# Victoria Station Upgrade

# Energy Demand Assessment

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Mott MacDonald

Transport for London UNDERGROUND

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# Energy Demand Assessment

| Approved by | Signature | Date |
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| Jane Barron | Jane Barron | 15th November 2007 |

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## Summary

This report presents the findings of an energy demand assessment and renewables feasibility study for the Victoria Station Upgrade (VSU) scheme. This scheme will increase the station's capacity and reduce congestion. It comprises new infrastructure that will reduce congestion at the Underground station and provide extra station capacity for future demand growth. Mott MacDonald has been requested to undertake an energy demand assessment and renewables feasibility study for the refurbishment and extension aspect of the scheme. This document will form part of the Environmental Statement in support of the application for an Order under the Transport and Works Act, 1992, for the VSU.

Planning Policy Statement 22[1] (Renewable Energy) and the Mayor of London's London Plan include a number of policies which relate to energy assessment, energy efficiency and renewable energy sources. In line with policy 4A.8 of the London Plan, it is proposed to follow the 'Mayor's Energy Hierarchy'. The development will adopt passive and energy efficient design strategies to minimise the energy consumption and corresponding carbon emissions.

The feasibility of potential renewable (low or zero carbon) energy sources for the VSU has been undertaken using the London Renewables Toolkit. Low and zero carbon energy resources will be incorporated, where feasible, to further reduce a building or development's carbon emissions beyond what can be achieved through energy efficient design.

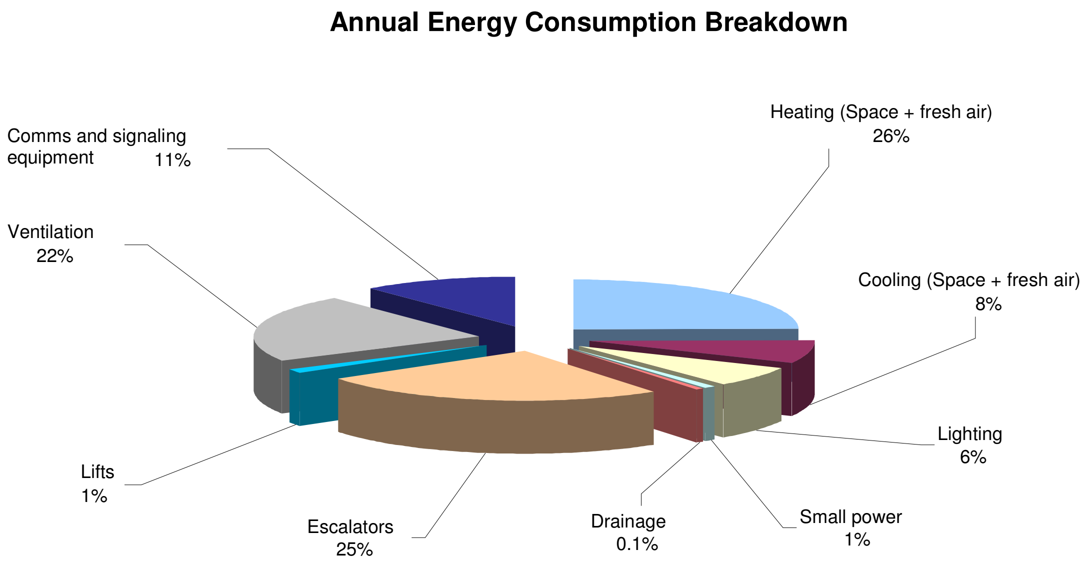
A preliminary assessment of the predicted annual energy consumption has been undertaken based on two models which represent,

- the current LU compliant design proposals and a conservative prediction of the operating hours of the north and south ticket halls and associated ancillary areas, referred to as the baseline energy demand assessment

- a modification to the current design proposals to reflect a more energy efficient design and a less conservative prediction of the operating hours of the north and south ticket halls and associated ancillary areas, referred to as the energy efficient energy demand assessment.

The baseline energy demand assessment suggests a total annual energy consumption of 6323 MWh for north and south ticket halls and associated ancillary areas. This is equivalent to carbon emissions amounting to 740 tonnes C/year.

[1] Planning Policy Statement 22: Renewable Energy, Office of the Deputy Prime Minister (now Communities and Local Government)




The energy efficient model results in significant reduction of up to 42% of the baseline prediction to 3687MWh. The energy efficient design strategies include:

- incorporating heat recovery on all tempered ventilation systems;
- using high efficiency electric motors on fans, pumps, lifts and escalators;
- limiting escalator operating times;
- incorporating power factor correction equipment;
- reducing lighting levels in public areas outside normal hours of use;
- incorporating a means to control lighting in staff facilities either through management strategies or timers and movement sensors;
- increasing ductwork sizes;
- incorporating variables speed pumping on the chilled and condenser water systems; and
- using chillers and packaged cooling equipment with higher Co-efficients of Performance (COPs) and “free cooling” modes of operation.

Further reductions could be achieved, if deviations from the LU standards were found to be acceptable, for example (for approval by LU);

- relaxation of environmental design temperatures; and

- reduction in ventilation rates, particularly in non-occupied spaces.

An assessment of the renewable energy options undertaken by Mott MacDonald has identified that using ground water for direct “free-cooling” and as a low grade heat source using a heat pump installation, to be the most feasible low carbon technology for the development. The source of groundwater will be from the track drainage system. Water collected by the drainage system is already proposed to be used for direct “free cooling” and a means of heat rejection for the Tunnel Cooling Project on the Victoria Line. It is estimated that around 25l/s of groundwater at 12-18$^{O}$C is available. The VSU project will also use this source of ground water, but for heat rejection only.

Direct free cooling will provide measurable savings in cooling energy requirements, by reducing the need for refrigerated cooling via a chiller. Instead the groundwater can be used to directly cool by incorporating a “free cooling” coil within the supply air handling plant, although this will mean increased fan energy consumption. Note that this is a more effective means of free cooling than a chiller incorporating a “free cooling” mode as suggested in the energy efficiency initiatives above. It has been estimated that a reduction of 1.2% of the annual energy consumption could be achieved through direct ground source cooling.

Using this groundwater as heat pump energy source in place of electrical heating would produce even greater reductions in energy consumption. It has been estimated that a reduction of 5.1% of the annual energy consumption could be achieved through this form of ground source heating.

All other low or zero carbon energy sources have been discounted. Biomass boilers and Combined Heat and Power (CHP) would not be acceptable under LU standards and would be difficult to accommodate in terms of space for plant rooms, fuel storage and access for fuel deliveries.  Solar thermals, photovoltaics and wind turbines are not feasible due to the limited external area available for mounting and overshading and obstruction caused by adjacent buildings.

# 1 Introduction

## 1.1 Energy and the VSU Scheme

1.1.1 The Victoria Station Upgrade (VSU) scheme comprises the extension and refurbishment of the existing Victoria Underground Station ticket hall and ancillary areas. The development, most of which is underground, includes new and refurbished entrances, ticket halls, public areas, staff facilities and offices, retail outlets and plant spaces. In addition, a new traction power substation will be located in the new part of the station which will replace the existing substation.

1.1.2 Mott MacDonald have been requested to undertake an energy demand assessment and renewables feasibility study for the upgrade scheme as part of the Environmental Statement to support the application to the Secretary of State for an Order under the Transport and Works Act, 1992 (TWA) that will grant permission for the construction and operation of the VSU. A detailed description of the works being undertaken to upgrade the Underground station is contained within the Environmental Statement (Document Reference MMD-V047-1159-ENV-50010).

1.1.3 The requirement for this study is in response to Planning Policy Statement 22[1] and the Mayor of London's London Plan[2]. The London Plan includes a number of policies which relate to energy assessment, efficiency and renewable energy sources.

1.1.4 Policy 4A.8 requires an assessment of the energy demand for major developments. The energy demand assessment should demonstrate the steps taken to apply the Mayor's energy hierarchy. The hierarchy indicates energy needs should be met through applying in sequence, the following factors:

- using less energy;
- using renewable energy; and
- supplying energy efficiently.

1.1.5 Policy 4A.9 requires designers to state how developments would generate a proportion of the sites electricity or heat needs from renewables, where feasible. In support of policy 4A.9, the Mayors Energy Strategy[3] includes the following statement under proposal 13,

[2] Mayor of London, The London Plan: Spatial Development Strategy for Greater London (2004), Greater London Authority
[3] Green Light to Clean Power, The Mayors Energy Strategy, Greater London Authority, February 2004

*"To contribute to meeting London's targets for the generation of renewable energy, the Mayor will expect applications referable to him to generate at least ten per cent of the site's energy needs (power and heat) from renewable energy on the site where feasible. Boroughs should develop appropriate planning policies to reflect this strategic policy."*

1.1.6 Referable applications are generally major developments typically in excess of 1000m$^2$. The refurbishment and extension of the Victoria Underground Station has a gross external area of approximately 7,000m$^2$ and so is classed as a major development.

