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Energy Statement

Chichester House
04 July 2007

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Energy Statement
Chichester House
July 2007

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Executive Summary

1 Executive Summary

1.1 Development Description

The site is situated on the south side of High Holborn in London. The site is surrounded by both commercial and residential buildings.

Chichester House is seven storeys high with a basement, the building includes residential units, a retail unit and offices.

The proposed uses of the building are set out below:

Basement:	Services plant room, cycle storage and WCs/showers
Ground Floor:	Retail unit, office entrance, residential entrance, office and loading bay
First to Fifth Floor:	Offices, toilets and residential units
Sixth to Seventh Floor:	Offices and toilets
Roof Floor:	Services plant rooms

1.2 Energy Demand

Faber Maunsell have used the industry standard IES 'Virtual Environment - version 5.6.1' software suite from Integrated Environmental Solutions Ltd., to produce a dynamic thermal simulation of the proposed Chichester House, which forms the basis for calculating the likely energy consumptions for options using Fan Coil Units (FCUs) and Chilled Beams.

Note the proposed cooling strategy for the office areas will be Chilled Beams.

Table 1 - Cooling system's implication on site carbon dioxide emission (tonne CO2 /year) Chichester House indicates the (Carbon Dioxide) CO_2 emissions estimated with FCUs and Chilled Beams as a comparison to identify the energy saving benefits of a chilled beam office cooling strategy.

Table 2 is a summary of the energy consumption (MWh) and energy demand split for the Chichester House. The resulting carbon dioxide emission from these energy consumptions are shown in Table 3.

Office Cooling System	Site carbon dioxide emission (tonne CO_2 /year)	Saving over FCUs
FCUs	511	-
Chilled Beams	455	11.0%

Table 1 - Cooling system's implication on site carbon dioxide emission (tonne CO2 /year) Chichester House

	Residential (MWh/year)	Commercial (MWh/year)	Total (MWh/year)
Electricity	13	841	854
DHW	16	40	56
Space Heating	9	77	86
Space Cooling	-	376	376
Total	38	1334	1372

Table 2 - Total Site Energy Demand (MWh/yearan) Chichester House

	Residential (tonne CO_2 /year)	Commercial (tonne CO_2 /year)	Total (tonne CO_2 /year)
Electricity	6	355	361
DHW	4	9	13
Space Heating	2	17	19
Space Cooling	-	62	62
Total	12	443	455

Table 3 - Total carbon dioxide emissions (tonne CO_2 /year) Chichester House

1.3 Part L2A Compliance

Part L compliance studies have been undertaken to check the proposed building against the Building Regulations Part L 2006 and also air conditioning options on the carbon dioxide emissions. Including:

- Fan coil units
- Chilled beams

The Part L assessment as summarised in table 4 below indicates that the CO_2 emissions for Chichester House with chilled beams is 47% below the notional building and 20% below the Part L requirement, with the use of chilled beam system.

	Carbon Dioxide Emission (kg CO_2 /m²/year)	Improvement over notional Building
Notional Building	52.5	-
Target Building	38.1	27%
Actual Building Option1 (FCUs)	34.8	34%
Actual Building Option 2 (Chilled Beams)	28.0	47%

Table 4 - Chichester House Part L compliance summary

1.4 Energy Efficiency Design Measures

The following energy efficiency and sustainability measure are currently being considered:

1. Chilled Beams (*1).

2. Free cooling using the dry air coolers on the roof, bypassing the chillers when the ambient temperature permits.

3. Heat Recovery with Thermal Wheels, a high efficiency heat recovery method to re-claim energy from the ventilation system. (*1)

4. High efficiency condensing boilers (*1).

5. High efficiency lighting equipment and controls (*1)

6. Variable volume inverter controlled pumping

7. High performance façade (*1)

8. A full building energy management system incorporating energy monitoring, plant monitoring and controls include optimisation and weather compensation routines. This system will also give warnings of out of range values (*1)

(*1) Included in the building energy demand assessment.

1.5 Heating, Cooling and Renewable Systems Proposed

Heating System Proposed

High efficiency boilers are proposed with low NOx emission modulating burners. The boilers will be condensing types to maximise energy efficiency. Water will be circulated to the building with duty/standby variable volume circulating pumps located in the boiler room. Inverter drives will be fitted to all circulating pumps.

The LTHW will be distributed to serve air handling unit heater batteries, terminal reheat coils, radiators and trench heating. Radiators and trench heating are proposed with thermostatic radiator valves for temperature control.

Cooling System Proposed

A chilled water supply will be provided by liquid water chillers and roof level mounted dry air coolers.

Chilled water will be circulated to serve the air handling unit cooling coils and passive chilled beams located in the office areas.

The chilled water will be circulated with duty/standby variable volume circulating pumps. Inverter drives will be fitted to all circulating pumps.

The control of the chilled water temperature off each chiller and the sequencing of chiller units will be regulated by the packaged chiller unit controls and be monitored by the building management system.

Provision will be made to optimise the operation of the dry air coolers for free cooling to the chilled beams when external ambient temperatures permit.

Proposed Ventilation System

The building will be provided with mechanical ventilation. The areas will be served by the following systems:

Area	**System**
Office areas / Entrance	Constant Volume Supply and Extract System
Toilet areas	Constant Volume from Extract System (supply transferred from office area)
Plant rooms and storages	Constant Volume Supply and Extract System

Fresh air AHUs will provide constant discharge temperatures throughout the year. Heat will be reclaimed by the use of a thermal wheels between the supply and extract systems.

General extract from the plant rooms and storage areas will be via a low velocity ductwork system with a single axial extract fan located at basement level. Extract systems will generally be rated at 95% of the supply systems to achieve a positive pressure regime to minimise infiltration. All fans will have inverter drives.

All supply and fresh air intake ductwork and plenums will be insulated against heat loss and surface condensation. Other than downstream of any reclaim coils, all recirculation and exhaust ductwork will be uninsulated.

Renewables Assessment

Potential CO_2 savings and capital costs from the following low and zero carbon technology options have also been reviewed (see table 5) for incorporation into Chichester House

- Combined Heat and Power
- Tri-Generation (Combined Heat and Power + Absorption Cooling)
- Solar Thermal Heating
- Solar PV
- Wind Turbines
- Biomass Heating
- Ground Source Heating
- Ground Source Cooling

Technology	System Size	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Capital Cost (£)	Cost per CO_2 Saving (£/tonnes CO_2 /year)	Recommended
Low Carbon Options						
CHP	18kW	1.6	7.297	90,000	12,280	No
CHP (Tri-Gen)	26kW	2.6*	11.83	120,000	10,100	No
Renewable Options						
GSHP – Heating	***180 KW***	***2.13***	***9.69***	***472,800***	***27,520***	***Yes***
GSHP – Cooling	***144 KW***	***1.62***	***7.37***			***Yes***
Solar Thermal Panels	140 m²	2.7	12.285	70,000	5,600	No
PV Panels	140 m²	2.6	11.762	168,000	14,200	No
Solar Thermal Panel + PV Panels	***120 m² PV panels & 20m² Solar Thermal Panels***	***(2.24+0.56) = 2.8***	***12.74***	***154,000***	***12,040***	***Yes***
3 No. Wind Turbines	18 kW	2.1	9.345	30,000	9,300	No
Bio Mass Boiler	30 kW	2.6	11.83	16,000**	1,340	No

Notes: ** CCHP has 1% extra saving over installing a simple CHP system*

*** Capital cost include biomass boiler only.*

All costs are indicate at present and are being verified by the cost consultant

Building CO2 emission of 455 tonne CO2 /year

Table 5 - Summarises the low and zero carbon technology options reviewed for Chichester House

The matrix (figure 1) below provides a summary of the low carbon and renewable technologies considered and how they can or cannot be integrated together. In general, those identified in the red and green blocks are not compatible to be used together.

	CHP	**CCHP**	**GSHP**	**Solar Thermal**	**PV**	**Wind**	**Biomass**
CHP	x						
CCHP		x	C				
GSHP		C	x				C
Solar Thermal				X			
PV					x	E	
Wind					E	x	
Biomass			C				x

	Competes for Roof Space
E	Competes for electricity
	Competes for Heating
C	Competes for Heating And Cooling

Figure 1 - Low carbon and renewable technologies integration matrix

Renewables Proposed

To optimise the potential carbon savings, GSHP's to meet a proportion of the buildings heating and cooling demand used in conjunction with both PV (for the offices electrical demand) and solar thermal (for the residential hot water/heating) are recommended that can be practicably integrated into the development. Table 6 indicated the potential CO_2 savings and capital costs from the proposed low and zero carbon technologies for incorporation into Chichester House

This has been estimated to provide a maximum of up to 6.55% CO_2 reduction. This will be subject to further detailed geotechnical studies and design development during the detailed design stages.

There are many other sustainability measures that the development has taken account of as well as the deployment of energy use on the development. These all need to be reviewed collectively to see the benefits that the development provides as detailed in the Sustainability Statement.

	System Size	CO2 Saving (%)	CO2 Saving (tonnesCO2/ year)	Capital Cost (£)	Cost per kg CO2 Saving (£/tonnes CO2/year)
Solar PV and Solar Thermal	120 m² PV panels & 20m² Solar Thermal Panels	(2.24+0.56) = 2.8	12.74	154,000	12,040
GSHP - Heating	180 KW	2.13	9.69	472,800	27,520
GSHP - Cooling	144 KW	1.62	7.37		
Total		6.55	29.8	626,800	

Note:

1. *All costs are indicate at present and are being verified by the cost consultant.*
2. *Building CO2 emission of 455 tonne CO2 /year*

Table 6 - Summarises the proposed low and zero carbon technologies for Chichester House

The renewable energy study has indicated that the development can achieve 6.55% CO_2 saving via the application of on site renewable energy technologies. There are technical and practical constraints that provide limitations on increasing the renewable CO_2 savings as details below:

Technical Constraints

1. Most of Low or zero carbon emission technologies, such as GSHP, CHP, Tri-gen CHP, Bio-mass and solar thermal are targeting heating demand of the building, and they can't be used together. The heating demand is relatively low for the development, and the building heating demand has been significantly reduced through a number of energy efficiency measures such as heat recovery system of ventilation system and high performance facade. Therefore, the carbon saving from heat targeting LZC technologies are limited.

Practical Constraints

1. The proposed GSHP cooling system enhances the carbon saving of the building, however because the site constraints, the size of GSHP cooling system is limited. Limited site area means the number of boreholes are limited, and hence limit the size of GSHP. The number

and positions of structural piles also limit the size of GSHP as the boreholes need to be spaced apart from the structural piles.

Cooling demand is relatively high (approximately 3 times more than the demand of space heating and DHW), however a limited size of GSHP cooling system limit its carbon savings

2. Insufficient roof space limits the use of PV panels and wind turbine. Because of site constraints, the roof is the only area for heat rejection plant, air intake ductwork/lourves and tenant's satellite dishes, and the window cleaning cradle system. These further reduce the useable area for PV panels and wind turbine.
3. The uncertainty of wind conditions in an urban environment, height restriction and sight line of the site made wind turbines not a preferable renewable option in this building.

Summary

The energy demand of this building has been significantly reduced through a number of energy efficiency measures; the chilled beams system for example reduces overall building CO_2 emissions by 11% when compared with a more conventional FCU installation. In addition to the energy efficiency measures, the building will include renewable technologies in the form of ground source heating/cooling, solar water heating and PV panels to provide 6.55% of the predicted building CO_2 emissions.

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Introduction

2 Introduction

2.1 Background

Faber Maunsell have been appointed by the developer, Hines to produce an Energy Statement for Chichester House in support of its planning application to London Borough of Camden. The report outlines how the proposed development addresses the Mayor's energy related policies as set out within the London Plan, as well as energy related Camden policies which are set out in the Camden Plan.

The report demonstrates that the project design team has given thorough consideration to all zero and low CO_2 technologies that could be technically employed to meet a proportion of the building's energy demand. The report draws on energy demand modelling which has been undertaken by the Faber Maunsell, as well as earlier project renewable energy feasibility studies, and sets out the indicative financial costs, potential CO_2 savings and design implications associated with each of the zero or low CO_2 options considered. Finally the report sets out the proposed energy strategy.

The report establishes the building energy demand and shows energy and related CO_2 savings that can be made through energy efficiency measures, efficient supply of energy (such as combined heat and power) and incorporation of a variety of renewable energy sources.

2.2 Description of the Site

The site is situated on the south side of High Holborn in London. The site is surrounded by both commercial and residential buildings.

Chichester House is seven storeys high with a basement, the building includes residential units, a retail unit and offices.

The proposed uses of the building are set out below:

Basement:	Services plant room, cycle storage and WCs/showers
Ground Floor:	Retail unit, office entrance, residential entrance, office and loading bay
First to Fifth Floor:	Offices, toilets and residential units
Sixth to Seventh Floor:	Offices and toilets
Roof Floor:	Services plant rooms

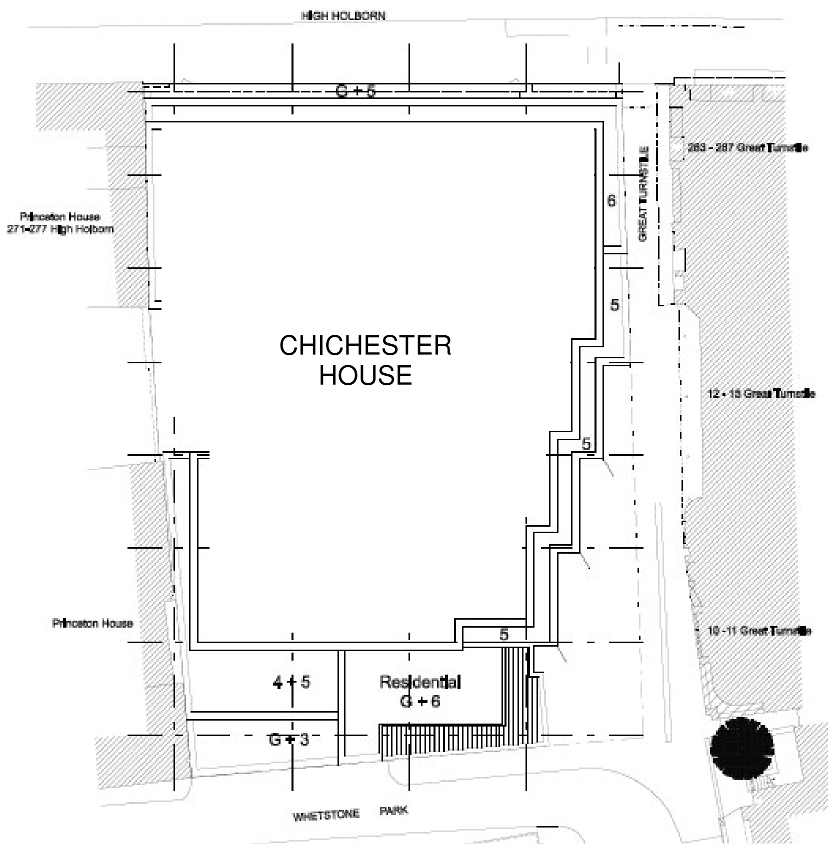

Figure 2 - Chichester House located on the south side of High Holborn

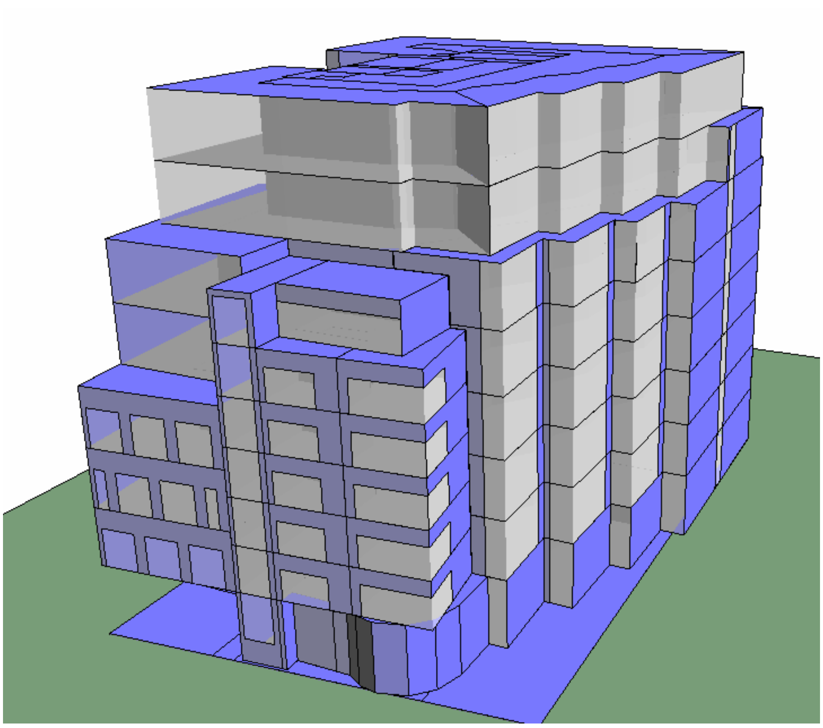

Figure 3 - Computer generated image of Chichester House

2.3 Contents of this Report

This report has been written to respond to the London Plan and the London Borough of Camden policies and identify how the Mayor’s Energy Hierarchy has been addressed.

