate Change

Climate change is an environmental phenomenon whose impact has been, and continues to be, detrimental to the ecological health of the planet. According to a 2014 report by the Intergovernmental Panel on Climate Change (IPCC), the leading international body that assesses climate change, human factors are the leading cause of the current rise in temperatures. (IPCC). The IPCC explains that human activity, between 1750 and 2011, has led to a cumulative carbon dioxide (CO_2) emissions level of 2040 +- 310 $GtCO_2$, with about half of those emissions happening within the last 40 years (Id). Those 40 years demonstrated an increase in GHG emissions with each passing year, with the greatest increases between the years 2000 and 2010, despite the implementation of new climate change mitigation policies (Id).

Climate change has been shown to increase the likelihood and severity of natural disasters throughout the world. Such natural disasters include flooding, drought, landslides, heat waves, and storm surges (IPCC, 2014). These extreme weather events are more than mere projections. A 2014 study conducted by the Stanford University concluded that the ongoing California drought, the longest in recorded history, was a result of the globe's changing climate (Diffenbaugh, 2015). Though different regions of the world are affected by these extreme weather events, London is particularly vulnerable to the drastic weather changes caused by climate change (Newcastle, 2009). A 2009 study conducted by the Tyndall Centre for Climate Change Research found that the city of London is specifically susceptible to the effects of flooding, as an increase in sea level and storms of great intensity from climate change would overwhelm London’s existing surge flood defenses (Id).

Today, much of the world's power needs are met through a narrow slice of power generation methodologies. According to the International Energy Agency, an environmental organisation who provides statistics on the international oil market and energy sectors, in 2012, around 60% of the world’s energy needs were met using oil and coal sources, while 30% was generated using natural gas (IEA). Nuclear energy generates approximately 5% of the world's energy needs. Oil, gas, nuclear energy, and coal energy generation methods need large power distribution networks, including miles of pipes and cables, which result in a notable amount of waste energy and carbon emissions (Id). The remaining 5% of the world's energy consumption is met using alternative sources - mainly biofuels (Id). These alternative means of energy generation hold the key to the GHG emissions reduction and energy-efficiency that their conventional counterparts cannot deliver, and we discuss these alternatives in the following section.

2.2 Alternative and Energy-Efficient Options

Environmentally-friendly and energy-efficient alternatives to conventional energy generation have been established in an effort to mitigate climate change and prevent the resulting irreversible effects. These alternatives are not only in regard to the systems that generate the energy, but also in the fuel choices that power those systems. The specific alternatives we explore here are Combined Heat and Power (CHP) schemes, decentralised energy, and diesel alternatives.

2.2.1 CHP Schemes

A CHP scheme is a method of power generation that converts excess energy, what would be waste energy to a conventional power plant, into heat (Association of Decentralised Energy [ADE], 2015). Thus, unlike conventional means of generating power and heat energy, which would require a power plant and a separate boiler, a CHP scheme can provide both within the same system. Since a CHP uses waste energy from electricity generation to produce heat rather than a separate fuel input, a CHP can produce more usable energy than its conventional counterparts (Id). Figure 1, below, visually compares a CHP scheme to a power plant and boiler in regard to their energy-efficiency.

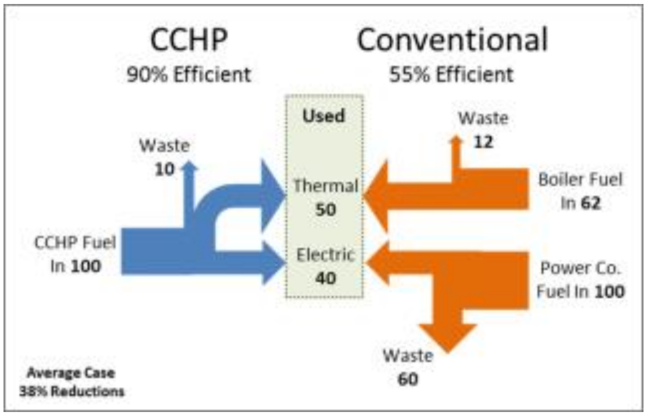

Figure 1: Efficiency of conventional energy generation compared to CCHP (United States Environmental Protection Agency [US EPA], 2015)

As seen in Figure 1, the CHP system is able to generate the same amount of electrical and thermal energy as the conventional generation methods while generating less waste energy and consuming less fuel. Lowering the amount of waste energy produced through energy-generating processes will lower the system's greenhouse gas emissions, thus reducing the system's carbon footprint (ADE, 2015).

As a further means of waste reduction, some CHP schemes have an added cooling component, making it a CCHP system. Through the incorporation of an absorption chiller, the CCHP system can convert the waste energy from power production into either heating, cooling, or a combination of both, giving the system more options in distributing its thermal output (ADE, 2015). The choice to provide heating or cooling makes the system more versatile throughout the year, as cooling would be beneficial during hotter months, and heating more so during the cooler ones. The use of these schemes' thermal energy can be further optimised through the implementation of a decentralised energy network.

2.2.2 Decentralised Energy

Electricity is conventionally provided through large power plants connected to the national grid. These power plants are usually far away from the buildings they provide power to, which requires extensive piping and cabling networks to connect the buildings to the power plant. Waste energy is given off when the electricity traverses through these pipes, and the longer the pipeline, the more waste energy is released (Carbon Trust, 2015). Power distribution networks such as these are known as centralised networks. Decentralised energy networks, unlike their counterparts, provide energy from smaller, local plants rather than the large plants connected to the grid (Id). These networks are also able to distribute thermal energy through district heating and cooling schemes (Id). Figure 2, below, depicts what a district heating and cooling scheme would look like.

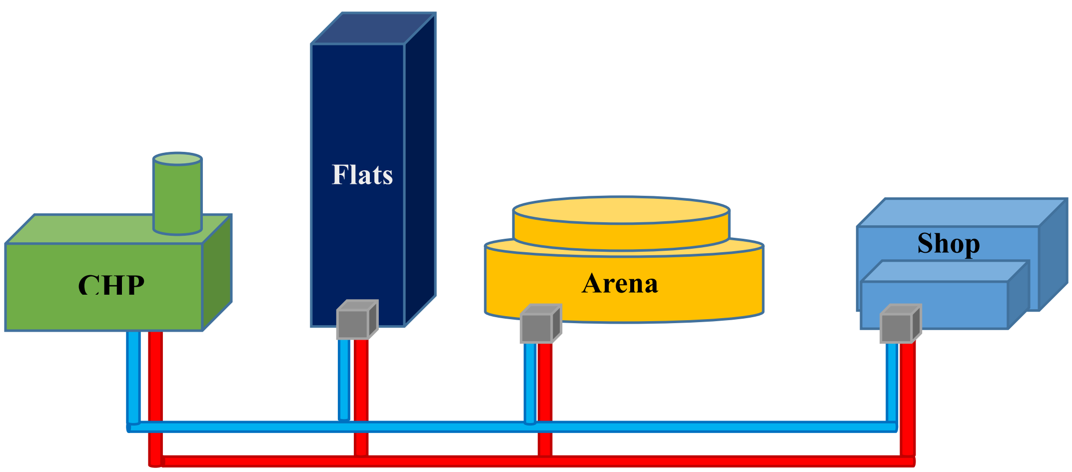

Figure 2: Diagram of District heating from the CCHP

Decentralised energy networks are made to provide energy to nearby buildings. Since the buildings are closer to the energy generation plant than a conventional power plant would be, less piping is required to establish the network. As a result, reduces the carbon emissions and energy loss of energy transmission (Carbon Trust, 2015). A CCHP plant would be the ideal source of energy for a decentralised energy network as the one depicted above. Since a CCHP can provide both heating and cooling, the plant can distribute its thermal energy to nearby buildings, reducing the local need for conventional boilers and chillers (ADE, 2015). In addition, since the CCHP can provide electricity, the local power supply could also be decentralised, removing the need for the surrounding buildings to procure energy from the national grid (Id). Thus, the combined use of a CHP or CCHP scheme with a decentralised energy network could be an energy-efficient means of reducing waste energy production and carbon emissions.

Further, CHP schemes are fuel neutral, meaning they can run on both diesel and diesel alternatives (ADE, 2015). Although the fuel choice in itself may have different environmental properties, the use of any compatible fuel type in a CHP scheme will have a more energy-efficient outcome than if the same fuel were used to run in separate power, heating, and cooling plants (Id). Despite the fuel neutral nature of CHP schemes, the additional ecofriendly nature of fossil fuel alternatives would be more in-line with global efforts toward a low-carbon and energy-efficient way of life. We detail the benefits of alternative fuels in the following section.

2.2.3 Alternative Fuels

Energy generation stations release waste energy, and therefore carbon emissions, during their production processes. The use of alternative fuels is a way to reduce those emissions. An alternative fuel is a fuel other than petrol or diesel (US EPA, n.d.). This section will focus on the pros and cons of biofuels and biofuel blends.

A biofuel is a fuel derived from organic matter (Biofuel, 2010). Biofuels can be separated into three categories: first, second, and third generation biofuels. First generation biofuels derive directly from food crops, such as corn, wheat, and sugarcane (Id). However, the carbon emissions from first generation biofuel production, along with the food scarcity that comes with their implementation since they come from food sources, do not make their use better than that of diesel (Id).

Second generation biofuels, on the other hand, are made from feedstock non-food sources, with exception for waste food no longer fit for human consumption (Biofuel, 2010). Some second generation biofuels are generated from grasses, seed crops, waste vegetable oil, and municipal solid waste (Id). Although second generation biofuels do not come from non-food sources, the high water demand of grasses has prevented their use as a biofuel from further expansion, and the use of seed crops require a land area comparable to that of first generation biofuels, which hinders the agricultural industry (Id). Waste vegetable oil and municipal solid waste, however, do not face those problems. Rather, waste vegetable oil's sole detriment is that it has the potential to decrease an engine's life if it is not properly refined, and since municipal solid waste would be going to waste anyway, conversion into a biofuel would be an ideal alternative since their carbon footprint is still less than that of fossil fuels (Id).

Third generation biofuels are the newest kind of biofuel, and refer to algae-based biofuels (Biofuel, 2010). Algae-based biofuels have shown potential as a biofuel source since not only is algae abundant and diverse by nature, but it also has the highest energy yields of any other biofuel, can be grown in a marginal land area, and may have the ability to convert carbon emissions into usable fuel, making third generation biofuels a no-emissions alternative fuel (Id). Despite the benefits of algae-based biofuels, the water, nitrogen, and phosphorus demands of growing the algae currently makes third generation biofuels more expensive than any of other existing fuel option, and the production of the algae may emit more GHGs than using the fuels would save (Id).

Due to the costly yet reduced carbon emissions of biofuel compared to diesel, a middle ground was established in the use of biofuel and diesel fuel blends (US EPA, n.d.). Despite the emissions from petroleum usage, blending petroleum with biofuel still reduces the emissions from the system running on the blend, though not as much as using a pure biofuel (Id). According to a 2012 study conducted at the École des mines de Nantes, biofuel and diesel blends produce less hydrocarbon and carbon dioxide emissions than pure diesel (Mrad, 2012). In other words, the study showed that as the percentage of biofuel in the fuel blend increased, the overall GHG emissions decreased (Id). Although the overall GHG emissions decreased, the emission of nitrous oxide increased with the percent biofuel (Id).

While the aforementioned alternative and energy-efficient fuels and technologies exist, their global implementation is not yet widespread despite their long-term environmental and potentially economic benefits (Biofuel, 2010). In an effort to increase the use of these alternative options, the international community has started to put laws and policies in place designed to set up the framework for a low-carbon and energy-efficient world.

2.3 Laws and Policies Regarding Climate Change

2.3.1 International Efforts

The United Nations (UN), an intergovernmental organization formed for the purposes of international cooperation on global phenomena, has recognized the issue of climate change, and have helped foster policies to combat it. The UN Framework Convention on Climate Change (UNFCCC) is an international treaty formed in 1992 as a global effort to mitigate greenhouse gas emissions and, therefore, climate change. The treaty itself did not directly set emissions reduction goals for each of the participating nations, but rather established soft guidelines for reduction of greenhouse gas emissions (UNFCCC, n.d.).

The UNFCCC set up a framework for regular meetings of the parties to the UNFCCC where nations could regularly visit their obligations and the impact of the UNFCCC requirements on climate change. As the parties to the Convention recognized the shortcomings of the Convention, they began negotiating a stronger set of commitments. The result was the Kyoto Protocol, adopted in 1997, which set emissions reduction targets for developed countries, binding all parties to the Protocol under international law. (UNFCCC, n.d.). There are currently 192 parties to the Kyoto Protocol. The reduction of greenhouse gas emissions is a global effort, and since developed countries are main contributors to the current high levels of greenhouse gases, the Kyoto Protocol focuses on the reduction of emissions in developed countries (Id).

During the 18th Kyoto Protocol Conference of the Parties, Parties established the Doha Amendment to the Kyoto Protocol (UNFCCC, n.d.). The amendment extended emissions reduction opportunities to developing country Parties through Nationally Appropriate Mitigation Actions (NAMAs) in accordance with the UN's pre-2020 emission reduction plan. NAMAs are, at the national level, formal declarations of intent to reduce greenhouse gas emissions while maintaining pursuit of national developmental goals (Id).

2.3.2 European Union Climate and Energy Package

One of the leaders in the development of the UNFCCC and the subsequent Kyoto Protocol was the European Union (EU) which, as of 2015, is a union of twenty-eight member states throughout Europe. The members of the EU plan to reduce their emissions by 20-30% of 1990 levels by 2020 (EC, n.d.). In an effort to meet the goals for the UN pre-2020 plan, the EU introduced their 2020 Climate and Energy Package. The 2020 Climate and Energy Package establishes the "20-20-20" targets, which serve to reduce greenhouse gas emissions by 20% from 1990 levels, increase energy consumption from renewable resources by 20%, and improve the

EU's energy efficiency by 20% (EC, n.d.). The EU has plans to further reduce emissions by 40% by 2030, 60% by 2040, with individual targets set for each of its member states.

EU member states are required to develop and sustain a Renewable Energy Guarantee of Origin (REGO) scheme. In an effort to promote renewable electricity production, REGO schemes encourage the use of renewable energy sources through the issuance of REGO certificates. Issued by the United Kingdom's (UK) Office of Gas and Electricity Markets (Ofgem), the REGO certificates serve as proof to potential consumers that the electricity purchased from these REGO-certified suppliers is, indeed, from a renewable energy source (Ofgem, 2015). The REGO schemes are mainly used for fuel mix disclosure (FMD), which explicitly details the components that make up the fuel, so customers can know exactly what their electricity is generated from. Though the REGO schemes do not directly influence the suppliers' need to mitigate emissions and use energy-efficient fuels, it does offer consumers the choice to purchase renewable or non-renewable electricity, serving as an incentive for suppliers to look to renewable energy sources for their power.