1.1.7 It should be noted that proposal 13 of the Mayor's Energy Strategy will effectively be superseded under The London Plan Further Alterations[4] which is planned to be adopted in 2008. This proposes to amend the wording of policy 4A.7 of the London Plan to read,

*"The Mayor will and boroughs in their DPDs should require developments to achieve a reduction in carbon dioxide emissions of 20% from onsite renewable energy generation".*

1.1.8 This report will examine options that might feasibly be considered in order to achieve the current 10% renewables energy target, in addition to examining options to reduce energy consumption and the associated carbon emissions in line with the London Renewables Toolkit.

[4] Draft Further Alterations to the London Plan, Greater London Authority, September 2006

# 2 Method of Assessment

## 2.1 Introduction

2.1.1 The energy demand assessment (EDA) and renewable energy feasibility study will be based on an appraisal of the design proposals following the Mayor's Energy Hierarchy.

## 2.2 Energy Demand Assessment

2.2.1 The energy demand assessment calculation will use peak loadings in kW and operational profiles across the year to determine the annual energy use in kWh. The calculation model will be built up from known data or an estimate of peak loading for each energy system associated with the station, as follows:

| Load Type | Description |
|---|---|
| Heating | Electrical power required to warm heated spaces and heat outdoor air supplied to mechanically ventilated spaces using electrical heating coils and room heaters (note there is no gas powered heating). |
| Cooling | Electrical power required to cool mechanically cooled spaces and outdoor air being supplied to mechanically ventilated spaces using some means of refrigerated cooling system including the pumps and fans required to deliver the cooling. |
| Small Power | Electrical power required to operate computer systems in management office spaces and ticket offices; and all other equipment supplied from general purpose socket outlets (e.g. cleaning equipment, kettles in staff mess room etc). |
| Lighting | Electrical power required to maintain all artificial lighting systems. |
| Ventilation | Electrical fan motor power required to maintain all fan systems serving mechanically ventilated spaces. |
| Escalators | Electrical motor power required to operate escalator installations. |
| Lifts | Electrical motor power required to operate lift installations. |
| Communications and Signalling | Electrical power required to operate all communications and signalling equipment associated with the station. |
| Drainage | Electrical motor power required to operate the drainage pumps. |

2.2.2 Loads will be compiled for each room or system. The effects of seasonal variations in temperature will be used to determine a thermal load profile over a typical calendar year. Operational profiles in terms of percentage of peak load and operational hours per day, throughout the year for each room or system type will then be applied to determine annual energy consumption. Carbon emissions will also be calculated using a carbon factor of 0.117kg/C/kWh as proposed by the Carbon Trust.[5]

[5] Energy and Carbon Conversion Fact Sheet, CTL004, The Carbon Trust, April 2006

2.2.3 Two models will be developed. A baseline energy model will be created based on the current design proposals and a conservative assumption of operational profiles for each space and its associated energy system. The design information will be taken from the current architectural drawings, room area schedules and the current M&E services equipment schedules. It is understood this design is compliant with LU standards. The operational profile will be assumed to be either fully operational for 24 hours a day, 365 days a year or operational between 6am and 1am (i.e. 19 hours per day) for 365 days a year.

2.2.4 An energy efficient model will be developed based on the base model, amended to incorporate a number of energy efficient design considerations and reduced operational times in some areas. These are described in more detail in the next section.

2.2.5 Full details of the input data used in both models are provided in Appendix A.

## 2.3 Renewable Energy Feasibility

2.3.1 In order to assess the feasibility of low or zero carbon (renewable) energy sources, the study will make use of the London Renewables Toolkit[6]. The Toolkit evaluates renewable energy sources in terms of reduction in emissions rather than energy, this report will provide data for both.

[6] London Renewables (2004), Faber Maunsell, Greater London Authority

# 3 Passive Design and Energy Efficiency

## 3.1 Introduction

3.1.1 The first tier of the Mayor's energy hierarchy calls for a reduction in energy usage. This can be achieved through passive and energy efficient design.

3.1.2 Policy 4A.8 of the London Plan states that:

*"The Mayor will expect all strategic referrals of commercial and residential schemes to demonstrate that the proposed heating and cooling systems have been selected in accordance with the following order of preference: passive design; solar water heating; combined heat and power, for heating and cooling, preferably fuelled by renewables; community heating for heating and cooling; heat pumps; gas condensing boilers and gas central heating. Boroughs should apply the same criteria to major developments."*

3.1.3 Passive design and energy efficiency are considered in further detail below.

## 3.2 Passive Design Strategies

3.2.1 The development benefits from a number of passive design strategies by being located below ground, including;

- high thermal insulation from the surrounding soil which minimises building fabric heat losses and gains, reducing heating and cooling loads;
- low air leakage as there are almost no external elements reducing infiltration heat losses and gains. This may be offset by the high rates of air movement between the tunnel and passenger entrances which may lead to leakage within those adjoining heated or cooled spaces; and
- no solar heat gains in cooled spaces as the development is below ground.

## 3.3 Energy Efficient Design

3.3.1 The London Renewables Toolkit, makes reference to a number of energy efficient design considerations. These are reproduced in the table below which also comments on whether these considerations are appropriate in the context of the VSU.

| Design Consideration | Toolkit Question | Comment |
|---|---|---|
| Orientation | Are buildings orientated so that main working spaces face within 45º of south (to take advantage of solar gain and ease of shading)?<br><br>This doesn't apply to all non-domestic buildings (e.g. offices and other buildings that have a large cooling demand). | Not applicable as building is below ground |
| | Where buildings (such as offices) will need cooling, are large west facing windows avoided (difficulty with shading)? | Not applicable as building is below ground |
| Daylighting | Are buildings designed to maximise use of daylight (and decrease the need for artificial light) during the day? | Very difficult to integrate as building is below ground with limited access to daylight. |
| | Are control systems to be fitted that optimise the use of daylight? | Will be considered for entrance areas. |
| Heating System | Is a CHP community heating system appropriate? Are there adjacent buildings with heat demand, such as a hospital or leisure centre, that could make CHP a viable option? | Could be considered although difficult to integrate as LU standards do not allow for gas/biomass heating/CHP systems. |
| | Could the development link up with an existing community heating / CHP system? | This will be considered, although there is no existing system – may link to future development. |
| | Are condensing and highly efficient boilers being fitted as standard? | Not applicable as no gas heating. |
| | Are ventilation heat recovery systems included? | Not in current scheme, but will be considered. |
| Insulation | Are insulation levels above building regulations being achieved? | Yes. |
| Lighting | Are dedicated energy efficient light fittings installed throughout the buildings? | Fluorescent lighting provided throughout. |
| | Is a lighting control system being installed? | Not in current scheme, but will be considered. |
| Glazing | Are high performance windows being specified (with U-values above building regulations)? | Negligible glazing proposed. |
| Cooling | Is adequate external shading being fitted where solar gain can cause overheating and/or increased cooling loads? | Cooling loads unaffected by solar gain. |
| | Is a mixed mode air-conditioning system possible (natural ventilation used when suitable with the option of using air-conditioning when necessary)? | Could be considered although could mean increase in fan energy requirements. |

| Design Consideration | Toolkit Question | Comment |
|---|---|---|
| Ventilation | Can the building be naturally ventilated either fully or partially? | Public areas are all naturally ventilated. |
| | If not, can mechanical ventilation be used to avoid active cooling systems? | See previous comments under cooling. |
| Controls | Is a suitable Building Management System (BMS) being installed? | Yes |

3.3.2 In addition to the energy efficiency considerations identified through the Toolkit, the following will be considered and will form the basis of the “energy efficient” calculation model:

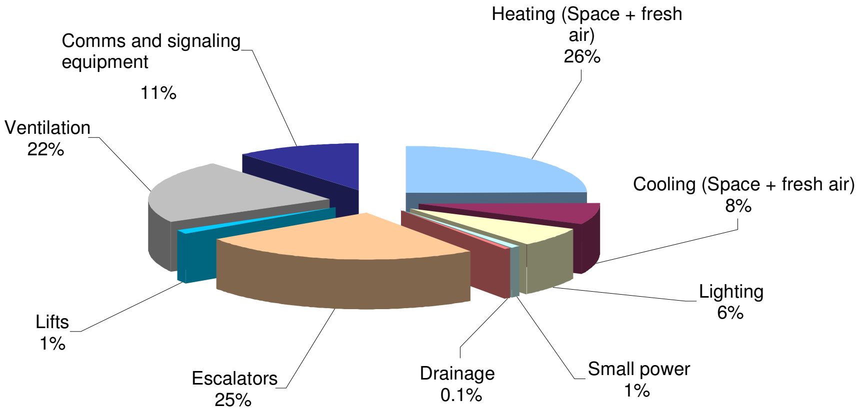
- chillers with a high coefficient of performance;
- reduced lighting levels in public areas outside operational hours;
- lighting control in staff facilities;
- variable speed pumps and fans to match output to demand;
- increased ductwork sizes to reduce air velocities to reduce fan energy;
- heat recovery on all ventilation systems;
- reduced escalator operating times; and
- power factor correction.

# 4 Estimated Energy Demand

## 4.1 Baseline Model

4.1.1 The baseline model based on the current design proposals has a total annual energy consumption of 6323 MWh/year (or 909 kWh/sq.m year). The equivalent carbon emissions are 740 tonnes C (or 106 kgC/sq.m year). In order to meet a renewables target of 10%, 632 MWh each year would need to be generated by low or zero carbon technologies. The breakdown of the energy uses for the whole development is shown below.