It includes:

- An energy demand assessment outlining the estimated MWh/yr expected and an overall annual carbon dioxide emissions figure. In detail, the assessment has included an estimation of the baseline carbon dioxide emissions from all energy use in the development.
- A review of the design of the building with reference to energy efficient design measures, and recommendations being considered for the development. This includes heating, cooling, ventilation, daylighting and artificial lighting, equipment and appliances, etc.
- An assessment of the feasibility of each renewable energy technology for this site, setting out possible size of plant that can be installed and carbon savings that would be achieved as a result of this installation.
- A statement setting out the technical consideration of CHP as it could be used in this development.
- A summary identifying which of the low and zero carbon energy options have been proposed for the development.

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Energy Demand Assessment

3 Energy Demand Assessment

3.1 Energy Model

Faber Maunsell has used the industry standard 'IES Virtual Environment - version 5.6.1' software suite from Integrated Environmental Solutions Ltd. to produce a dynamic thermal simulation of the proposed Chichester House. This software is included in the CIBSE AM11 Software Compliance Checklist. AM11 provides guidance for engineers on building energy and environmental modelling and is approved by the DCLG for calculating carbon dioxide emissions for the purposes of building regulations part L2A.

IES V5.6.1 is an integrated suite of applications based around a 3D geometrical model. The modules used for this project include "ModelIT" for model construction and "ApacheSim" for thermal simulation.

- *ModelIT* is used to generate the geometry of the 3D models.
- *ApacheSim* is a dynamic thermal simulation program, based on first-principles mathematical modelling of the heat transfer processes occurring within and around a building. It qualifies as a Dynamic Model in the CIBSE system of model classification, and exceeds the requirements of such a model in many areas. The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use. This module also houses the construction database which defines all the construction U-values for the various elements.

The models were simulated using the CIBSE test reference year (TRY) weather data for London, as required by Building Regulations Part L2A 2006. This data is based on the mean weather data from 1976 to 1995 and has a summertime peak dry bulb temperature of 30.1℃ and wintertime minimum of –4.5℃.

A full list of the thermal modelling assumptions is included within this report as Appendix B.

The Part L2A assessment of Chichester House outputs include hourly kW demands for heating (DHW, mechanical ventilation and perimeter room heating), cooling (mechanical ventilation) and electricity (including small power, lighting and electrical consumption from mechanical ventilation systems).

These outputs, have allowed gas and electrical consumption and related CO_2 emissions from the Chichester House to be calculated and the 10% CO_2 reduction target to be established.

3.2 Delivered Energy Demand

Table 7 and Chart 1 below outline the Chichester House annual site energy demands split between space heating, DHW, space cooling and electricity. The total site energy demand is 1372 MWh/year. This is the sum of energy calculated in Part L, extra energy to temper the incoming fresh air, and electricity used by machines in the building.

	Residential (MWh/year)	Commercial (MWh/year)	Total (MWh/year)
Electricity	13	841	854
DHW	16	40	56
Space Heating	9	77	86
Space Cooling	0	376	376
Total	38	1334	1372

Table 7 - Total Site Energy Demand (MWh/year) Chichester House

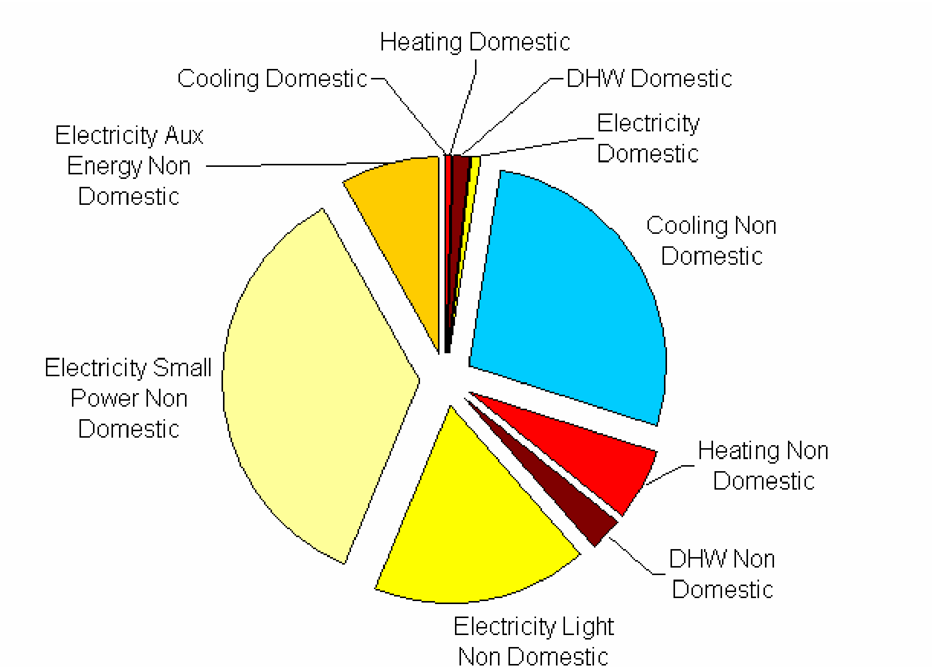

Chart 1 - Showing proportional usage of energy on the site

The energy demands outlined in Table 7 and Chart 1 above have been multiplied by the carbon dioxide emission factors for gas and electricity, taking account of distribution losses and gas boiler efficiencies where appropriate, and the resulting emissions are shown in table 8 and Chart 2.

	Residential (tonne CO_2 /year)	Commercial (tonne CO_2 /year)	Total (tonne CO_2 /year)
Electricity	6	355	361
DHW	4	9	13
Space Heating	2	17	19
Space Cooling	0	62	62
Total	12	443	455

Table 8 - Total carbon dioxide emission (tonnes CO2 /year) Chichester House

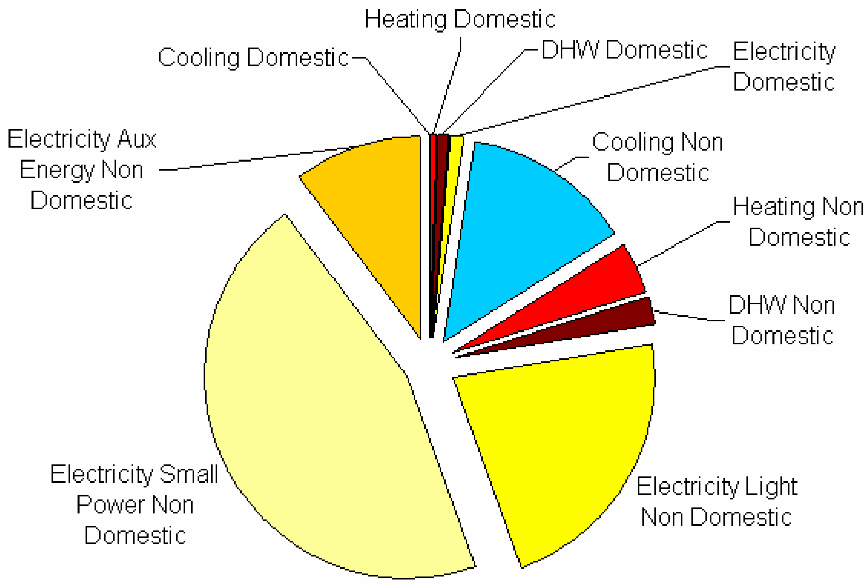

Chart 2 - Showing proportional CO2 emissions on the site

Throughout this report the carbon dioxide emission factors used are as given in Table 2 of Building Regulations, Conservation of Fuel & Power, Part L2A. ie

Fuel	**Kg CO_2 per KWh**
Gas	0.194
Electricity	0.422
Electricity Not Used Due To On Site Generation	0.568

Based on the energy modelling that Faber Maunsell have undertaken for Chichester House, predicted CO_2 emissions from the site are 455 tonnes CO_2/year

The model included diversity factors to reflect varying energy consumption in different parts of the building at different times, and took account of the fact that the office building would be closed on the weekends and that energy demands would be lower during holiday periods.

After taking account energy efficient methods, the total CO_2 emissions for the site are 455 tonnes of CO_2 per year. Therefore, the target CO_2 reduction from renewables is 45.8 tonnes per year.

3.3 Assumptions / Benchmark Data

The site energy was calculated by taking "Part L" hourly loads for the commercial part of the building, and adding on hourly loads present in the site but not falling under Part L, for example the electricity needed to power computers in the offices. Energy needed to heat the air before entering the building was then added. A simulation of the loads in the residential areas was performed, on an hourly basis, and then these loads were scaled to known domestic benchmark values.

3.4 Part L 2A CO2 Emissions

The Part L 2A compliance results are shown on Table 9 below. These results do not include the residential areas as these are not covered under Part L 2A.

Building model	$kgCO_2/m^2/year$	Actual building percentage reduction over Notional building
Part L 2A Notional building	52.459	–
Part L 2A target	38.1215	27.33%
Part L 2A Chilled Beams BER	28.0	47%

Table 9- Carbon dioxide emissions results - Part L2A model

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Energy Efficiency Measures

4 Energy Efficiency Measures

4.1 Introduction

This section outlines how the energy demands of Chichester House have been reduced in line with the first part of the Mayor's Energy Hierarchy:- Use less energy (be lean)

Before considering renewable energy, the building has been designed to reduce energy use. High efficiency cooling delivery is achieved by using chilled beams, rather than higher energy consuming fan coil units. Chilled beams both deliver cooling more efficiently, as less energy is wasted on fans and also are able to run at higher temperatures allowing the chilling plant to run more efficiently.

High specification glazing is to be used, limiting solar heating gains, while allowing in daylight thus saving on lighting energy.

A thermal wheel is to be used to recover heat from the building and pre-heat or pre-cool the incoming air, saving heating and cooling energy. Highly efficient boilers and chillers are to be used.

The provision of free cooling via the roof mounted dry air coolers will be provided to operate when outside ambient temperatures permit thereby reducing the low load running time of the building chillers.

4.2 Lighting

Daylight controls will ensure lighting is switched off when it is not required within the perimeter zone. High performance glazing will reduce the solar gains, especially on its south facing façade, this will reduce demand for cooling in the summer.

4.3 Insulation Standards

Chichester House will be built with minimum area weighted U-values as set out in Part L2A (2006). Simulations of the building have been performed with improved insulation, and have shown an increase in carbon usage. This is because the building is comprised mainly of modern office space, so the need for heating is small and significant cooling loads are present even when the external air temperature is low. Extra insulation leads to a small decrease in heating related carbon emissions, but a larger increase in cooling related carbon emissions.

4.4 Heating System

The heating system energy requirements have been reduced by introducing the following features to the design:

1. Thermal wheel heat recovery with high operating efficiencies is proposed within all main AHUs. This significantly reduces the heating required to warm up incoming fresh air in winter
2. Some of the LTHW circuits have variable volume flow rates, which require less pumping energy.
3. All trenches heaters and radiators have TRV control to reduce wastages via more precise control.
4. Heating will be provided by high efficiency, low NOx, condensing boilers. All selected plant will out perform the minimum Building Regulation Part L2A efficiency requirement.
5. Heating coils in Air Handling Units will be operated at lower water temperature than is standard practice, which will allow the proposed ground source heat pump system to work at higher efficiency.

4.5 Cooling System

The cooling system energy requirements have been reduced by introducing the following features to the design:

1. The use of passive chilled beams provide cooling by natural convection and hence save energy on fan power over the more standard FCU designs.
2. Passive chilled beams operated at a higher chilled water temperature, which offer opportunities of free cooling during the mid season.
3. A higher chilled water temperate allow chillers to operated at higher efficiency
4. All selected plant will out perform the minimum Building Regulation Part L2A efficiency requirement.

4.6 Ventilation System

The energy requirements have been reduced by introducing the following features to the design:

1. WC extract fans operate on a variable volume basis and are provided with inverter control driven off occupancy sensors.
2. All selected plant will out perform the minimum Building Regulations Part L2A efficiency requirements.

4.7 Lighting and Appliances

All general lighting within the building will consist of high efficiency T5 fluorescent luminaries, with some decorative and specialist lighting in the reception area.

The proposed programmable lighting controls will utilise movement detectors and daylight linking to decrease energy demands

Target lighting levels are given in the CIBSE Interior Code for Lighting, as below:

- General Office space - 500lux
- Corridors - 150lux
- Plant Rooms - 200lux
- Lift Lobbies - 150lux
- Toilets - 150lux.

4.8 Energy Management

Load logging of electrical power, supplementary cooling, heating and gas requirements will be captured on the BMS, to assist the building manager in monitoring and tuning the performance of the M&E systems to operate at better efficiencies. All major plant items can be monitored. This will be formatted to capture and present information on hourly/daily/weekly/monthly or annual basis, such that any unreasonably high energy consumption trends can be readily identified, investigated and remedied.

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CHP Study

5 CHP Study

5.1 Introduction

This section outlines a CHP energy study for the development.

Supply Energy Efficiently (be clean)

The Mayor of London is very keen to encourage the use of CHP in the Capital. Proposal 7 in the Mayoral Energy Strategy states that:

> *"London should maximise its contribution to meeting the national target for combined heat and power by at least doubling its 2000 CHP capacity by 2010."*

Currently all costs are capital installation costs only.

The following are options considered:

1. CHP
2. Tri-Generations CHP (for heat load and cooling load)

Appendix A shows the background information of CHP and Tri-Generation CHP and Appendix D shows the written steps of CO_2 savings calculations of CHP and Tri-Generation CHP

5.2 CHP

5.2.1 *Overview*

A Combined Heat and Power (CHP) plant consists of an electrical generator powered by a gas turbine or a gas- or oil-fired combustion engine. The excess thermal energy, which in conventional plant would be wasted, is used in a subsidiary system, providing low or medium temperature hot water (or, in some cases, steam) for heating. This makes the overall energy efficiency greater than that of a conventional generator, and the total energy use and carbon dioxide emissions for which a building is responsible can be reduced. There are government incentives (www.eca.gov.uk) to support CHP.

5.2.2 *Options Considered for Chichester House*

CHP plants can not run efficiently at small fractions of their maximum output. They are also limited by the heat needs of the building.

Assuming the following COPs

CHP electricity	0.31
CHP heat	0.44
Standard Water Heater	0.94

A number of hourly simulations have been performed with different sizes of CHP plants and heat storage vessels. For each hour, the CHP plant can run if there is a sufficient heat load to the building, or to heat the thermal storage tank.

A maximum carbon saving has been found for a CHP plant with maximum thermal output of 26kWh. This CHP plant will operate with a thermal storage tank of radius 1m and height 2m.

The size of the CHP plant is assessed based on the loads as can be seen in the figure 4, and figure 5 shows how the energy is delivered to the building.