The International policies are supported by regional ones.

2.3.3 Regional Policies

The different regions of the UK each have their policies regarding climate change, and they are all geared to contribute to the UK emission reduction targets of the EU's 2020 Climate and Energy Package. The UK set an ambitious goal to reduce their emissions by 29-43% of 1990 levels by 2020, and has described its intention to reduce greenhouse gas emissions by 80% by 2050 (Brent Council Environment and Culture Directorate for Brent Climate Change Strategy Steering Group et al., n.d.). In order to achieve these energy and emission reduction goals, the UK implemented the following three policies, among others: the Renewable Obligation (RO);

the Carbon Reduction Commitment Energy Efficiency Scheme (CRC); and the Climate Change Levy (CCL).

The RO requires UK electricity suppliers to source a specific amount of electricity from renewable sources. Generators must report the amount of electricity generated from renewable sources to the Ofgem and, based on the amount of renewable energy reported, the Ofgem will issue Renewable Obligation Certificates (ROCs) to said generator. These ROCs are then sold to energy suppliers, which serve as their testament to the distribution of renewable energy (Low Carbon, 2015). The amount of ROCs necessary to meet each supplier's obligation increases with the amount of electricity sold, and if the suppliers do not present enough ROCs to meet their obligation, they must pay the remainder of what their ROCs did not cover (Id).

The CRC applies to UK organizations which use more than 6,000 Megawatt hour (MWh) per year of electricity, with the exception of state funded schools. The CRC scheme is managed by the UK's Department of Energy and Climate Change (DECC) and is comprised of three parts: participating organizations must measure and report their annual electricity and gas related carbon emissions to the respective representative of the DECC (England and Wales report to the Environment Agency); participating organizations must purchase allowances similar to the European Union (EU) Allowances of the EU Emissions Trading System; and lastly, each participant must make information relevant to their energy use and emissions available to the public (Carbon Trust, 2015).

The CCL is a tax for electricity and fossil fuel providers, which charge the providers based on the carbon emissions of their products (HM Revenue & Customs, 2014). Electricity and fossil fuels are some of the leading contributors to carbon emissions, and the CCL was put in place in an effort to promote more environmentally-friendly and efficient ways of using them

(Id). The movement toward a low carbon environment can be seen in the variety of CCL exemptions. The exemptions from the main rate of CCL are methods of sustainable energy production and low carbon impact, such as the use of CHP stations, the generation of electricity from renewable resources, and fossil fuels for export rather than consumption (Id).

The policy-making efforts to mitigate emissions-reduction further extends to the local level. In 2004, then Mayor of London, Ken Livingstone, developed the London Plan, which focuses on the development of the economic, social, transport, and environmental framework of the city through 2036. The London Plan requires each London borough to contribute to climate change mitigation by reducing emissions by 20% by 2016, and 60% by 2025 (Brent Climate, n.d.). The London Plan is supported by the Mayor's Climate Change Mitigation and Energy Strategy called Delivering London's Energy Future, which was established in October 2011. The strategy includes a number of programmes for London regarding energy efficiency: (1) RE:NEW, which is aimed toward energy efficiency in homes; (2) RE:FIT, focusing on public sector buildings; (3) RE:CONNECT, which further the reduction of CO_2 in low carbon zones; and (4) a decentralised energy programme, with the goal of supplying 25% of London's energy from district heating (Greater London Authority [GLA], 2011).

Although laws and policies regarding climate change mitigation are in place, the existence of a framework for a low-carbon future is not sufficient to attract buy-in from main contributors to the world's carbon emissions. As a further means of convincing these entities to follow the framework set before them, environmental organisations have created incentive programs that reward those who incorporate low-carbon and energy-efficient technologies and practices.

2.4 Incentive Programmes

Incentive programs provide another method for facilitating climate change mitigation. Organizations such as the Building Research Establishment (BRE) and DECC have developed incentive programs to motivate corporations to consider sustainable practices and development when thinking of future construction projects. Some incentive programs reward organizations for their energy-efficient technologies through accreditations and certifications; others provide funding for new and existing projects. Some existing energy-efficiency and emissions reductions incentive programs include: BREEAM; the Combined Heat and Power Quality Assessment (CHPQA); the Joint European Support for Sustainable Investment in City Areas (JESSICA) initiative; the Renewable Heat Incentive (RHI); and the Mayor's London Green Fund.

BREEAM is an internationally-recognised scoring mechanism used to rate buildings on their energy usage, and is one of the leading sustainable building incentive programs in the world (BREEAM, n.d.). The benchmarks required for a BREEAM certification promote the implementation of sustainable and eco-friendly building practices and design. Buildings can qualify for the BREEAM In-Use certification after a few years of operation (BREEAM, 2015). The BREEAM In-Use assessment is designed to reduce the running costs of the building and improve its existing environmentally-friendly factors (Id). The BREEAM In-Use assessment ensures that buildings which were originally BREEAM certified are continuing with their sustainable practices (Id). Following BREEAM guidelines can contribute to the reduction of the participating buildings' carbon footprint (Id).

The CHPQA is a government initiative led by the DECC used to assess UK CHP schemes based on their energy efficiency and environmental friendliness. The CHPQA promotes energy-efficient CHP schemes by offering qualifying CHPs with a certification that comes with a number of benefits, such as money rewards and tax exemptions, for contributing to the UK's low carbon efforts. Some of these benefits were discussed above and include ROCs, the RHI, CCL exemption, and preferential business rates (DECC, 2014).

Another incentive program is the JESSICA initiative. Developed by the European Commission (EC), the European Investment Bank (EIB), and Council of Europe Development Bank (CEB), the JESSICA initiative provides financial aid for energy-efficient and sustainable urban development schemes. JESSICA allows for EU countries to invest in relevant urban development schemes with revolving funds, or investments that will come back to them in time, as a way of incentivizing funding for regeneration of areas which could benefit from a more energy efficient design, furthering Europe's movement toward a low carbon environment (EC, 2014). To help the EU members communicate in regard to the JESSICA initiative, the EC set up the JESSICA Networking Platform, further supporting the implementation of JESSICA.

Another environmental incentive program offered by the UK government is the RHI. The RHI program is the world's first long term financial subsidy for renewable heat. The program works by paying participants that generate and use or export renewable energy (Low Carbon, 2015). The RHI's non-domestic scheme promotes the use of CHP systems, energy from waste, and economic support for sustainable energy practices. However, support for CHP from the RHI is limited, and subsidies are mostly allocated to generators of solar power (Tariffs, 2015). See Appendix A for the tariff and RHI rates relevant to power generation.

In London specifically, the Mayor and the Greater London Authority (GLA), along with the EIB and the London Waste and Recycling Board (LWARB), set up the London Green Fund, which provides funding for London's sustainable energy projects. The London Green Fund is comprised of two smaller funds: Urban Development Funds (UDFs), and direct investments for relevant waste and energy efficiency projects (LWARB, 2015). Of the £100 million available per annum for investment from the London Green Fund, £50 million is allocated for Waste UDFs, and £35 million for energy efficiency UDFs, leaving £15 million for direct investments toward projects (Id). The money that is not directly controlled by the GLA is distributed by independent agencies such as Foresight Group LLP and Amber Infrastructure (Id.) Project sponsors can contact these agencies to see if they qualify to receive funding from the London Green Fund.

The London Borough of Brent, in particular, has demonstrated interest in the aforementioned incentive programs, and in the laws and policies regarding climate change. We describe the organisation of the London Borough of Brent and the Brent Council in the following section.

2.5 London Borough of Brent

The London borough of Brent is one of 19 Outer London boroughs. According to the GLA, as of 2015, the borough had an estimated population of 325,400 people in 117,300 households (GLA). This makes Brent the most dense Outer London Borough (Id). Figure 3, below, depicts the Borough's 21 wards, or divisions.

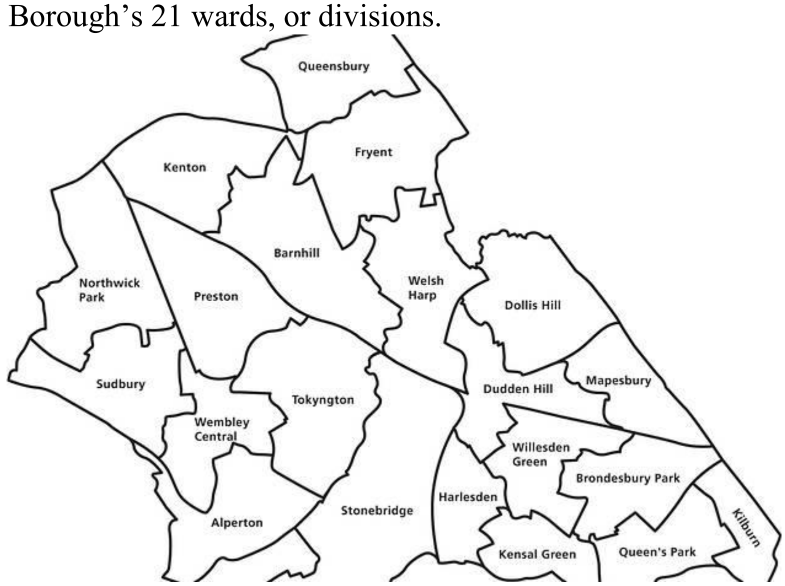

Figure 3: A map of the London borough of Brent, depicting its 21 wards (Brady, 2011).

The Brent Council is comprised of the general council, Cabinet, and Mayor (Brent Council, n.d.). The council has 63 elected councillors with a leader and is responsible for creating policies for the borough (Id). The council leader forms a Cabinet which includes seven other senior councillors (Id). The role of the Cabinet is to implement and carry out the policies that have been created by the council (Id). The council appoints a Mayor each year whose job is to handle local, national, and international matters as relevant to the borough, such as emissions reductions (Id).

To carry out all the tasks that the council must accomplish, the Council uses a detailed budget. The Brent Council is committed to transparency so a large amount of data including the budget is publicly available on the brent.gov.uk website. For the 2015/16 year, the council plans to spend £994 million on services (Brent Council n.d.). £88 million are raised from taxes. The rest comes from government grants (Id).

The Council's efforts to operate sustainability is illustrated by construction and operation of their new Civic Centre. We describe the Brent Civic Centre in the following section.

2.6 Brent Civic Centre

The creation of the Brent Civic Centre was an effort to bring the entire council and operation under one roof. Figure 4, below, shows the floor plans of the nine story building and some of its features (Brent Civic, 2015).

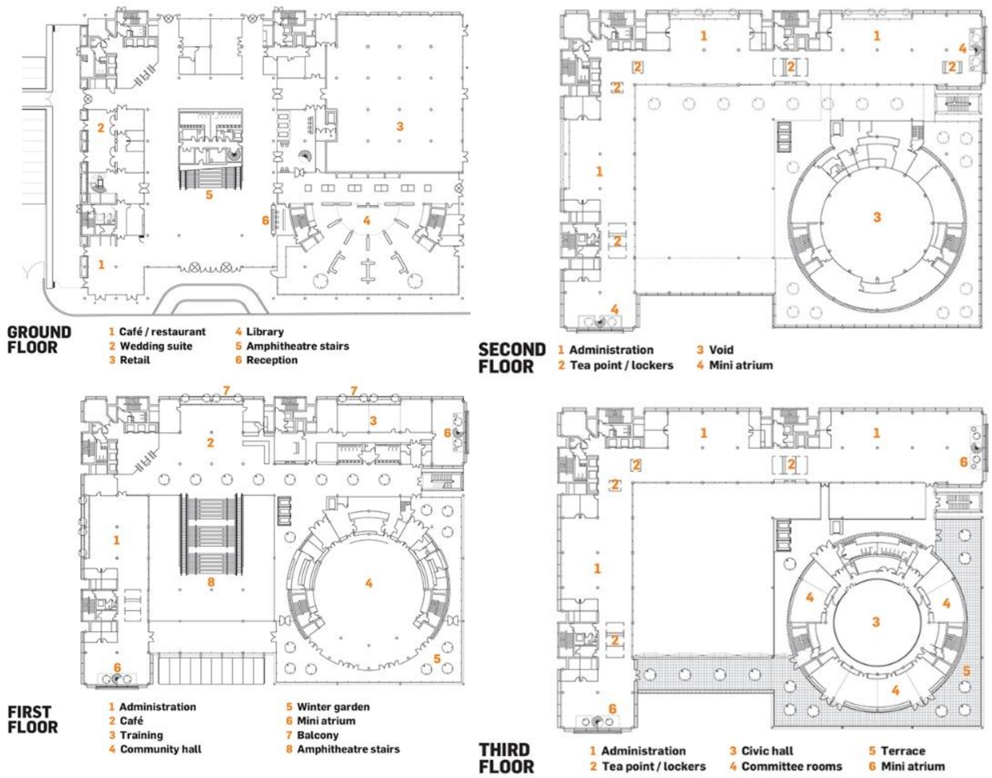

Figure 4: Floor plans of the ground, first, second, and third floors of the Brent Civic Centre. (Brent Civic, 2015).

The Civic Centre houses the following four Brent Council departments: (1) Adult Social Care; (2) Children and Young People; (3) Regeneration and Growth; and (4) Chief Operating Officer's department. Other features of the Civic Centre include the Wembley Library, exhibition space, and community rooms (Brent Civic, 2015).

The Council planned for a sustainable design for the Civic Centre, which the Council hoped would actively improve the occupants' quality of life (BREEAM, n.d.). The Council was able to do this by using cost-effective strategies to find practical solutions to reduce its carbon emissions (Id). The building received an "Outstanding" BREEAM rating, with a 92.55% score for design and 93% for post-construction review stages (Brent Council n.d.). In other words, 90% of the design and construction qualities of the Civic Centre constitute energy-efficient and sustainable building practices, as defined by BREEAM[1].

However, sustainable building practices must persist past the initial construction of the building with proper building use and management. With this in mind, the Brent Council installed a Building Management System (BMS), which is an online interface used to monitor the building's mechanical and electrical components, such as lighting and energy metering. Equipped with over 40,000 meters and sensors, the BMS is capable of sensing and regulating every aspect of the building, from the climate of every room to the health status of every light fixture. For energy use the BMS is hooked into a wide array of power and gas meters and submeters. Submeters are small, localized, meters which provide power usage data for a much smaller scope than the primary building meters. For instance, a gas submeter is installed on each of the buildings hot water boilers, and an electric submeter on each floor. Submeters allow for granular tracking the buildings energy use and every single one of them are tied into the BMS for easy convenient tracking. However, the BMS is not the greenest technology built into the Civic Centre.