**Annual Energy Consumption Breakdown – Baseline Model**

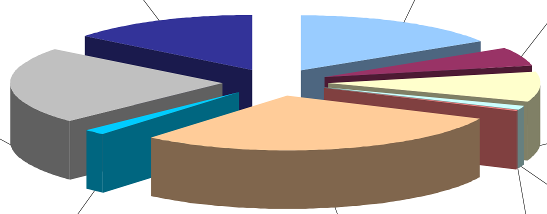



| Estimated Annual Energy Demand – Baseline Model | | | |
|---|---|---|---|
| **Energy System** | **Peak Load** | **Annual Energy Consumption** | **Annual Carbon Emissions** |
| | **kW** | **MWh** | **tonnes C /yr** |
| Heating (Space + fresh air) | 431 | 1558 | 182 |
| Cooling (Space + fresh air) | 59 | 488 | 57 |
| Lighting | 83 | 406 | 48 |
| Small power | 8 | 68 | 8 |
| Drainage | 25 | 20 | 2 |
| Escalators | 533 | 1610 | 188 |
| Lifts | 156 | 75 | 9 |
| Ventilation | 144 | 1401 | 164 |
| Comms and signalling equip. | 72 | 698 | 82 |
| **Total** | **1512** | **6323** | **740** |
| **Total (W/m$^2$,kWh/m$^2$,kg C/m$^2$)** | **217** | **909** | **106** |
| **Notes** | | | |
| 1 – All energy is supplied by electricity<br>2 – Carbon emissions based a carbon factor of 0.117 kgC/kWh<br>3 – Refer to Appendix A for model assumptions | | | |

## 4.2 Energy Efficient Model

4.2.1 The energy efficient model incorporates a number of energy efficient design considerations (as described below) and reduced operational times in some areas. Using this model, the predicted total annual energy consumption is 3687 MWh/year (or 530 kWh/sq.m year). This represents a 42% reduction in energy consumption compared to the baseline model. The equivalent carbon emissions are 431 tonnes C (or 62 kgC/sq.m year). Based on this reduced energy consumption, in order to meet a renewables target of 10%, 368 MWh each year would need to be generated by low or zero carbon technologies. The breakdown of the energy uses for the whole the development is shown below.

**Annual Energy Consumption Breakdown – Energy Efficient Model**




| Estimated Annual Energy Demand – Energy Efficient Model | | | |
|---|---|---|---|
| Energy System | Peak Load | Annual Energy Consumption | Annual Carbon Emissions |
| | kW | MWh | tonnes C /yr |
| Heating (Space + fresh air) | 141 | 594 | 70 |
| Cooling (Space + fresh air) | 29 | 209 | 24 |
| Lighting | 83 | 328 | 38 |
| Small power | 4 | 33 | 4 |
| Drainage | 24 | 18 | 2 |
| Escalators | 506 | 1068 | 125 |
| Lifts | 148 | 71 | 8 |
| Ventilation | 101 | 838 | 98 |
| Comms and signalling equip. | 50 | 529 | 62 |
| **Total** | **1088** | **3687** | **431** |
| **Total (W/m$^2$,kWh/m$^2$,kg C/m$^2$)** | **156** | **530** | **62** |
| **Notes** | | | |
| 1 – All energy is supplied by electricity<br>2 – Carbon emissions based a carbon factor of 0.117 kgC/kWh<br>3 – Refer to Appendix A for model assumptions | | | |

## 4.3 Analysis of Results

4.3.1 The baseline model suggests the largest uses of energy are the heating system, escalators and ventilation plant. The communications & signalling equipment and cooling systems also have significant energy demands. All these energy systems should be the target of energy efficiency design initiatives.

### Heat Recovery

4.3.2 The heating system energy loads are from either the room heaters or mechanical ventilation systems which include electrical heaters to temper the air being supplied from outside. While electrical heating is highly efficient (almost 100%) compared with gas fired wet systems (60-70% on average, even if condensing boilers are considered), the carbon emissions associated with electrical heating are almost twice that of a gas fired system.

4.3.3 However, as gas fired heating is not acceptable under LU standards, a reduction in heat loads is the only way of reducing the heating energy and hence carbon emissions. The heat loads associated with the mechanical ventilation systems could be reduced by the inclusion of heat recovery in these systems. In the energy efficient model, heat recovery with an effective efficiency of 60% has been considered. This resulted in a reduction of 62% of the heating energy requirements or 15% of the total baseline energy figure.

### Escalator Usage

4.3.4 The escalator system can be looked at in terms of the motor efficiency of the traction plant and perhaps more significantly, the hours of operation. In the baseline model all escalators were assumed to operate for 19 hours per day, 365 days per year. In the energy efficient model, operation was reduced such that only 4 of the 6 operated 19h/day 365 days per year. The remaining 2 were assumed to operate 4h per day to represent operation during peak hours only. In addition an improvement in the overall motor efficiency of 5% was considered in the energy efficient model. This resulted in a reduction of 33% of the escalator energy requirements, a reduction of 9% of the total baseline energy figure.

### Specific Fan Power

4.3.5 The mechanical ventilation systems rely on electrically driven fans to distribute air around the station. The electrical power required to move the air is dependent on the amount of air that needs to be distributed (i.e. the number of air changes per hour or fresh air supply rate), the velocity at which the air is moved and the efficiency of the fan and motor. The efficiency of a fan system is described in terms of the specific fan power, which is the electrical power required to generate a specific volumetric flow of air. Specific fan power can be reduced by using more efficient fans and motors and also increasing the ductwork size which reduces the velocity of the air as it passes through a duct system. Ventilation energy will also depend on hours of operation of the system.

4.3.6 On the basis that the amount of air cannot be reduced without deviating from LU standards, a reduction of specific fan power by 30% has been considered in the energy efficient model. This could be through a combination of increased ductwork sizes and improved fan and motor efficiencies. This resulted in 40% reduction in the ventilation energy requirements, a reduction of 9% of the total baseline energy figure.

**Communications and Signalling Equipment**

4.3.7 The communications and signalling equipment loads have been taken from information supplied by the design team. It is assumed these represent miscellaneous loads for specialist equipment. In the baseline model a conservative view has been taken that these will operate at peak load 24 hours a day, 365 days a year. In the energy efficient model, the annual energy consumption has been reduced by 20% to represent a reduced average load and/or reduced operational hours. This could represent a more realistic average peak load for these systems and/or a realistic estimate of the hours of operation. This equates to a reduction of 3% of the total baseline energy figure.

**Chiller Co-Efficient of Performance and Pump Efficiency**

4.3.8 The cooling system is a combination of a water cooled chiller, rejecting heat to the ground water source and a number of smaller packaged air cooled systems. The cooling loads are largely internal loads and therefore cannot be reduced by passive measures, such as solar control. The energy requirements associated with the cooling systems are dependent on the efficiency of the refrigeration equipment and the cooling ventilation fans and motors; the chilled and condensing water pumps motors; and pipework transmission losses as the fluid used to transfer cooling energy gains heat as it is circulated around the building. The efficiency of a chiller is normally defined as the Co-efficient of Performance (COP) which is the amounted of cooling output per unit input of power. The overall performance of the cooling system has been allocated a COP to allow for motor efficiencies and distribution losses. In addition the hours of operation of the cooling system will determine cooling energy requirements.

4.3.9 In the energy efficient model, the COP of the cooling system has been increased from 2 to 4. This resulted in a reduction of 57% of the cooling energy requirements and a reduction of 4% of the total baseline energy figure.

**Low Energy Lighting, Control and Usage**

4.3.10 The lighting system loads have been assumed to be 12W/sq.m throughout in the baseline model. Operational hours have been taken to be 24 hours in public and staff facility areas, 19 hours per day in ticket offices and an average 15 minutes per day in plant areas. In the energy efficient model, the following has been considered:

- in public areas, switching 50% of the lights off (manually or automatically) or dimming to 6W/sq.m during the unoccupied period only (i.e. 5 hours per day); and
- in staff facilities, reducing the operational hours by 50% by switching off the lights (manually or automatically).

4.3.11 This resulted in a reduction of 19% of the lighting energy requirements, a reduction of 1% of the total baseline energy figure.

**Small Power Equipment and Usage**

4.3.12 Small power usage is dependent on the extent, usage and power requirements/efficiency of the equipment that is connected to the general power system. A power density of 12W/sq.m has been assumed in ticket offices and staff facilities. Operational hours are as for lighting, i.e. 24 hour in staff facility areas and 19 hours per day in ticket offices. Small power energy consumption could be minimised through the use of low energy appliances and computers. In the energy efficient model a 50% reduction in energy consumption has been considered which could represent lower energy equipment or a reduction in average usage. This equates to a reduction of 0.6% of the total baseline energy figure.

