# Carbon Reduction and Energy Optimization Strategy for one NHS Trust

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## Abstract

Energy managers at many National Health Service (NHS) hospitals are now under intense pressure to radically investigate and develop energy and carbon reduction strategies. Factors contributing to this pressure include new Government and NHS carbon reduction targets, reduced energy budgets, increase of energy demand and energy cost. The increase in energy demand in many NHS hospitals is also influenced by the age of the infrastructure, rapid demand and expansion along with increased use of energy intensive medical kits in certain specialist hospitals.

This paper presents a detailed analysis of energy data spanning 6 years for The Royal Marsden NHS Foundation Trust. The analysis, together with a survey of existing systems forms the basis for profiling the hospital historical energy consumption trend and to determine the average “Business As Usual” growth rate for energy, and the resultant costs.

Further investigation of short and long term energy saving measures was undertaken based on the analysis of the effects of previously implemented measures and the hospital energy profiles. New energy savings measures have also been identified using financial and carbon emission savings studies.

## 1.0 Introduction and background information

According to the Carbon Trust [1], the UK’s healthcare sector spends more than £400 million per year on energy and the latest available energy consumption statistics for 2012-13, gives the total energy used by the UK Health services as 19771 GWh (Gigawatt Hours). In addition, energy consumption in hospitals and related health services establishments is growing steadily, and in order for NHS England to fulfil its pledge of a 34% $CO_2e$ reduction on the 1990 baseline [2], a significant amount of work has to be done to improve energy efficiency in the healthcare sector. However, at the same time, this has to be designed and implemented without compromising the health and comfort of the patients and staff.

With regard to London, the Estates Return Information Collection (ERIC) report that there are 71 NHS hospitals in London occupying a gross area of 4,983,717 $m^2$, with over 2363 GWh of total energy used in the year 2009/10 [3] (see table 1 for more information). This equates to approximately 12% of the UK NHS energy use. For the same period, the overall carbon emission for the London based NHS hospitals was reported to be 760,733 tonnes$CO_2e$ [3].

| London NHS Hospitals Energy Use (GWh) | | | |
|---|---|---|---|
| | 2007/2008 | 2008/2009 | 2009/2010 |
| Electricity | 791 | 782 | 761 |
| Gas | 1507 | 1562 | 1490 |
| Oil | 127 | 141 | 112 |
| Totals: | 2,426 | 2,485 | 2,363 |

**Table 1 - London NHS Hospitals Energy Use (GWh). [3]**

There are already a significant number of healthcare units that are feeling under pressure, especially as the overall hospitals budgets are shrinking every year, while the energy demand due to expansion and use of specialist equipment is increasing along with yearly increases in energy costs.

By implementing a few simple measures, the energy consumed and consequently the energy costs for hospitals can be reduced. The cost savings can also release significant funds for use elsewhere in medical and treatment services.

Also, in accordance with the Climate Change Act, the NHS Sustainable Development Unit has revised its carbon reduction targets. **Figure 1** shows the current NHS England Carbon Footprint and new proposed reduction targets.

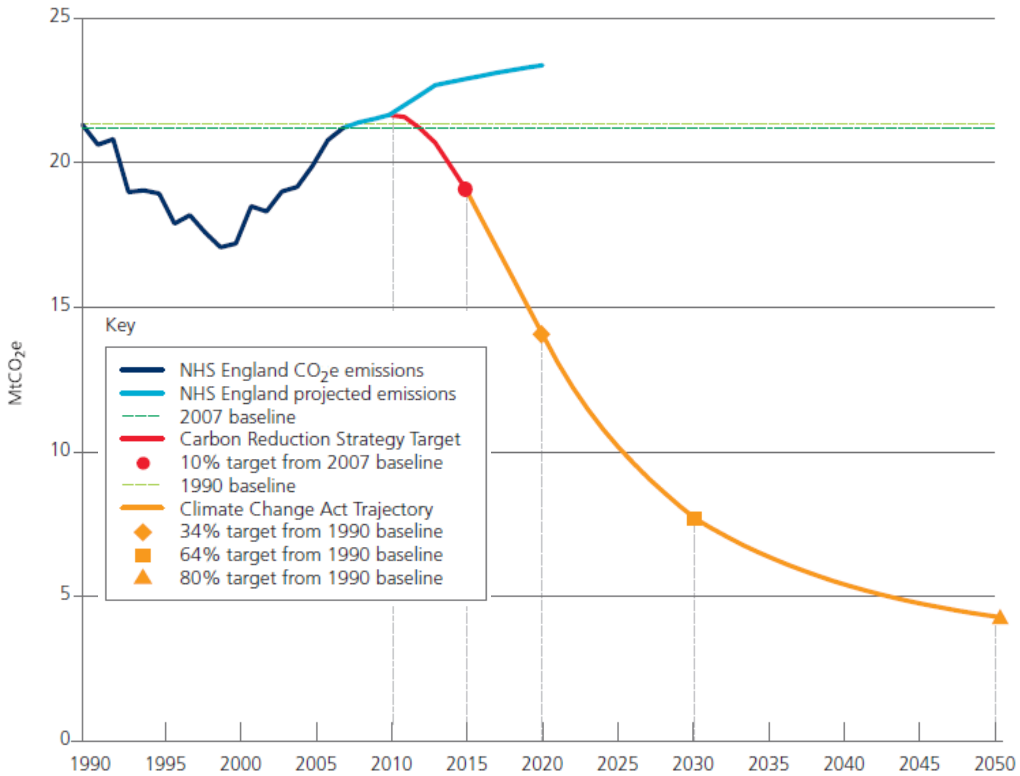



**Figure 1 - NHS England $CO_2e$ emissions from 1990 to the present day, and the required trajectory between 2015 and the 2020 climate change targets. [2]**

## 2.0 Methodology

The work presented in this paper is based on a technical feasibility study originally completed as an MSc project [4]. The project started by studying the trust historical energy data to establish the base lines and energy saving targets that are in line with the NHS Carbon Policy. This was followed by a survey of the buildings and systems at the site to determine the load and energy breakdown. An investigation of efficiency improvement solutions and potential energy saving measures was also conducted and followed by financial evaluation of the measures. This resulted in the generation of a list of quick win and long term energy saving measures.

## 3.0 Site description

The Royal Marsden Trust consists of two London hospitals, one located in Chelsea) and the other in Sutton. Most of the areas (on both sites) operate on a 24 hours, seven days a week basis. The type of medical activities and services differ between wings and include units such as surgery, intensive care units and X-rays units, plus consultant rooms and patients wards. Approximately 3,700 staff work within the Royal Marsden Trust, and care for over 40,000 patients each year from across the UK and abroad. The Trust has an overall carbon foot print of 14,341 tonnes $CO_2$e across a gross area of 61,133 $m^2$.

In terms of construction works and projects, the Trust has experienced large scale developments at both sites in the last three years. As a result of the re-development projects, some medical areas such as High Dependency Units, Operating Theatres, Wards, Medical Day Units, Diagnostic and Imaging Units, and Radiotherapy Units, have been built or fully refurbished at both sites.

For the purpose of this report, the Chelsea site only is considered, and the data presented here should not be considered the same for both sites.

### *3.1 Energy data*

Actual electricity and gas consumptions figures have been collated from the site energy management records and date back to the financial year 2005/6. The consumption data is graphically represented in **Figure** 2 for the Chelsea site.