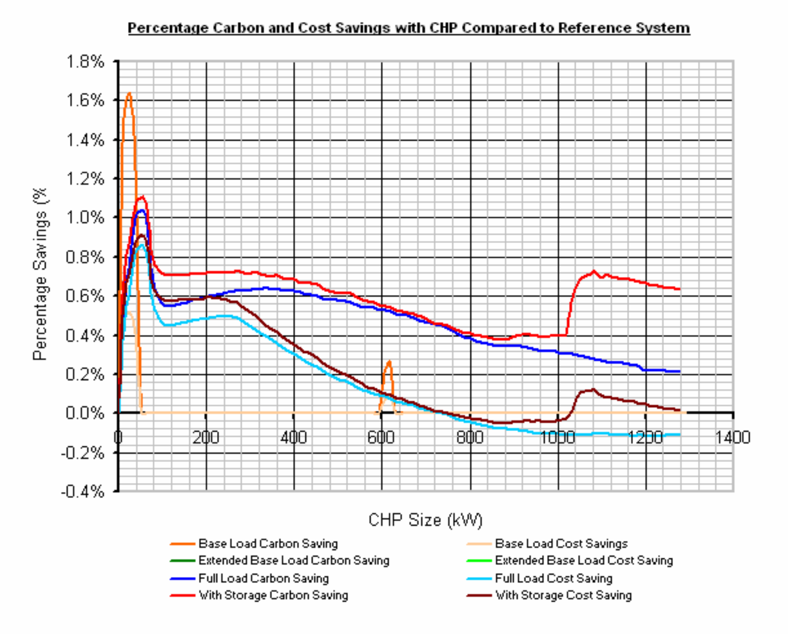

Figure 4 - Percentage carbon and cost saving with CHP compared to reference system

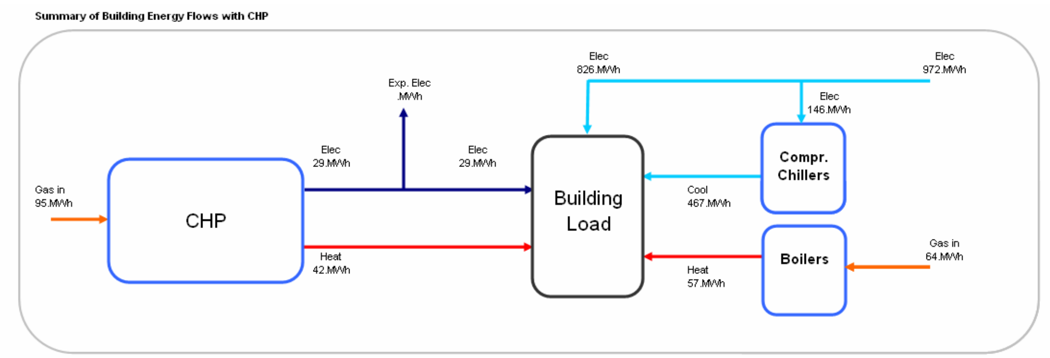

Figure 5 - Summary of building energy flows with CHP

Using the CHP plant in this way will save 7.297 tonnesCO_2/year. It is expected that a CHP plant of this size will cost around £90,000 giving a capital cost of £12,280 per tonne of CO_2 saved per year. The CHP plant will save 1.6% of the site's total CO_2 emissions.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
Combined Heat and Power	18kWe	90,000	1.6	7.297	12,280

Note: Building CO2 emission of 455 tonne CO2 /year

Table 10 - Summary of CO2CO2 savings and cost of CHP

5.3 Tri-generation

5.3.1 *Overview*

Where there is little demand for heat, but a demand for cooling, the heat from a CHP plant can be used for cooling using an absorption chiller. This system is known as tri generation as it is capable of generating heat, power and cooling. As the efficiency of absorption chillers is low, more heat rejection plant will be needed at roof level.

5.3.2 *Options Considered for Chichester House*

As can be seen in the previous sections, the heating demand for the site is small, where as the cooling and electricity demands are high. A combined heat and power system, where the heat is used to power an absorbing chiller is now considered.

CHP electricity	0.31
CHP heat	0.44
Standard Chiller	3.10
Absorption Chiller	0.70

Installing a 26 kW system will reduce the site emissions of CO_2 by 2.6%, a 1% extra saving over installing a CHP system. This calculation is based on an hourly simulation of a tri-generation system, where heat can be sent to the buildings heating, or to an absorption chiller.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
Tri-Generation Combined Heat and Power	26kW	120,000	2.6 %*	11.83	10,100

*Notes: *1% extra saving over installing a simple CHP system*
Building CO2 emission of 455 tonne CO2 /year

Table 11 - Summary of CO_2 savings and cost of CCHP

Renewable Energy Technologies

6 Renewable Energy Technologies

6.1 Introduction

This section outlines what renewable energy technologies have been considered:

- Use renewable energy (be green)

Each renewable energy technology has been assessed separately in the first instance. In section 6.9 (Proposals for planning submission) scenarios will be explored for using more than one technology in combination.

Appendix A shows the background information of renewable technologies and Appendix D shows the written steps of CO_2 savings calculations of renewable technologies.

6.2 Solar Thermal Water Heating

6.2.1 *Description*

Solar thermal systems are conceptually simple; they use solar collectors to supplement a boiler in heating water, reducing the work done by the boiler. They can meet up to 70% of a residential building's requirements. Commercial systems are typically sized to meet 45-50% of the annual DHW demand.

Solar water heating systems use the energy from the sun to heat water, most commonly in the UK for hot water needs.

There are two standard types of collectors used - flat plate collectors and evacuated tube collectors. The flat plate collector is most commonly used in solar domestic hot water systems, as they tend to have a lower cost for each unit of energy saved. Evacuated tube collectors are generally slightly more expensive due to a more complex manufacturing process (to achieve the vacuum) but manufacturers claim better energy performance, particularly in winter to capture the low level sunlight.

Figure 6 - Solar Thermal Panels

6.2.2 *Chichester House Case*

The areas highlighted in red (in Figure 7) have been identified as possible locations for solar panels in the roof top area. Other areas have been set aside for roof top plant, or green space.

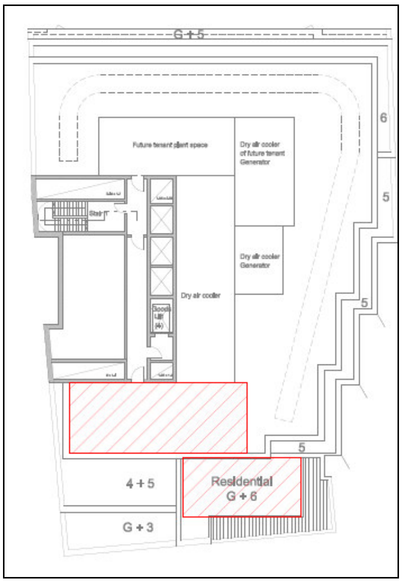

Figure 7 - Proposed Mounting Position for Solar Panels (in red colour) on roof level of Chichester House

This represents 140m² of space. To minimise the profile of the panels, it is assumed that they will lie flat on the roof. The panels will not be shaded for much of the day, however there will be times where some of the panels are in some way shaded. This shading will be assessed in more detail when a renewable strategy is developed further.

Space is limited, so it is anticipated that the more expensive and effective evacuated tube technology will be used. With these limitations, the building energy usage is as in Figure 8.

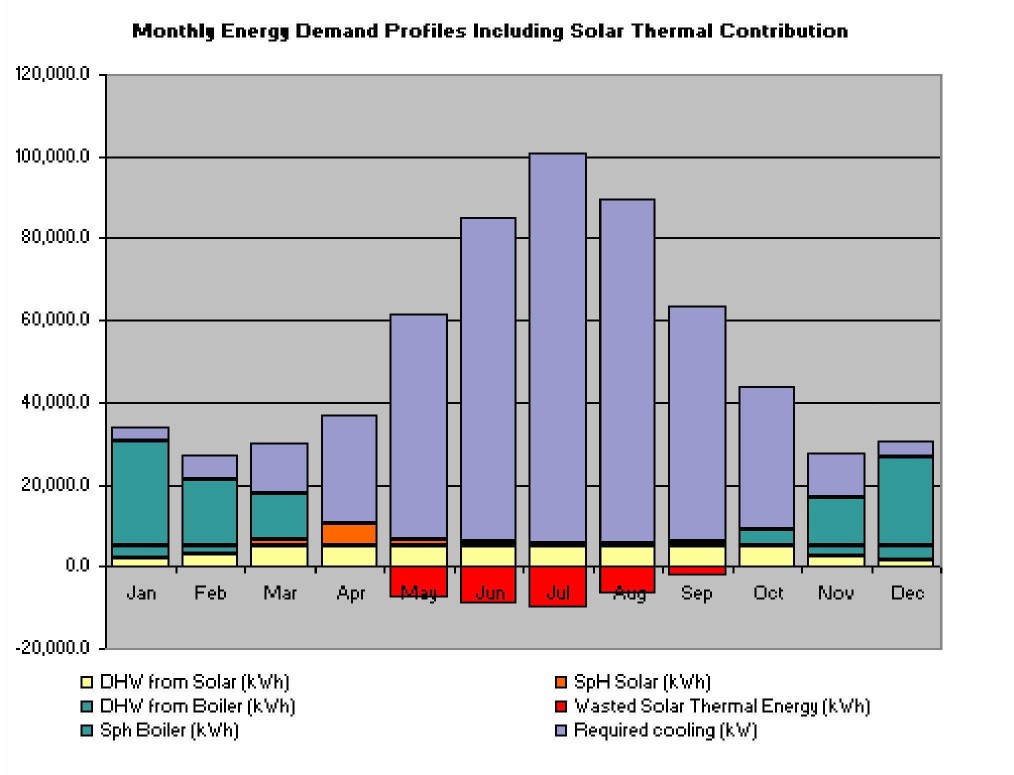

Figure 8 - Monthly energy demand profiles including solar thermal contribution

It can be seen that the solar heating system is able to meet almost all the demand for hot water and space heating during the summer months, however in the winter; there is still need for heating.

This renewable system will generate a carbon saving of 2.7% of the total site energy. A significant proportion of the energy is wasted in the summer months, and must be disposed of, however this is needed to maximises the renewable percentage.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
Solar Thermal Panel	140m²	70,000	2.7	12.285	5,600

Note: Building CO2 emission of 455 tonne CO2 /year

Table 12 - Summary of CO_2 savings and cost of solar thermal panels

6.2.3 *Issues for Consideration*

During detailed design further investigations will be undertaken looking at sun path analysis and shading to optimise the positioning of the roof panels.

6.3 Photovoltaic

6.3.1 *Description*

Overview

Solar Photovoltaic (PV) cells produce a direct electrical current from the energy in solar radiation. A film of silicone containing deliberate specific impurities (eg. Boron) is exposed to sunlight. The impurities create gaps in the electron array. This means that when electrons are excited by electromagnetic radiation of the correct frequency they are able to move, producing an electric current.

The energy output of the cell is dependant on the how much sunlight is available, and on the efficiency on the cell. Maximum efficiencies are around 28%, but this is only attainable at 0°C and drops off as the temperature rises. It is possible to install solar collectors to focus more light on the cells and include cooling systems to help increase efficiency, but these add to an already high capital cost. Typical operating efficiencies are between 5 and 15%.

As they use energy from the Sun, solar PV cells are environmentally friendly and cheap to run. As such, they are subject to government grant schemes aimed at reducing carbon dioxide emissions. This makes PV cells worth considering even though at the moment they are an expensive way of supplying energy to a building.

Figure 9 - Photovoltaic Panels

6.3.2 *Chichester House Case*

The areas highlighted in blue (in figure 10) have been identified as possible locations for solar panels in the roof top area. These are the same areas that have been identified for solar thermal heating. The upper façade of the building is almost entirely glazed. As the building is in an enclosed site, it was not thought sensible ot place PV on the lower façade, due to shading considerations.

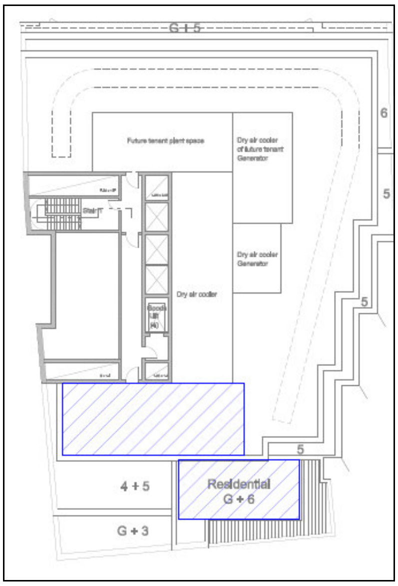

Figure 10 - Proposed Mounting Positions for Photovoltaic Panels (in blue colour) on roof level of Chichester House

As in the previous study, it is assumed that the panels will lie flat, and if this technology is chosen, a more detailed shading study will be required. Fitting 140 m² of PV panels gives a load profile as in the Figure 11:

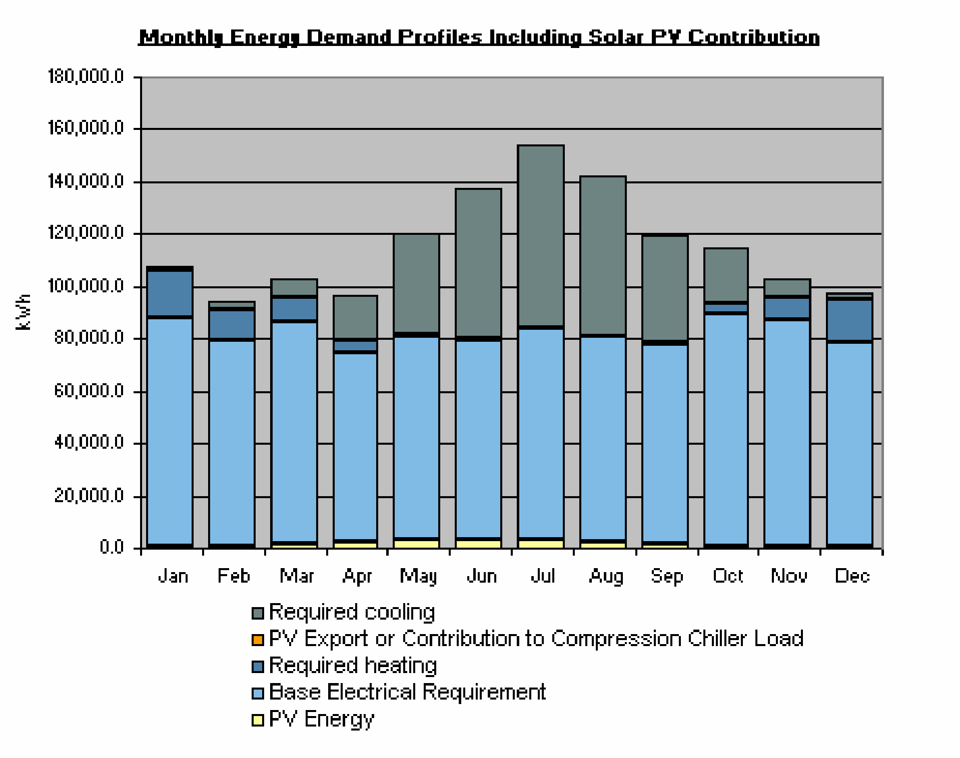

Figure 11 - Monthly energy demand profiles including solar PV contribution

It is expected that this system will cost £168,000 and will output 20.708 MWh of electricity per year and so save 11,762 kg of CO_2 per year or 2.6% of the site carbon emissions. Our models show that all of the energy can be used on site.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
PV Panels	140m²	168,000	2.6	11.762	14,200

Note: Building CO2 emission of 455 tonne CO2 /year

Table 13 - Summary of CO_2 savings and cost of Solar Thermal Panels

6.3.3 *Issues for Consideration*

During detailed design further investigations will be undertaken looking at sun path analysis and shading to optimise the positioning of the roof panels.