The main contributor to the Centre's 'outstanding' BREEAM accreditation is the 300 kilowatt CCHP liquid bio fuel engine. The CCHP engine can deliver a minimum of 29% saving of CO_2 emissions when compared to supplying the power, heat, and cooling from separate sources (ADE, 2015). The CCHP can run on eleven different fuels and, according to the UK Department of Energy and Climate Change and Ofgem, fish oil residue has the lowest carbon

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[1] A case study prepared by the Building Research Establishment (BRE) details the design and construction of the Civic Centre, and can be found at this link: http://brent.gov.uk/media/6147637/Brent%20Civic%20Centre%20building%20case%20study%20for%20BREEAM%20November%202013.pdf

footprint of all the current biofuels. Consequently, the CCHP runs on fish oil residue. However, though fish oil residue has the lowest carbon footprint, it is costly, and poses as an economic obstacle for the operation of the CCHP (Biofuel, 2010).

Beyond the economic feasibility of running the CCHP on fish oil, the engine is currently underutilized. The lack of energy demands calling for the full use of the engine has led to talk among the Brent Council of establishing a decentralised heating, cooling, and power network with the CCHP. The decentralised energy network could bring clean energy to surrounding buildings and generate revenue for the Council while making efficient use of the engine (ADE, 2015). Decentralised networks reduce the amount of energy lost in the transmission of power across long distances by decreasing the distance between generation and use (Id).

With the increasing cost of alternative fuels - namely, fish oil residue, - and the current under-utilization of the CCHP in the Civic Centre, the Brent Council reached out to Worcester Polytechnic Institute’s London Project Center and asked for a group of students to: help evaluate the different fuel options for the CCHP; analyse the most cost-effective and eco-friendly alternative to fish oil; and assess the feasibility of setting up a decentralised energy network with the CCHP. Consequently, that was the goal of our project. Our process to achieve these goals is detailed in the methodology portion of this report.

3.0 METHODOLOGY

The Brent Council, in an ongoing effort to reduce their carbon emissions, is investigating the use of their Combined Cooling, Heat, and Power (CCHP) engine in its Civic Centre. We were tasked with developing recommendations for the best economic and environmental use of the CCHP. Specifically, we evaluated the Brent Civic Centre's energy load in comparison to the CCHP's total capacity, the best way to match the thermal load of the building to the capabilities of the CCHP, and performed an analysis of the possible fuel options for the CCHP. In conjunction with our analysis, we conducted a preliminary assessment of the Civic Centre's energy efficiency qualifications for Building Research Establishment Environmental Assessment Methodology (BREEAM) In-Use accreditation. In order to accomplish our goals, we developed the following five objectives:

- **Objective 1: Compare the Brent Civic Centre's energy usage to the CCHP's energy output potential.**
- **Objective 2: Recommend optimal energy-use cases for the CCHP.**
- **Objective 3: Analyse the CCHP's possible fuel options and identify the ideal fuel choice.**
- **Objective 4: Evaluate the Brent Civic Centre on its BREEAM In-Use energy qualifications.**
- **Objective 5: Develop a recommendations report for the Brent Council based on our findings.**

We discuss each objective and the steps required to complete them in detail below.

3.1 Objective 1: Compare the Brent Civic Centre's energy usage to the CCHP's energy output potential.

The CCHP's energy usage hinges upon the energy load provided by the building. The steps we took to match the building load to the CCHPs potential, led us to an understanding of buildings monitoring systems and, critically, an understanding of what aspects within these systems needed improvement.

To compare the Brent Civic Centre's energy usage to the CCHP's energy output potential, we analysed the electrical load of the Civic Centre and compared that to the CCHP's maximum electrical outputs. In order to accomplish this, we attended two training sessions on 29 May 2015 and 12 June 2015 about the use of SystemsLink, the database used by the Brent Council to monitor and track their energy usage. These two sessions were facilitated by Neil Luscombe, the Brent Council's Data Monitor and Sustainability Officer, and Mike Matthews, a SystemsLink representative, respectively. Using SystemsLink, we generated the profile of the building's electrical usage. Since the 2013 construction of the Civic Centre, SystemsLink has recorded the electrical usage of the building based on half-hourly electric meter readings. Using the electrical recordings, SystemsLink provided us with a visual and concise electric profile for the building.

We continued our analysis by compiling a comprehensive thermal profile of the Brent Civic Centre, which incorporates both the heating and cooling elements of the building. We reviewed the work done by the Building Research Establishment (BRE), presented in a 2014 report to the Council, and used it as a starting point. The BRE is a well-respected British building design organisation, and are responsible for the creation and maintenance of the BREEAM building accreditation. They became involved with the operation of the CCHP at the request of the Brent Council, and their report outlines their findings and recommendations for optimal CCHP usage. Aside from the BRE report, we investigated the historical energy use records for the Civic Centre's heating and cooling load, starting with the monthly gas invoices. The invoices were easy to follow as they had previously been loaded into SystemsLink. However, unlike the electric meters, the gas meter data was only reported through the monthly invoices. To determine the cooling load of the building, we needed historical data of the electrical submeters that were attached to the two electric chillers on the roof. To supplement our investigation of the building's historical thermal usage, we took manual meter readings on weekdays at 12:30 PM for the last four weeks of our project, starting on 2 June 2015, to give us a better understanding of the building's energy load.

Next, we worked to identify the CCHP's total electrical and thermal energy generation capacity. Initially, we used the 2014 BRE report as our guideline. However, documentation by Skanska, the company that constructed the Brent Civic Centre, indicated that the CCHP was sized to different specifications than the BRE report indicated. After consultation with Anís Robinson, the energy manager of the Brent Council and our sponsor, we located the CCHP's Operation and Management manual, which had within more consistent CCHP operational figures.

Using the building's energy profiles, in conjunction with the final figures for maximal CCHP output, we constructed an Microsoft Excel widget that compared actual building load to the available power from the CCHP across a year. From that comparison, the widget also computed the annual savings that would be achieved in running the CCHP to the levels specified by the thermal profiles. We developed an operator's manual for this widget and left it with Anís Robinson for future use and refinement.

3.2 Objective 2: Recommend optimal energy-use cases for the CCHP.

For the Brent Council to achieve the greatest return on their initial investment into the CCHP, they must be able to utilize its thermal output in an effective manner. In order to accomplish this objective, we calculated approximate internal and external thermal usage possibilities for the engine, and held meetings with relevant personnel who could further our understanding of the feasibility of our recommendations.

During our time at the Brent Civic Centre, the building did not have the means to use the excess thermal energy produced from the CCHP, should it exceed the load of the building. While in one of our weekly meetings with Anís Robinson, the team collectively generated the idea to precondition the Civic Centre. Preconditioning is the concept of keeping the building at a comfortable climate even when unoccupied, which can distribute thermal load more evenly over a 24 hour period. Preconditioning the building would increase its thermal load and make more use of the CCHP's thermal output. We speculated about the building's occupancy patterns based on the building's electrical profile to determine when it would be best to release the CCHP's excess thermal load throughout the building. We then inferred which type of thermal energy, heating or cooling, would be ideal for the building based on weather patterns throughout a year. In other words, if the weather was hot out, the CCHP would dump cooling, or if it was cold, then the CCHP would dump heat.

We considered increasing the cooling load of the datacentre located in the building. We examined the server room section in the Building Management System (BMS), focusing on the four Stulz cooling units which cool the datacentre. We used the following formula on the Stulz data in the BMS to calculate the cooling load of each unit:

$$\text{Change of energy in water} = \text{specific heat of water} \times \text{change in temperature} \times \text{flow}$$

We combined the results for each unit to get the total cooling load of the datacentre. We repeated this multiple times across a couple weeks to develop an average instantaneous cooling load for the datacentre. We investigated the maximum output of the four cooling units and read through the Central Equipment Room Cooling System Replacement binder for the revamping of the cooling in the datacentre; Richard Ubertowski, the Brent Council's Building Project Manager, gave us the binder. We used the maximum output of the cooling units to determine the maximum safe cooling load for the datacentre. We visited the datacentre on ten separate occasions with Richard Ubertowski and Russell Burnaby, the Performance Manager of the Council. We counted the total number of racks and the amount of open space of each to determine how much space was left for additional servers.

Another option we investigated was a district heating scheme with the buildings surrounding the Brent Civic Centre. To complete this part of our objective, we attended a meetings for the economic aspect of the scheme, gathered necessary information for potential clientele, and contacted the necessary people to retrieve the information we could not find ourselves. The idea came up during our first conference phone call with Anís Robinson before we arrived as a possible solution to optimise CCHP thermal use.

When we arrived to the Civic Centre, she provided us with a list of preliminary requests from Nicholas Allen, Head of Commercial Solution for SSE, for us to fill out before SSE considers the possibility of a district heating scheme with the Civic Centre's CCHP. We maintained a checklist of these requests, and crossed them off as we gathered the necessary information from the Council's archives.

When information was not available to us in the archives, we contacted those with permissions to the information and asked them to share it with us. We contacted Russell Burnaby, Michael Murray, an Electrical Engineer with Bilfinger Europa, the company in charge of maintenance in the Brent Civic Centre, Neil Luscombe, Richard Ubertowski, and Fleetsolve, the company responsible for manufacturing, maintaining, and providing fuel for Brent Civic Centre's CCHP, for the information we could not find. We were unable to get information from Fleetsolve during our time at the Civic Centre. We further investigated the feasibility of a decentralised energy network by a meeting with Alex Gilbert, a representative from Amber

Infrastructure, a company that could provide funding for the decentralised system. We took note of the economic feasibility of establishing the network during this meeting.

3.3 Objective 3: Analyse the CCHP's possible fuel options and identify the ideal fuel choice.

The CCHP was manufactured to run on one of 16 different fuels. The preferred fuel for the engine was a fish oil residue produced as a byproduct of the pharmaceutical industry. However, due to the increased costs of the fish oil, we investigated the possibility of using one of the other fuel options for the engine. We set out to identify four key metrics for each fuel option:

1) Fuel cost per liter

2) Fuel rate consumption in liters per hour

3) Kilograms of CO_2 emitted per kilowatt of fuel consumed

4) The number of Renewable Obligation Certificates (ROCs) received per megawatt of energy produced

We acquired the list of possible fuels on which the engine could run from Fleetsolve. We assessed the first and second key metric, because they are critical to calculating the yearly operating cost of the engine. Carbon Dioxide (CO_2) emissions are necessary for calculating the total cost of the Carbon Reduction Commitment (CRC) tariffs, which charge based on the amount of CO_2 emitted. ROCs are issued by the United Kingdom's Office of Gas and Electricity Markets (Ofgem) as a way of incentivizing the use of environmentally conscious energy and can be sold on an open market. These four key metrics enabled us to develop tools that comparatively analyse the possible fuel choices based on costs associated with the CRC tariffs as well as engine maintenance, against benefits of using the power generated from the engine. To complete the cost benefit analysis, we entered data on the four key metrics into our Microsoft Excel tool.

We obtained documents from Fleetsolve's website about the emissions and performance of the engine when each of the available fuels were used. In addition to attempted contact with Fleetsolve, Anís Robinson put us in contact with the Energy Institute of the United Kingdom (UK) for a second opinion. The Energy Institute is a forefront provider of information on energy-related information for the UK and has a range of publications covering a wide variety of different energy sources. We contacted them via email regarding the market fuel prices, CO_2 emissions and CCHP burn rates for each of the potential fuel candidates. We followed up in person with a visit to their main office in central London, where we perused their physical library and digital catalogue.

3.4 Objective 4: Evaluate the Brent Civic Centre on its BREEAM In-Use energy qualifications

As per request by Anís Robinson to help demonstrate that the Brent Civic Centre is being operated in an energy-efficient manner, we investigated the Civic Centre's eligibility for a BREEAM In-Use accreditation, specifically the energy portion. This accreditation is an international scheme issued by the BRE that is used to evaluate the environmental performance and design of buildings after three years in operation. Each category is evaluated in three parts: the evaluation of sustainable assets, asset management, and occupier management.

In order to conduct our evaluation, on 26 May 2015, we attended a presentation given by Kiruthiga Balson, a representative of the BRE, which supplemented the information we read in the BREEAM In-Use technical manual, documents, and information packets. The manual, documents, and packet were in-depth and could be confusing, and Kiruthiga Balson's presentation clarified the intentions of the BREEAM In-Use accreditation. Her presentation focused on the components of the accreditation relevant to our project. We also consulted our Anís Robinson, an accredited BREEAM assessor, requesting for the BREEAM In-Use guidelines so we could keep an ongoing checklist of energy qualifications pertinent to the Civic Centre and its CCHP. The BREEAM In-Use questionnaire was updated on May 31, 2015 and we received them a few days later from Anís Robinson's contact, Jasmine Atkins, a BREEAM In-Use Scheme Manager.

We answered each question from the BREEAM In-Use questionnaire through research on the Civic Centre and the CCHP through data stored in the Brent Council shared network drives. We completed the energy portion of the questionnaire, with the help of Russell Burnaby, Neil Luscombe and, Michael Murray.

3.5 Objective 5: Develop a recommendations report for the Brent Council based on our findings

Using the data and information we collected in the previous objectives, we compiled our findings and recommendations into a condensed report, highlighting our recommendations for moving forward with the operational optimization of the CCHP. Although we were not able recommend an ideal fuel option for the operation of the CCHP, we were able to provide a cost-benefit analysis spreadsheet which can be used to determine the ideal fuel once more fuel data is available. We were unable to complete the cost-benefit analysis due to our unsuccessful attempts to connect with Fleetsolve. As a result, we compiled feasible options for the CCHP's excess thermal energy capacity, if it exists.

For our recommendations, regarding fuel and excess energy options, we compiled our findings on each option into a user friendly Microsoft Excel widget. At the conclusion of our project, we delivered our final findings and recommendations report to Anís Robinson and Richard Barrett, Operational Director Property & Projects, for further distribution within the Council.

In the next chapter we describe the findings discovered in the course of completing the methods outlined above. In addition we discuss the recommendations we built in reaction to those findings.

4.0 FINDINGS AND RECOMMENDATIONS

Based on our data collection and analyses processes as carried out above in our methodology section, we developed the following recommendations based on our findings:

- **Recommendation 1:** Establish the Civic Centre's thermal profile.
- **Recommendation 2:** Overnight preconditioning of the building.
- **Recommendation 3:** Increase the datacentre load.
- **Recommendation 4:** Decentralised Energy Network.
- **Recommendation 5:** Contact Fleetsolve for fuel data.