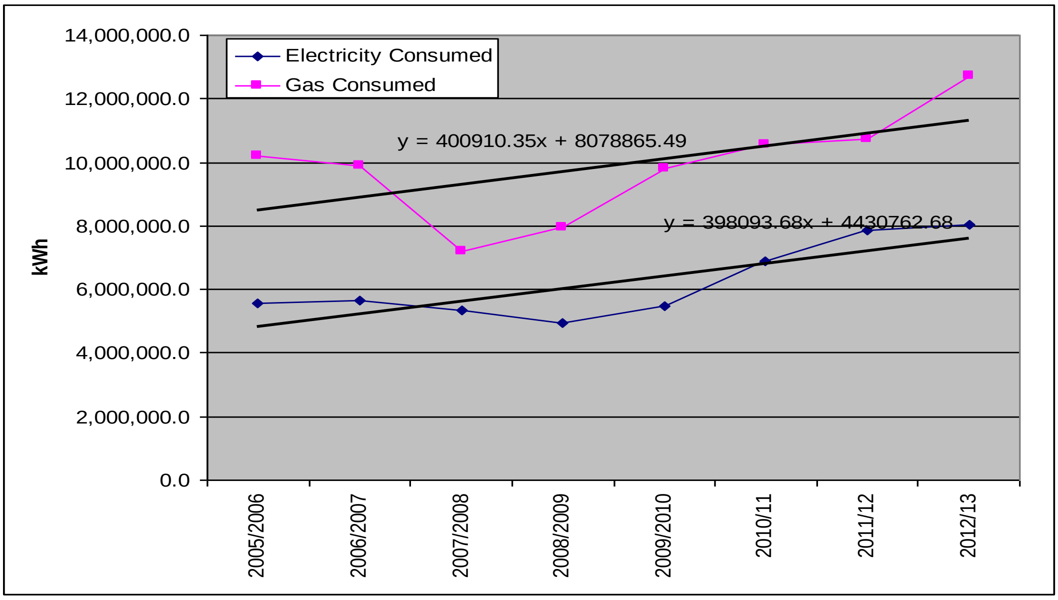



**Figure 2 - Electricity and Gas consumption data.**

The figure shows a decline of energy usage during 2008 which is believed to be due to a fire incident during that period which resulted in the closure of some medical wards and units on the Chelsea site. Since 2008, total energy usage has increased gradually by approximately 12 % each year, to reach 8 GWh of electricity usage and 12.7 GWh of gas usage during 2012/13.

In terms of carbon emissions and utility costs, Figure 3 shows the performance of the site over the period 2005 to 2013. As can be seen from the figure, the combined electricity and gas carbon footprint for 2012/3 was 6,730 tonnes $CO_2$e. This is an increase of 7.2% compared to the previous year.

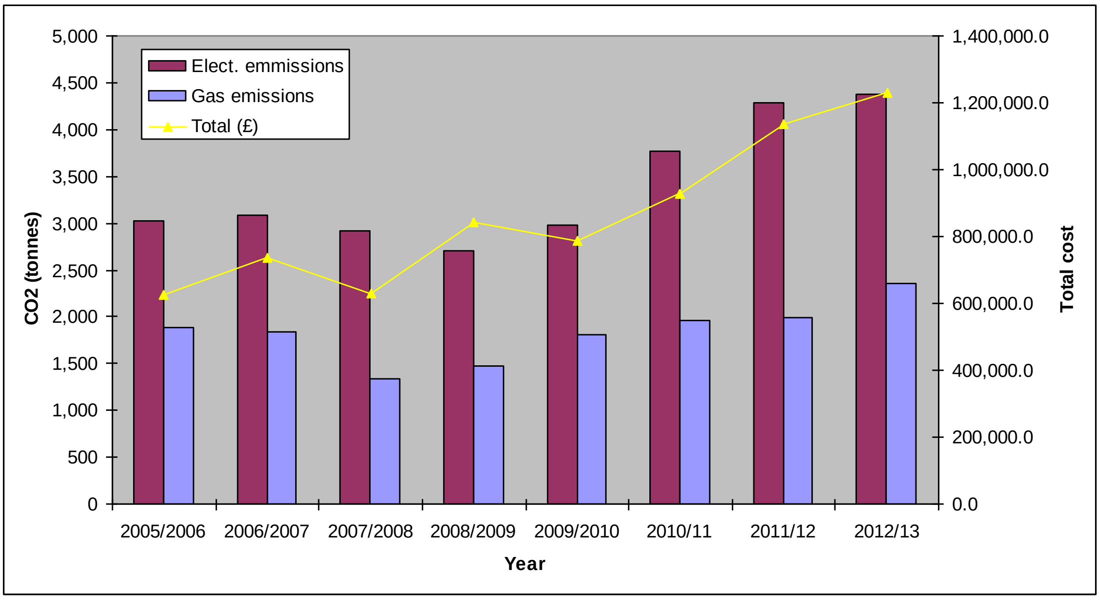



**Figure 3 - Carbon emissions and costs.**

Total energy costs were of the order of £1.2m in 2012/13 which was an increase of 8.3% over the previous year, and almost double that for 2005/6. The main reason for this increase is linked to a significant increase in energy use and the increase in utilities unit costs.

### *3.2 Comparison with Benchmarks*

The Trust energy figures have been analysed and compared to CIBSE benchmarks (CIBSE Guide F). The Trust's main task of providing medical services puts it under the category of "Teaching and Specialist" Hospitals. It can also be argued that as a diagnostic, treatment and research hospital, it may use much more energy than the benchmark Teaching and Specialist category. However, since no such specific category exists for hospitals of this nature, only Good Practice and Typical Practice for Teaching and Specialist hospitals has been considered in Table 2, for the purpose of analysing the Trust's energy performance.

| | Good Practice | | Typical Practice | |
|---|---|---|---|---|
| | Fossil Fuel | Electricity | Fossil Fuel | Electricity |
| Hospitals : Teaching and specialist (kWh/m²) | 339 | 86 | 411 | 122 |
| RMH foot print in 2013 (kWh/m²) | 518 | 326 | 518 | 326 |
| RMH footprint reduction required to meet CIBSE benchmark (%) | -34% | -74% | -21% | -63% |
| Average reduction % | -54% | | -42% | |

**Table2 - RMH Trust Vs CIBSE Benchmark value.**

The result of the comparison revealed that compared to the benchmarks, the trust uses over 42% more than a Typical Practice hospital and up to 54% more than for a Good Practice hospital. If the Trust were to cut its emissions accordingly to the CIBSE benchmark, a significant reduction in energy usage by improvement of systems efficiencies would be required.

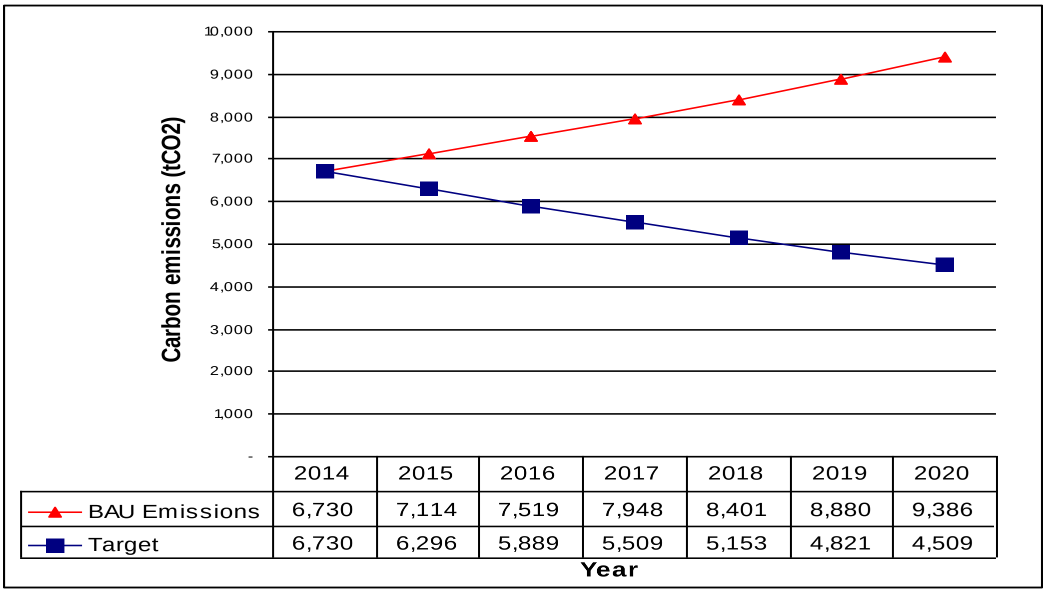
Also, in conjunction with the Climate Change Act, NHS England have set a carbon reduction target of 33% by 2020 compared to the 2007 emissions. Table 3 shows the NHS England carbon emissions of 21 million tonnes in 2007 and the target for reduction to be 14 million tonnes in 2020.