6.4 Integration of Solar Thermal Water Heating and Photovoltaic

6.4.1 *Chichester House*

The areas highlighted in blue in figure 12 have been identified as proposed locations for photovoltaic panels (90m²) on the roof top area of Chichester House. And the areas highlighted in blue & red in figure 13 have been identified as proposed locations for photovoltaic panels (30m²) and solar panels (20m²) on the roof top area of residential units of Chichester House

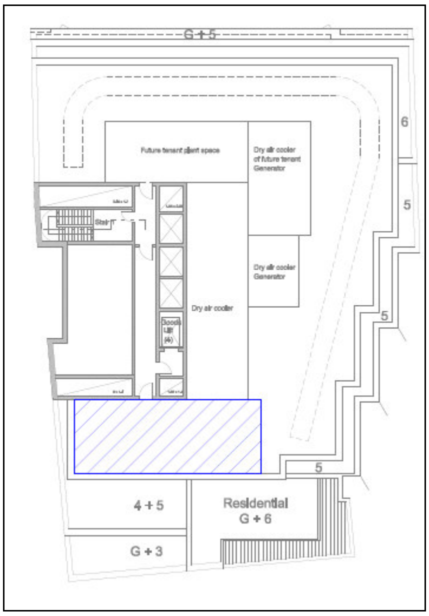

Figure 12 - Proposed Mounting Position for 90m² Photovoltaic Panels (in blue colour) on roof level of Chichester House

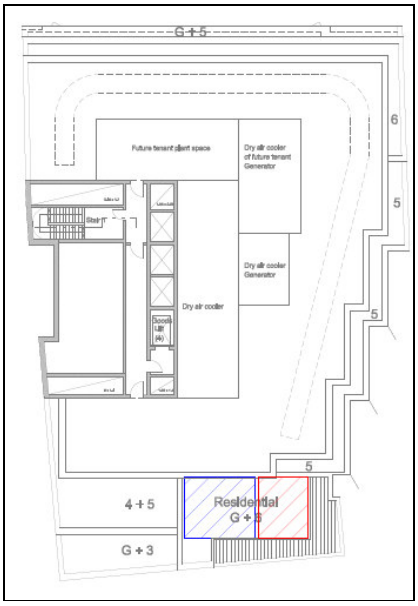

Figure 13 - Proposed Mounting Position for 30m² Photovoltaic Panels (in blue colour) and 20m² Solar Panels (in red colour) on residential roof level of Chichester House

The area of PV panels on the roof is 120m², and the area of solar thermal panels on the roof is 20m². PV panels to portion of the offices electrical demand while solar thermal panels to meet a portion of the residential domestic hot water and space heating.

It is expected that this system will cost £154, 000 and with 2.8% of the site carbon emissions.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
PV Panels	120m²	144,000	2.24	10.192	14,100
Solar Thermal Panel	20m²	10,000	0.56	2.548	3,920
Total		154,000	2.8	12.74	12,040

Note: Buikding CO2 emission of 455 tonne CO2 /year

Table 14 - Summary of CO2 savings and cost of Solar Thermal Panels and PV panels

6.5 Wind Power

6.5.1 Chichester House

Chichester House could use wind turbines of as small as possible height to limit the visual impact on the building.

The building is located in London, where turbulence levels are high. This will have a detrimental effect on power produced, as can be seen in the Figure 14.

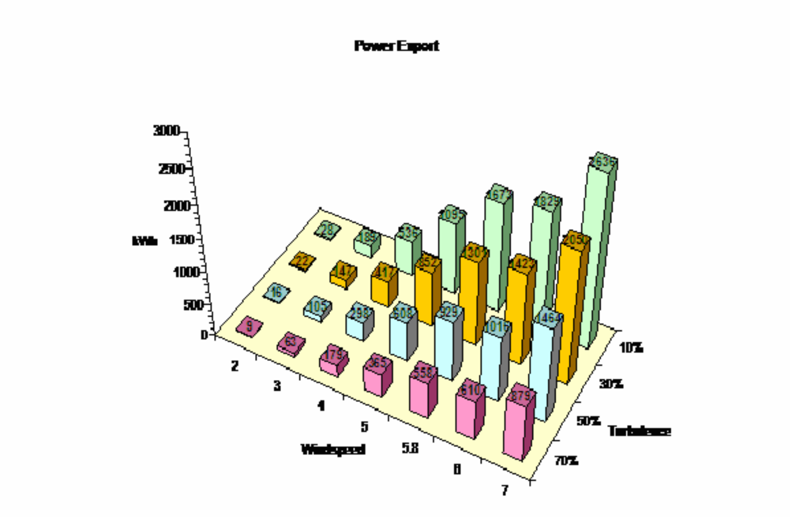

Figure 14 - Detrimental effect of turbulence on power production

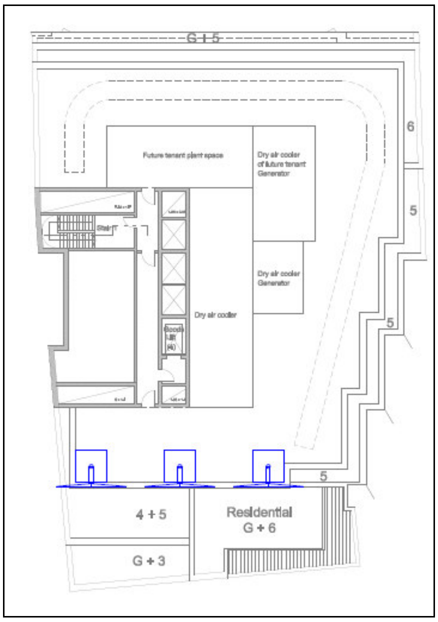

Figure 15 - Proposed mounting positions for 3 no. of wind turbines (in blue colour) roof level of Chichester House

For this location where there is not space to fit a wind turbine away from the building, and in a location as urban as this, it is not considered practical to install a wind turbine. If a 6KW wind turbine were to be fitted, using manufacture's data and wind data from the DTI website, it is estimated that 0.7% (per wind turbine) of the buildings energy requirement could be met. However experience has shown that these calculations are very unreliable, especially in urban areas.

The expected cost of the 3 no. of wind turbines (see figure 15) are around £30,000 giving a carbon efficiency of £9, 300 per tonne of CO_2 saved per year, with 2.1% of the site carbon emissions.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
3 No. Wind Turbines	18 kW	30,000	2.1	9.345	9,300

Notes: Building CO2 emission of 455 tonne CO2 /year

Table 15 - Summary of CO_2 savings and cost of Wind Turbine

6.5.2 *Issues for Consideration*

- Building mounted wind turbines have limited data on monitored outputs; this is especially true in urban locations such as where Chichester House are located. Outputs may be less than predicted in this report.
- Fixing methods for any of these turbines will need to be developed as part of the building design. These will need to resolve any potential wind loading and vibration issues.
- They will have a visual impact being 2m (or larger) in diameter, which will need to be considered
- Turbines will typically increase total building height

6.6 Biomass Heating

6.6.1 *Description*

Biomass burners apply modern, high-efficiency boiler technology to burning wood for heat.

Figure 16 - Bio-mass Boiler

6.6.2 *Chichester House*

Biomass boilers work best at full load, however that they are difficult to run at lower capacities. Thus there may be times when there is a low heating demand that they are unable to match. This problem can be lessened by storing heat in a buffer tank.

Figure 17 shows the results of the optimisation study. Where different sizes of boiler are plotted on the x-axis against the carbon and cost savings that can be achieved. These results are from an hourly simulation of the boiler. The boiler will run if there is enough demand for heat in the building and the thermal storage tank. This is compared to the reference system, using a boiler with an efficiency of 94%.

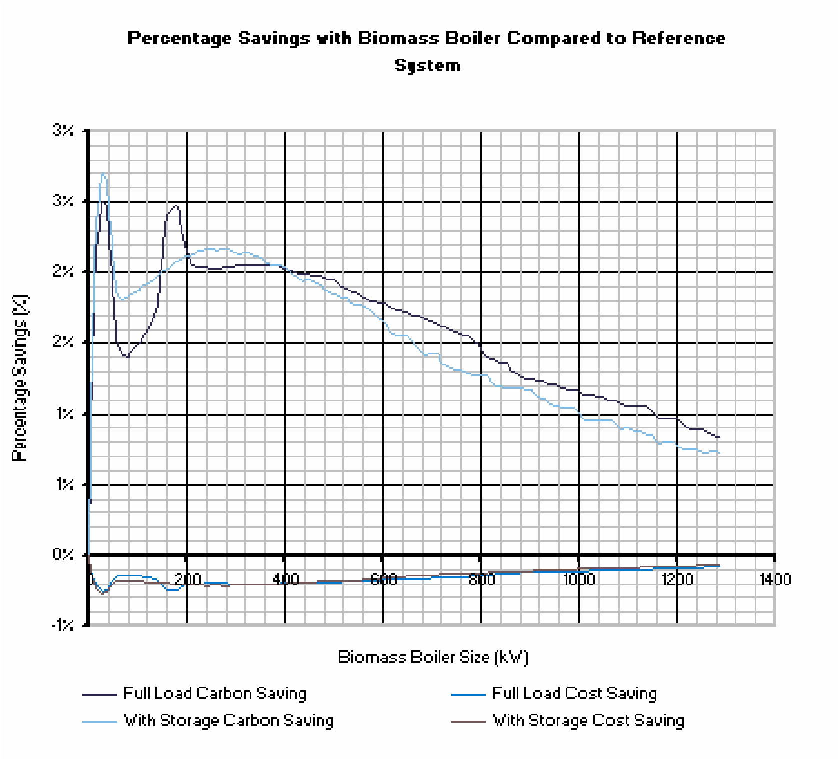

Figure 17 - Percentage Savings with Biomass Boiler compared to reference system

Balancing boiler size, complexity and size of storage needed, a 30KW biomass boiler has been chosen, with a 2 meter high, 4 meter diameter buffer tank. This can be seen as the highest point on the graph.

Wood pellets are normally delivered on pallets or via tanker with air blower and hose. A Tanker with air blower and hose is considered the most efficient method of resupply and delivery. So storage at basement level will allow delivery. Tankers normally carry up to 30 tonnes with a minimum delivery of 5 tonnes per customer, and it is expected that this minimum delivery is used. The calorific value of wood pellets is 3.16 MJh/m3 and a storage space requirement of 1.5 m^3 per tonne, plus a 20% loss factor (as the storage should never be fully empty) is needed. This room needs to be located within 30m of tanker delivery point. The room needs to be waterproof. The room needs to be separate fire compartment, and directly adjacent to boiler room or position. A storage space of 6 meters cubed will be required, with 4 deliveries required per year.

It is estimated that capital outlay will be around £16,000, giving a carbon efficiency of £1,340 per tonne of CO_2 saved per year.

This option will lead to a reduction in site CO_2 demand of 2.6%.

	System Size	Capital cost (£)	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
Biomass - heating	30 kW	16,000*	2.6	11.83	1,340

*Note *   Capital cost include biomass boiler only.*
Building CO2 emission of 455 tonne CO2 /year

Table 16 - Summary of CO_2 savings and cost of Bio-mass heating

6.6.3 *Issues for Consideration:*

- Will require a large plant room area (space for buffer tank and fuel storage)
- Will require access for fuel delivery lorries
- Will require a flue to the full height of the building
- Will require contracts to be set up for the delivery of fuel
- Will require a management function to maintain the boiler and bill tenants for the energy used

- Maintenance costs will be higher than for gas boilers
- Fuel store must be dry and fire protection would be required.

6.7 Ground Source Heat Pumps

6.7.1 *Description*

Ground source heat pumps (GSHPs) are electrically powered systems use the earth's relatively constant temperature to provide heating, cooling, and DHW. The environmental gain is due to the higher performance of the cooling equipment when coupled to the ground.

Ground source heat pumps can be categorised as closed or open loop.

For closed loop systems, water or antifreeze solution is circulated through plastic pipes buried beneath the earth's surface. During the winter, the fluid collects heat from the earth and carries it through the system and into the building. During the summer, the system reverses itself to cool the building by pulling heat from the building, carrying it through the system and placing it in the ground. This process creates free cooling in the summer and delivers substantial hot water savings in the winter.

Open loop systems depend more strongly on the ground conditions, as it may be impossible to draw the required volume of water and due to the limited area of the site there is insufficient space to accommodate both an abstraction borehole and recharge borehole on the development. The only way to test this is by construction of a test borehole. For this reason, a closed loop system has been examined in this section.

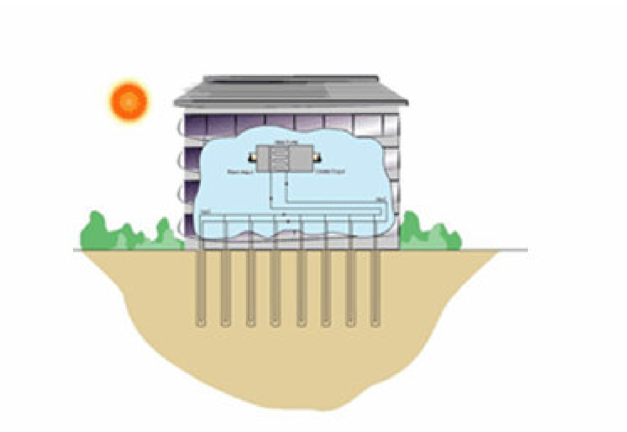

Figure 18 - Ground Source Heat Pump

6.7.2 *Chichester House*

A relatively detailed calculation of GSHP was used, in which we assume a number of piles under the building, and that the output of these piles is limited, refer to Appendix C for details of the calculation. This method does not examine the long term thermal build up of heat in the ground, and this will need to be examined at a later stage.

The following three options of GSHP system were considered:

Option 1 - 25 no. of 120m depth boreholes (see table 17)

Option 2 - 25 no. of 120m depth boreholes + 63 no. of 25m depth structural piles (see table 18)

Option 3 - 30 no. of 120m depth boreholes + 90 no. of 25m depth structural piles* (see table 19)

Option 1 – 25 of 120m deep boreholes					
	System Size	Cost Estimation (£)	CO_2 Saving***	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
GSHP - Heating	180 KW	472,800	2.13	9.69	-
GSHP - Cooling	144 KW		1.62	7.37	-
Total			3.75	17.06	27,520

Table 17 - Summary of CO_2 savings and cost of option 1 of GSHP

Option 2 – 25 no. of 120m depth boreholes + 63 no. of 25m depth structural piles					
	System Size	Cost Estimation (£)	CO_2 Saving***	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
GSHP - Heating	275 KW	547,800	2.37%	10.55	-
GSHP - Cooling	219 KW		2.13%	9.67	-
Total			4.5 %	20.22	26,810

Table 18 - Summary of CO_2 savings and cost of option 2 of GSHP

Option 3 – 30 no. of 120m depth boreholes + 90 no. of 25m depth structural piles*					
	System Size	Cost Estimation (£)	CO_2 Saving***	CO_2 Saving (tonnesCO_2/year)	Cost per tonnes CO_2 (£)
GSHP - Heating	351 KW	678,800**	2.5%	11.38	-
GSHP - Cooling	280 KW		2.42%	11.01	-
Total			4.92 %	22.39	30,120

Table 19 - Summary of CO_2 savings and cost of option 3 of GSHP

Notes:

** Retained existing basement slab (near to High Holborn) to be demolished, to accommodate additional piles (5no. of boreholes and 27 no. of structural piles)*

*** Cost excludes the demolishing cost of retained existing basement slab*

**** CO_2 Saving have been based on heating and cooling requirement of the commercial areas only, while solar thermal panels to meet the heating requirement of residential units*

Building CO_2 emission of 455 tonne CO2 /year

It is calculated that 2.13 – 2.5% of carbon saving from heating mode, and 1.62 – 2.42 % of carbon saving from cooling mode can be achieved. A total of 3.75 – 4.92 % of carbon can be saved depended on the options.

Early indications suggest that option 1 is the most suitable GSHP option, it allows 3.75% reduction in site CO_2 emissions and can be generated using ground source heating and cooling at a capital cost for installation of around £472,000. This equates to a cost per tonnes CO_2 saved of £27,520.

There is a potential 0.75% increase of CO_2 saving, if option 2 used instead of option 1. However, the feasibility of option 2 depends on the numbers and positions of structural piles, and therefore a conservative option (option 1) is proposed at this stage.