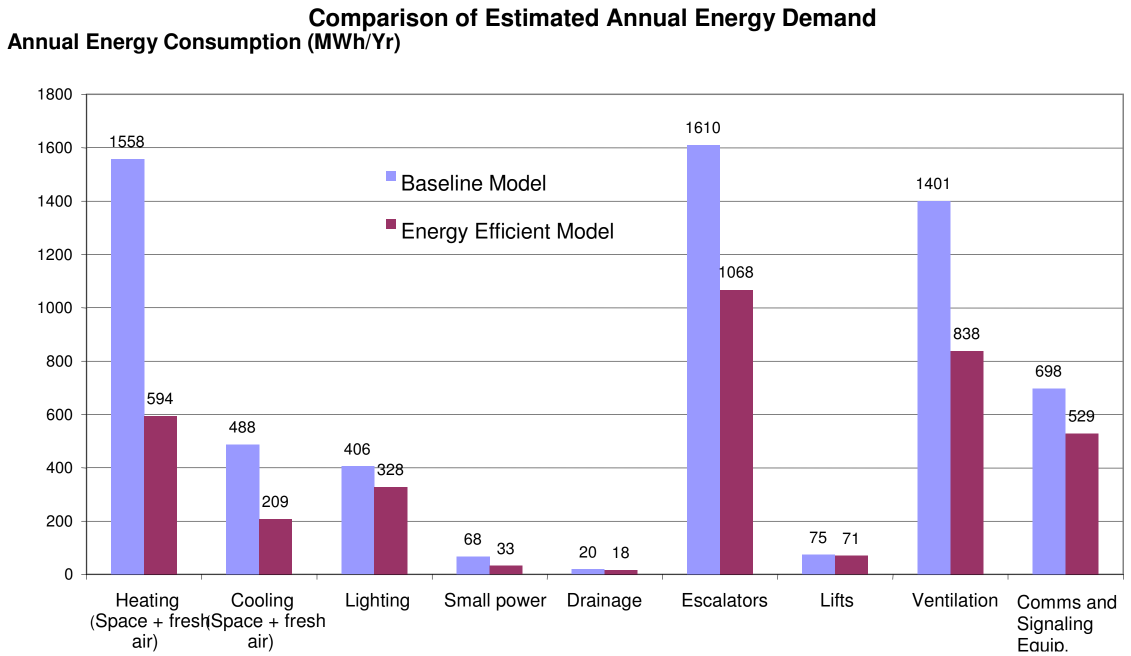
**Lift Usage**

4.3.13 The lift system can be looked at in terms of the motor efficiency and the hours of operation. Lift usage will depend on passenger and staff movements via the lifts. Lift usage was considered to be low in the baseline model at 10% over a 24hour period. An improvement in the overall motor efficiency of 5% was considered in the energy efficient model. This resulted in a reduction of 0.06% of the total baseline energy figure.

## Drainage Pumps

4.3.14 The energy consumption of drainage pumps can be considered in terms of the motor efficiency and the hours of operation. Hours of operation will depend on actual rainfall patterns, drainage rates and sump storage capacities and are therefore difficult to predict, however, an estimate of this has been made by the drainage system designers. The baseline model assumes the pumps operate for 30 minutes per day. An improvement in overall motor efficiency of 5% was considered in the energy efficient model. This resulted in a reduction of 0.03% of the total baseline energy figure.

4.3.15 A comparison of energy consumption between the baseline and energy efficient model for each component is shown below.



# 5 Low and Zero Carbon Energy Sources

## 5.1 Introduction

5.1.1 Low and zero carbon energy sources can be used in place of fossil fuel energy sources to reduce building carbon and $CO_2$ emissions. The second tier of the Mayor's Energy Hierarchy emphasises the importance of using renewables technologies to minimise emissions and the Mayor's Green Light to Green Power report puts forward a target of 10% of a buildings energy usage from "renewable energy". The following sections assess the feasibility of various low and zero carbon technologies. All data quoted, unless stated otherwise, has been taken from the London Renewables Toolkit.

## 5.2 Wind Turbines

### Overview

5.2.1 Wind turbines are usually installed in non-urban areas. In parallel with the design and development of ever bigger machines which are deemed to be more efficient and cost effective, it is being increasingly recognised that smaller devices installed at the point of use, i.e. urban settings, can play an important role in reducing carbon emissions if they are to become mainstream.

5.2.2 At present there is a wide range of available off-the-shelf wind products, many manufactured in the UK and EU with proven good performance and durability. The dominant type is a horizontal axis wind turbines (HAWT) which are typically ground mounted. Vertical axis wind turbines (VAWT) have limited market presence and there is a trade off between lower efficiency and potentially higher resistance to extreme conditions. Capacity ranges from 500W to more than 1.5MW, but, for practical purposes and in urban areas in particular, machines of more than 6-15kW are unlikely to be suitable. The main drawback of smaller building integrated turbines is the high capital cost per kW installed for smaller turbines, plus local constraints, such as visual intrusion and noise. The wind profile in urban areas is also a concern owing to higher wind turbulence which reduces potential electricity output.

5.2.3 In most cases, wind turbines are connected to the electricity grid and all generated energy is used regardless of the building demand fluctuations. The output largely depends on the wind speed and the correlation between the two is a cube function. This means that in short periods of above average wind speeds the generation increases exponentially. As a result, it is difficult to make precise calculations of the annual output of a turbine. The typical output of different turbines is scheduled in the table below, although these may not be appropriate for an urban setting.

**Figure 5.1 – Typical Wind Turbine Performance (based on Proven Energy Ltd)**

| Rated Output | Type | Rotor Diameter | Annual Output | Noise @ 5m/s |
|---|---|---|---|---|
| kW | | m | kWh | dBA |
| 0.6 | Horizontal | 2.55 | 900 – 1,500 | 35 |
| 2.5 | Horizontal | 3.5 | 2,500 – 5,000 | 40 |
| 6 | Horizontal | 5.5 | 6,000 – 12,000 | 45 |
| 15 | Horizontal | 9 | 15,000 – 30,000 | 48 |

## London Renewables Toolkit Assessment

### Stand Alone Turbines (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Is there an average wind speed of at least 6m/s on site? | According to the DTI wind speed database[7] the average wind velocity in the area is 4.6m/s (this takes no account of the effect of surrounding buildings etc.). | No |
| Is the area free from obstructions that could cause turbulence, such as tall buildings, other structures, trees? | The site is surrounded by tall buildings, which, is likely to cause significant turbulence. | No |
| Is there sufficient land on the development to allow the placement of the turbines away from residential areas? | There are residences local to the site which may be subject to noise issues from the turbines. | No |
| Is the site in or near a conservation area or area of historic interest or in Green belt or Metropolitan Open Land? | The site is situated in a heritage-listed area. | No |
| **Toolkit Conclusion:** Chose another renewable energy option | | |

[7] http://www.dti.gov.uk/energy/sources/renewables/renewables-explained/wind-energy/page27326.html

### Roof Mounted Turbines (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Is there an average wind speed of at least 3.5m/s on site? | According to the DTI wind speed database the average wind velocity in the area is 4.6m/s (this takes no account of the effect of surrounding buildings etc.). | Yes |
| Is there sufficient land on the development to allow the placement of the turbines away from residential areas? | The smaller roof mounted turbines are less likely to present any noise issues. | TBC |
| Is the site in or near a conservation area or area of historic interest or in Green belt or Metropolitan Open Land? | The site is situated in a heritage-listed area. | No |
| **Toolkit Conclusion:** Potentially Feasible | | |

### Feasibility

5.2.4 The analysis indicates stand alone turbines would not be feasible for this site because the wind speed is low and likely to be turbulent, external surface space is limited as the installation is predominantly below ground and due to the prospect of potential noise issues for the local residences and businesses.

5.2.5 While the Toolkit conclusion suggests roof mounted wind turbines are “potentially feasible”, the lack of roof area available for mounting of them precludes their inclusion in the proposals.

### Energy Analysis

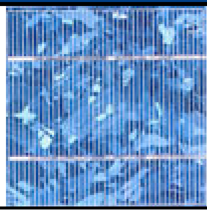
Not applicable

## 5.3 Photovoltaics

### Overview

5.3.1 Solar photovoltaic (PV) cells harness the ability of some semi conductor materials to generate DC electricity from sunlight. PV cells are formed into modules that can be supplied in different forms, which have different costs and efficiencies. The relative performance of different forms of PV are summarised below.