| | 2007 | 2020 |
|---|---|---|
| NHS England emissions footprint $MtCO_2e$ | 21 | |
| NHS England emissions reduction target $MtCO_2e$ | | 14 |
| NHS England carbon footprint reduction percentage | -33% | |

**Table 3 - The Trust Reduction target.**

### *3.3 Established Trust reduction target and base line analysis*

Taking into account the average yearly increase in energy demand at the site, Business as Usual (BAU) emission rates have been forecast up to 2020 and compared to the ideal reduction targets to fulfil the set obligation by National Health England, as shown in Figure 4.




| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| BAU Emissions | 6,730 | 7,114 | 7,519 | 7,948 | 8,401 | 8,880 | 9,386 |
| Target | 6,730 | 6,296 | 5,889 | 5,509 | 5,153 | 4,821 | 4,509 |

**Figure 4 - Carbon value at stake.**

As a result of the reduction target plan, it is predicted that the Trust will achieve:

- Absolute reduction of 2,221 $tCO_2e$ in 2020 over base line year 2014(Figure 4).
- Final year annual $tCO_2e$ saving of 4,877.
- Cumulative $tCO_2e$ saving of 17,071.
- Relative emissions reduction target 52%.

### *3.4 Financial value at stake*

By following and implementing the carbon reduction plan and meeting the reduction target, a final year annual cost saving of £1,188,002 and cumulative cost savings of £3,863,107 can be achieved.

In addition to the energy and fuel costs savings, there will also be £80,000 savings due to qualification for the CRC Energy Efficiency Scheme.

## 4.0 Load analysis and systems selection

The chart presented in Figure 5 details the Trust's energy consumption breakdown. This has been analysed to see where the biggest savings can be made. As can be seen from the Figure 5, the highest percentage of energy use is for Space heating (38%). DHW, lighting and HVAC are also areas with high energy use at the Trust. Therefore, these areas should be focused on when considering strategies to reduce the energy use of the Trust.

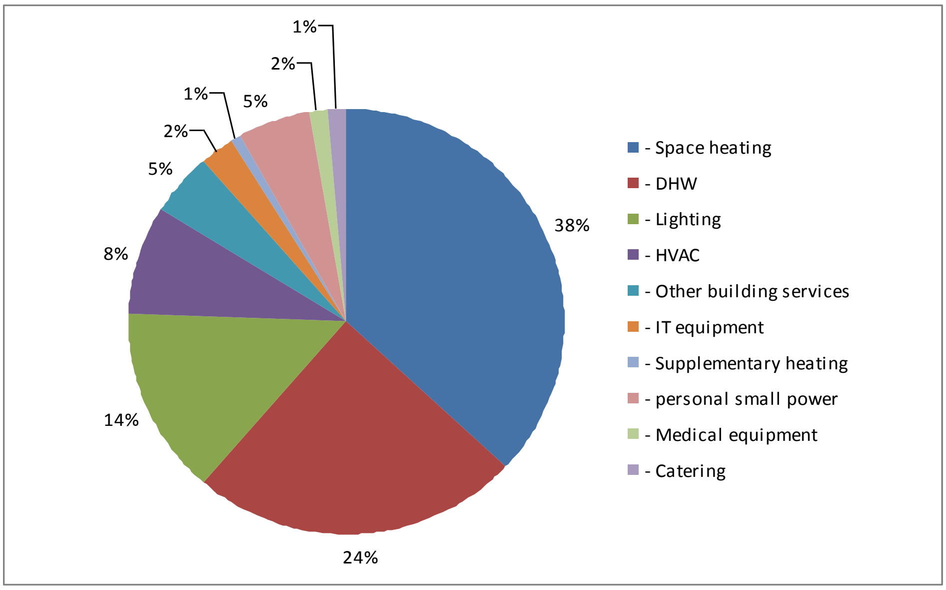



**Figure 5 - Trust based energy consumption breakdown.**

## 5.0 Systems selection criteria

Engineering based solutions for the energy and carbon reduction proposal at the Trust, were considered, based on value engineering with the Priority Scoring Matrix Criteria from the ASHRAE HVAC System Selection method [5]. In this method, each system is rated on specific quality criteria such as Environmentally Alert, Energy Use, Carbon footprint, and Performance. Table 4 shows the Priority Scoring Matrix Criteria for the system selection. The criteria scores are ranked in this table to meet the Trust objectives in order of importance.

The scoring matrix method was used to choose the most suitable systems for power supply, heating and domestic hot water systems, lighting, HVAC, medical equipment, IT equipment and data centres. The method suggests a list of prioritised systems which are explored in more detail in the following section.

| Ranking Position | Quality Criteria | Criteria Score | Criteria Weighting |
|---|---|---|---|
| 1 | Environmentally alert | 9 | 10.65% |
| 2 | Energy use | 9 | 10.65% |
| 3 | Carbon Footprint | 8 | 9.47% |
| 4 | Performance Requirement | 8.5 | 10% |
| 5 | Level of Control | 7 | 8.19% |
| 6 | Capacity Requirements | 6.5 | 7.6% |
| 7 | Reliability | 6.5 | 7.6% |
| 8 | Noise Level | 5 | 5.85% |
| 9 | Spatial Requirements | 5 | 5.85% |
| 10 | Maintainability | 8 | 9.47% |
| 11 | Capital cost | 8 | 9.47% |
| 12 | Flexibility | 4 | 4.68% |

**Table 4 Priority Scoring Matrix Criteria.**

*5.1 The Prioritised systems are:*

- Heating system decentralisation, decommissioning of old systems, and replacement of the Trust's steam boilers with more energy efficient heating systems such as CHP.
- CHP is a potential system to be used to provide the vast majority of the electricity demand along with Solar PhotoVoltaic panels to further support self-generation for the site. Also national grid connection is being used as a standby system to secure the supply of power to the site in the case of any failure of the CHP or PV systems.
- CHP is a potential system to be used to supply the heating requirements of the Trust. In addition, modular condensing boilers can be used as a standby generator if the CHP system fails or requires maintenance.
- An LED lighting upgrade project would help the Trust by improving the efficiency of its lighting systems and deliver a better environment for patient treatment and staff productivity.
- Medical gas systems should be analysed and energy efficient improvement measures implemented.
- IT and data centres studies to be undertaken and solutions for improving system efficiencies should be implemented.

## 6.0 Energy saving measures:

### *7.1 Decentralised and de-steamed Heating System*

The RMH Trust steam boilers are dual fuel, running on gas or gasoil and are over 40 years old. They are part of the original infrastructure installed in the 1970s. The efficiency of the boilers has been calculated by determining the ratio between heat exported in steam and heat provided by fuel. The records of fuels usage and steam generation records have been found in the RMH Trust archive for a period of 38 months between 2008 and 2011. More recent data were not as useful, as the steam and condensation figures were not recorded as a result of a failed meter.

Efficiency profiles for the steam boilers and condensation return are shown in Figures 6 and 7 respectively.