6.7.3 Issues for Consideration

- To accurately establish the ground thermal parameters using a Geothermal Response Test. This test will measure the ground thermal conductivity, heat capacity, temperature gradient and borehole resistance. Possible effects of natural ground water movement will be measured as well. Both the total size of the ground source heat exchanger as well as the optimal spacing between adjacent boreholes depends to a large extent on these parameters.
- Requires a detailed assessment by a geotechnical engineer and detailed design input from the structural engineers.
- Requires additional space within the plant room for the heat pumps and heat exchangers which is currently allowed.
- Will require additional calculation to ensure ground overheating and loss of COP does not occurred (geotechnical study).
- Perform a further economical and thermal optimisation of the system (selecting component capacities and ground source heat exchanger size).

6.8 Summary of Renewable and Low Carbon Energy Options

Technology	System Size	CO_2 Saving (%)	CO_2 Saving (tonnesCO_2/year)	Capital Cost (£)	Cost per CO_2 Saving (£/tonnes CO_2 /year)	Recommended
Low Carbon Options						
CHP	18kW	1.6	7.297	90,000	12,280	No
CHP (Tri-Gen)	26kW	2.6*	11.83	120,000	10,100	No
Renewable Options						
GSHP – Heating	***180 KW***	***2.13***	***9.69***	***472,800***	***27,520***	***Yes***
GSHP – Cooling	***144 KW***	***1.62***	***7.37***			***Yes***
Solar Thermal Panels	140 m²	2.7	12.285	70,000	5,600	No
PV Panels	140 m²	2.6	11.762	168,000	14,200	No
Solar Thermal Panel + PV Panels	***120 m² PV panels & 20m² Solar Thermal Panels***	***(2.24+0.56) = 2.8***	***12.74***	***154,000***	***12,040***	***Yes***
3 No. Wind Turbines	18 kW	2.1	9.345	30,000	9,300	No
Bio Mass Boiler	30 kW	2.6	11.83	16,000**	1,340	No

*Notes: * CCHP has 1% extra saving over installing a simple CHP system*

*** Capital cost include biomass boiler only.*

All costs are indicate at present and are being verified by the cost consultant

Building CO2 emission of 455 tonne CO2 /year

Table 20 - Summarises the low and zero carbon technology options reviewed for Chichester House

6.9 Proposal for Planning Submission

Figure 19 below shows the matrix of low carbon and renewable technologies considered and how they can or cannot be integrated together. Those identified in the red and green blocks are not compatible to be used together.

Based on the assessments undertaken, the following low carbon technologies were considered but are incompatible with one or more of the proposed technologies:

- Bio-mass heating - this is incompatible with the application of GSHP as the GSHP system meets part of the space heating demands. And GSHP is a preferable option because it serves both the cooling and heating loads in the building, in which cooing demand is approximately 3 times greater.

  Bio-mass heating delivers 2.6% carbon saving with a potential for 5.4% when used in conjunction of PV and solar thermal. which is lower than the recommended strategy using GSHP's with PV and solar thermal (6.55%).

- CHP and trigeneration - these are incompatible with the application of GSHP as the GSHP system meets part of the space heating demands and

CHP or Trigeneration delivers a 2.6% carbon saving with a potential for 5.4% when used in conjunction with PV and solar thermal which is lower than the recommended strategy using GSHP's with PV and solar thermal (6.55%).

There are also practical constraints of the use of CHP or Trigeneration, 1) those will create a lot of acoustic issues to treat noise generated by the plant so as not to effect retail and residential occupants. 2) As part of the planning discussions we have had to minimise the plant space on the roof, the additional heat rejection plant(s) of CHP or Trigeneration on the roof against the planning discussions, and 3) will also reduce the usable area for PV panels and/or solar thermal panels

The following renewable technologies were also considered but not recommended:

- Wind turbines. 1) In this inner city site, the average wind speed may be below the threshold for it to operate, 2) the planning constraints such as site's sight lines and high restriction 3) technical uncertainty of wind turbines such as vibration from wind turbine masts.

	CHP	**CCHP**	**GSHP**	**Solar Thermal**	**PV**	**Wind**	**Biomass**
CHP	x						
CCHP		x	C				
GSHP		C	x				C
Solar Thermal				X			
PV					x	E	
Wind					E	x	
Biomass			C				x

	Competes for Roof Space
E	Competes for electricity
	Competes for Heating
C	Competes for Heating And Cooling

Figure 19 - Low carbon and renewable technologies integration matrix

To optimise the potential carbon savings, GSHP's to meet a proportion of the buildings heating and cooling demand used in conjunction with both PV (for the offices electrical demand) and solar thermal (for the residential hot water/heating) are recommended that can be practicably integrated into the development. Table 21 indicated the potential CO_2 savings and capital costs from the proposed low and zero carbon technologies for incorporation into Chichester House

This has been estimated to provide a maximum of up to 6.55% CO_2 reduction. This will be subject to further detailed geotechnical studies and design development during the detailed design stages.

The proposed renewable technologies have the following advantages;

- GSHP, PV and solar thermal are to meet different types of energy demands (office heating, office cooling, office electricity and residential hot water/heating) of the building, hence avoid competition and maximise the combined CO_2 saving
- PV panels and solar thermal panels have less visual impact on the building compare to wind turbines. And GSHP will not be visible once the infrastructure is in place.
- PV panels and solar thermal panels are located outside the plant enclosure on roof level, and with less space required compare to other renewable energy technologies like Bio mass and CHP/Tri-generation, which is vital because it has less implication of planning application.

There are many other sustainability measures that the development has taken account of as well as the deployment of energy use on the development. These all need to be reviewed collectively to see the benefits that the development provides as detailed in the Sustainability Statement.

<table>
<tr><th></th><th>System Size</th><th>CO2 Saving (%)</th><th>CO2 Saving (tonnesCO2/ year)</th><th>Capital Cost (£)</th><th>Cost per kg CO2 Saving (£/tonnes CO2/year)</th></tr>
<tr><td>Solar PV and Solar Thermal</td><td>120 m^2 PV panels & 20m^2 Solar Thermal Panels</td><td>(2.24+0.56) = 2.8</td><td>12.74</td><td>154,000</td><td>12,040</td></tr>
<tr><td>GSHP - Heating</td><td>180 KW</td><td>2.13</td><td>9.69</td><td rowspan="2">472,800</td><td rowspan="2">27,520</td></tr>
<tr><td>GSHP - Cooling</td><td>144 KW</td><td>1.62</td><td>7.37</td></tr>
<tr><td colspan="2">Total</td><td>6.55</td><td>29.8</td><td>626,800</td><td></td></tr>
</table>

Note

1. All costs are indicate at present and are being verified by the cost consultant.

2. Building CO2 emission of 455 tonne CO2 /year

Table 21 - Summarises the proposed low and zero carbon technologies for Chichester House

The renewable energy study has indicated that the development can achieve 6.55% CO_2 saving via the application of on site renewable energy technologies. There are technical and practical constraints that provide limitations on increasing the renewable CO_2 savings as details below:

Technical Constraints

1. Most of Low or zero carbon emission technologies, such as GSHP, CHP, Tri-gen CHP, Bio-mass and solar thermal are targeting heating demand of the building, and they can't be used together. The heating demand is relatively low for the development, and the building heating demand has been significantly reduced through a number of energy efficiency measures such as heat recovery system of ventilation system and high performance facade. Therefore, the carbon saving from heat targeting LZC technologies are limited.

Practical Constraints

1. The proposed GSHP cooling system enhances the carbon saving of the building, however because the site constraints, the size of GSHP cooling system is limited. Limited site area means the number of boreholes are limited, and hence limit the size of GSHP. The number and positions of structural piles also limit the size of GSHP as the boreholes need to be spaced apart from the structural piles.

   Cooling demand is relatively high (approximately 3 times more than the demand of space heating & DHW), however a limited size of GSHP cooling system limit its carbon savings

2. Insufficient roof space limits the use of PV panels and wind turbine. Because of site constraints, the roof is the only area for heat rejection plant, air intake ductwork/lourves and tenant's satellite dishes, and the window cleaning cradle system. These further reduce the useable area for PV panels and wind turbine.

3. The uncertainty of wind conditions in an urban environment, height restriction and sight line of the site made wind turbines not a preferable renewable option in this building.

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Summary

7 Summary

This section summarises how Chichester House has been designed to address the Mayor's Energy Hierarchy:

- Use less energy (be lean)
- Supply energy efficiently (be clean)
- Use renewable energy (be green)

This section outlines the energy efficiency measures and low CO_2 or renewable energy technologies that are to be incorporated into the design of the Chichester House.

7.1 Use Less Energy (be lean)

The building has been designed to be energy efficient. It benefits from good daylighting and has high efficiency lighting equipment and controls. The facades (the fully glazed façade in particular) will be prone to high solar heat gains and so high performance glazing will be used, which will reduce the demands for cooling in the summer.

Proposed heating, cooling and ventilation system included a number of features which serve to reduce the heating energy requirements, these include:

Proposed Heating System

- Thermal wheel heat recovery with high operating efficiencies is proposed within all main AHUs. This significantly reduces the heating required to warm up incoming fresh air in winter.
- Some of the LTHW circuits have variable volume flow rates, which require less pump energy.
- All trenches heaters and radiators have TRV control to facilities less wastage via more precise control.
- Heating will be provided by high efficiency, low NOxx, condensing boilers. All selected plant will exceed the minimum Building Regulation Part L2A efficiency requirement.
- Heating coils in the Air Handling Units will be operated at a lower water temperature, allowing the proposed ground source heat pump system to work at higher efficiency.

Proposed Cooling System

- The use of passive chilled beams which cooling air by natural convection and hence save energy on fan power
- Passive chilled beams operated at a higher chilled water temperature, allowing free cooling during the mid season.
- A higher chilled water temperate allow chillers to operated at higher efficiency
- All selected Plant will outperform the minimum Building Regulation Part L2A efficiency requirement.

Proposed Ventilation System

- WC extract fans operate on a variable volume basis and are provided with inverter control driven off occupancy sensors.
- All selected plant will exceed the minimum Building Regulations Part L2A efficiency requirements.

Lighting and Appliances

- All general lighting within the building will consist of high efficiency T5 fluorescent luminaries
- The proposed programmable lighting controls using movement detectors and daylight linking will decrease energy requirements.

7.2 Supply Energy Efficiently (be clean)

CHP and Trigeneration have been included as part of this study, and have been discounted as the site is small compared to those where a CHP or Trigeneration plant would be considered practical.

7.3 Use Renewable Energy (be green)

Potential CO_2 savings and capital costs from the following technologies have been reviewed for incorporation into Chichester House

- Building Mounted Wind Turbines
- Solar PV
- Solar Water Heating
- Biomass Heating
- Ground Source Heating
- Ground Source Cooling

The proposed solution is to use a combination of solar thermal water heating, Solar PV, Ground Source Heating and Cooling, which combined produce CO_2 emissions savings of 6.55%.

7.4 Summary

The energy demand of this building has been significantly reduced through a number of energy efficiency measures; the chilled beams system for example reduces overall building CO_2 emissions by 11% when compared with a more conventional FCU installation. In addition to the energy efficiency measures, the building will include renewable technologies in the form of ground source heating/cooling, solar water heating and PV panels to provide 6.55% of the predicted building CO_2 emissions.

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Appendices

Appendix A - Background Information - Low and Zero CO_2 Technologies

CHP

A CHP plant is an installation where there is simultaneous generation of usable heat and power (usually electricity) in a single process. The basic elements of a CHP plant comprise one or more prime movers usually driving electrical generators, where the heat generated in the process is utilised via suitable heat recovery equipment for a variety of purposes including: industrial processes, community heating and space heating. More recently the heat generated has been used to drive absorption cooling as a way of utilising the heat through out the year. This type of installation is often referred to as trigeneration or CCHP (Combined Cooling, Heating & Power).

The main factor in the economic viability of CHP is the difference between the cost of electricity and gas, referred to as the "spark gap". The greater the cost of electricity over gas is the more likely a CHP installation is to be viable.

Wind Turbines

Wind energy can be one of the most cost effective methods of renewable power generation. Wind turbines can produce electricity without carbon dioxide emissions ranging from Watts to Megawatt outputs.

Building Integrated Wind Turbines

Small turbines of 1 to 2.5 kW can be mounted on buildings and whilst there are currently few practical implementations of building mounted wind turbines in the UK, we believe that this technology will become fairly common in 1 or 2 years time, as several manufacturers are gearing up for mass production. These products achieve relatively good carbon savings compared to their cost, they typically range in price from around £2,000 to £30,000 and are rated between 1and 6kW.

The small scale or micro turbines have a diameter of around two metres and require mounting on a pole which increases the turbine overall height to at least 4m. Typically these turbines are mounted above roof level, as the increased height usually means greater wind speeds.

Wind turbines on buildings are usually very visible and can have implications on planning especially in conservation areas. Installation of building mounted wind turbines should be consulted on with the local authority planning department.

Solar Water Heating

There are two standard types of collectors used - flat plate collectors and evacuated tube collectors. The flat plate collector is the predominant type used in solar domestic hot water systems, as they tend to have a lower cost for each unit of energy saved. Evacuated tube collectors are generally more expensive due to a more complex manufacturing process (to achieve the vacuum) but manufacturers generally claim better winter performance.

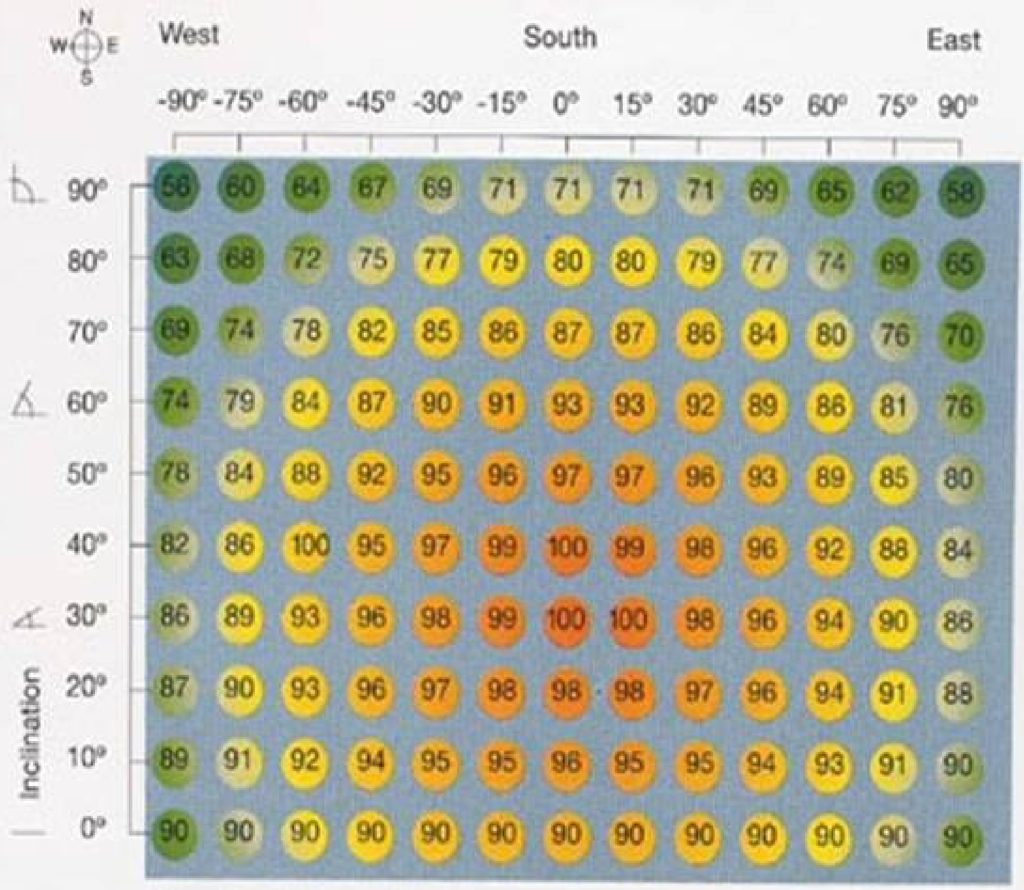
Filsol flat plate system on Wedgewood Visitor Centre (photo courtesy of John Blower), serving washrooms

Viessmann evacuated tube system, London Borough Of Camden (photo courtesy of LB Camden), serving washrooms for office accommodation, library and health centre.