Further, we included our findings for the preliminary Building Research Establishment Environmental Assessment Methodology (BREEAM) In-Use energy assessment of the Civic Centre. The findings and recommendations chapter are organised in the following sections: data monitoring, optimal Combined Cooling, Heat, and Power (CCHP) usage, CCHP fuel choice, and BREEAM In-Use.

4.1 Data Monitoring

The brain of the Civic Centre is a Siemens DESIGO Building Management System (BMS), which is responsible for reading and analyzing over 40,000 sensors and meters spread throughout the building. These sensors monitor everything in the building; the temperature of every room, the dimmer setting of every light fixture, the electricity used by every submeter, the flow of gas to the boilers used to heat the building, and much more. However, much of the data is inaccurate or missing due to translation problems between the meters and the BMS. A list of the irregularities in reported data relevant to the operation of the CCHP can be found in Appendix B.

Of particular importance are the submeters that provide real-time data from the CCHP, which have been unresponsive ever since the CCHP was first brought online. Ideally, these meters provide data on the electrical output, the amount of amount of energy used for heating the building, and the amount of energy used to cool the building. These meters are critical to understanding the actual performance of the CCHP and whether it is being used effectively. However, all meters relevant to the CCHP currently read zero on the BMS, cannot be correct since they remain as zeroes when the engine is running.

Further, the physical meters monitoring the CCHP's electricity usage are within the acoustic chamber of the engine, and are only accessible to relevant Fleetsolve, the company responsible for manufacturing, maintaining, and providing fuel for Brent Civic Centre's CCHP, employees. Since the electrical meters currently display zeroes for the CCHP's electricity usage on the BMS, we could not determine the CCHP's electricity usage. To remedy the issue, we recommend installing a window in the CCHP's acoustic chamber that allows for external view of the electrical meters. In addition, we recommend acquiring access to Fleetsolve's live feed of the CCHP's energy use, which would display the information the BMS is supposed to at any given time. We also recommend getting the CCHP's usage data from Fleetsolve regarding its most recent period of operation, which started on 26 May 2015. Beyond the electrical and thermal output of the CCHP, the Council should also acquire data on the CCHP's fuel consumption rate from Fleetsolve. Although there is metering in place that shows how much fuel is left in the engine's fuel tank, we cannot determine how many hours the engine has been running, how quickly the engine has been burning fuel, nor how much the Council is actually spending on fuel without the consumption rate.

The CCHP's metering is not the only group of meters with irregularities in data. The submeter data for the two electric chillers that cool the building when the CCHP is unable to meet the demand have been out of order since we started accessing the BMS, around 25 May 2015, and have not yet been repaired as of our final report date, 25 June 2015. For the duration of our data gathering period, the BMS reported these two submeters at a constant 41.1 kilowatt electric (kWe) for chiller one, and 0 kWe for chiller two, regardless of whether either chiller was actually running.

The overall cooling demand of the Civic Centre cannot be determined until the submetering for the electric chillers are fixed. However, the CCHP and electric chiller meters are not the only ones out of order. The submeters used to monitor the datacentre's power usage are also inaccurate, reading a power usage level many times greater than the known consumption rate of the chillers, and other electrical submeters displaying the Civic Centre's instantaneous electricity usage do not add up to the total the BMS is showing. The inaccurate display of data on the BMS is problematic to the Council not only in the difficulties it causes in future data collection and analysis regarding the Civic Centre and the CCHP, but also in that some of these numbers are displayed in the atrium of the Civic Centre. The graphs being displayed in the Civic Centre's atrium are located in Appendix C.

In addition to the inaccuracies in the data being reported by the BMS, the BMS is currently being underutilized. According to Siemens, documentation, and the existence of a disabled "Trend Viewer" button on the BMS interface, the BMS is capable of recording and analysing historical building data. We recommend enabling the "Trend Viewer" button in order to generate important information regarding the building's energy usage. Of particular importance to the CCHP would be a comprehensive thermal profile for the building, a critical piece of data which is currently unavailable. A thermal profile is an hour-by-hour tracking of the amount of energy used for both the heating and cooling of the building. Historically, this data has been unrecorded and therefore the amount of energy used for heating the building can only be determined on a monthly basis via the invoices provided by the gas supplier. Critically though, the amount of energy used to cool the building is unknown. Due to the submeter issues and the lack of historical recording by the BMS, the energy used by the electric chillers, even on a monthly scale, cannot yet be determined. As a result, we recommend performing a detailed inspection of why the BMS is out of sync with the Brent Civic Centre and how to best enable the dormant historical analysis feature.

The BMS is not the only method of data analysis available on the building. Due to the recent installation of SystemsLink, there is a fair amount of data on the overall use of electricity by the Civic Center. SystemsLink records the building's half-hourly power usage and loads it for viewing in graph form. We display the SystemsLink view of the building's electrical usage in Figure 5 below.

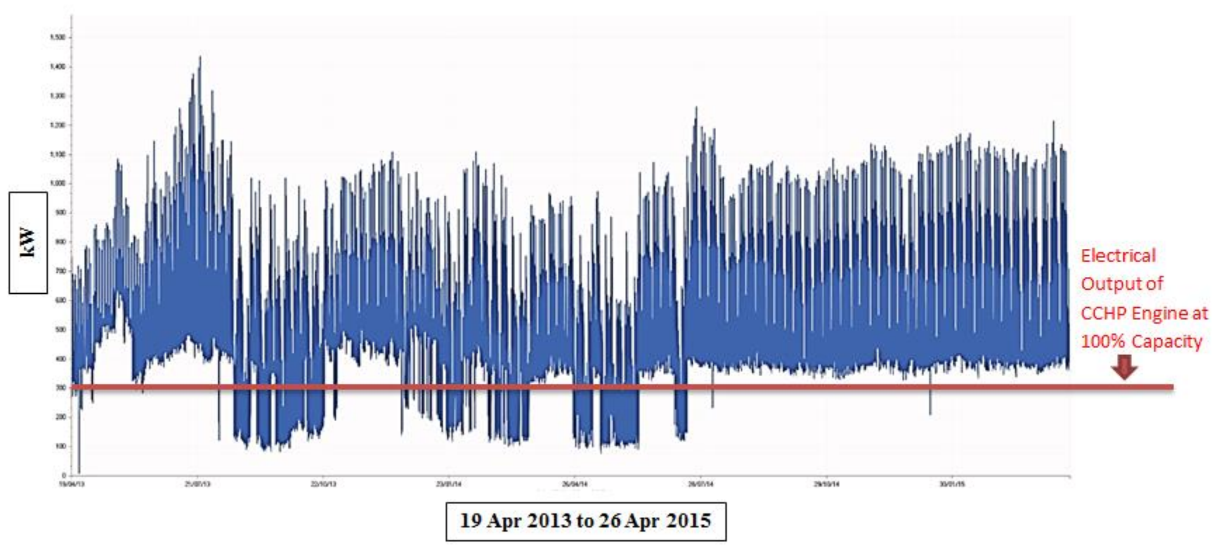

Figure 5: 2 Years of Electricity Profiles for the Civic Centre

Figure 5 shows the electrical usage in kilowatt (kW) for the building from its construction through the middle of our project. It allowed us to easily determine the minimum electrical consumption by the building, which is ~400 kWe, a critical number for determining the proper use of the CCHP. Additionally, SystemsLink is capable of tracking the electrical submeters, but the data must be provided by the BMS, making it even more critical to get the meters reporting properly in the BMS.

We recommend that the Council starts immediate investigation into the root cause of the issues with the BMS, and starts recording data regarding the building's thermal use as soon as possible. The sooner the building data is recorded, the sooner a thermal profile can be generated. In addition, the thermal profile will inform the Council of the difference between the maximum output of the CCHP and load used by the building, a value crucial to the optimal use of the CCHP. With a thermal profile in hand, the Council can utilize the tools we have developed to understand the true costs and benefits of operating the CCHP. We have left the tools we developed with the Council's Energy Manager, Anís Robinson. The user guides for the tools can be found in Appendix D.

4.2 Optimal CCHP Usage

We have determined that the Civic Centre will have the electrical load necessary to run the CCHP at maximum kWe output if it maintains its current electrical usage patterns. According to SystemsLink, the baseline electrical load of the Civic Centre on any given day at any given time is approximately 400 kWe. The maximum electrical output of the CCHP is 300 kWe. Therefore, barring any structural changes, the building's electrical load should exceed the CCHP's maximum electrical output, meaning no electricity output from the CCHP will be wasted. Further, the CCHP is capable of exporting up to 150 kWe back to the grid. Thus, the Civic Centre's electrical load can be as low as 150 kWe, and all of the CCHP's electrical output will still be used. If the Civic Centre's electrical load is reduced to a range between 150-299 kWe, then not only will the Civic Centre use 100% of the CCHP's electrical output, but the electricity exported back to the grid could generate additional savings on the Council's electric bill. Figure 6, below, depicts the CCHP's energy output distribution.

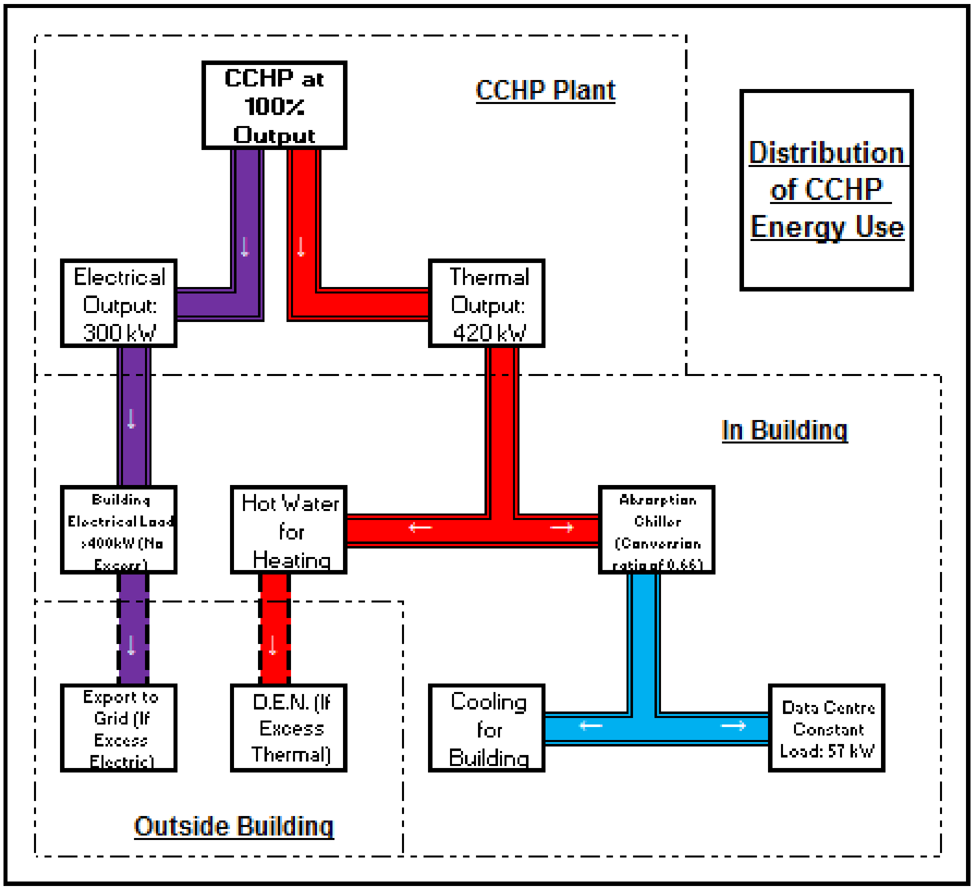

Figure 6: Schematic of CCHP's Energy Output and Use

Since it is possible to run the CCHP at full electrical output at all times without wasting electrical energy, the most efficient use of the CCHP involves running the CCHP at full electrical output at all times, while also using 100% of the CCHP's thermal output. The CCHP can output up to 420 kilowatt thermal (kWth), with a maximum of 240 kWth going to cooling. When the thermal profile of the Civic Centre has been established, the Council can not only determine whether or not the Civic Centre already has the thermal load necessary to utilize all 420 kWth provided by the CCHP, but also decide the best means of using the excess thermal energy if it does not. For optimal usage of the CCHP's excess thermal energy, we recommend the following:

preconditioning of the building, increasing the cooling load of the datacentre, or establishing and supplying a decentralised energy network.

4.2.1 Overnight Preconditioning

The overnight preconditioning of the Brent Civic Centre is an internal means of maximizing the use of the CCHP's thermal energy output. To precondition a building is to either cool or heat the building during off-peak hours so that the building will be at an optimal and comfortable temperature when the building occupants initially arrive. Rather than turning on the boilers or chillers first thing in the morning via manual temperature adjustments, the CCHP will have already conditioned the building to an optimal temperature upon arrival, thereby reducing the need for other means of heating and cooling and overall energy use. Preconditioning the Civic Centre overnight would be the best option, assuming the building's occupancy is at its lowest in the late hours. During the hotter months, the CCHP can provide cooling overnight - or heating during the colder ones, - while utilizing 100% of the CCHP's total energy output. Of our three suggestions, the preconditioning of the Civic Centre would be the simplest to implement, as the building is already equipped with the necessary tools to make it happen once the thermal profiles of the building have been established.

4.2.2 Increasing Datacentre Load

Although the preconditioning of the Civic Centre has the potential to use up to 100% of the CCHP's energy output, there is no opportunity for monetization and it does not account for building energy usage during the building's peak hours of operation. Thus, we recommend that the Council look into other means of optimizing the CCHP's energy use in addition to the preconditioning of the building. One option is to increase the size of the Civic Centre's datacentre. The CCHP was originally sized to cool a larger datacentre than is currently installed, but due to present and future technological advances, such as cloud technology, the actual datacentre is smaller than originally intended. Therefore, the datacentre has a smaller cooling demand than anticipated. We recommend increasing the datacentre's cooling demand, so the CCHP can put more of its thermal energy to cooling in an effort to approach the maximization of the use of the CCHP's energy output. Figure 7, below, shows the available cooling for the datacentre.