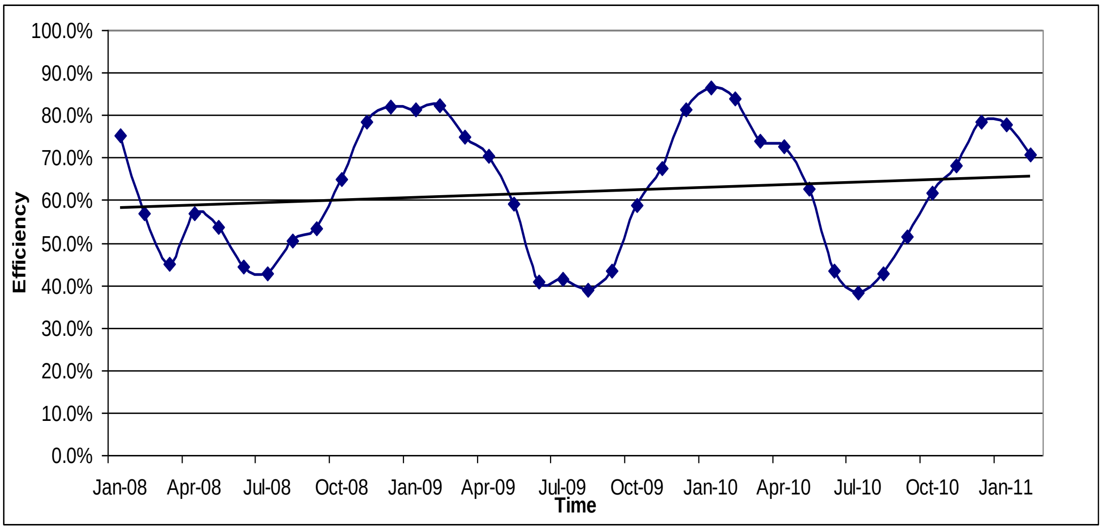



**Figure 6 - RMH steam boiler efficiency.**

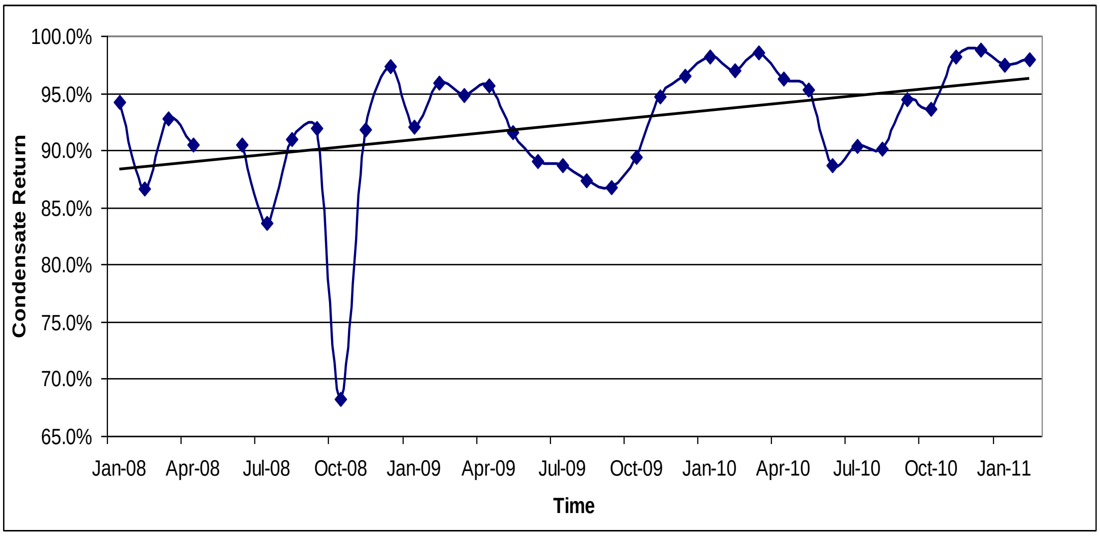



**Figure 7 - RMH condensation return efficiency.**

The average seasonal efficiency of the RMH steam system is 60%. This efficiency dropped to 40% in the warmest months of the year when the system runs on part load. Condensation return losses of 10% also demonstrate the fact that the steam condensation line is not in its optimum operation.

Improving the efficiency of the heating system could be achieved by implementing a pressurised hot water system [PHWS] instead of steam. A typical pressurised hot water system has a minimum efficiency of 80% in commercial applications [6].

As a result of replacing the existing steam system with a more efficient PHWS, will provide the potential for improving the fuel efficiency by 20%. There is a significant cost implication for this type of scheme, however, this upgrade can be financially viable by taking into account:

- Existing steam boilers are very expensive to maintain and operate compared to Low Temperature Hot Water [LTWH] systems. Therefore Energy cost savings can be achieved by installing an energy efficient heating system.
- Existing steam boilers are coming to the end of their life expectancy and hence a replacement would be required.

The inevitable cost of future replacement of existing steam boilers and the low seasonal efficiency of existing systems, means that decentralised PHWS could be a suitable option that should be considered for bringing forward in the future plan for the heating system at the hospital.

### 6.1.2 Energy and cost benefits of a de-steamed heating system

As a result of implementing PHWS and improving the boilers efficiency by 20%, an annual cost saving of £96,000 in gas bills could be achieved. The Trust would also reduce its carbon emissions by 463 tonnes $CO_2$e of which equates to 21% of the Trust's reduction target. Table 5 shows potential savings associated with the anticipated improved efficiency compared to the Trust's current energy use.

| Improved efficiency (%) | Saving on gas energy (kWh) | Saved costs included CRC (£) | Saved $tCO_2$ | Percentage of reduction target |
|---|---|---|---|---|
| 20 | 2,500,000 | 96,000 | 463 | 21 |

**Table 5 - Heat system improved efficiency savings.**

## *6.2 CHP Feasibility Analysis*

The RMH Trust has a constant and considerable demand for heating, power and water. As a result, the application of a CHP plant installation is a very realistic approach for improving the Trust's energy efficiency. The following sections present the feasibility of a CHP system implementation and the overall installation benefits to the Trust, such as energy cost savings and reduction in carbon emissions.

### 6.2.1 Heating Profile

The 2013 Half Hourly (HH) consumption data for gas use have been used to calculate the monthly average heating load for the hospital 8 over a 24 hour period. The results are shown in Figure 8.

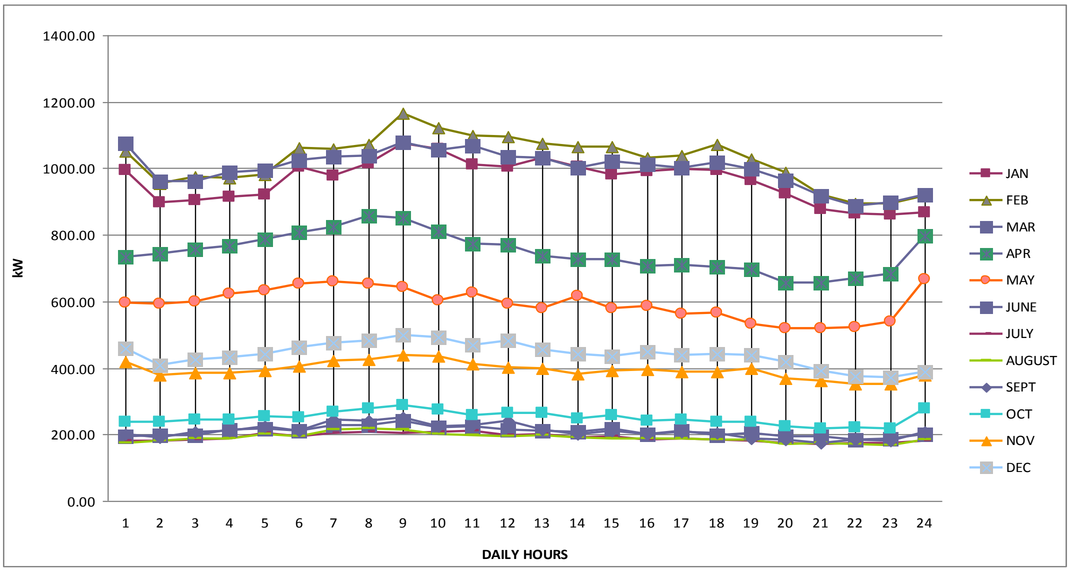



**Figure 8 - CHP Total Heat Load Profile.**

It is seen from Figure 8, that there are heating demands all year around in the hospital. This heating demand is at its lowest point of 200 kW in June, July and August, which could be considered to be the Domestic Hot Water base load. On the other hand, the maximum energy demand of 1200 kW occurred in January, which suggests that the maximum space heating requirement is approximately 1000kW.

### 6.2.2 Power Profiles

The electricity load for the Trust includes lighting, small power equipment, building services pumps, medical equipment, information systems and air conditioning systems.

The Half Hourly (HH) electricity usage data, averaged on a monthly basis, between January and December 2013, are presented in Figure 9.