Photovoltaics

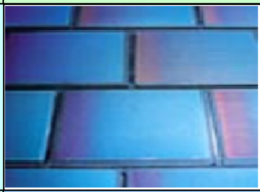
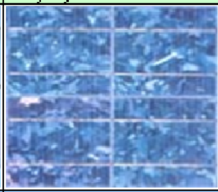
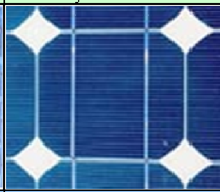
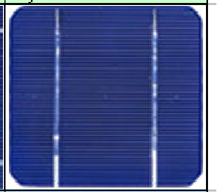
Photovoltaic (PV) systems convert energy from the sun into electricity through semi conductor cells. Systems consist of semi-conductor cells connected together and mounted into modules. Modules are connected to an inverter to turn their direct current (DC) in to alternating current (AC), which is usable in buildings. PV can supply electricity either to the buildings they are attached to, or when the building demand is insufficient electricity can be exported to the electricity grid.

For PV to work effectively it should ideally face south and at an incline of 30º to the horizontal, although orientations within 45º of south are acceptable. It is essential that the system is unshaded, as even a small shadow may significantly reduce output. The figure below shows how PV efficiency varies depending on panel orientation and pitch.



Solar Sundial showing energy yield relative to the inclination and orientation of your roof

PVs are available in a number of forms including monocrystalline, polycrystalline, amorphous silicon (thin film) or hybrid panels that are mounted on or integrated into the roof or facades of buildings. The table below from PV supplier Solar Century shows carbon savings per metre squared or output of panel for all the various forms, which is useful for comparing the various PV technologies currently available.

	'Thin Film'	Polycrystalline	Monocrystalline	'Hybrid'*
Appearance				
Description	The most efficient in poor light conditions. An extremely sturdy, vandal-proof PV.	Also highly efficient in good light conditions. Less embodied energy than monocrystalline.	The most efficient of the PV technologies in good light conditions	A combination of monocrystalline and thin-film technologies, this has high peak output coupled with excellent performance in poor light conditions
Efficiency at STC**	Good 7 - 8%	Very good 11 - 13%	Very good 14 - 16%	Excellent 17 - 19%
Efficiency in overcast conditions	Excellent	Good	Good	Excellent
Area needed per kWp***	Kaneka module: 15.5m2 Unisolar modules: 16m2	Sharp modules: 8m2	Sharp modules: 7m2	Sanyo modules: 6.5m2
Area needed per kWp	Solar metal roofing: 23.5m2 Glass-glass laminate: 25m^2	C21 tile: 10m2 Glass-glass laminates: 10m^2 - 30m^2	Sunslate: 10m2 Glass-glass laminates: 8m^2 - 30m^2	n/a
Annual energy generated per kWp	900 kWh/kWp	750 kWh/kWp	750 kWh/kWp	900 kWh/kWp
Annual energy generated per m^2	55 - 60 kWh/m^2	90 - 95 kWh/m^2	105 - 110 kWh/m^2	125 - 135 kWh/m^2
Annual CO_2 savings per kWp	390 kg/kWp	325 kg/kWp	325 kg/kWp	390 kg/kWp
Annual CO_2 savings per m^2	25 kg/m^2	40 kg/m^2	45 kg/m^2	55 - 60 kg/m^2
Annual Carbon savings per m^2	6.8 kgC/m^2	10.90 kgC/m^2	12.27 kgC/m^2	15 - 16.36 kgC/m^2

* 'Hybrid' PV combines both monocrystalline and thin-film silicon to produce cells with the best features of both technologies

** Standard Test Conditions are: 25 °C, light intensity of 1000W/m2, air mass = 1.5

*** kWp = kilowatt 'peak'. Solar PV products and arrays are rated by the power they generate at STC

PV system size is measured in kWp. This is the peak possible KW output. A 1kWp polycrystalline system will cost around £5,500 and will generate around 750kWh of electricity a year. The size of the PV systems can be varied to match the carbon saving required.

A relatively new PV mounting system called Solion Sunmount, provides a neat solution for flat roofs, using an interlocking mounting system where intergral PV panel system are inclined at10 degrees. Solion Sunmount panels can be placed on flat roofs without requiring any roof penetrations, so will not interfere with the integrity of the roof.

Another option for flat roofs is the Kalzip AluPlusSolar system, which involves a flexible PV laminate (PVL) adhered to the surface of a specific Kalzip profiled standing seam roof, constructed in the normal manner and still retaining the full choice of structural decking, liner deck or tray. The system can be installed on roofs from 3.5º and 60º.

PV panels angled at 10º on flat roofs

Kalzip AluplusSolar standing seam roof

Biomass Heating

Biomass is normally considered a carbon neutral fuel, as the carbon dioxide emitted during burning has been (relatively) recently absorbed from the atmosphere by photosynthesis and no fossil fuel is involved. The wood is normally seen as a by-product of other industries and the small quantity of energy for drying, sawing, pelleting and delivery are discounted. Biomass from coppicing is likely to have some external energy inputs, for fertiliser, cutting, drying etc. and these may need to be considered in the future. Currently the London Mayors' Energy policy considers biomass fuels to have zero net carbon emissions.

Wood from forests, urban tree pruning, farmed coppices or farm and factory waste can be burnt directly to provide heat in buildings, although nowadays most of these wood sources are commercially available in the form of wood chips or pellets, which makes transport and handling on site easier.

Modern systems can be fed automatically by screw drives from fuel hoppers. This typically involves daily addition of bagged fuel to the hopper, although this process can also be automated with use of augers, conveyors or walking floors. Electric firing and automatic de-ashing are also available and systems are designed to burn smokelessly to comply with the Clean Air Act.

The most common application of biomass heating is as one or more boilers in a sequenced (multi-boiler) installation where there is a communal i.e. block or district heating system.

Issues which can prevent uptake up biomass boiler technology are:

- On site access problems for large lorries delivering wood chip, especially for urban locations
- Lack of space for a large fuel storage area in the basement plant area of the building (and therefore a need for more frequent loads of fuel to be delivered by a lorry to the site).
- Lack of an adequate supply chain in place *currently* to provide a regular and cheap biomass supply.

Ground Source Heat Pumps

Ground source heat pumps use the refrigeration cycle to take low grade heat from the ground (a renewable resource) and deliver it as higher grade heat to a building. Heat pumps take in heat at a certain temperature and release it at a higher temperature, using the same thermodynamic process as a chiller. As the ground stays at a fairly constant temperature throughout the year (ground source temperature in London is typically 12°C) heat pumps can use the ground as the source of heat. The ground temperature is not necessarily higher than ambient air temperature throughout the entire winter but it is more stable whereas air has a greater temperature range.

The technology is very efficient, typically delivering 3-5 units of heat for every 1 unit of electrical power consumed. Limiting factors are the rate at which energy can be drawn out of the ground and the maximum temperatures at which heat can be delivered to the building (typically 50-55°C). The measure of efficiency of a heat pump is given by the Coefficient of Performance (CoP), which is defined as the ratio of the output, divided by quantity of energy put in. Annual seasonal CoPs of 3 or more are achievable with ground sourced heat pump systems, giving good energy and running cost savings.

Whilst a ground sourced heat pump is clearly not a wholly renewable energy source as it uses electricity, the renewable component is considered as the heat extracted from the ground, measured as the difference between the heat output, less the primary electrical energy input.

Typical ground sourced heating systems will use vertical boreholes for installing the piping system. When considering buildings with piled foundations, the pipes can be integrated in the design using several piling systems.

View down a ground source energy pile

Ground level view – ground source energy pile

For heating systems, the thermal energy extracted from the ground via the foundation structures is then raised to a higher temperature, suitable for heating purposes by the heat pump. While the average temperature to be found in the concrete foundations is in the region of 12℃, the heat pump increases the temperature between 25℃ and 40℃ in the heat transfer medium (water or mixture of water and anti-freeze), which is suitable for radiant heating systems such as floor slab or concrete core heating.

These systems can be used for both heating and cooling purposes. The heat transfer medium, which circulates through the integrated piping system is cooled by the ground in the summer and heated in the winter. For cooling systems, water can be introduced directly in the building or if the capacity of the soil is inadequate, a refrigerator unit or a reversible heat pump can be integrated into the system. When the system is used both for heating and cooling the building, the investment and running costs are particularly economical as the cool ground temperatures can be used at virtually no cost. The energy obtained can be used in conventional air-conditioning systems, low-temperature heating systems, wall, floor and ceiling heating systems and also chilled ceilings.

In the case of piles or other foundation structures, closed circuits of piping are incorporated in the concrete. The piping units are either attached to the reinforcing cages at the factory or on site. The rigged cages are then placed in the locations determined by the structural engineer and cast in the concrete. The individual circuits are subsequently joined up via connecting lines. Pipes are laid primarily in the ground slab and along the exterior face of the outer wall of the building, which is in contact with the soil.

Energy piles can be used in several different structures, depending on the structural engineering requirements of the building and the soil conditions.

A ground water system can be either a closed or open loop system. In a closed loop system, water (or another fluid) is circulated through pipes buried in the ground and passes through a heat exchanger in the heat pump that extracts heat from the fluid. In an open system, water is pumped out of the ground, through the heat exchanger and into a waste water system or discharged directly back to the aquifer.

Detailed geological/geotechnical assessment is required on a site by site basis to ensure that sufficient energy can be extracted from the ground on each site. The ease of which energy piles or open injection, abstraction bore holes can be drilled is dependant of the site specific geology. The yield of the open boreholes or limitations on the number of piles can limit energy which can be extracted from the ground.

Appendix B - Energy Modelling / Part L Assumptions

Part L assumptions are shown in the tales below:

Construction U-values
All U-values are overall area weighted U-values.

Construction Type	Description	Area weighted U-value (W/m^2K)
External Wall	Standard Wall – Brick, insulation, concrete, palster	0.35
Ground Floor	Standard floor construction	0.25
Glazing	SKN 172	1.50
Roof	Flat Roof	0.25

Glazing Specifications
All U-values are overall area weighted U-values.

Glazing Type	Description	g-value	Shading Coefficient
SKN 172	6mm SKN 172, 12mm argon, 6mm Planilux clear	0.41	0.47

HVAC Systems Settings

Radiators **Entrance/reception, LV Switch, Plant, Store**	
Heating System	
UK NCM system type	Central heating using water: radiators
Generator (Boiler) Fuel type	Gas
Generator seasonal efficiency	0.94
Heating delivery efficiency	0.9
System seasonal coefficient of performance (SCOP)	0.846
Heat recovery type	Run around or plates
Ventilation heat recovery effectiveness	N/A
Heat recovery return air temperature	N/A
Cooling System	
Cooling Mechanism	Natural ventilation
Generator (Chillers) Fuel type	N/A
Generator seasonal EER	N/A
Cooling Delivery efficiency	N/A
System seasonal EER	N/A
Auxiliary Energy	
Auxiliary Energy (W/m^2)	4.239
Auxiliary Energy as default or manually calculated? *(Calculations must be saved in the project directory and referenced and should be carried*	Default

out by experienced users only)	
Ventilation System	
Ventilation method	Natural ventilation
SFP (W/l/s)	N/A
Ductwork and AHU leakage	
Ductwork CEN classification	A
AHU CEN classification	L2

Chilled Beams **Lobby, Office Int, Office Per, Retail**	
Heating System	
UK NCM system type	Chilled Beams
Generator (Boiler) Fuel type	Gas
Generator seasonal efficiency	0.94
Heating delivery efficiency	0.9
System seasonal coefficient of performance (SCOP)	0.8461
Heat recovery type	Plates or pipes
Ventilation heat recovery effectiveness	0.65
Heat recovery return air temperature	24℃
Cooling System	
Cooling Mechanism	Air Conditioning
Generator (Chillers) Fuel type	Electricity
Generator seasonal EER	3.2
Cooling Delivery efficiency	0.8
System seasonal EER	2.25
Auxiliary Energy	
Auxiliary Energy (W/m²)	3.5
Auxiliary Energy as default or manually calculated?	Default
Ventilation System	
Ventilation method	Air con
SFP (W/l/s)	2.50
Ductwork and AHU leakage	
Ductwork CEN classification	Class A
AHU CEN classification	Class L2

Air heating/cooling **Toilets**	
Heating System	
UK NCM system type	Constant volume system (fixed fresh air rate)
Generator (Boiler) Fuel type	Gas
Generator seasonal efficiency	0.94
Heating delivery efficiency	0.9
System seasonal coefficient of performance (SCOP)	0.846
Heat recovery type	None
Ventilation heat recovery effectiveness	N/A
Heat recovery return air temperature	N/A
Cooling System	
Cooling Mechanism	Air conditioning via AHU
Generator (Chillers) Fuel type	Electricity

Generator seasonal EER	3.2
Cooling Delivery efficiency	0.8
System seasonal EER	2.56
Auxiliary Energy	
Auxiliary Energy (W/m²)	21.983
Auxiliary Energy as default or manually calculated? *(Calculations must be saved in the project directory and referenced and should be carried out by experienced users only)*	Default
Ventilation System	
Ventilation method	Air conditioning
SFP (W/l/s)	2.0
Ductwork and AHU leakage	
Ductwork CEN classification	Class A
AHU CEN classification	Class L2

All other zones have no heating or cooling.

DHW	
Heating System	
UK NCM system type	N/A
Generator (Boiler) Fuel type	Central gas boilers
Generator seasonal efficiency	0.94
Heating delivery efficiency	0.9
System seasonal coefficient of performance (SCOP)	0.846
DHW delivery efficiency	
DHW delivery efficiency	0.65

Model Location Data

Model location data	
Location	
Location name	London/Heathrow, United Kingdom
Latitude (°)	51.48 N (default for London)
Longitude (°)	0.45 W (default for London
Simulation Weather Data	
Weather data file	LondonTRY05.fwt

Lighting Efficiency

Zone	W/m²/100 lux
Lift lobby	3.50
LV switch	2.50
Office internal	2.50
Office Perimeter	2.50 (lights reduce to 50% when external solar reaches 250W/m²)
Plant	2.50

Retail	3.50
Stairs	3.50
Store	2.50
Toilets	3.50
Riser	N/A

Part L 2A actual building lighting efficiencies

Lighting Controls and Metering

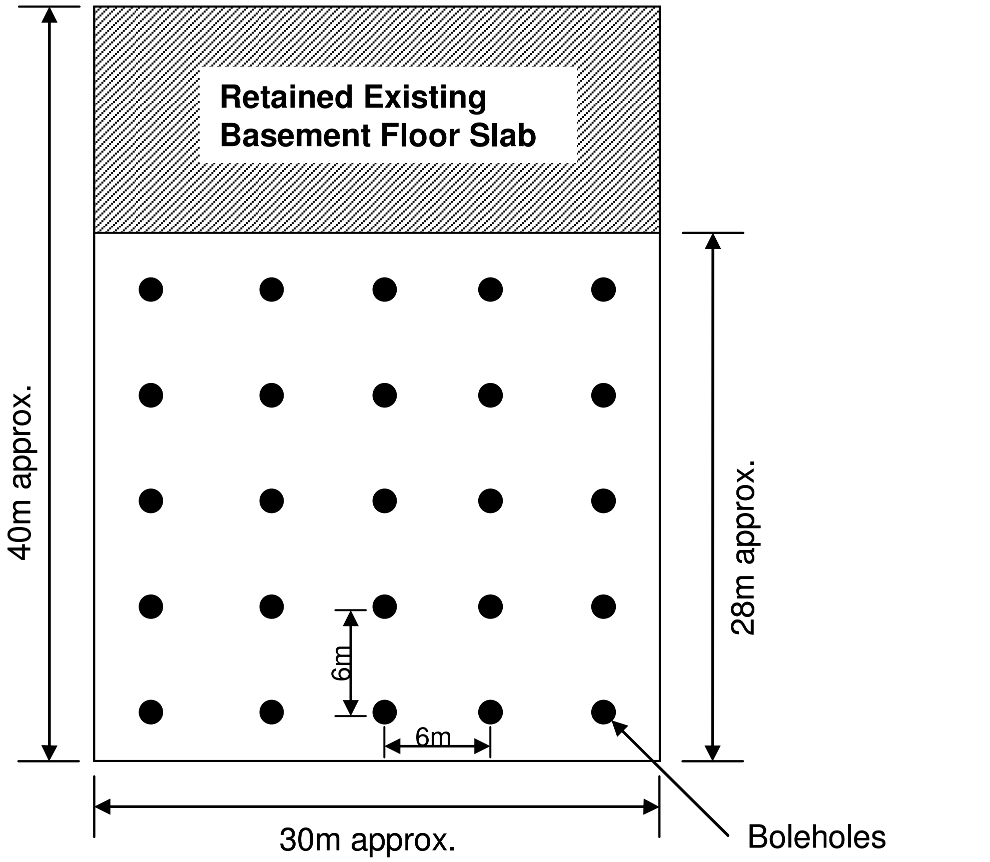
Lighting systems do not have management controls for metering (small power and lighting will be taken together).