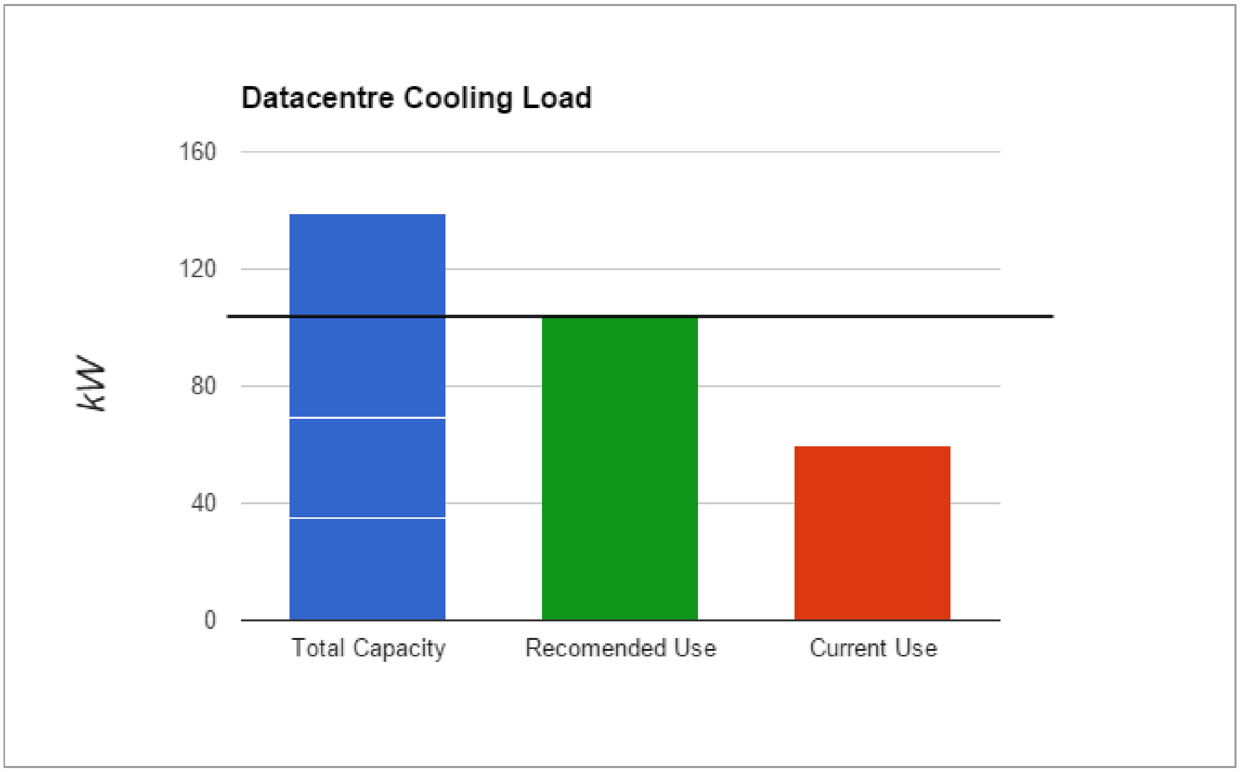

Figure 7: Breakdown of Datacentre cooling.

The datacentre is cooled with by four Stulz chilled air units, which takes chilled water from the CCHP's absorption chiller and converts it to cooled air for the datacentre. The Stulz system can provide up to 139 kWth cooling to the datacentre. Currently, the datacentre requires an average cooling load of 60 kWth. Although the datacentre chillers are capable of cooling another 80 kWth, we recommend not exceed a cooling demand of 104 kWth for redundancy purposes with the split-system. The Stulz system has three cooling units that add up to approximately 104 kWth cooling, with the fourth making up the excess to reach 139 kWth. Maintaining a datacentre cooling load of 139 kWth would mean that if one of the units ever failed, there would be a severe risk of damage to the physical servers and, therefore, data loss. With a load of no more than 104 kWth cooling, one of the cooling units could fail and there would still be enough cooling to sustain the datacentre's cooling load, leaving approximately 44 kW of cooling left for the datacentre.

In an ideal scenario, the Council will have increased the datacentre load to a constant 104 kWth cooling. This would leave 263 kWth for the rest of the building. 136 kWth can go to further cooling. We assume the building will have the thermal load during the colder months, and at least the cooling load during the hotter ones. So long as the thermal load is addressed during peak building occupancy hours, the rest of the thermal energy can be used throughout the building overnight. Indeed, less thermal energy would be used to precondition the Civic Centre overnight, but those 104 kW of cooling will be put to good use for the datacentre, and make money for the Council - something overnight preconditioning could not do alone.

In order to achieve an increase in the datacentre's load, we recommend that the Brent Council investigate hosting the datacentre's of other neighboring borough Councils within the Civic Centre. Hosting area borough's datacentres will allow the Civic Centre to increase the cooling demand of the datacentre, use more of the CCHP's thermal output, and provide revenue to the Brent Council by charging the other Councils for the hosting service, making money rather than just saving it. The Brent Council has started negotiations with Lewisham Council to host their datacentre, and doing so would be a good start to accomplishing the outcomes above. As technology continues to advance, there may be the possibility of further reduction of the physical datacentre's size and therefore cooling load, just as it had with the widespread use of cloud technology. If this happens, it would open up the possibility of hosting more Councils' datacentres, and provide additional revenue to the Brent Council, as long as the thermal limits outlined are adhered to.

4.2.3 Decentralised Energy Network

Despite the benefits of increasing the datacentre's cooling load, we still cannot say for sure that the Civic Centre will have the thermal demand necessary to utilize the CCHP to its fullest capacity. A way to ensure the CCHP's output energy is utilized at all times is through the establishment of a decentralised energy network, with the CCHP. A decentralised energy network, or district heating scheme, is a system where power is generated at one location and distributed to surrounding areas. According to the Mayor's London Heat Map, the Civic Centre is in a prime location for district heating, as indicated below by the purple area in Figure 6.

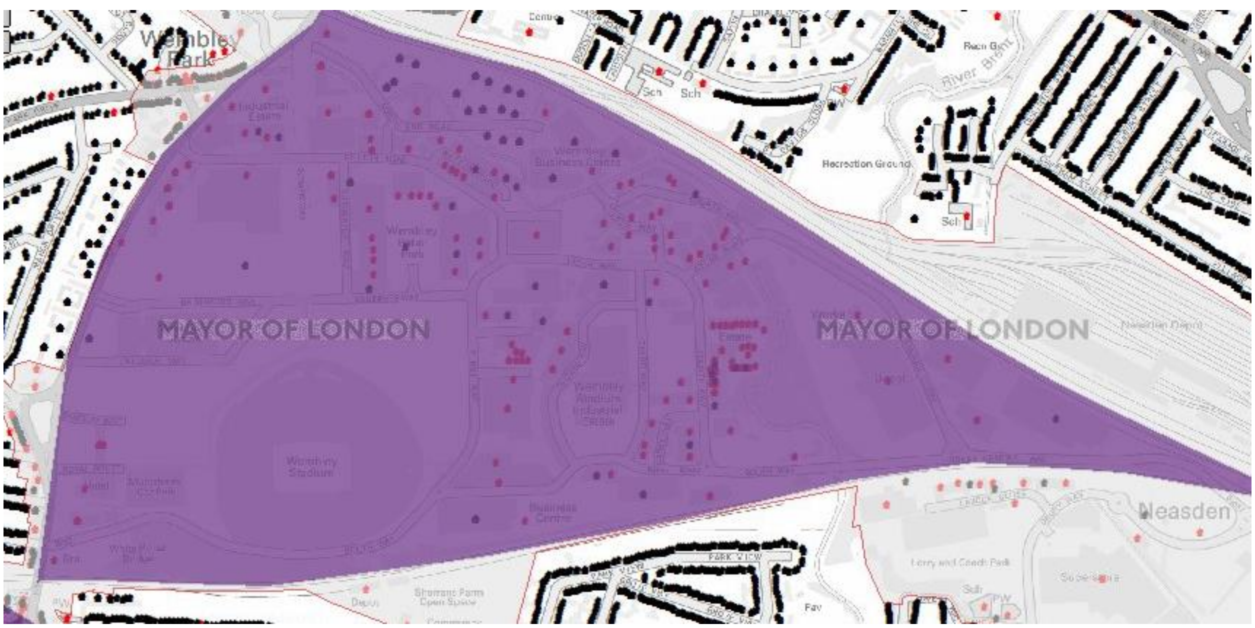

Figure 8: The Mayor of London's Heat Map focused on Wembley.

Setting up a decentralised energy network would mean that the Council would not have to worry about finding the thermal load within the Civic Centre, but rather finding potential clientele in the surrounding community. If the Council can find clientele for such a network, all the excess thermal energy could be distributed through the network regardless of the available amount. In this way, the Council could not only save money by fully utilizing the energy output by the CCHP, but also increase revenue by selling the excess energy to nearby users, similar to how one would sell excess electricity back to the grid. The Council's financial output would be limited to the cost for the installation of the necessary piping. Alternatively, Amber Infrastructure, a company that could provide funding for the decentralised system, has already proposed to loan the funds to the Council through the London Energy Efficiency Fund (LEEF) if the Council proceeds with a plan for decentralised energy. In addition to the cost of laying the piping, depending on contractual terms, the Council may also be responsible for maintaining the underground pipes. We recommend that the Council look into ways to either fund the maintenance of these pipes, or convince the clientele to maintain it themselves.

The Council started preliminary discussions with SSE to perhaps set up a district heating scheme with SSE Arena. SSE has provided the Council with a list of prerequisite information before continuing conversations with the Council. SSE would be an ideal client for the CCHP decentralised energy network, as the arena is right across the street from the Civic Centre and would require the least amount of piping of all potential clientele. In order to gather the necessary information for SSE's requests, we recommend the Council contact Fleetsolve and Bilfinger Europa, the company in charge of maintenance in the Brent Civic Centre, for the outstanding information, which can be found in Appendix E.

Another potential client would be Quintain, the company that owns most of the land surrounding the Civic Centre. With their construction and regeneration projects either underway or in the design process, we recommend that the Council inquire about the possibility of setting up a district heating scheme with them. If the Council provides a decentralised energy network for Quintain, then Quintain will not have to build their own district heating scheme in order to construct larger buildings. The London Plan requires buildings of a certain size to be capable of using decentralised energy. If the Brent Council provided Quintains a means of doing so, then not only could Quintain save money by not establishing their own scheme, but the Council could profit by selling Quintain their services.

If Quintain already proposed a conventional heating and cooling scheme in their design plans, we recommend the Council consider suggesting the implementation of thermal storage units directly connected to the CCHP. The addition for thermal storage units would supplement their original heating schemes regardless of its design. If partnered with the Brent Council, Quintain's properties would have backup thermal energy stored in case something happens with their boilers or chillers. This would allow the Council to profit from the CCHP's relationship with Quintain while also using the CCHP to its fullest capacity.

Further, the decentralised energy option could potentially pair well with increasing the datacentre's load; alternatively, district heating could also negate it. If the ideal decentralised energy network is found to be feasible before that of increasing the datacentre load, then all the excess energy from the CCHP could be distributed through the network even with the current load of the datacentre, thereby negating the need to increase the datacentre's load. However, if the increased datacentre load is found first, then a decentralised energy network could still be established afterwards, with less thermal energy to distribute due to the datacentre's increased cooling load. Regardless, just as the size of the datacentre has decreased before, future advances in technology could potentially call for smaller physical datacentre's in the future, which could lead to more available energy for the decentralised energy network, or more space in the datacentre for hosting. Nonetheless, the feasibility of all available options depends on the amount of excess energy the CCHP is actually outputting.

4.3 CCHP Fuel Choice

Data regarding the available fuels for the CCHP has been restrictively scarce. Since every engine burns different fuels in different ways, only Fleetsolve has accurate information regarding a fuel's carbon emissions and estimated burn rate for the specific CCHP in the Civic Centre. In addition, the Council has a binding contract with Fleetsolve that only allows the Council to purchase the fuel options Fleetsolve provides. Therefore, the cost per litre provided by Fleetsolve would be the most relevant to the Council.

If the Council were to purchase fuel for the CCHP from another biofuel provider or switch to diesel, it would break Fleetsolve's contract. Complicating matters, Fleetsolve also maintains the Civic Centre CCHP, and would likely discontinue their maintenance if the Council breaks the contract. It is difficult to estimate the financial impact of switching fuel providers since prices for the fuels specific to the Civic Centre's CCHP, with the exception of diesel, are not readily available.

Switching to diesel comes with its own complications. Diesel would not be a cost-effective choice for the Council. The use of diesel would eliminate any Renewable Obligation Certificate revenue, increase carbon emission tariffs for the engine, and tarnish the Council's efforts of optimising the operation of the Civic Centre's CCHP. Figure 9, below, shows an estimated comparison between the continued use of fish oil and the use of diesel in the CCHP.

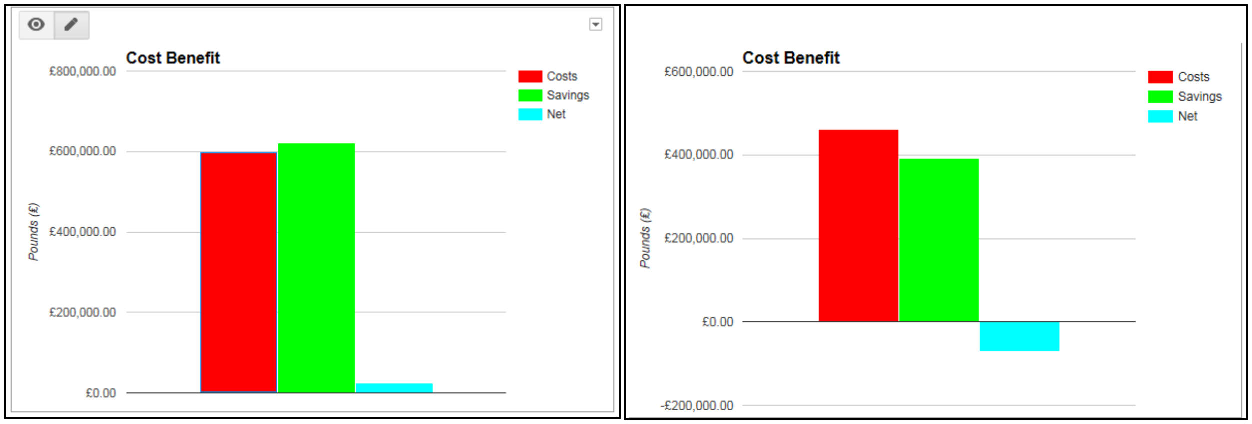

Figure 9: Estimated Cost Benefit comparison between fish oil (left) and red diesel (right).