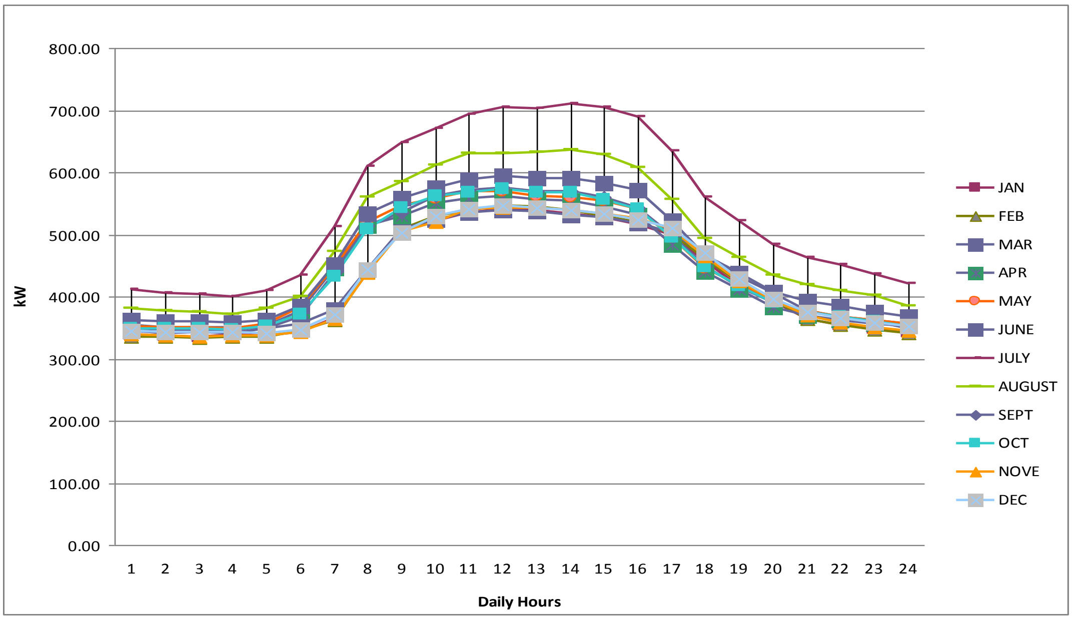



**Figure 9 - Daily average power load profile.**

As can be seen from the power profile in Figure 9, the peak load occurs in May and is approximately 700 kWe and the lowest loads occurred in January and are approximately 420 kW. The maximum load occurred at midday when the site reaches its maximum occupancy and the mechanical plants and medical equipment are in full mode operation. There is a gradual reduction on the load after 5pm and before 7am, as there are smaller occupancy and less use of electrical appliances.

### 6.2.3 CHP Plant Selection

Three EDINA-make CHP plants [7] were considered in this academic feasibility study. Table 6 shows the CHP plant details supplied by the manufacturer, and the cost data (capital and maintenance costs), which were obtained from the Carbon Trust guide GPG388 [8].

| CHP unit | Thermal Output (kWt) | Electric output (kWe) | Gas Input (kW) | CHP Capital Cost (£/K) | Maintenance Cost (£/kWh) |
|---|---|---|---|---|---|
| EDINA 400 kWe | 427 | 400 | 945 | 280* | 0.009 |
| EDINA 600 kWe | 654 | 600 | 1000 | 390* | 0.009 |
| EDINA 800 kWe | 854 | 800 | 1885 | 520* | 0.009 |

**Table 6 - CHP Performance and Cost Data.**

Figure 10, shows CHP capital cost data from GPG3388 [7]


**Figure 10:- Small Scale CHP Installation Costs. [7]**

The CHP capital costs in Table 6 have been calculated by using the unit costs per electrical output of the engine. In order to provide more realistic figures on costs, the following factors, and estimated additional costs of 300% on the capital cost are included in the calculations presented below:

- Fuel connection costs

- Cost of CHP plant (engine and alternator, heat recovery system, heat dump system, control system)
- Power connection cost (switchgear and cabling, G59/1 protection, PES chargers)
- Structural work (civil works, building works) costs
- Plant installations and commissioning costs
- Management fees / time
- In-house engineering costs
- Contingencies

In order to calculate the carbon footprint resulting from a CHP installation, a comparison is made with the proposed LPHW boilers described in this report. In order to calculate the Trust's carbon savings, recently updated conversion factors emissions are used [9]

The following formulas are used to calculate the system efficiencies:-

- Total efficiency = $kW_{input} \div (kWe + kWt)$
- Efficiency electrical = kWe ÷ kWinput
- Efficiency heat = $kWt \div kW_{input}$

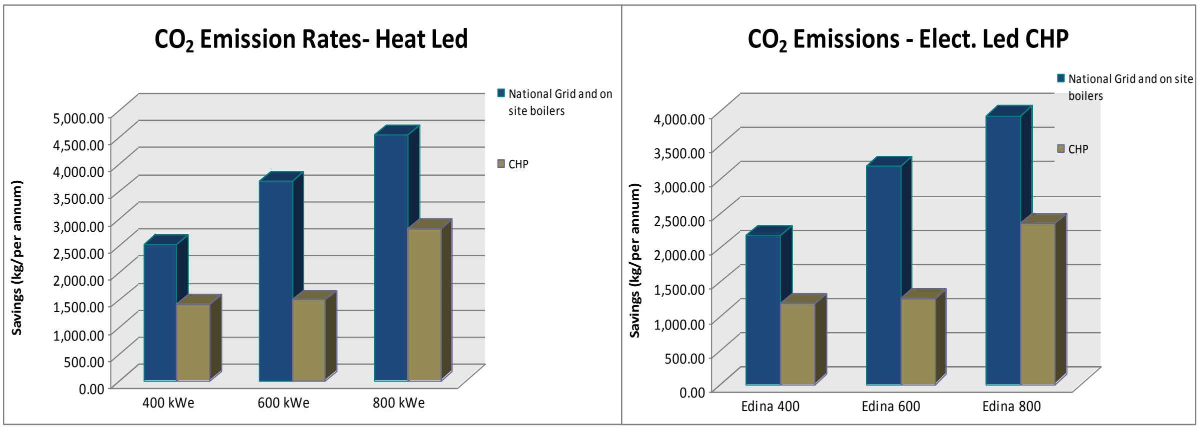



**Figure 10 - $CO_2$e Emission Rate for Electric & Heat Led.**

Figure 10 indicates that the Trust's carbon emissions can be significantly reduced if a CHP system is implemented and replaces the existing system of gas boilers and the grid imported electricity.

The highest carbon saving was achieved by the Edina 600 kWe engine for the heat led system. An annual carbon saving of 2,200 tonnes $CO_2$e and corresponding CRC cost savings of £35,000 can be achieved by implementing the 600 kWe engine.

### 6.2.4 Summary of savings

The financial analysis carried out on the three EDINA CHP models resulted in the EDINA 600 kWe in heat led control mode being selected as the best option of the three investigated models. This is due to its excellent financial benefits and calculated $CO_2$e savings. The summary of annual savings in Table 7 suggests that this CHP installation can help the Trust to achieve 99% of its carbon reduction target.

| CHP Unit – EDINA 600 kWe | |
|---|---|
| Annual Net costs saving | £550,000 |
| Improved Payback period | 2.8 years |
| NPV at end of the year 10 | £100,000 |
| Annual carbon saving | 2,200 $TCO_2$ |
| Annual CRC cost saving | £38,000 |

**Table 7 - Potential CHP plant's annual savings.**

This unit will generate approximately 4,685 MWh of heat and 4,730 MWh of electricity per annum for the Trust.

### *6.3 LED lighting upgrade*

The Royal Marsden Hospital lighting systems were surveyed in April 2013 (by one of the authors of this report (E. Sattar)) and details of the existing lamps and occupancy hours gathered for the whole site.

As a result of this survey, it was noticed that the Trust has a large number of buildings with lighting installations using energy inefficient fluorescent lamps. These are inefficient in terms of lamp power, light output, lamp life and whole life operation of the fluorescent tubes.