## Figure 5.3 – Comparison of PV Types

| | 'Thin Film' | Polycrystalline | Monocrystalline | 'Hybrid'* |
|---|---|---|---|---|
| Appearance |  |  |  |  |
| Efficiency at STC | 7 - 8% | 11 - 13% | 14 - 16% | 17 - 19% |
| Relative efficiency in overcast conditions | Excellent | Good | Good | Excellent |
| Area needed per kWp (for modules) | Kaneka module: 15.5m$^2$ | Sharp modules: 8m$^2$ | Sharp modules: 7m$^2$ | Sanyo modules: 6.5 - 7m$^2$ |
| Area needed per kWp (for Building Integrated PV) | Solar metal roofing: 23.5m$^2$ Glass-glass laminate: 25m$^2$ | C21 tile: 10m$^2$ Glass-glass laminates: 10m$^2$ - 30m$^2$ (depends on cell spacing) | Sunslate: 10m$^2$ Glass-glass laminates: 8m$^2$ - 30m$^2$ (depends on cell spacing) | N/A |
| Annual energy generated per kWp (for south-facing system, 30° tilt) | 900 kWh/kWp | 750 kWh/kWp | 750 kWh/kWp | 900 kWh/kWp |
| Annual energy generated per m$^2$ (for south-facing modules, 30° tilt) | 55 - 60 kWh/m$^2$ | 90 - 95 kWh/m$^2$ | 105 - 110 kWh/m$^2$ | 125 - 135 kWh/m$^2$ |

5.3.2 Unlike most renewable technologies, PV cells have no moving parts and are therefore silent in operation. However, they do require a significant amount of additional equipment, for example to convert DC to AC and if the system is not grid connected for batteries to store electrical energy when the available output is in excess of the demand. Photovoltaics are also typically very expensive per KWh in the UK climate and the embodied energy associated with their construction is often greater than the energy produced by the units.

## London Renewables Toolkit Assessment

### Photovoltaics (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Will or can the building have an east to west (through south) facing roof or flat roof? | Roof space is severely limited, with only canopies above entrances presenting a possible area for mounting, although these are expected to be flat. | No |
| Will or can the roof façade be free from overshadowing for most of the day from other buildings and structures? | The canopies are likely to be overshadowed by adjacent tall buildings for periods during of the day | No |
| Is the building an office block or residential tower where high quality cladding materials may be used? | The development is predominantly below ground with only station entrances presenting a possible space for mounting PVs. High cost cladding may be used for these entrances in which PV cells could be incorporated. | No |
| **Toolkit Conclusion:** Chose another renewable energy option | | |

### Feasibility

5.3.3 There is almost no potential to incorporate PV cells into the design due to lack of roof and cladding area as the development is predominantly below ground. The surrounding tall buildings may also overshadow any array reducing the potential output.

### Energy Analysis

5.3.4 Not applicable

## 5.4 Solar Thermal

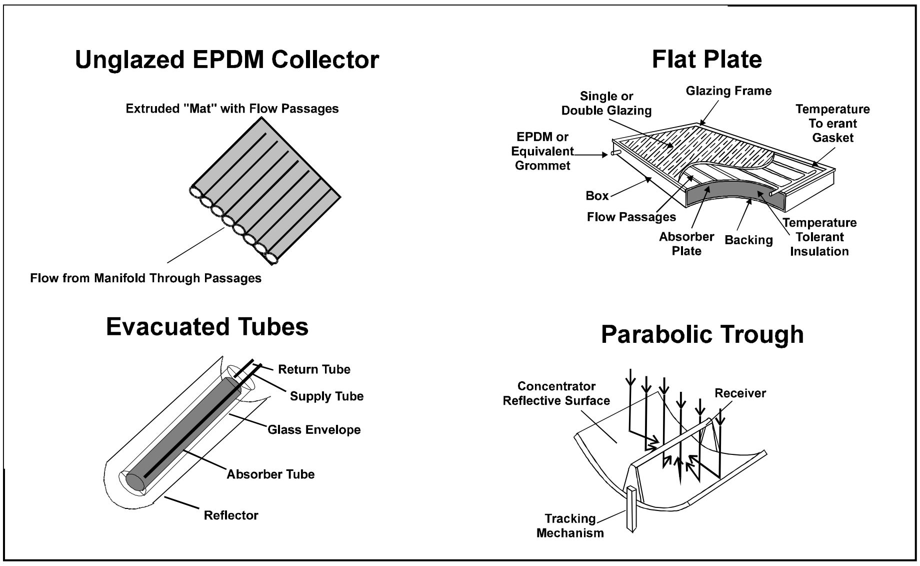
### Overview

5.4.1 Solar thermal collectors make use of the sun's energy to heat a fluid. The collector panel incorporates an absorber plate to which fluid circulation tubes are attached. The absorber, usually coated with a dark selective coating, assures the conversion of the sun's radiation into heat, while fluid circulating through the tubes carries the heat away where it can be used or stored. The heated fluid is pumped to a heat exchanger, which is a coil in a storage vessel or an external heat exchanger where it gives off its heat and is then circulated back to the panel to be reheated.

5.4.2 There are four main types of collector, see Figure 5.5:

- unglazed EDPM collector – used primarily for heating of swimming pools where the desired temperature of the water is close to that of the ambient temperature;
- flat plate collectors – used for domestic hot water and heating hot water generation where the desired hot water temperature is no more than 50 degrees above the ambient temperature;
- evacuated tube collectors – more expensive and harder to mount than flat plate collectors but more efficient for domestic hot water and heating hot water generation where the required water temperature is greater than 50 degrees above the ambient; and
- Parabolic collectors – parabolic troughs focus the suns energy in a single point enabling high temperatures to be generated. Not suitable for cloudy climates such as the UK, as they are relatively ineffective without direct solar radiation. Collectors also need to track the sun's path to maintain focus, this increases the cost and complexity of the units.

**Figure 5.5: Solar Thermal Panel Types**

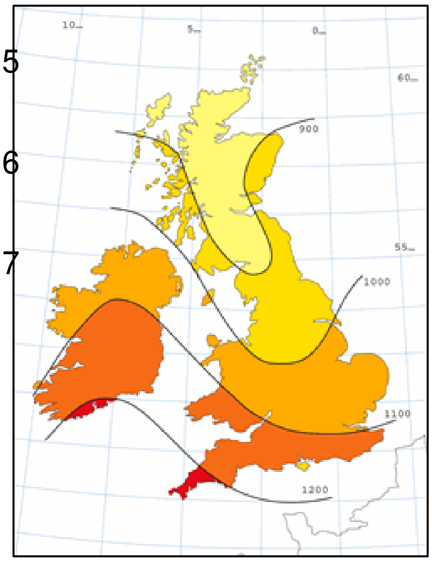



5.4.3 For maximum efficiency in the UK, solar collectors need to be mounted south facing at a 30° inclination and away from any shadows from trees, surrounding buildings or chimneys. Figure 5.7 shows the total average solar radiation falling on one square metre surface inclined at 30 degrees to the horizontal, measured in kilowatt hours. Solar heating systems will typically convert 40 to 50% of the solar energy falling on the solar collectors into useful heated water.

5.4.4 The main consideration for solar collector installations is whether the system operates as a pre-heat system, or part of a dual heating arrangement. In either case the solar collector heating system is supplemented by another heating source. Considerations have to be given to freezing and overheating, leading to leakage. There are also particular issues relating to Legionella growth which need to be properly addressed in the design.

**Figure 5.6 – Solar Thermal Panels**

**Figure 5.7 – Annual total solar irradiation (kWh/m$^2$)**




5.4.5

5.4.6

5.4.7

### London Renewables Toolkit Assessment

### Solar Thermals (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Will the building have a year round hot water demand (e.g. canteen, showers, industrial process)? | The domestic water demand for the stations is minimal as there are no showers or baths and only small mess room kitchens. Space heating demand is low as the ticket halls are subterranean and peaks will occur in winter when the useful solar output is at its lowest. | No |
| Will the building have an open aspect south-east to south-west facing roof (or flat roof)? | There is no roof space as the development is below ground. | No |
| Is there space for a hot water cylinder close to the panels? If not can the design be altered to provide sufficient space? | There is no available plant space near to the panels and so the cylinders would need to be located below ground in the ticket halls. | No |

| Criteria | Assessment | Compliance |
|---|---|---|
| Is the site in or near a conservation area or area of historic interest or in Green belt or Metropolitan Open Land? | There are four listed structures within the vicinity and it is adjacent to a conservation area | No |
| **Toolkit Conclusion:** Chose another renewable energy option | | |

### Feasibility

5.4.8 There is no potential to incorporate solar thermal panels into the design, as the development is predominantly below ground. The surrounding tall buildings may also overshadow any array reducing the potential output.

### Energy Analysis

5.4.9 Not applicable

## 5.5 Biomass

### Overview

5.5.1 Biomass is organic matter of recent origin. It doesn't include fossil fuels, which have taken millions of years to evolve. The $CO_2$ released when energy is generated from biomass, is balanced by that absorbed during the fuel's production. The use of biomass fuel is therefore considered a carbon neutral process.

5.5.2 This option proposes to use a wood biomass heating installation. Wood biomass comes from forestry by-products and energy crops such as willow short rotation coppice. The biomass fuel proposed for this would be wood pellets. Alternatively, wood chips could be used. The relative performance of wood pellets and chips is shown below.

**Figure 5.10 – Comparison of Biomass Fuels**

| | Energy Content kWh/kg | Density kg/m$^3$ | Space Requirement m$^3$/kWh | Cost £/kg (11/2005) | Cost £/kWh (11/2005) |
|---|---|---|---|---|---|
| Wood Chips | 3.89 | 475 | 0.000541 | 5.8 to 8.2p | 1.5 to 2.1p |
| Wood Pellets | 5.14 | 650 | 0.000299 | 15.4 to 18p | 3 to 3.5p |

5.5.3 While wood chips are cheaper, it would require larger storage areas as the energy content is lower in comparison to pellets.