As of publication, we have been unsuccessful in obtaining the data regarding fuel specifications from Fleetsolve. As an alternative, we investigated the Energy Institute, a forefront provider of information on energy-related information for the United Kingdom, to see if they had any data we could use to compare the different biofuel options for the CCHP. Although the data we would get from them would not be precise, we could use it to approximate the quantitative qualities of the different fuel options, such as their individual carbon emissions and possibly cost. Unfortunately, the data the Energy Institute was able to provide mostly pertained to traditional fuel sources and not to the biofuels that power the CCHP. We confirmed this through email inquiries and by exploring their physical and online catalogues, which also only had general information on biofuels. Fleetsolve would be the only ones to have the specific data for the different viable fuel options for the CCHP. Therefore, we recommend that the Council contact Fleetsolve in order to determine the best fuel choice for the CCHP for the duration of the Council's contract with Fleetsolve.

When the specific data for the different fuels has been obtained - namely, the average national cost and kilogram of carbon dioxide (CO_2) per litre of biodiesel, - then the fuel comparison can be made. We have developed a tool that should make this analysis fairly straightforward. It is our recommendation that the Council follow up with Fleetsolve and use the tool to compare operating costs of the available biofuel options. The fuel analysis tool, like the energy-usage ones mentioned before, has been left with Anís Robinson, and the user guide can be found in Appendix D.

4.4 BREEAM In-Use

The BREEAM In-Use qualifications were updated on 31st May, 2015, and with them an updated evaluation questionnaire was distributed. We have completed the energy portions of the questionnaire, which evaluates the building on factors such as total energy consumption and the use of energy efficient lighting sources. The completed questionnaire has been left with Anís Robinson, to aid in the completion of the BREEAM In-Use evaluation in the coming year. However, since the weighting and scoring for these questions is not known and will only be calculated when all sections are completed, an individual score for the energy section cannot be determined. Therefore, it is unknown the level to which the Civic Centre is performing on the BREEAM In-Use scale.

5.0 CONCLUSION

In order to determine an optimal means of operation for the Civic Centre's Combined Cooling, Heat, and Power (CCHP) engine, the Council needs to establish the necessary data collection framework for creating a thermal profile for the building. We have found that the Civic Centre, with its current electricity usage patterns, will have the electrical load to run the CCHP at maximum electrical capacity at all times. Without the thermal profile of the building, we could not assess whether the Civic Centre has the internal thermal demand to run the CCHP at maximum thermal capacity.

To develop the thermal profile, the Council must not only ensure that the Building Management System (BMS) is accurately reporting data, but also ensure that the relevant meters and submeters are accessible and functioning properly. We have provided best-use recommendations to optimize the use of the CCHP's thermal energy if there proves to be excess available in the future.

In order to determine the best fuel choice for the engine, the Council must obtain fuel data from Fleetsolve. Fuels behave differently with different engines, and since Fleetsolve is the provider of both the CCHP and its fuels, Fleetsolve is the only source of accurate information regarding the fuel options. The Council can then use our cost-benefit and energy-usage tools to determine which fuel choice best suits their needs, and how best to use the thermal energy the CCHP provides.

As for Building Research Establishment Environmental Assessment Methodology (BREEAM) In-Use, we have gathered some of the necessary information for the energy qualifications, and there are a lot of steps that need to be taken in regard to the completion of the other key performance indicator sections before officially registering for accreditation.

The Civic Centre's CCHP is already an energy-efficient and environmentally friendly technology. The Council's optimisation of the CCHP's operation, along with continued investigation of the BREEAM In-Use accreditation, will only strengthen the Brent Council's image as an active contributor toward a low carbon climate.

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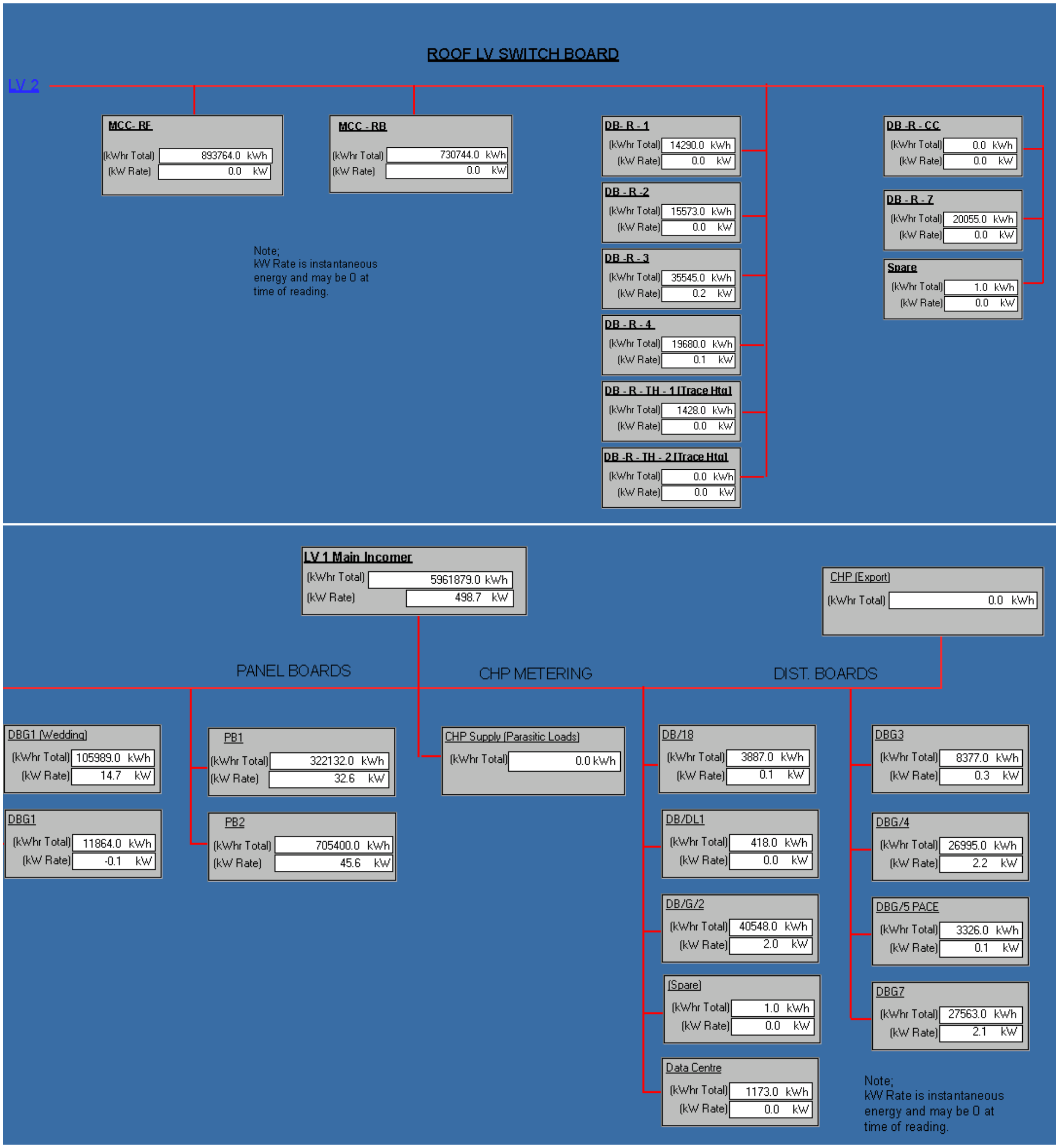
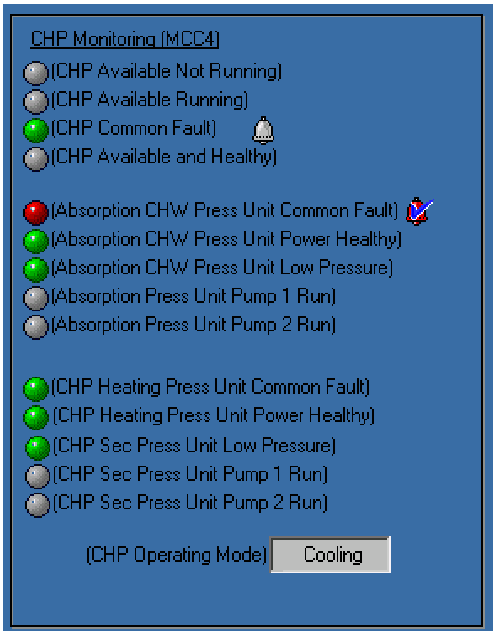
APPENDICES

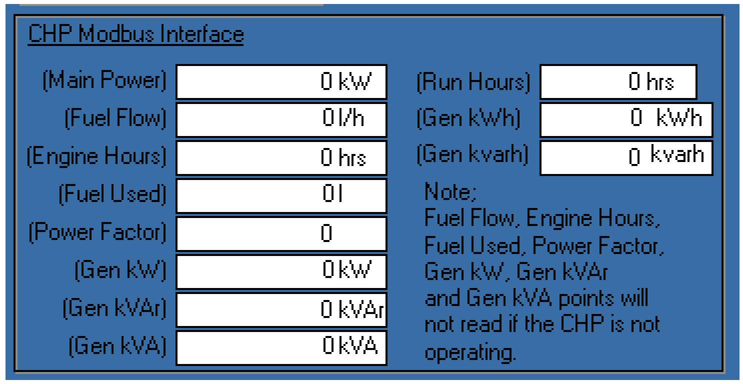
Energy Source	Scale	Type / Rate	Tariff (p/kWh)	
			< 30/9/14	> 1/10/14
Anaerobic digestion	≤250kW		12.46	11.21
Anaerobic digestion	>250kW - 500kW		11.52	10.37
Anaerobic digestion	>500kW		9.49	9.02
Hydro	≤15 kW		21.12	19.01
Hydro	>15 - 100kW		29.72	17.75
Hydro	>100kW - 500kW		15.59	14.03
Hydro	>500kW - 2MW		12.18	10.96
Hydro	>2MW - 5MW		3.32	2.99
Micro-CHP	<2 kW	(limited)	13.24	13.24
Solar PV	≤4 kW	Higher rate	14.38	14.38
Solar PV	≤4 kW	Medium rate	12.94	12.94
Solar PV	>4 - 10kW	Higher rate	13.03	13.03
Solar PV	>4 - 10kW	Medium rate	11.73	11.73
Solar PV	>10 - 50kW	Higher rate	12.13	12.13
Solar PV	>10 - 50kW	Medium rate	10.92	10.92
Solar PV	>50 - 150kW	Higher rate	10.34	10.34
Solar PV	>50 - 150kW	Medium rate	9.31	9.31
Solar PV	>150 - 250kW	Higher rate	9.89	9.81
Solar PV	>150 - 250kW	Medium rate	8.90	8.90
Solar PV	≤250kW	Lower rate	6.38	6.38
Solar PV	>250kW - 5MW		6.38	6.38
Solar PV	≤5MW	Standalone	6.38	6.38
Wind	≤100kW		17.78	16.00
Wind	>100 - 500kW		14.82	13.34
Wind	>500kW - 1.5MW		8.04	7.24
Wind	>1.5MW - 5MW		3.41	3.07
Any	existing systems transferred from RO		10.49	10.49

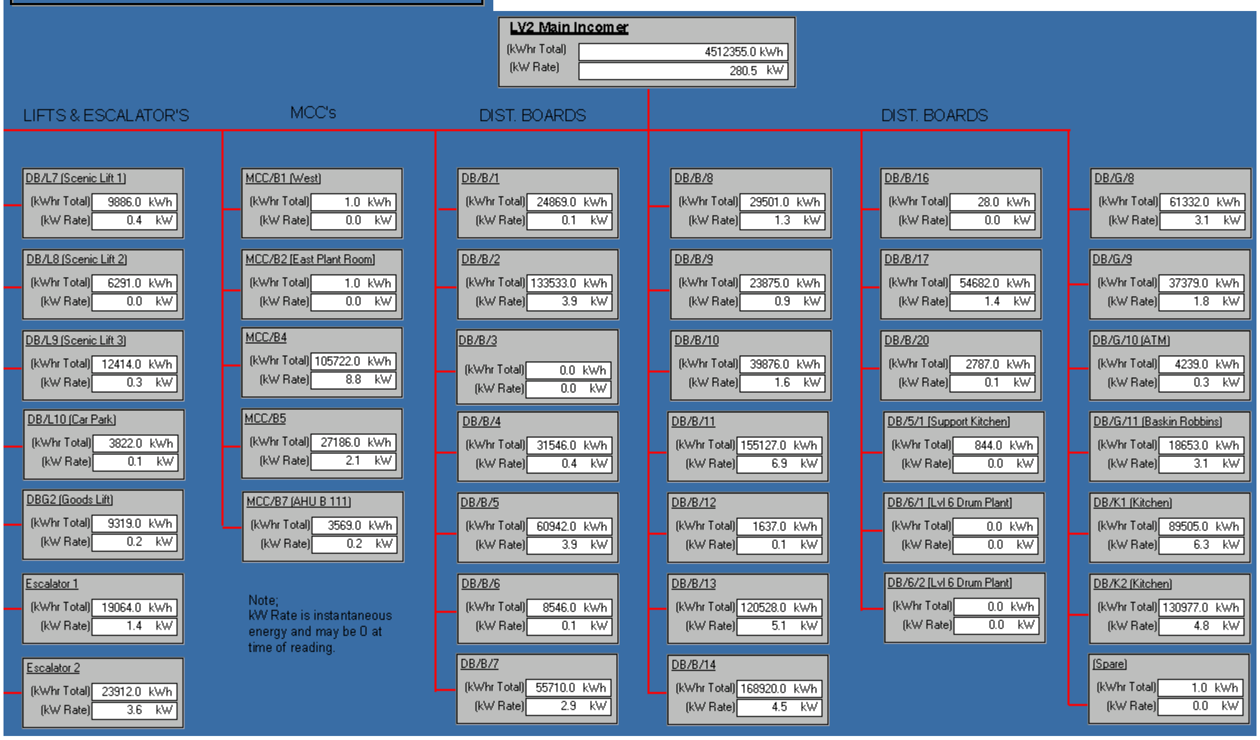
Appendix A: Listing of all Generation Tariffs for the RHI (Tariffs, 2015)

Issue:	**Explanation:**
CHP Readings, under Plant Viewer -> Metering Overview -> Electrical Meters (CHP), are all zero all the time.	The meters in the CCHP plant room are not properly hooked into the BMS.
Electric Chiller Reading, under Plant Viewer -> Metering Overview -> Electrical Meters (Roof LV) -> MCC-RF & MCC-RB, show the value 0 kW at all times no matter if the chillers are running or not.	The electric meters attached to the two chillers on the roof are not properly configured in the BMS.
The Datacentre Power Distribution units, under Plant Viewer -> Metering Overview -> Electrical Meters (Mezz) -> DataCentre PDU's -> PDU/DC/A & PDU/DC/B both show absurdly high kW rates, though we believe the total kWhs to be possibly accurate.	The datacentre electric meter is miss-calibrated in the BMS.
The readings for the CCHP and Datacenter are not displayed under LV1, under Plant Viewer -> Metering Overview -> Electrical Meters (LV1), the Parasitic CHP, CHP Export and Datacentre all read zeros.	The CCHP and Datacentre meters are not properly configured in the BMS
The CHP Modbus readings, under Plant Viewer -> Miscellaneous Monitoring {MCC4}, are all zero all the time. They don't appear to be hooked to anything, but contain information such as instantaneous power readings (kW) and fuel flow to the engine (L/hr).	The CHP modbus is not connected to the BMS, it was possibly removed during repair in late May 2015.
For LV1 & LV2, under Plant Viewer -> Metering Overview -> Electrical Meters (LV1) & Electrical Meters (LV2), the total for the Main Incomer, which is accurate, is not the total of all the sub meters. Many submeters are reading zero.	The submeters total power usage is less than the total power of the meter they all connect to. This indicates that some submeters are inaccurate or missing.