The proposed solution is to replace these inefficient fluorescent tubes with energy saving LED or T5 tubes in areas with a minimum of 15 hours consumption like corridors and wards.

Benefits to the Trust:

Reduced energy costs. For instance, LED tubes have a lower wattage power demand per unit length compared to the existing lamps. A 4ft length fluorescent tube is rated at 36 W, with 4 W losses through the ballast control gear (a total of 40 W). An equivalent LED tube has a power demand of 16.5 W with zero losses

Reduced maintenance costs. The life of an LED lamp is estimated to be 30-50,000 hours which will result in reduced ongoing maintenance costs for labour, materials and waste disposal.

Reduced CRC costs

Reduced $CO_2$e emissions

LED tubes minimise waste recycling requirements as less toxic materials are used in manufacturing.

As a result of this lighting upgrade work, the Trust is expected to achieve savings of the order indicated in Figure 11.

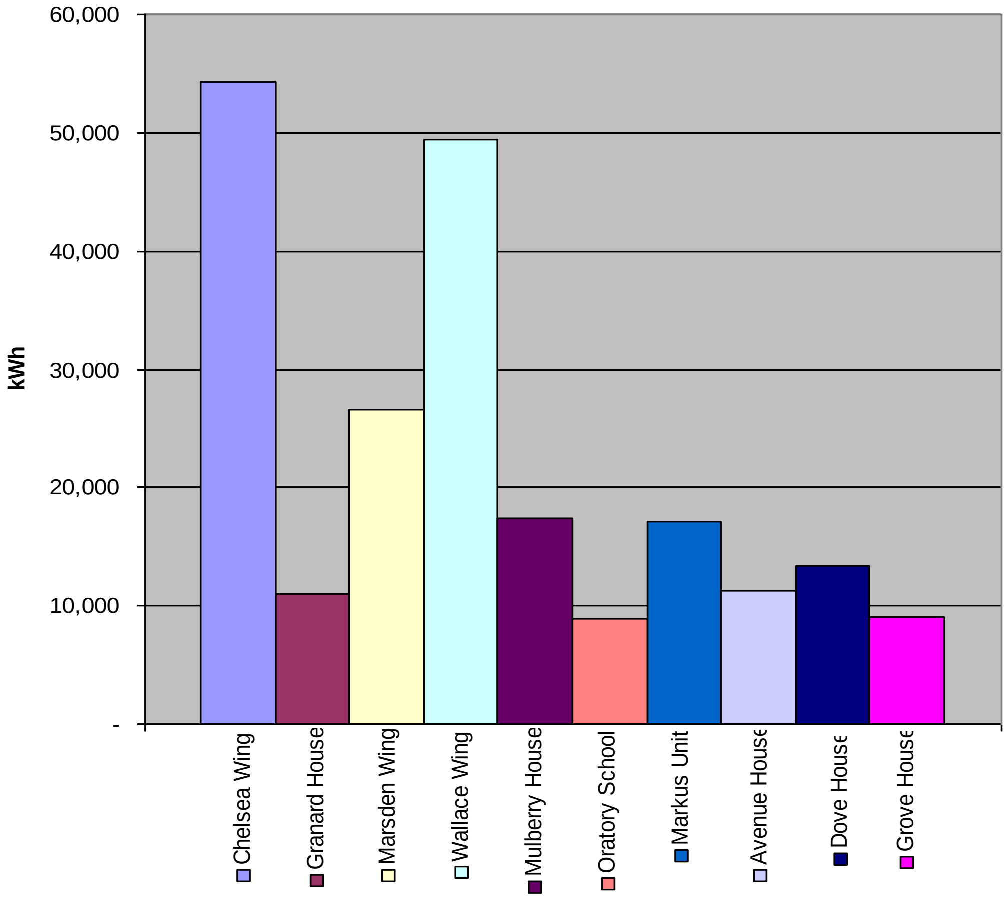



**Figure 11 - RMH lighting energy saving potential per hospital blocks.**

In summary, the Trust can achieve the following savings as a result of investing £130,000 (Estimated) in this lighting upgrade project:

Total energy saving of 218,000 kWh

£45,000 savings in electricity, maintenance and CRC costs per year at the Chelsea site

Reduction in the Trust's carbon footprint of 124 tonnes per year

A project payback period of 3 years

The summary of the savings suggests that lighting upgrade of the Trust's estate would make a significant contribution towards reducing the Trust's carbon emissions, energy use and costs. The potential energy saving on lighting can be improved further by considering lighting controls for lamps or by fittings replacement.

## *6.4 Medical Gas System*

Royal Marsden hospital has two 30 kW air medical compressors located at the basement of Chelsea Wing. The system is supported by two drier towers similar to the system in Figure 12.

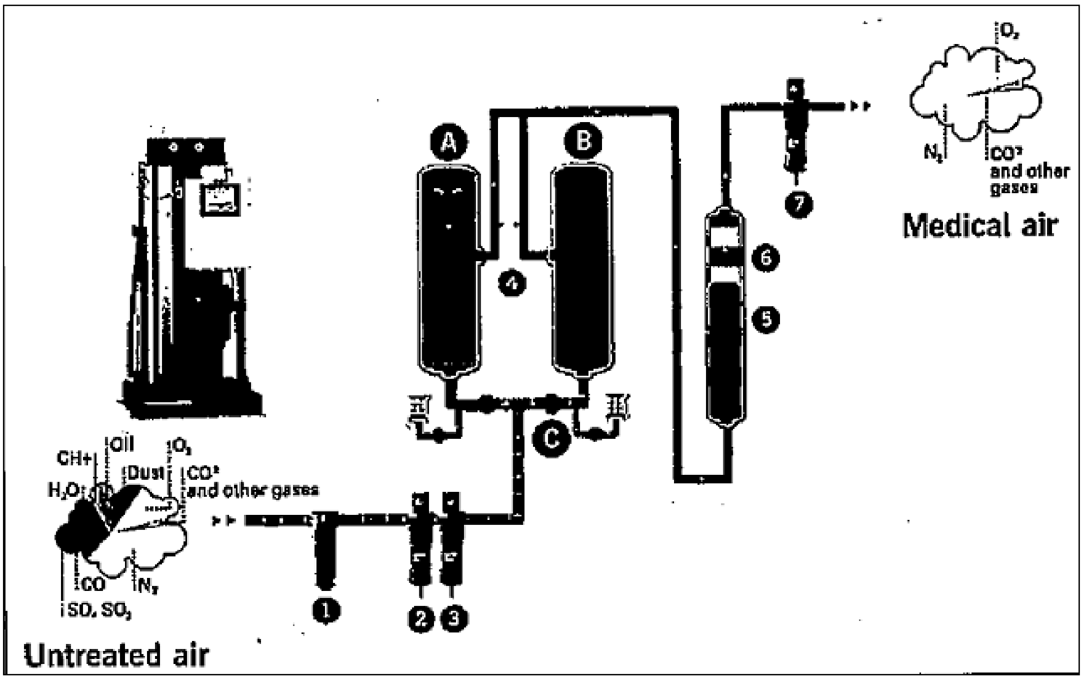



**Figure 12 - A medical air plant system. [10]**

6.4.1 Air drier towers - savings potential

Appropriate purging controls can make the drier more efficient. In recent years, a new system known as “PurgeSaver” has been introduced to the market. It is claimed that the new system can save up to 90% of the energy lost during non-controlled purging and it has a payback period of two years depending of the type and size of the air medical installation.

In the PurgeSaver system, the switching time between the active and inactive drier is extended. This active drier runs until the Pressure Dew Point reaches its minimum level, however, as soon as this is achieved, dry air is preferred and the inactive drier becomes active.