**Figure 5.11 and 5.12 – The most often used biomass fuels, wood pellets (left) and wood chips (right)**

5.5.4 The most significant drawback of biomass is the requirement to store the fuel and additional $CO_2$ emissions resulting from the cultivation, harvesting and delivery of the fuel. There are also concerns that delivery of wood biomass by lorry will have local pollution, noise and safety implications.

5.5.5 It is also noted that emissions (in the form of $NO_X$, $SO_X$ and particulates) from the combustion of wood biomass in heating installation is less clean compared with natural gas, although this will be controlled by the Clean Air Act, 1993 and other pollution control legislation. Biomass boilers should have been tested by the manufacturer who will normally supply certification of the anticipated combustion products.

5.5.6 Other issues surrounding biomass heating are plant reliability due to failure of the fuel feeding mechanisms. Biomass plant will require more routine maintenance (and therefore operating costs) than conventional gas boiler plant. To ensure heating supply, conventional boiler plant to supplement or possibly back up the main biomass heating plant is normal practice.

## London Renewables Toolkit Assessment

### Biomass (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Is there the potential for a local supply, delivery and storage for biomass fuel? | It is unlikely a local source would be available and so fuel would have to be transported from far. Delivery would present a problem due to the vehicle and pedestrian traffic around the station. Accommodating a large fuel store in the below ground installation would be difficult. | No |
| Can the boiler house be located so it is suitable for biomass supply, with sufficient storage capacity? | There is no above ground space available to house the boilers or store. Accommodating a biomass boiler installation below ground in the ticket halls is likely to present problems. | No |
| Will the boiler be part of a modular system to allow for shutdown and cleaning? | The boiler could be installed as part of a modular installation. | Yes |
| **Toolkit Conclusion:** Chose another renewable energy source | | |

### Feasibility

5.5.7 While it is acknowledged that biomass heating could provide a significant contribution to achieving the carbon reduction target, it is accepted that there is limited room to accommodate a fuel store below ground. Also there are concerns in relation to the traffic impact of fuel deliveries in central London. In addition to this in accordance with LU standards hot water heating in below ground stations is to be by electric means and so this precludes the use of a biomass heating.

### Energy Analysis

5.5.8 Not applicable

## 5.6 Biomass Combined Heat and Power (CHP)

### Overview

5.6.1 During electricity generation, a large amount of low-grade heat is produced as a by-product. In conventional power stations this heat is lost, resulting in an efficiency of around 30-35%. In combined heat and power (CHP) systems, an internal combustion engine is used to generate electricity on site and the heat produced is used for space and domestic water heating purposes.

Additional energy savings are made as electricity is generated locally, thereby avoiding Grid transmission losses.

5.6.2 Combined heat and power plants need to be carefully selected to match anticipated load profiles to ensure the engines are working at maximum efficiency and all the useful heat that can be used is being extracted. It is therefore important to have year round heat demands or at least heat demands when the building is in use.

5.6.3 There are concerns over the reliability of CHP plant and therefore it is not normal practice to rely solely on CHP equipment to provide all the heating demand.

5.6.4 This normally means providing conventional boiler plant as a minimum to supplement or possibly back up the CHP plant. This also means a premium may need to be paid to the electrical supply company to ensure the additional capacity is available from the Grid should the CHP plant fail.

**Figure 5.13 – Combined Heat and Power (CHP) plant**

5.6.5 In addition, CHP plant will require more routine maintenance (and therefore operating costs) than conventional gas boiler plant. A further consideration with CHP is that of noise, requiring special acoustic enclosures for CHP plant. Depending on the fuel source, which can be gas, diesel or biomass, there will be issues with emissions and fuel storage and deliveries.

## London Renewables Toolkit Assessment

### Biomass CHP (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Will the development have a year-round demand for heat, and a communal heating system? | Because the development is below ground the heating demand is likely to be relatively low and the heating season short. | No |
| Is a reliable guaranteed CHP system available at the appropriate size? | Due to the relatively low heating demand for much of the year either a very small portion of the sites electrical demand would be met by the system or if electrically lead a large quantity of heating energy would be wasted. | No |
| Is there potential for a local supply, delivery and storage for biomass fuel? | It is unlikely a local source would be available near to the site and so fuel would have to be transported from far. Delivery would present a problem due to the vehicle and pedestrian traffic around the station. Accommodating a large fuel store in the below ground installation would be difficult. | No |
| Can a CHP repair and maintenance system be put in place in the completed development? | A repair and maintenance regime could be implemented. | Yes |
| **Toolkit Conclusion:** Chose another renewable energy source | | |

### Feasibility

5.6.6 While it is acknowledged that biomass CHP could provide a significant contribution to achieving the carbon reduction target, it is accepted that there is limited room to accommodate a fuel store below ground. Also there are concerns in relation to the traffic impact of fuel deliveries in central London. In addition to this because the hot water demand for much of the year is minimal, for most of the year either only a small proportion of the sites electrical load would be met by CHP or if electrically lead, heating energy would be wasted. For these reasons a biomass CHP installation is considered unfeasible for this development.

### Energy Analysis

5.6.7 Not applicable.

## 5.7 Ground Source Heating and Cooling

### Overview

5.7.1 Heat pumps make use of refrigeration processes to take heat from one source, transferring it to another at a higher temperature. Ground coupled heat pumps use the stable temperature of the earth as the low temperature heat source. Normally water is used as a heat exchange medium between the ground and the heat pump. Water may be present in the ground and can be drawn directly from an underground water source such as an aquifer. Alternatively, water can be circulated through a buried loop of pipework.

5.7.2 In an open system where water is drawn directly from the ground (normally from a single borehole) the abstracted water is either discharged to drain or re-injected back to ground through a separate borehole thus maintaining the aquifer. In a closed loop system, the loop can be horizontal or vertical through a series of boreholes or potentially integrated into piled foundations.

5.7.3 Ground source cooling can mean either using the earths stable temperature to cool ventilation air or circulating water cooled by the earth either directly to cooling systems (sometimes referred to as “free cooling”) or via chillers, which effectively use the ground cooled water as a heat sink. Using the ground as a heat sink has the benefit of avoiding the requirement for heat rejection plant (such as cooling towers or air cooled condensers) which use the ambient air as the heat sink.

5.7.4 Heat pumps can operate in reverse, effectively acting as chillers, and thus a ground source heat pump installation can operate as a ground source cooling installation in summer.

5.7.5 Abstraction of water from an underground aquifer is not guaranteed and requires consent from the Environment Agency. Test boreholes have to be drilled to check the aquifer yield which will depend on ground/soil conditions and water table etc. It is also normally difficult to obtain consent to discharge the “used” water to drain and makes more sense to re-inject it back into the aquifer. This can effect the aquifer temperature (and therefore output) depending on how the distance between the abstraction and injection boreholes.

5.7.6 Closed loop systems do not rely on the presence of an aquifer, although the output is likely to be greater if a vertical arrangement is installed with the loop within the aquifer region. Because of the additional heat exchange step, the output of a single closed loop is relatively small. It is therefore necessary to install a large number of closed loop boreholes for the same output of a single open loop borehole system. Integrating the loops into piled foundations can avoid the need to drill dedicated boreholes.

**Figure 5.14 – Ground Source Heat Pump**

5.7.7 It has been highlighted that the old River Tyburn seeps approximately 100 l/s into the District and Circle line at 10m below ground and that there may an opportunity to use some of this water for cooling purposes. This water could be passed through a heat exchanger to pre-cool return water to chillers, significantly reducing the chiller load. It has been estimated that 25 l/s could be utilised as part of a grey water cooling system for the tickets halls.

5.7.8 The $CO_2$ emissions that a ground coupled heating and/or cooling system will displace is a combination of the natural gas or electricity (that would have been required for boiler plant), the additional Grid supplied electricity (which would be used to operate the heat pump and chiller at a low efficiency than a cooling only chiller and borehole pumps) and reduced Grid supplied electricity (that would have been required to operate the cooling towers or other heat rejection equipment).

### London Renewables Toolkit Assessment

### Ground Source Heat Pump (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Will there be room for a horizontal buried loop? | There is insufficient area for a horizontal loop adjacent to the development. | No |
| Is the ground accessible for a vertical pipe system? | Further study would be required to determine this. | TBC |

| Criteria | Assessment | Compliance |
|---|---|---|
| Is the ground free from ground obstructions, sewers, tunnels etc? | The volume of services and tunnels below ground is extensive, further study would be required to determine whether a system could avoid disrupting these. | TBC |
| Decide on the amount of heating to be supplied by the ground system. Can an adequate length of pipe be installed to provide this heating requirement? | Further study would be required to determine this. | TBC |
| Can the heating system be designed to accommodate low temperature circulation water (such as underfloor heating)? | Due to the relatively low ceiling height, installing under floor heating is unlikely to be feasible as this would further reduce this height. | No |
| **Toolkit Conclusion:** Consider a feasibility study before ruling out | | |

### Ground Source Cooling (Toolkit Feasibility Assessment)

| Criteria | Assessment | Compliance |
|---|---|---|
| Does the development need a cooling system? | The substation and below ground staff facilities will require cooling. | Yes |
| Will there be room for a horizontal buried loop? | There is insufficient area for a horizontal loop adjacent to the development. | No |
| Is the ground accessible for a vertical pipe system? | Further study would be required to determine this. | TBC |
| Could an open borehole system be used? | Seepage from the river Tyburn into the railway tunnels could be extracted and used for cooling. | Yes |
| Decide on the amount of cooling to be supplied by the ground system. Can an adequate length of pipe be installed to provide this heating requirement? | It is believed 25 l/s of water could be extracted from the tunnels, which is expected to be sufficient to meet the site cooling load. | Yes |
| **Toolkit Conclusion:** Site is likely to be suitable for ground cooling | | |

### Feasibility

5.7.9 The analysis suggests that a ground source heating system may be feasible although ground conditions, in particular the volume of services and tunnels below ground, may preclude this. As it is a relatively small site, there is insufficient area to accommodate a horizontal heat exchanger and so such a system was discounted. The low temperature hot water typically achieved with ground source heating is ideally suited to an underfloor heating installation, although due to the low floor to ceiling heights this would not be feasible in this case.