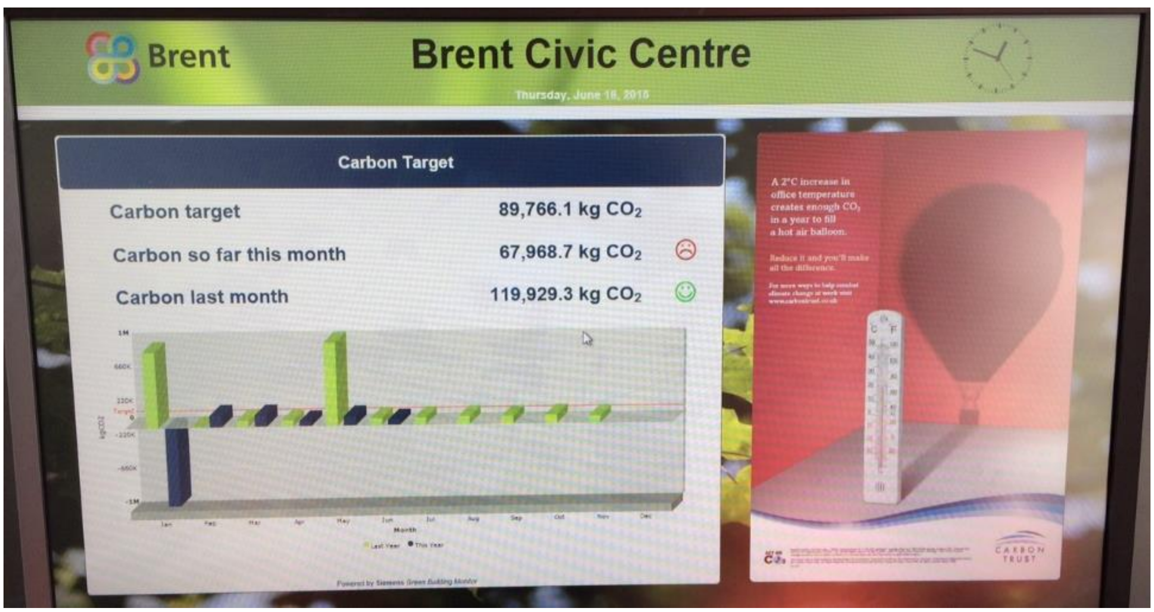

ROOF LV SWITCH BOARD
LV 2
MCC- RF (kWhr Total) 893764.0 kWh (kW Rate) 0.0 kW
MCC - RB (kWhr Total) 730744.0 kWh (kW Rate) 0.0 kW
DB- R - 1 (kWhr Total) 14290.0 kWh (kW Rate) 0.0 kW
DB - R -2 (kWhr Total) 15573.0 kWh (kW Rate) 0.0 kW
DB -R - 3 (kWhr Total) 35545.0 kWh (kW Rate) 0.2 kW
DB - R - 4 (kWhr Total) 19680.0 kWh (kW Rate) 0.1 kW
DB - R - TH - 1 (Trace Htg) (kWhr Total) 1428.0 kWh (kW Rate) 0.0 kW
DB -R - TH - 2 (Trace Htg) (kWhr Total) 0.0 kWh (kW Rate) 0.0 kW
DB -R - CC (kWhr Total) 0.0 kWh (kW Rate) 0.0 kW
DB - R - 7 (kWhr Total) 20055.0 kWh (kW Rate) 0.0 kW
Spare (kWhr Total) 1.0 kWh (kW Rate) 0.0 kW
Note; kW Rate is instantaneous energy and may be 0 at time of reading.
LV 1 Main Incomer (kWhr Total) 5961879.0 kWh (kW Rate) 498.7 kW
CHP (Export) (kWhr Total) 0.0 kWh
PANEL BOARDS
CHP METERING
DIST. BOARDS
DBG1 (Wedding) (kWhr Total) 105989.0 kWh (kW Rate) 14.7 kW
DBG1 (kWhr Total) 11864.0 kWh (kW Rate) -0.1 kW
PB1 (kWhr Total) 322132.0 kWh (kW Rate) 32.6 kW
PB2 (kWhr Total) 705400.0 kWh (kW Rate) 45.6 kW
CHP Supply (Parasitic Loads) (kWhr Total) 0.0 kWh
DB/18 (kWhr Total) 3887.0 kWh (kW Rate) 0.1 kW
DB/DL1 (kWhr Total) 418.0 kWh (kW Rate) 0.0 kW
DB/G/2 (kWhr Total) 40548.0 kWh (kW Rate) 2.0 kW
(Spare) (kWhr Total) 1.0 kWh (kW Rate) 0.0 kW
Data Centre (kWhr Total) 1173.0 kWh (kW Rate) 0.0 kW
DBG3 (kWhr Total) 8377.0 kWh (kW Rate) 0.3 kW
DBG/4 (kWhr Total) 26995.0 kWh (kW Rate) 2.2 kW
DBG/5 PACE (kWhr Total) 3326.0 kWh (kW Rate) 0.1 kW
DBG7 (kWhr Total) 27563.0 kWh (kW Rate) 2.1 kW
Note; kW Rate is instantaneous energy and may be 0 at time of reading.

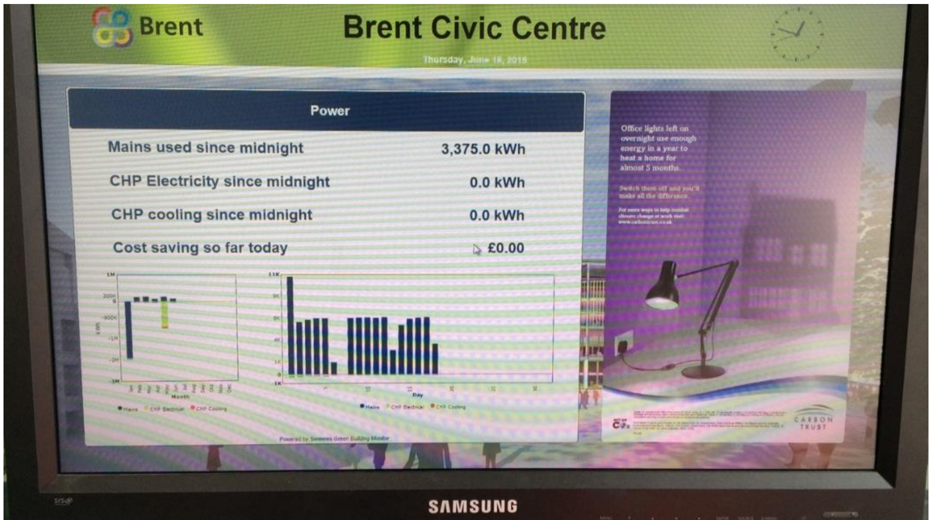

CHP Monitoring (MCC4)
(CHP Available Not Running)
(CHP Available Running)
(CHP Common Fault)
(CHP Available and Healthy)
(Absorption CHW Press Unit Common Fault)
(Absorption CHW Press Unit Power Healthy)
(Absorption CHW Press Unit Low Pressure)
(Absorption Press Unit Pump 1 Run)
(Absorption Press Unit Pump 2 Run)
(CHP Heating Press Unit Common Fault)
(CHP Heating Press Unit Power Healthy)
(CHP Sec Press Unit Low Pressure)
(CHP Sec Press Unit Pump 1 Run)
(CHP Sec Press Unit Pump 2 Run)
(CHP Operating Mode) Cooling

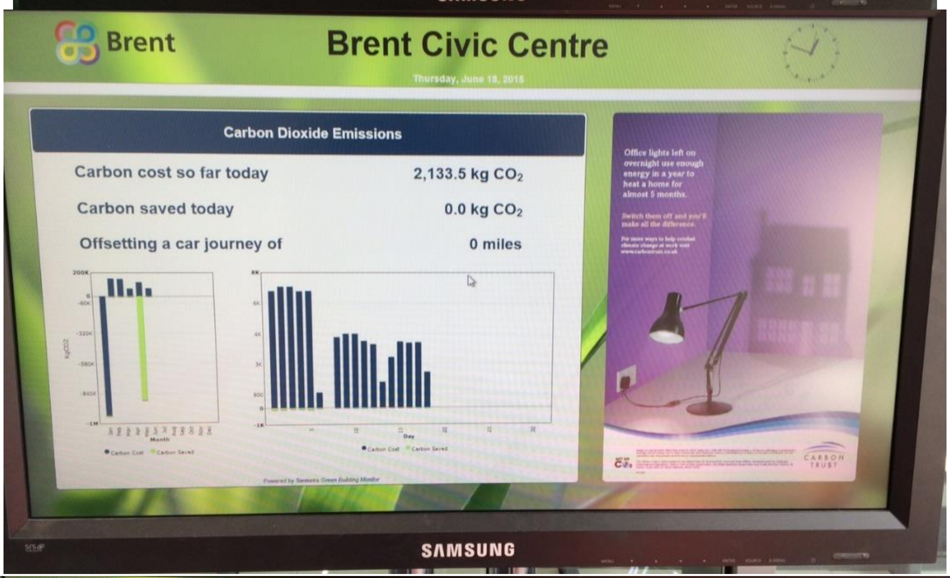

CHP Modbus Interface
(Main Power) 0 kW
(Fuel Flow) 0 l/h
(Engine Hours) 0 hrs
(Fuel Used) 0 l
(Power Factor) 0
(Gen kW) 0 kW
(Gen kVAr) 0 kVAr
(Gen kVA) 0 kVA
(Run Hours) 0 hrs
(Gen kWh) 0 kWh
(Gen kvarh) 0 kvarh
Note;
Fuel Flow, Engine Hours, Fuel Used, Power Factor, Gen kW, Gen kVAr and Gen kVA points will not read if the CHP is not operating.