From the data in the performance sheet, the Trust’s existing air medical plant uses 87,660 kWh of electricity annually. By taking into account the typical 16% energy savings available from implementing the “PurgeSaver” system, there is potential for an annual electrical energy saving of 14,026 kWh. As a result of this energy saving, the Trust can also benefit from:

A reduction of £1,543 in electricity bills annually ( at 11 pence/kWh)

A saving of almost 8000 tonnes of $CO_2$e annually (Assuming a carbon factor of 0.5418 Kg $CO_2$e/kWh)

7.4.2 Compressors – Saving potential

The Trust’s existing plant in the Chelsea Wing uses two 30 kW air compressors. Both compressors operate at part load and the load is consequently switching between the two machines. The system uses traditional start/stopping which is capable of only 100% or zero speed (On/Off).

By studying the performance sheets for these two compressors, it is apparent that the actual demand for energy is 10 kW (equivalent to 0.65 $m^3$/min of air). This demand is actually 65% lower than the existing capacity. As a result, it can be said that the compressors are wasting a large amount of energy due to the part load operation of two oversized devices.

It is believed the efficiency of this system could be significantly improved by implementing technology such as Variable Speed Drive (VSD) compressors and Fans. The available saving potential of 60% related to the annual energy use (87,660 kWh) of VSD applicable systems, can help the Trust to achieve savings of:

52,596 kWh on energy use annually

£5,785 on electricity bills annually ( at 11 pence/kWh)

28.5 tonnes $CO_2$e annually ( 0.5418 Kg$CO_2$e/kWh)

### *6.5 Data Centre – Energy efficiency analysis*

The Trust's data centre is located within an existing building. In terms of supporting infrastructure, the data centre is in a good condition with power and heat rejection equipment in close proximity. Furthermore, the data centre benefits from having two separate power supply systems each with its own transformer and generator, which greatly increases resilience. The UPS system serving the data centre has a maximum load of 288 kW. With respect to cooling, each of the three Mitsubishi cooling units provide 56 kW of cooling, which provides a maximum capacity of around 168 kW, which is lower than the maximum for the UPS system.

In addition, it is likely that the cooling capacity stated is the gross total capacity, rather than a net sensible capacity that also accounts for latent cooling and fan heat gains. It is also common for air conditioning manufacturers to state cooling capacities at higher temperatures than those actually being maintained within the real data centre. Therefore the actual cooling provided to the data centre may be much lower than stated, possibly only 50 kW per unit. This gives a maximum capacity of around 150 kW, which is significantly lower than the UPS maximum capacity of 288kW.

ASHRAE recommends five design goals to be considered in data centres [11]:

IT equipment reliability

Low power usage effectiveness (PUE)

Suitable means of ventilation;

Maximum use of ambient conditions

Limiting the use of mechanical cooling

By taking into the account the ASHRAE recommendations and observations made on PUE and air flow principles, the following assessment is made of the Trust's data centre.

The Power Usage Effectiveness (PUE) is calculated for the Trust's data centre by using actual meter readings taken on site. Figure 13 shows the calculated PUE value for each month. An average value of 1.8 is achieved, which this indicates reasonable energy efficiency (in line with current average performance for data centres) from the supporting infrastructure.

Figures 14 and 15 show schematics of the Trust's data centre at the Chelsea hospital site. The IT equipment is located in the centre room and is surrounded by supply and extract air conditioning units, as well as a UPS system.

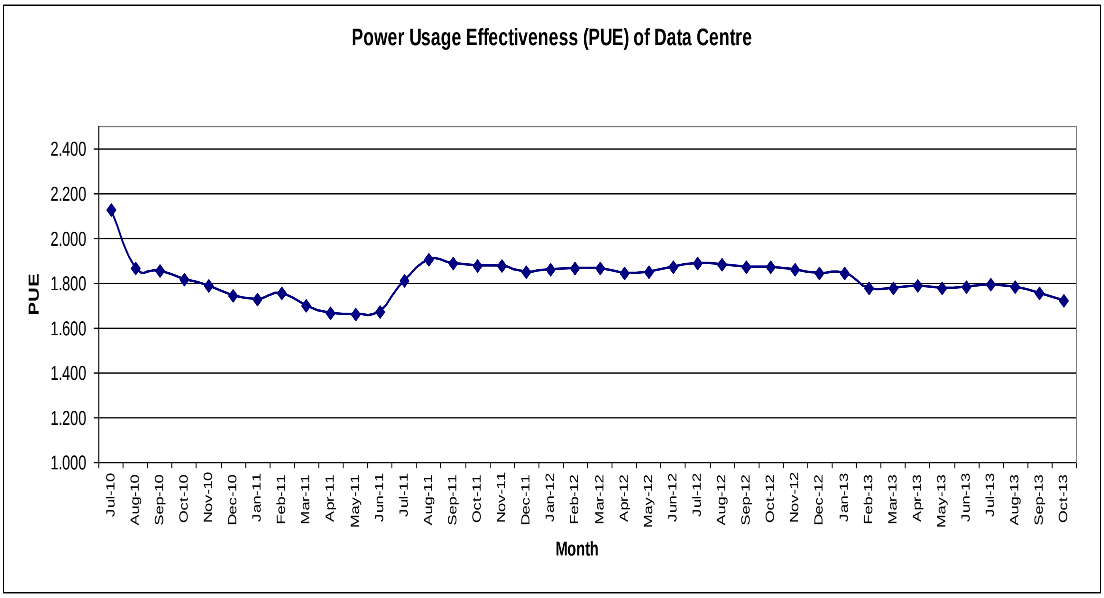



**Figure 13 - Calculated PUE for the RMH data centre.**

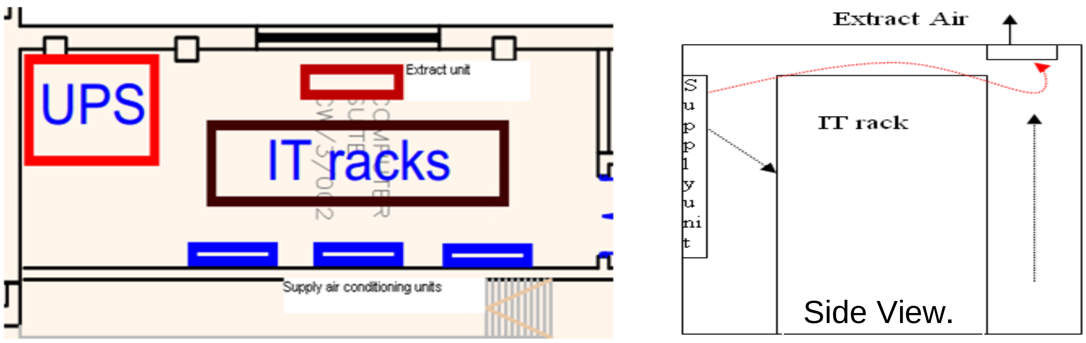



**Figure 14 - Schematic of the RMH data centre.**

The air passages are shown in Figure 15. The normal air route through the racks is acceptable but the bypass air passage (in red) is not effective to the IT equipment i.e. represents a cooling efficiency loss. It can be seen in the schematic that the supply air travels above the rack without experiencing any resistance and is then discharged through the extract grill.

This bypass air can be avoided by filling the huge gap at the top of the racks and isolating the two sides i.e. the supply and extracts aisles completely. Consequently, the only path for the incoming supply air is to travel through the racks and to be discharged at the other side i.e. into the hot aisle). It is believed that this containment strategy can improve the data centre performance, so that the energy waste resulting from bypass is prevented.

Assessment of the utilization of free cooling for the data centre during the colder months has been considered and potential energy savings have been calculated, and are presented below,

Initially, the average number of hours that ambient temperature is below 13$^{o}$C in a year has been determined from meteorological data to be 5,040 hours [12]. The approximate power consumption by the compressors for a 168 kW (3 X 56 kW) cooling load = 67.2 kW (A typical COP of 2.5 is assumed).

Unit cost of electricity = 11.5 p/kWh

Annual cost saving = 67.2 kW x 5,040 hours x 0.115 £/kWh = £38,949

Annual energy saving = 67.2 kW x 5,040 hours = 338,688 kWh

Annual carbon saving = 338,688 kWh x 0.5418 kg$CO_2$/kWh = 183.5 tonnes $CO_2$e

### *6.6 PV panels performance analysis*

The building of the Children's and Young Persons' Centre (CYPC) has two main roof areas which are facing south and west. The size of solar panels installed on west and south roofs are 150 and 60 $m^2$ (1 $m^2$/panel) respectively.