Electric Power Factor

It is assumed that the power factor correction achieves a whole building power factor of at least 0.95.

Appendix C - Ground Source Heat Pump Calculation

Option 1: Use Boreholes for GSHP



Simplified basement layout

GSHP - Heating System

⇒ Estimated 25 boreholes can be located in 6m spacing

⇒ Estimated system size from boreholes
25 (No. of piles) x 120m (pile depth) x 60 W/m (heat from ground in linear meter) = **180kW**

GSHP - Cooling System

⇒ Estimated system size from boreholes = 25 piles x 120m x 60W/m = 180 kW
⇒ While 20% of energy will be consumed by compressor(s) of the heat pumps, and therefore system size = 180kW x 80% = **144 kW**
⇒ With assumed COP of Heat Pumps is 4

Option 2: Structural Piles and Boreholes for GSHP

GSHP - Heating System

⇒ Estimated System Size from structural piles
90 (No. of piles) x 25m (pile depth) x 60 W/m (heat from ground in linear meter) = 135kW

Note:
- Sources of approx. number of structural piles from Whitbybird
- Approximately 30% of existing basement floor slab to be retained. Therefore the no. of structural piles is to be reduced by 30%.

⇒ Reduced System size = 135kW x 70% = **94.5kW**

⇒ Estimated system size from boreholes (from option 1)= **180kW**

⇒ Estimated Heating System Size from structural piles and boreholes
94.5kW + 180kW **= 274.5kW**

GSHP - Cooling System

⇒ Estimated System Size from structural piles
90 (No. of piles) x 25m (pile depth) x 60 W/m (heat from ground in linear meter) = 135kW

Note:
- Sources of approx. number of structural piles from Whitbybird
- Approximately 30% of existing basement floor slab to be retained. Therefore the no. of structural piles is to be reduced by 30%.

⇒ Reduced System size = 135kW x 70% = 94.5kW
⇒ While 20% of energy will be consumed by compressor(s) of the heat pumps, and therefore system size = 94.5kW x 80% = **75.6 kW**
⇒ With assumed COP of Heat Pumps is 4

⇒ Estimated system size from boreholes (from option 1)= **144kW**

⇒ Estimated Cooling System Size from structural piles and boreholes
75.6kW + 144kW **= 219.6kW**

Option 3: Structural Piles and Boreholes on whole basement floor for GSHP

GSHP - Heating System

⇒ Estimated System Size from structural piles
90 (No. of piles) x 25m (pile depth) x 60 W/m^2 (heat from ground in linear meter) = **135kW**

Note:
- Sources of approx. number of structural piles from Whitbybird
- No existing basement floor slab to be retained.

⇒ Estimated system size from boreholes
30 (No. of piles) x 120m (pile depth) x 60 W/m (heat from ground in linear meter) = **216kW**

⇒ Estimated Heating System Size from structural piles and boreholes
135kW + 216kW **= 351kW**

GSHP - Cooling System

⇒ Estimated System Size from structural piles
90 (No. of piles) x 25m (pile depth) x 60 W/m (heat from ground in linear meter) = 135kW

Note:
- Sources of approx. number of structural piles from Whitbybird
- No existing basement floor slab to be retained.

⇒ Estimated system size from boreholes
30 (No. of piles) x 120m (pile depth) x 60 W/m^2 (heat from ground in linear meter) = 216kW

⇒ While 20% of energy will be consumed by compressor(s) of the heat pumps, and therefore system size = (135kW + 216kW) x 80% = **280.8 kW**

⇒ With assumed COP of Heat Pumps is 4

⇒ Estimated Cooling System Size from structural piles and boreholes
= 280.8kW

The carbon savings made by sending energy through the ground source heat pump are found by using the COP in the table below:

System	**COP**
GSHP	4
Conventional Chiller	3.2
Conventional Heater	0.94

Appendix D - Steps of CO_2 savings calculations of LZC technologies

Cogeneration

- Space heating and domestic hot water loads are provided for each hour of the year.
- These are summed for each hour to give hourly heat load
- A thermal store volume is chosen, and converted to MJ storage size by assuming a temperature difference between a thermally full and empty store
- A CHP thermal efficiency is assumed for electrical and thermal production
- A maximum turndown is assumed below which the system can not function
- Simulations with CHP sizes between 0KW and 400KW, in total 200 simulations are run, and the CHP size with the best carbon saving is chosen.
- For each hour of the simulation, the load from the building is added to the spare capacity in the thermal store giving the maximum possible load to the boiler.
- If this maximum CHP load is greater than the maximum CHP turndown value, the CHP runs for the maximum value of the maximum CHP load and the CHP size.
- Heat not sent to the building, is added onto the thermal store.
- Heat demand not met by the CHP is subtracted from the store, where this heat is present, and provided to the building.
- Heat demand not met by the CHP boiler, or the thermal store is met by a conventional boiler.
- Electricity provided by the CHP plant is multiplied by 0.568 to give an extra carbon saving.
- The carbon saving is the difference between running this calculation with a specified CHP, and running the calculation with a 0KW CHP plant size.

Trigeneration

- Space heating and domestic hot water loads and cooling loads are provided for each hour of the year.
- These are summed for each hour to give hourly heating and cooing load
- A thermal store volume is chosen, and converted to MJ storage size by assuming a temperature difference between a thermally full and empty store
- A CHP thermal efficiency is assumed for electrical and thermal production
- Absorption chiller efficiency is chosen.
- A maximum turndown is assumed below which the CHP can not function
- A maximum turndown is assumed below which the absorption chiller can not function.
- Simulations with CHP sizes between 0KW and 400KW, in total 200 simulations are run, and the CHP size with the best carbon saving is chosen.
- For each hour of the simulation, the load from the building is added to the spare capacity in the thermal store giving the maximum possible load to the boiler.
- If this maximum CHP load is greater than the maximum CHP turndown value, the CHP runs for the maximum value of the maximum CHP load and the CHP size.
- Heat not sent to the building, is added onto the thermal store.
- Heat demand not met by the CHP is subtracted from the store, where this heat is present, and provided to the building.
- Heat demand not met by the CHP boiler, or the thermal store is met by a conventional boiler.
- Electricity provided by the CHP plant is multiplied by 0.568 to give an extra carbon saving.
- The carbon saving is the difference between running this calculation with a specified CHP, and running the calculation with a 0KW CHP plant size.

NOTE: IN OUT CALCULATIONS WE HAVE PICKED A SYSTEM SIZE AND NOT USED THE OPTIMISATION.

Biomass Boiler

- Space heating and domestic hot water loads are provided for each hour of the year.
- These are summed for each hour to give hourly heat load
- A thermal store volume is chosen, and converted to MJ storage size by assuming a temperature difference between a thermally full and empty store
- A maximum turndown is assumed below which the boiler can not function
- A boiler thermal efficiency is assumed
- Simulations with boiler sizes between 0KW and 400KW, in total 200 simulations are run, and the boiler size with the best carbon saving is chosen.
- For each hour of the simulation, the load from the building is added to the spare capacity in the thermal store giving the maximum possible load to the boiler.
- If this maximum boiler load is greater than the maximum boiler turndown value, the boiler runs for the maximum value of the maximum boiler load and the boiler size.
- Heat not sent to the building, is added onto the thermal store.
- Heat demand not met by the boiler is subtracted from the store, where this heat is present, and provided to the building.
- Heat demand not met by the biomass boiler, or the thermal store is met by a conventional boiler.
- The carbon saving is the difference between running this calculation with a specified biomass boiler, and running the calculation with a 0KW biomass boiler size.

Solar Thermal

- An area of solar thermal is chosen.
- A type of solar thermal is chosen, giving a range of efficiencies.
- The azimuth and altitude of orientation is found.
- For each hour of the year, the dot product of the solar position and the forward facing normal of the system are found. Dot products less than 0 are set to 0.
- Diffuse light falling on the panel is proportional to the amount of sky in view and the intensity of diffuse light on a horizontal plane.
- Diffuse ground reflected light falling on the panel is proportional to the amount of ground in view and the intensity of diffuse light on a horizontal plane.
- Direct light falling on the panel is proportional to the dot product and the intensity of light on a plane parallel to the direction of travel of the light.
- The sum of Diffuse, Diffuse Ground and Direct are multiplied by the efficiency and area to give thermal power output.
- Thermal power output is compared with the gas needed to run a reference boiler and this leads to the calculated carbon dioxide savings.

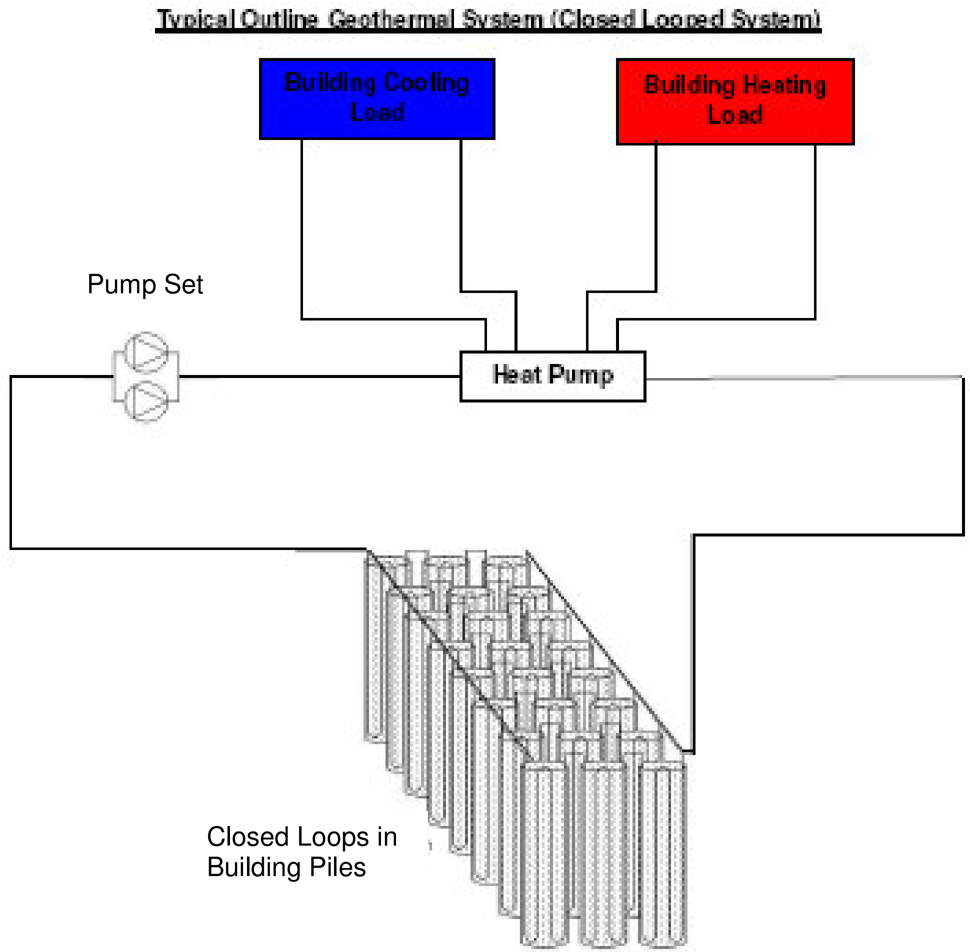
PV

- An area of PV is chosen.
- A type of PV is chosen, giving efficiencies between 5% and 15%.
- The azimuth and altitude of PV orientation is found.
- For each hour of the year, the dot product of the solar position and the forward facing normal of the system are found. Dot products less than 0 are set to 0.
- Diffuse light falling on the panel is proportional to the amount of sky in view and the intensity of diffuse light on a horizontal plane.
- Diffuse ground reflected light falling on the panel is proportional to the amount of ground in view and the intensity of diffuse light on a horizontal plane.
- Direct light falling on the panel is proportional to the dot product and the intensity of light on a plane parallel to the direction of travel of the light.
- The sum of Diffuse, Diffuse Ground and Direct are multiplied by the efficiency and area to give electrical power output.
- Electrical power output is multiplied by 0.568 to give carbon dioxide emissions saving.

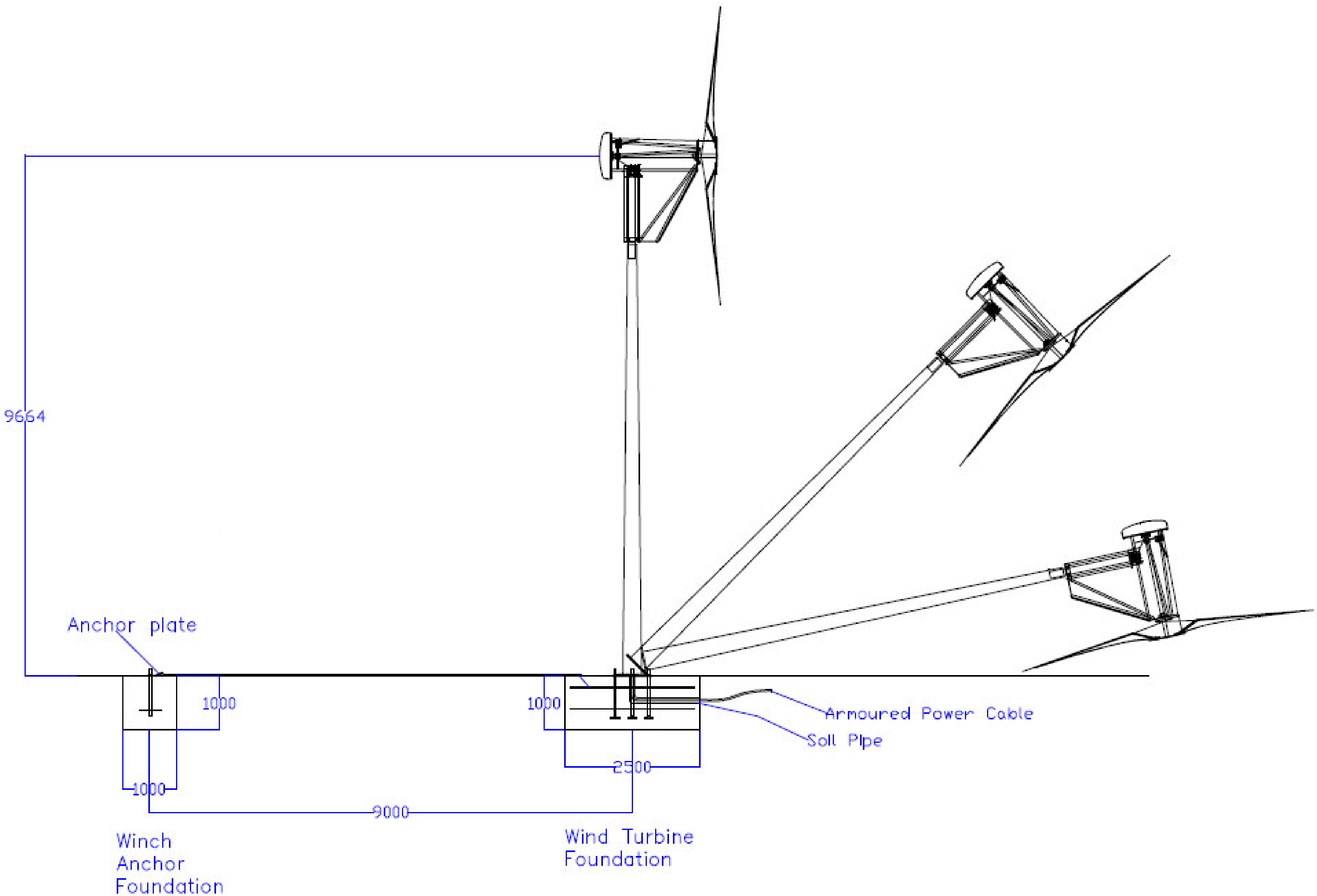
GSHP Calculation

- Pile lengths are found
- W/m maximum loads are assumed
- From these maximum system sizes for heating and cooling can be found
- For each hour, the maximum value chosen from boiler demand and GSHP system size is chosen. The resulting values are summed over the year to give energy passing through GSHP
- This method is repeated for cooling with the chiller.
- The carbon savings are found by multiplying the energy passing through by the difference between the carbon factor for electricity divided by the COP of the GSHP and the carbon factor for the reference fuel divided by the COP of the reference system.