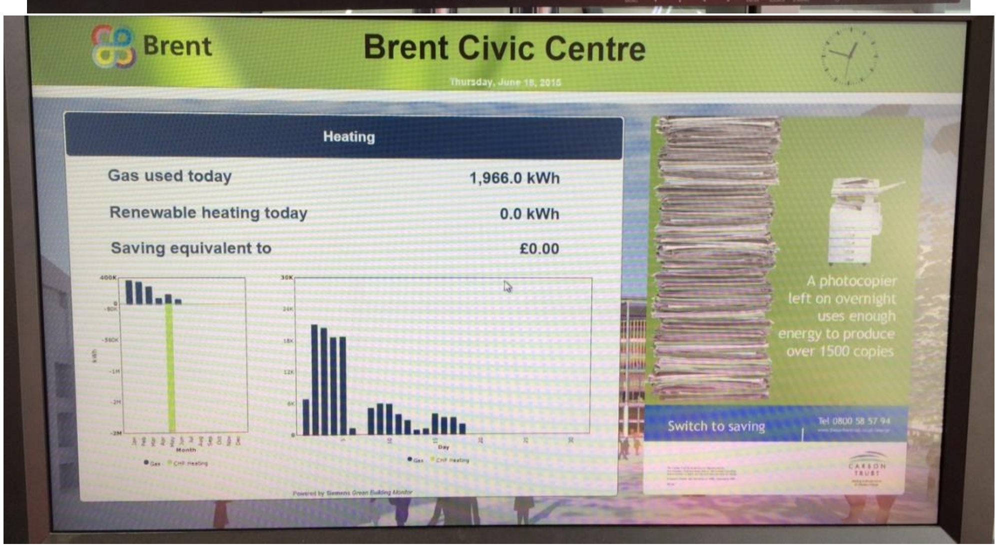

LV2 Main Incomer
(kWhr Total) 4512355.0 kWh
(kW Rate) 280.5 kW
LIFTS & ESCALATOR'S
MCC's
DIST. BOARDS
DIST. BOARDS
DB/L7 (Scenic Lift 1) (kWhr Total) 9886.0 kWh (kW Rate) 0.4 kW
DB/L8 (Scenic Lift 2) (kWhr Total) 6291.0 kWh (kW Rate) 0.0 kW
DB/L9 (Scenic Lift 3) (kWhr Total) 12414.0 kWh (kW Rate) 0.3 kW
DB/L10 (Car Park) (kWhr Total) 3822.0 kWh (kW Rate) 0.1 kW
DBG2 (Goods Lift) (kWhr Total) 9319.0 kWh (kW Rate) 0.2 kW
Escalator 1 (kWhr Total) 19064.0 kWh (kW Rate) 1.4 kW
Escalator 2 (kWhr Total) 23912.0 kWh (kW Rate) 3.6 kW
MCC/B1 (West) (kWhr Total) 1.0 kWh (kW Rate) 0.0 kW
MCC/B2 (East Plant Room) (kWhr Total) 1.0 kWh (kW Rate) 0.0 kW
MCC/B4 (kWhr Total) 105722.0 kWh (kW Rate) 8.8 kW
MCC/B5 (kWhr Total) 27186.0 kWh (kW Rate) 2.1 kW
MCC/B7 (AHU B 111) (kWhr Total) 3569.0 kWh (kW Rate) 0.2 kW
Note;
kW Rate is instantaneous energy and may be 0 at time of reading.
DB/B/1 (kWhr Total) 24869.0 kWh (kW Rate) 0.1 kW
DB/B/2 (kWhr Total) 133533.0 kWh (kW Rate) 3.9 kW
DB/B/3 (kWhr Total) 0.0 kWh (kW Rate) 0.0 kW
DB/B/4 (kWhr Total) 31546.0 kWh (kW Rate) 0.4 kW
DB/B/5 (kWhr Total) 60942.0 kWh (kW Rate) 3.9 kW
DB/B/6 (kWhr Total) 8546.0 kWh (kW Rate) 0.1 kW
DB/B/7 (kWhr Total) 55710.0 kWh (kW Rate) 2.9 kW
DB/B/8 (kWhr Total) 29501.0 kWh (kW Rate) 1.3 kW
DB/B/9 (kWhr Total) 23875.0 kWh (kW Rate) 0.9 kW
DB/B/10 (kWhr Total) 39876.0 kWh (kW Rate) 1.6 kW
DB/B/11 (kWhr Total) 155127.0 kWh (kW Rate) 6.9 kW
DB/B/12 (kWhr Total) 1637.0 kWh (kW Rate) 0.1 kW
DB/B/13 (kWhr Total) 120528.0 kWh (kW Rate) 5.1 kW
DB/B/14 (kWhr Total) 168920.0 kWh (kW Rate) 4.5 kW
DB/B/16 (kWhr Total) 28.0 kWh (kW Rate) 0.0 kW
DB/B/17 (kWhr Total) 54682.0 kWh (kW Rate) 1.4 kW
DB/B/20 (kWhr Total) 2787.0 kWh (kW Rate) 0.1 kW
DB/5/1 (Support Kitchen) (kWhr Total) 844.0 kWh (kW Rate) 0.0 kW
DB/6/1 (Lvl 6 Drum Plant) (kWhr Total) 0.0 kWh (kW Rate) 0.0 kW
DB/6/2 (Lvl 6 Drum Plant) (kWhr Total) 0.0 kWh (kW Rate) 0.0 kW
DB/G/8 (kWhr Total) 61332.0 kWh (kW Rate) 3.1 kW
DB/G/9 (kWhr Total) 37379.0 kWh (kW Rate) 1.8 kW
DB/G/10 (ATM) (kWhr Total) 4239.0 kWh (kW Rate) 0.3 kW
DB/G/11 (Baskin Robbins) (kWhr Total) 18653.0 kWh (kW Rate) 3.1 kW
DB/K1 (Kitchen) (kWhr Total) 89505.0 kWh (kW Rate) 6.3 kW
DB/K2 (Kitchen) (kWhr Total) 130977.0 kWh (kW Rate) 4.8 kW
(Spare) (kWhr Total) 1.0 kWh (kW Rate) 0.0 kW

Appendix C: Graphs being displayed in the Atrium




Brent
Brent Civic Centre
Thursday, June 18, 2015
Power
Mains used since midnight
3,375.0 kWh
CHP Electricity since midnight
0.0 kWh
CHP cooling since midnight
0.0 kWh
Cost saving so far today
£0.00
SAMSUNG

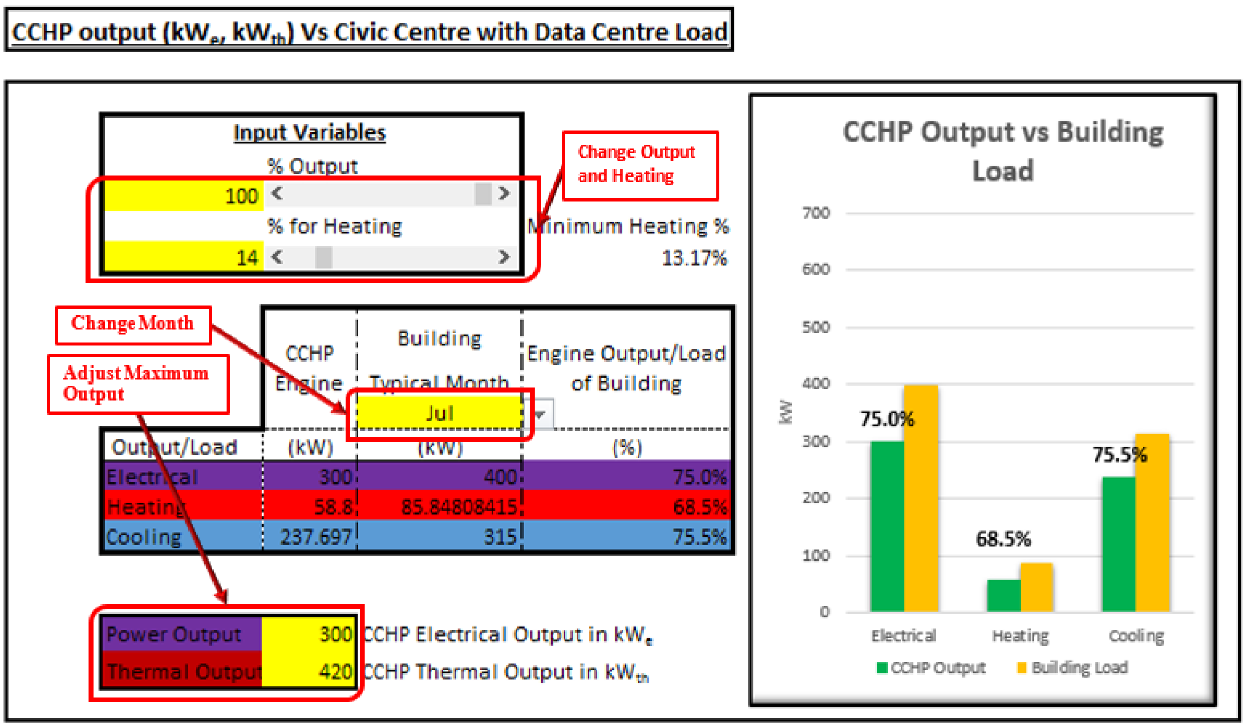

Brent
Brent Civic Centre
Thursday, June 18, 2015
Carbon Dioxide Emissions
Carbon cost so far today
2,133.5 kg CO2
Carbon saved today
0.0 kg CO2
Offsetting a car journey of
0 miles
SAMSUNG


Brent
Brent Civic Centre
Thursday, June 18, 2015
Heating
Gas used today
1,966.0 kWh
Renewable heating today
0.0 kWh
Saving equivalent to
£0.00
A photocopier left on overnight uses enough energy to produce over 1500 copies
Switch to saving

D1 Title: CCHP Output Widget

<u>Description:</u> Compares Output of the engine to load of the building for an average month.

<u>How to use it:</u> Yellow on the "Widget" sheet denotes user interaction. Percent output, percent thermal for heating, and month can be changed. The output of the engine can be updated once confirmed numbers are found. On the "Data" sheet, heat load, cooling load and datacentre cooling load can be updated with more accurate numbers (in instantaneous rate kW)



Month	Avg Heat Load (kW) [Invoices]	Avg Cooling Load with Data Center(kW)	Min Electric Load (kW)	Load of the Data Centre(kW)	Avg Heat Load (kW) [BRE]	Avg Cooling Load (kW) [BRE]
Jan	629	65	400	65	538	0
Feb	492	65	400	65	428	0
Mar	323	165	400	65	207	100
Apr	295	165	400	65	188	100
May	118	[illegible]	[illegible]	[illegible]	75	200
Jun	79	[illegible]	[illegible]	[illegible]	52	200
Jul	86	[illegible]	400	65	[illegible]	250
Aug	115	[illegible]	400	65	63	250
Sep	197	[illegible]	400	65	63	200
Oct	231	[illegible]	400	65	188	100
Nov	439	65	400	65	451	0
Dec	454	65	400	65	547	0

Input Average Monthly Instantaneous Heat Load

Input Minimum Instantaneous Electric Load

Input Cooling Load of Data Centre

Change Average Monthly Instantaneous Cooling Load w/o Data Centre

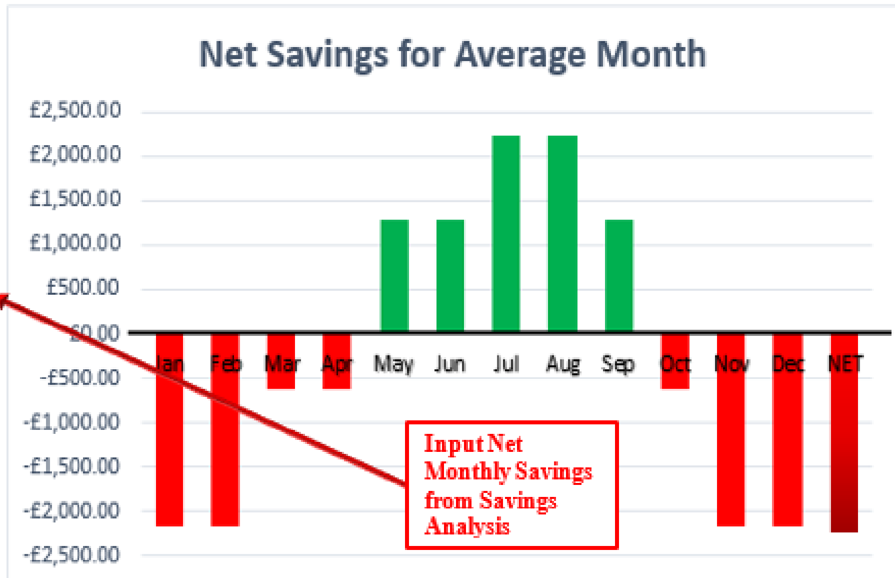
D2 Title: Monthly Savings

Description: Visually represents the net savings of the CCHP over an average year by month.

How to use: Input net savings data from one of cost benefit spreadsheets in the yellow area

CCHP Net Savings over an Average Year

Month	Net Savings (£)
Jan	-£2,156.34
Feb	-£2,156.34
Mar	-£630.53
Apr	-£630.53
May	£1,276.72
Jun	£1,276.72
Jul	£2,230.35
Aug	£2,230.35
Sep	£1,276.72
Oct	-£630.53
Nov	-£2,156.34
Dec	-£2,156.34
NET	-£2,226.07



D3 Title: Savings Analysis

Description: This spreadsheet shows the cost/benefit of running the engine at different settings for a year.

How to use: On the 'Analysis' sheet the fuel, output percent, and percent heating can be changed to look at the effects. Power and thermal output can be adjusted on this sheet to reflect confirmed numbers. On the 'Fuel' sheet fuel information should be filled in to make the model more accurate.

D4 Title: Savings Analysis Monthly

Description: This spreadsheet shows the cost/benefit of running the engine at different settings for each month based on cooling lead.

How to use: On the 'Analysis' sheet the fuel and month can be changed to look at the effects. Percent heating is automatically changed to be cooling lead. Power and thermal output can be adjusted on this sheet to reflect confirmed numbers. On the 'Fuel' sheet fuel information should be filled in to make the model more accurate. On the 'Monthly' sheet, heat load, cooling load without datacentre, and datacentre cooling load can be updated with more accurate numbers (in instantaneous rate kW) On the 'Yearly' sheet monthly savings numbers can be inputted and plotted on a chart.

SSE Enterprise, Wembley Arena

- **CHP Electrical and Thermal Capacity**
    - 300kWe, 420kWth
- **CHP Operational/Production report for past 12 months**
    - Get data from Fleetsolve.
- **CHP remaining life span**
    - Might be in the O and M manual for the engine given by Fleetsolve.
- **Electricity and gas utility use for past 12 months**
    - Found in either SystemsLink or the raw invoices
- **Number of existing boilers**
    - 4 conventional boilers found on roof
    - 1 boiler found in the CCHP
- **Capacity of existing boilers**
    - We were unable to locate this information but Richard U. or Russell or Martin Bailey should know where to find it.
- **Boilers remaining life span**
    - We were unable to locate this information but Richard U. or Russell or Martin Bailey should know where to find it.
- **Boilers operational/production report for past 12 months**
    - Bilfinger Europa should have this information.
- **Description and layout of existing heat network and any connections already built in**
    - Reach out to Wembley Planning.

Non-domestic buildings:

Year	Improvement on 2010 Building Regulatons
2010 – 2013	25 per cent
2013 – 2016	40 per cent
2016 – 2019	As per building regulations requirements
2019 - 2031	Zero Carbon

Appendix F: Changes to Carbon Emission Regulations in the London Plan (London 2015)

A table summarising the banding levels for the banding review period (2013-17) in England and Wales:

Band	13/14 support (ROC/MWh)	14/15 support (ROC/MWh)	15/16 support (ROC/MWh)	16/17 support (ROC/MWh)
Advanced gasification/pyrolysis	2	2	1.9	1.8
Anaerobic Digestion	2	2	1.9	1.8
Co-firing (low-range)	0.3	0.3	0.5	0.5
Co-firing (mid-range) *	0.6	0.6	0.6	0.6
Co-firing (high-range) *	0.7	0.9	0.9	0.9
Co-firing (low-range) with CHP*	0.8	0.8	1**	1**
Co-firing (mid-range) with CHP*	1.1	1.1	1.1**	1.1**
Co-firing (high-range) with CHP*	1.2	1.4	1.4**	1.4**
Co-firing of regular bioliquid	0.3	0.3	0.5	0.5
Co-firing of regular bioliquid with CHP	0.8	0.8	1**	1**
Co-firing of relevant energy crops (low range)	0.8	0.8	1	1
Co-firing of relevant energy crops with CHP (low range)	1.3	1.3	1.5	1.5
Conversion (station or unit)	1	1	1	1
Conversion (station or unit) with CHP	1.5	1.5	1.5	1.5
Dedicated biomass	1.5	1.5	1.5	1.4
Dedicated biomass with CHP	2	2	1.9	1.8
Dedicated energy crops	2	2	1.9	1.8
Energy from waste with CHP	1	1	1	1
Geothermal	2	2	1.9	1.8
Geopressure	1	1	1	1
Hydro	0.7	0.7	0.7	0.7
Landfill gas – closed sites	0.2	0.2	0.2	0.2
Landfill gas heat recovery	0.1	0.1	0.1	0.1
Microgeneration	2	2	1.9	1.8
Onshore wind	0.9	0.9	0.9	0.9
Offshore wind	2	2	1.9	1.8
Sewage gas	0.5	0.5	0.5	0.5
Solar PV				
Building mounted solar PV	1.7	1.6	1.5	1.4
Ground mounted solar PV	1.6	1.4	1.3	1.2
Standard gasification/pyrolysis	2	2	1.9	1.8
Tidal barrage	2	2	1.9	1.8
Tidal lagoon	2	2	1.9	1.8
Tidal stream***	5	5	5	5
Wave***	5	5	5	5

*Includes solid and gaseous biomass and energy crops

**These support levels are only available in circumstances where support under the RHI is not available

*** 5 ROCs subject to 30 MW cap at each generating station. 2 ROCs for any additional capacity added above 30 MW cap.

Appendix G: ROC Banding (ROC 2014)