The west roof panels are connected in 5 arrays of 3 DC strings each – 10 modules per string, 30 per array. On the south roof, 60 solar modules are installed connected in 2 x arrays of 3 DC strings each – again 10 modules per string, 30 per array.

For both roofs, each array is connected to a dedicated inverter mounted in the electrical switch room. In terms of power output, the west roof peak power output is 32.25 kW and for the south roof 12.9 kW – a total of 45.15 kWp

PV installations for the CYPC roof have been energised since November 2010, and first full month of energy generation data measured was in the following month (i.e. December 2010). The installations have been operating for more than a year now, and for the first calendar year, 36,501 kWh of electricity was generated.

The regression method has been used to assess the performance of PV panels for the CYPC building. Figure 15, shows the relationship between the site solar power generation and the availability of solar irradiation over 12 months of operation. As could be seen from the figure, the relationship on average is linear but not best fit with $R^2$ of 90%. This means the generated power is consistent with the solar irradiation and overall represent an efficiency of approximately 16%.

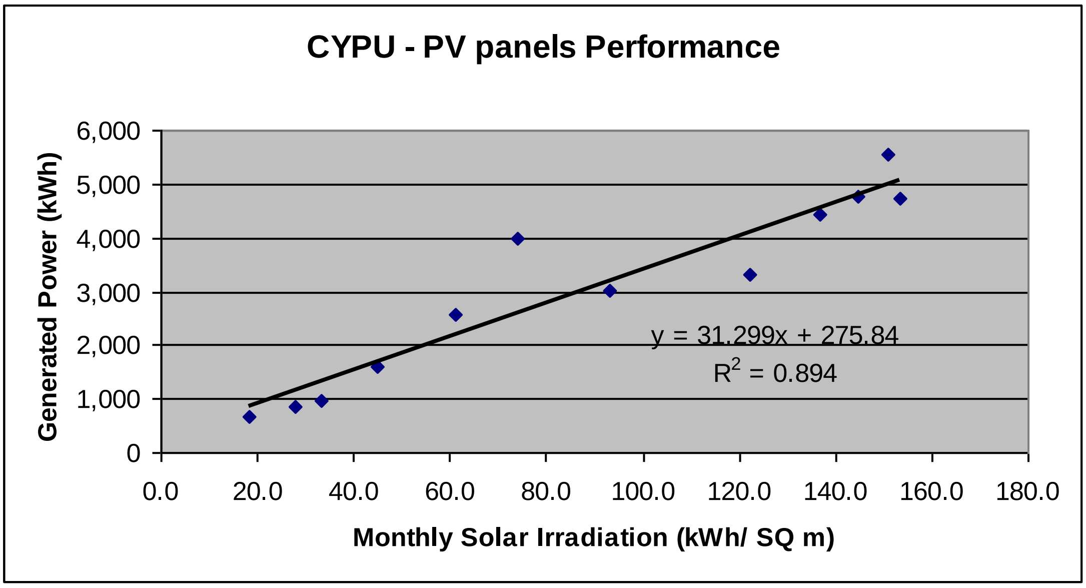



**Figure15 - CYPU PV panels performance analysis.**

In order to maintain the full output performance, it is highly recommended that the panels should be cleaned once every six months, and a monthly visual check be carried out. A service contract on the performance of the inverters is also recommended to be carried out once a year.

Additional energy saving surveys have been conducted in the main study, such improving the controls for HVAC systems, replacement of older, less efficient mechanical systems (R22 chillers and inefficient pumps and fans), improved metering and implementation of an efficient energy monitoring system. However, due to space constraints they could not be included in this paper.

## 7.0 Conclusions and recommendations

At the time of this investigation, the energy usage at RMH was found to be approximately 42% and 54 % above the typical and good practice Benchmarks (based on the CIBSE benchmarks) for hospital of this type, respectively. The hospital strategy for energy management has been developed to meet the NHS England Footprint reduction target of 33% by 2020 based on the 2014 baselines. Further improvements can be included at the end of the plan to meet the industry typical practice.

As a result of the reduction target plan, it is predicted that the Trust could achieve:

- An absolute reduction of 2,221 tonnes $CO_2$e by 2020 over the base line of year 2014.
- Final year annual $CO_2$e savings of 4,877 tonnes.
- Cumulative $CO_2$e savings of 17,071 tonnes.
- Relative emissions reduction target of 52%.

The assessment of the site energy breakdown identified the highest percentage of energy use is for Space heating (38%). DHW, lighting and HVAC are also areas with high energy use, 24 %, 14 % and 8 % respectively.

Systems survey was also carried out and the result are summaries in table 8 which shows the areas identified as having potential for significant savings:

| Measures | Annual energy reduction (kWh) | Annual cost savings (£) | Annual carbon footprint reduction (tonnes $CO_2$) |
|---|---|---|---|
| Pressurised Low Temperature Hot Water systems | 2,500,000 | 96,000 | 463 |
| CHP Plant | 1,031,660 | 550,000 | 2,200 |
| LED lighting upgrade | 115,490 | 13,000 | 62 |
| Data centre energy efficiency | 338,688 | 38,949 | 184 |
| Medical air plant | 66,622 | 7,328 | 36 |
| PV panels | 3,600 | 500 | 2 |
| Modular boilers | 172,972 | 6,054 | 32 |
| Water pumps | 240,240 | 24,024 | 130 |
| Total calculated saving potentials | 4,469,272 | 735,855 | 3,109 |

**Table 8 - Energy efficiency measures and potential savings.**

Energy monitoring and the checklist for system efficiencies can also be added to Table 8. However, the anticipated savings for such measures has not been obtained due to the scope of the project.

The upgrades offering the highest costs savings are (in order):

CHP Plant

Pressurised Low Temperature Hot Water systems

Data centre energy efficiency

water pumps

LED lighting upgrade

medical air plant

PV panels

The potential saving of 3,109 tonnes $CO_2$e and overall cost saving of £700,000 per year could be achieved by implementing the recommended energy conservation measures. This saving would help the Trust to achieve greater carbon savings compared to its reduction target of 2,221 tonnes $CO_2$e by 2020.

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## 8.0 References:

(1) Carbon Trust, Hospitals - Healthy budgets through energy efficiency, (2010). [Online]. Available at: http://www.carbontrust.com/media/39216/ctv024_hospitals.pdf (Accessed: 5th October 2014).

(2) NHS Carbon Reduction Strategy, 2010. [Online], 3. Available at: http://www.sdu.nhs.uk/corporate-requirements/nhs-carbon-reduction-strategy.aspx [Accessed 10 July 2013].

(3) Health & Social care Information Centre, Carbon use indicator for London, 2010. [ONLINE] Available at: http://www.hscic.gov.uk/. [Accessed 01 October 14].

(4) Sattar, E., RMH - Carbon Reduction and Energy Management, MSc dissertation, London South Bank University, 2014.

(5) ASHRAE Handbook, HVAC Systems and Equipment SI Edition. 1st ed.Atlanta: ASHRAE Publication. 2012, 1.4&1.5.

(6) Northcutt, M., Do what it says on the tin. CIBSE Journal. November 2013 (1), p55.

(7) EDINA. EDINA GAS ENGINES, 2013. Available: http://www.mwm.net/en/products/gas-engines-power-generators/tcg-2016/ . Last accessed 15/12/2013

(8) Carbon Trust, Action Energy GPG388 Combined Heat & Power for Buildings, 2006.

(9) Environmental Agency. CRC conversion table, 2010, Available: http://www.adlassociates.co.uk/assets/crc-conversion-table.pdf . Last accessed 01/06/2013.

(10) Tudor, A., Cutting energy, reducing costs. Health Estates Journal. April 2013 (37), pp.37.

(11) ASHRAE, HVAC Systems and Equipment SI Edition. 2008, 1st ed. Atlanta: ASHRAE Publication.

(12) Beier, C., Cooler customers. CIBSE Journal. November 2010 (1), pp. 54 - 59.