5.7.10 The feasibility of a ground source heating system is likely to be low but should not be ruled out unless ground conditions preclude it.

5.7.11 Ground source cooling using water seepage into the tube tunnel system from the River Tyburn is likely to be feasible. Initial reports suggest approximately 25 l/s of water at temperatures between 12 and 18ºC may be available, which preliminary calculation suggests should be more than sufficient to meet the site cooling load.

### Energy Analysis

**Figure 5.15: Ground Source Heating - Carbon Emissions Reduction Calculation**

| STEP | | | |
|---|---|---|---|
| 1 | 594423 | kwh/year | Total annual space and domestic heating Load |
| 2 | 0.95 | Factor | Estimated heating system efficiency in base build |
| 3 | 564702 | kwh/year | End use demand met accounting for system efficiency |
| 4 | 1 | Factor | Proportion of end use demand to be met by GSH |
| 5 | 564702 | kwh/year | Annual Demand met by GSH. |
| 6 | 3 | Factor | COP of ground source heat pump[1] |
| 7 | 188234 | kwh/year | Electrical energy used by heat pump |
| 8 | 3686963 | kwh/year | Total base building electrical energy |
| 9 | 188234 | kwh/year | Delivered elec requirement substituted by GSH |
| 10 | 3498729 | kwh/year | Remaining energy to be provided by electricity |
| 11 | 0.117 | Kg C/kWh | Electricity Carbon Emissions Factor[2] |
| 12 | 409351 | KgC/year | Building Carbon emissions due to delivered electricity with GSH |
| 13 | 3686963 | kwh/year | Delivered base elec energy |
| 14 | 0 | kwh/year | Calculated delivered gas requirement with GSH |
| 15 | 0.0518 | Kg C/kWh | Gas Carbon Emissions Factor[2] |
| 16 | 0 | KgC/year | Calculated Carbon emissions due to delivered gas with GSH |
| 17 | 409351 | KgC/year | Total building carbon emissions with GSH |
| 18 | 431375 | KgC/year | Calculated Base building total carbon emissions |
| 19 | 22023 | KgC/year | Calculated reduction in carbon emissions with GSH |
| 20 | 5.1 | % | Percentage reduction in carbon emissions with GSH |
| 21 | 5.1 | % | Percentage of energy delivered by GSH |

**Notes:**

1 - Typical COP suggested by the London Renewables Toolkit.

2 - Based on the emissions rates quoted by the Carbon Trust, i.e. Gas - 0.0518 kgC/kWh, Grid supplied electricity - 0.117 kgC/kWh

| Figure 5:16 Ground Source Cooling - Carbon Emissions Reduction Calculation | | | |
|---|---|---|---|
| **STEP** | | | |
| **1** | 834245 | kwh/year | Total annual space cooling load |
| **2** | 4 | Factor | Estimated cooling system COP in base build[1] |
| **3** | 208561 | kwh/year | Base build electrical demand |
| **4** | 0.25 | Factor | Proportion of end use demand to be met by GSC |
| **5** | 52140 | kwh/year | Annual Demand met by GSC. |
| **6** | 8300 | kwh/year | Electrical energy used by the additional pump |
| **8** | 3686963 | kwh/year | Total base building electrical energy |
| **9** | 43840 | kwh/year | Delivered elec requirement substituted by GSC |
| **10** | 3643122 | kwh/year | Remaining energy to be provided by electricity |
| **11** | 0.117 | Kg C/kWh | Electricity Carbon Emissions Factor[2] |
| **12** | 426245 | KgC/year | Building Carbon emissions due to delivered electricity with GSC |
| **13** | 0 | kwh/year | Calculated delivered gas requirement with GSC |
| **14** | 0.0518 | Kg C/kWh | Gas Carbon Emissions Factor[2] |
| **15** | 0 | KgC/year | Calculated Carbon emissions due to delivered gas with GSC |
| **16** | 426245 | KgC/year | Total building carbon emissions with GSC |
| **17** | 431375 | KgC/year | Calculated Base building total carbon emissions |
| **18** | 5129 | KgC/year | Calculated reduction in carbon emissions with GSC |
| **19** | 1.2 | % | Percentage reduction in carbon emissions with GSC |
| **20** | 1.2 | % | Percentage of energy delivered by GSC |

**Notes:**

1 - Typical COP for a vertical closed loop system.

2 - Based on the emissions rates quoted by the Carbon Trust, i.e. Gas - 0.0518 kgC/kWh, Grid supplied electricity - 0.117 kgC/kWh

5.7.12 It is estimated that a ground source heating system sized to meet 100% of the heating annual consumption could reduce electrical energy by as much as 5.1%. A ground source cooling system sized to meet the whole cooling load could potentially reduce building energy by as much as 1.2%.

## 5.8 Renewables Cost Analysis

5.8.1 Figures 5.17 and 5.18 detail estimated capital costs of the various renewable options available based on indicative values indicated in London Renewables Toolkit. Available renewables grants have not been included in the calculation of these figures, as they may not necessarily be applicable in this instance or available when construction is due commence after 2009.

5.8.2 The results suggest ground source heating would be the most cost effective renewable energy source per unit kWh generated and kg Carbon reduced at approximately twice as cost effective as ground source heating and four times more than solar thermal heating and wind electrical generation per kWh. It should be noted that only the installation costs have been considered and so it excludes any costs associated with operating and maintaining of the plant. Photovoltaics proved to be the least cost effective energy source at 35 times more expensive than ground source cooling per kWh.

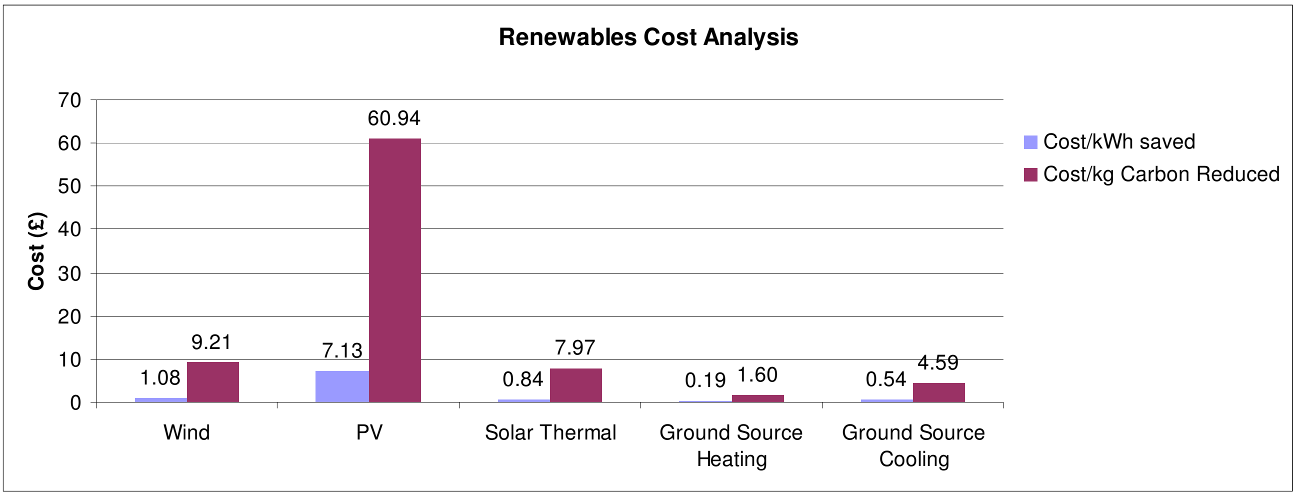
**Figure 5.17: Renewables Cost Assessment**

| Energy Source | System Size | Energy Provided | | Carbon Reduction | | Capital Cost[1] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | kW or m2 | KWh | % | KgC | % | £/m2 or £/kWh | £ | £/kwh saved | £/kg C saved |
| Wind | 0.08 | 74 | 0.002 | 9 | 0.002 | 1000 | 80 | 1.08 | 9.21 |
| PV | 18 | 2146 | 0.1 | 251 | 0.1 | 850 | 15300 | 7.13 | 60.94 |
| Solar Thermal | 10 | 4768 | 0.1 | 502 | 0.1 | 400 | 4000 | 0.84 | 7.97 |
| Ground Source Heating | 44 | 188234 | 5.1 | 22023 | 5.1 | 800 | 35292 | 0.19 | 1.60 |
| Ground Source Cooling | 118 | 43840 | 1.2 | 5129 | 1.2 | 200 | 23528 | 0.54 | 4.59 |
| | Total : | 239062 | 6.5 | 27914 | 6.5 | | | | |