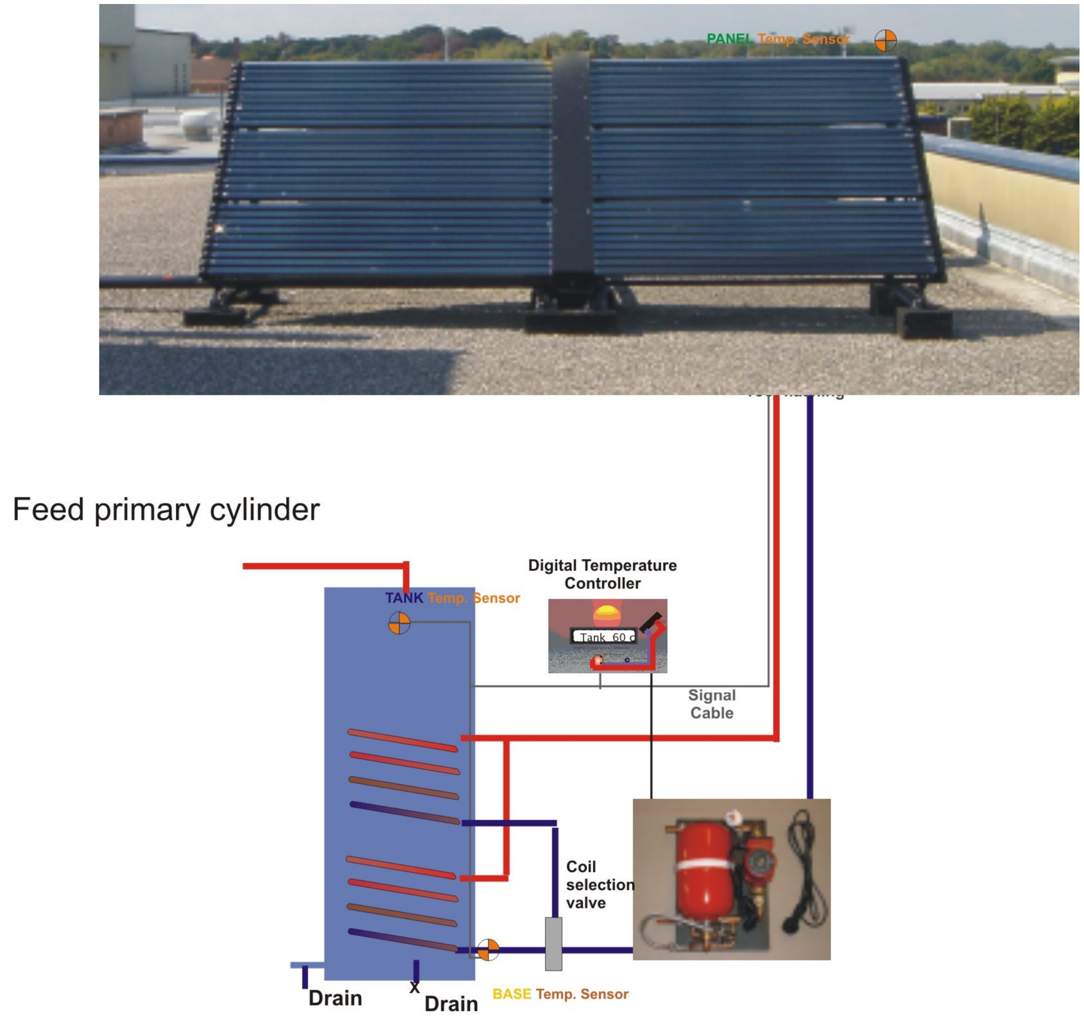
Appendix E - Drawings of Low and Zero CO_2 Technologies



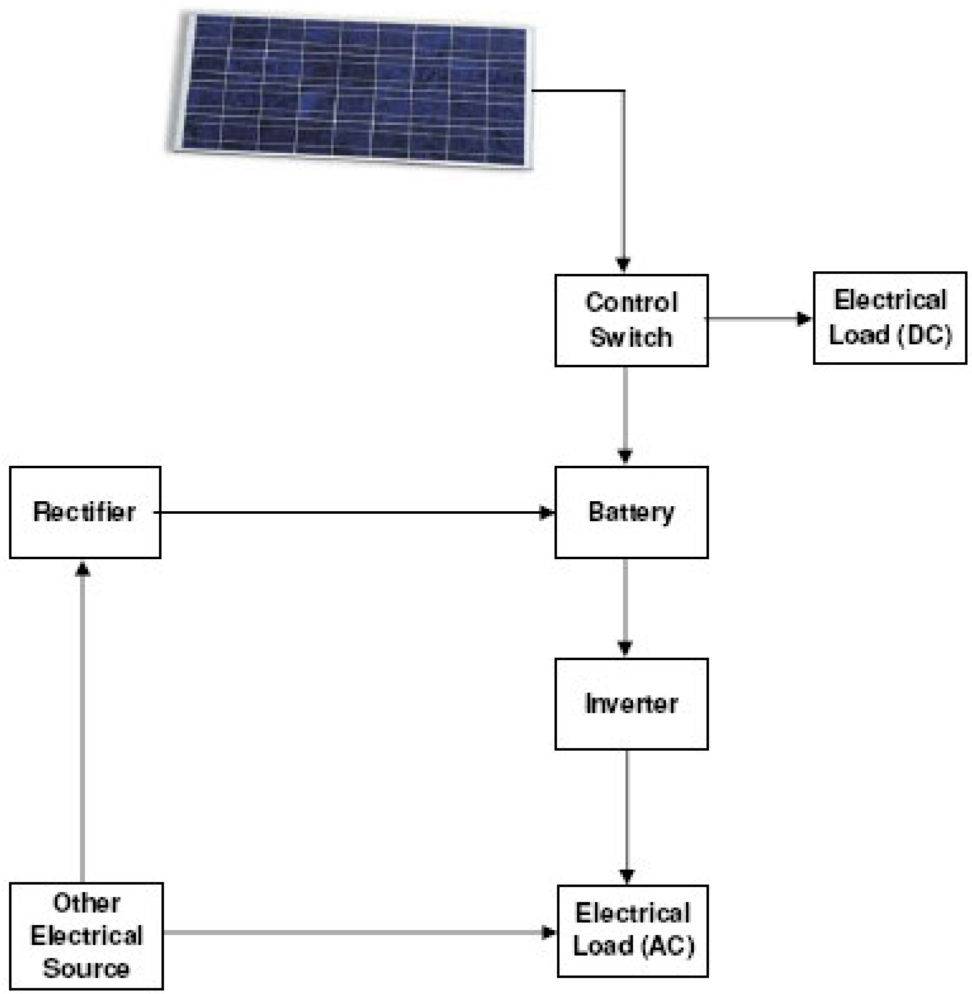
Typical Geothermal Closed Loops schematic



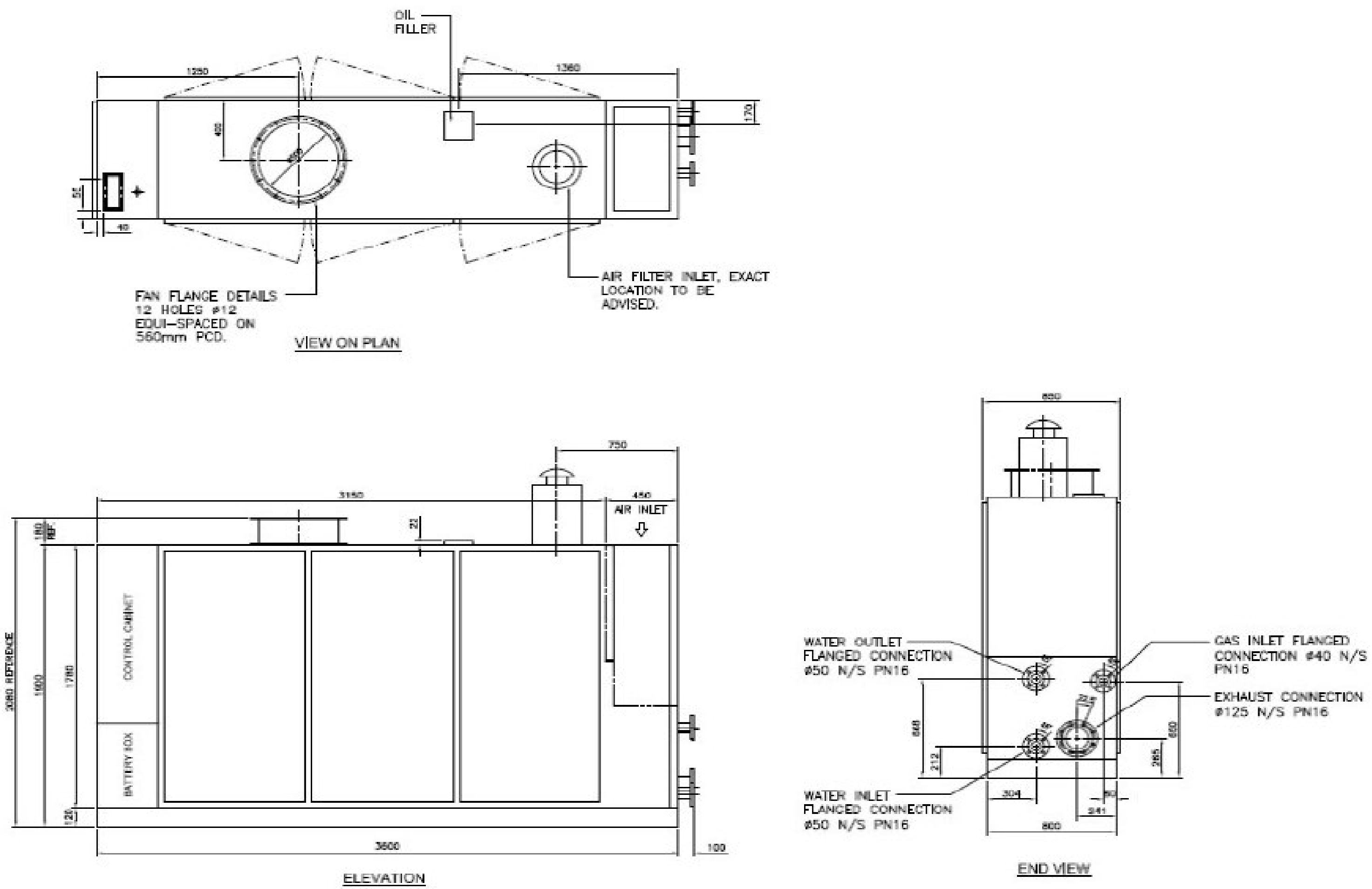
Wind turbine



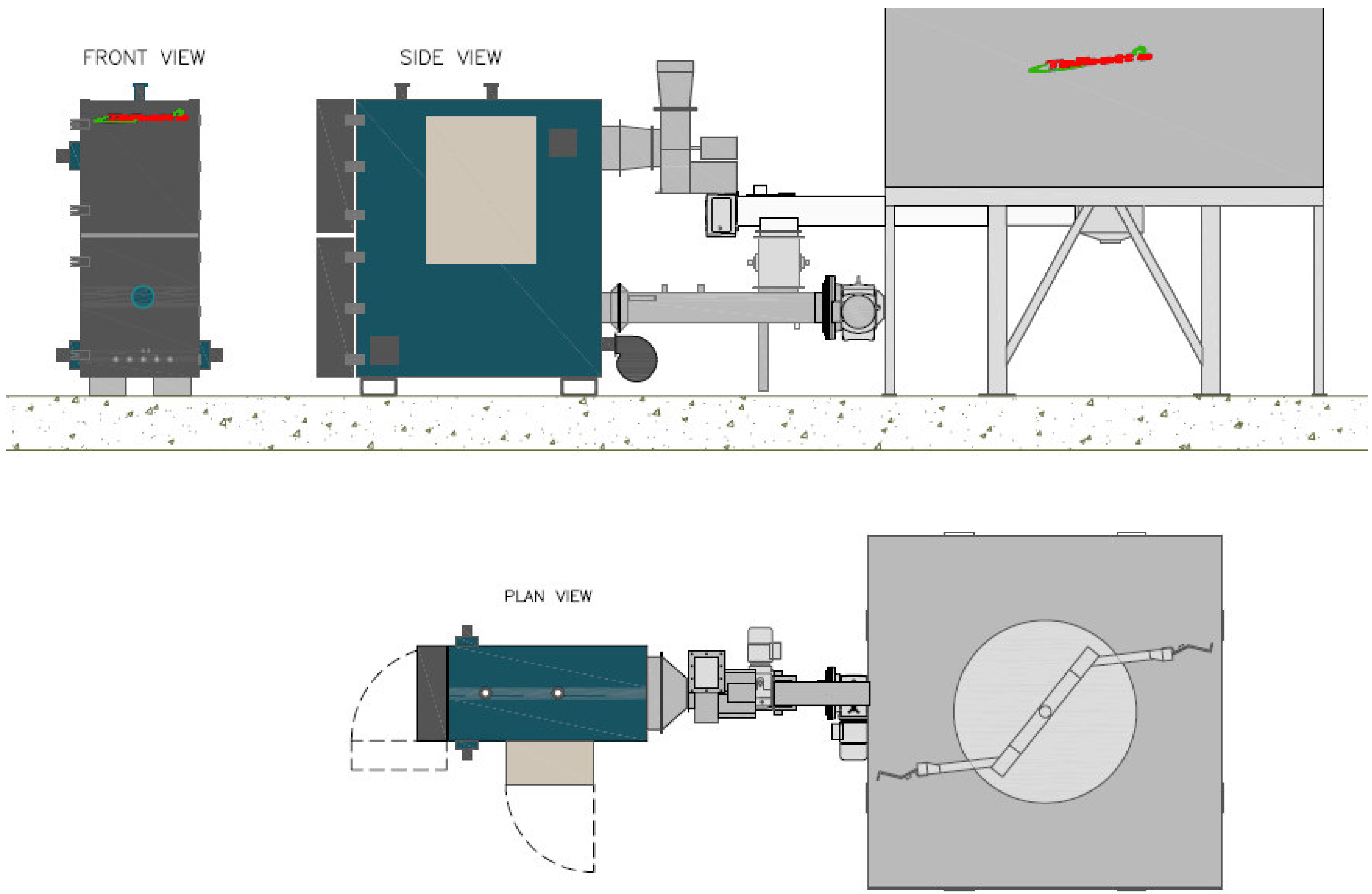
Typical Solar Thermal schematic



Typical Photovoltaic schematic



Combined Heat and Power (CHP) Plant



Bio – Mass Boiler