Notes:

1 - Renewables Toolkit suggested cost figures

**Figure 5.18: Installation Cost per Unit**



## 5.9 Feasibility of Renewables Options

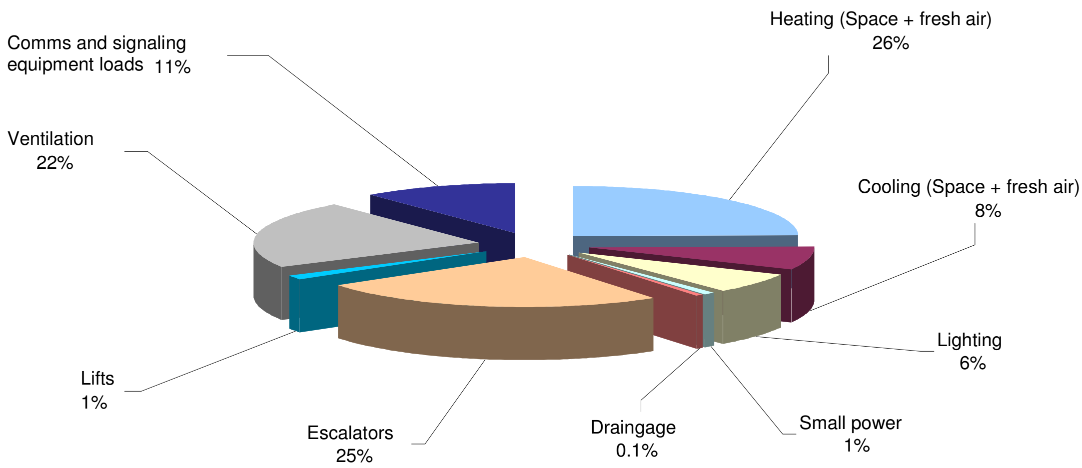
| Source | Advantages | Disadvantages | Feasibility |
|---|---|---|---|
| **Wind Turbines** | Relatively cheap, gives building an easily identifiable green image. | Not ideally suited for an urban environment due to turbulent winds. No above ground space to position wind turbines. | Zero |
| **Photovoltaics** | Silent, no moving parts so low maintenance requirements, can be integrated into the building canopy or entrance facade minimising visual impact. | Very expensive, inefficient, high embodied energy, no area for mounting. | Zero |
| **Solar Thermal** | Relatively cheap per KWh, can be integrated into the building canopies minimising visual impact. | Low building domestic hot water demand and so can only generate a very small percentage of the buildings energy, no roof area for mounting. | Zero |
| **Biomass** | Setup costs relatively low, not dependent on external climatic conditions. | Requires backup boilers due to associated maintenance issues, requires large plant and fuel storage area, requires regular delivery of fuel to site and ash removed, emissions issues may make obtaining planning permissions difficult. | Low |
| **Biomass Combined Heat and Power** | Can generate a high percentage of the buildings energy, not dependent on external climatic conditions. | Expensive, requires backup boilers due to associated maintenance issues, requires large plant and fuel storage area, requires regular delivery of fuel to site and ash removed, emissions issues may make obtaining planning permissions difficult. | Low |
| **Ground Source Heating** | Efficient, doesn't affect buildings image or depend on external climatic conditions. | Expensive, insufficient space for horizontal loop, vertical loop may not be suitable due to ground conditions, requires large area for drilling of boreholes. | Medium |
| **Ground Source Cooling** | Very efficient, potential to generate a significant proportion of the buildings total energy | Potentially high pumping energy, may partially offset benefit, potential issues with discharge and treatment | Medium/ High |

# 6 Conclusions

## 6.1 Energy Demand and VSU Conclusions

6.1.1 The energy demand assessment predicts an annual energy consumption of 6323 MWh based on the current design proposals and a conservative assumption of equipment efficiencies and hours of operation. The equivalent carbon emissions are 740 tonnes C/year. The major uses of energy are the heating system, escalators and ventilation plant.

**Annual Energy Consumption Breakdown**




6.1.2 Using a less conservative view of operational profiles and adopting a number of energy efficient design proposals and operational strategies, results in significant reduction of up to 42% of the baseline prediction to 3687MWh. The energy efficient design strategies include:

- incorporating heat recovery on all tempered ventilation systems;
- using high efficiency electric motors on fans, pumps, lifts and escalators;
- limiting escalator operating times;
- incorporating power factor correction equipment;
- reducing lighting levels in public areas outside normal hours of use;
- incorporating a means to control lighting in staff facilities either through management strategies or timers and movement sensors;

- increasing ductwork sizes;
- incorporating variables speed pumping on the chilled and condenser water systems; and
- using chillers and packaged cooling equipment with higher COPs and “free cooling” modes of operation.

6.1.3 Further reductions could be achieved, if deviations from the LU standards were found to be acceptable, for example:

- relaxation of environmental design temperatures; and
- reduction in ventilation rates, particularly in none occupied spaces.

6.1.4 An assessment of the renewable energy options has identified that using ground water for direct “free-cooling” and as a low grade heat source using a heat pump installation, to be the most feasible low carbon technology for the development. The source of groundwater is the track drainage system. Water collected by the drainage system is already proposed to be used direct “free cooling” and a means of heat rejection for the Tunnel Cooling Project on the Victoria Line. It is estimated that around 25l/s of ground water at 12-18$^{o}$C is available. The VSU project is also using this source of groundwater, but for heat rejection only.

6.1.5 Direct free cooling will provide measurable savings in cooling energy requirements, by reducing the need for refrigerated cooling via a chiller. Instead the groundwater can be used to directly cool by incorporating a “free cooling” coil within the supply air handling plant, although this will mean increased fan energy consumption. . Note that this is a more effective means of free cooling than a chiller incorporating a “free cooling” mode as suggested in the energy efficiency initiatives above. It has been estimated that a reduction of 1.2% of the annual energy consumption could be achieved through direct ground source cooling.

6.1.6 Using this groundwater as heat pump energy source in place of electrical heating would produce even greater reductions in energy consumption. It has been estimated that a reduction of 5.1% of the annual energy consumption could be achieved through this form of ground source heating.

6.1.7 All other low or zero carbon energy sources have been discounted. Biomass boilers and CHP would not be acceptable under LU standards and would be difficult to accommodate in terms of space for plant rooms, fuel storage and access for fuel deliveries. Solar thermals, photovoltaics and wind turbines are not feasible due to the limited external area available for mounting and overshading and obstruction caused by adjacent buildings.

# Annex A Modelling Assumptions for Standard Practice Demand Assessment

| Modelling Assumptions for Standard Practice Demand Assessment | |
|---|---|
| Occupancy density in offices and staff facilities | 5 person/m$^2$ |
| Carbon factor for each unit of electricity | 0.117 kgC/kWh |
| Fresh air per person for occupied spaces | 12 l/s |
| Unoccupied spaces (excluding WC's) | 2 ACH |
| WC/Changing rooms | 10 ACH |
| Peak electrical loading | 12 W/m$^2$ |
| Peak small power loading | 12 W/m$^2$ |
| Peak space heating load (staff facility and office areas only) | 10 W/m$^2$ |
| Average equivalent, peak rate space heating hours per day (October to March) | 5 |
| Heating system COP | 0.95 |
| Cooling system COP | 2 |
| Power factor correction | 0.9 |
| Frequency of lift usage (% of Day) | 10% |
| Escalator running hours per day | 19 |
| Pump absorbed power fraction of total connected load | 0.8 |
| Office cooling, lighting and small power operational hours per day. | 19 |
| Staff facility cooling, lighting and small power operational hours per day. | 24 |
| Public areas lighting operational hours per day. | 24 |
| Plant lighting and small power operational hours per day. | 0.25 |

Data used:

- Fan power and cooling requirements obtained from Mott MacDonald VSU – W5M&E Equipment Schedules Rev D01
- Floor areas as per current layout drawings.
- Other electrical loadings as per MM VSU – Electrical Load Schedule Rev A (July 16th 2007)

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# Annex B Modelling Assumptions for Best Practice Demand Assessment

| Modelling Assumptions for Best Practice Demand Assessment | |
|---|---|
| As Annex A with the following exceptions: | |
| Cooling System COP | 4 |
| Power Factor Correction | 0.95 |
| Ventilation heat recovery efficiency | 0.6 |
| Escalator Running Hours per day | 13 |
| Lighting reduced energy usage factor | 0.85 |
| Low energy/reduced energy usage small power appliance factor | 0.5 |
| Low velocity ductwork reduced fan energy consumption factor | 0.7 |
| More efficient COMMS and signal equipment reduced energy consumption factor | 0.8 |