ANALYSING THE ECONOMIC AND CARBON DIOXIDE REDUCTION VIABILITY OF GSHPS IN THE UK INTO THE FUTURE

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Abstract: This paper seeks to consider the application of GSHPs in the UK context by considering the future electricity generation mix and changing energy prices. This is against a backdrop of increased national legislative pressure to implement low carbon technologies from recent building regulations triggered by the European Performance in Buildings Directive. From an economic standpoint increasing gas prices versus electricity have made this technology more competitive against the historically dominant techniques of space heating and cooling in the UK.

A number of scenarios are used to present both the economic and environmental variation throughout the assumed lifetime of the GSHP. In economic terms, electricity and gas prices are projected by considering recent trends whilst the carbon dioxide intensity is reviewed using current government guidelines and projections.

The case study is used to demonstrate the effect of dynamic carbon dioxide factors and compares the results against static carbon dioxide factors commonly used by building services engineers. Consideration is further given to changing energy prices to highlight the effect on the economic payback which is frequently a constraint to the application of GSHPs in the UK.

In conclusion, it can be argued that although the application of GSHPs in the UK remains promising a more accurate dynamic model would be useful to consider the range of future carbon dioxide and operational savings. This would also aid comparison against other low or zero carbon dioxide approaches. Furthermore, post occupancy evaluation of buildings and GSHPs in the UK is needed to understand the sensitivity of design decisions on the actual performance.

Key Words: ***built environment*, *GSHPs, energy prices, carbon dioxide emissions, sensitivity analysis***

1 INTRODUCTION

Recent changes in UK building legislation, driven by the European Performance in Buildings Directive (EPBD 2002), have led to a move away from traditional forms of heating and cooling commercial buildings. The latest publication of the UK Building Regulations (ODPM 2006) is the leading set of national legislation but regional government departments, e.g. Greater London Authority, and Local Authorities, e.g. Merton, are also enforcing planning requirements for renewable, low carbon technologies and respective carbon dioxide reduction in new buildings. In parallel, utility unit costs have been increasing (DTI 2007a) forcing building occupiers to focus attention on reducing energy use throughout their respective portfolios. Added to this is the more subjective phenomenon of corporate social responsibility which is leading many public and private companies to “green” their image.

Previously in the UK the most competitive form of heating has been gas-fired condensing boiler plant with space cooling delivered by dry or wet chillers rejecting to ambient temperatures (CIBSE 2004a; CIBSE 2004b). Most commercial buildings still have dominant heating loads in the UK apart from certain buildings in the urban environment with lightweight structures, high IT concentration and glass façades.

Developers and building designers are now required to make decisions regarding the most appropriate measures to take that minimise the economic impact to projects whilst also ensuring new and immature technologies are fully understood. Certainly the capital cost is still paramount in decision making but where technologies are perceived to reduce the ongoing financial burden for the building occupier, the comparable respective operational costs can then become a dominant factor to consider.

Similarly where the new approach or technology has a high embodied energy or still requires significant energy input over its lifetime it becomes necessary to consider manufacturing and construction energy as well as ongoing comparable carbon dioxide emissions. Some “passive” techniques, such as thermal massing, may require more intensive energy use in manufacture whilst “active” technologies such as gas-fired Combined Heat and Power (CHP) plant and Heat Pumps require more significant on going gas and electrical energy.

Possibly due to their maturity and low maintenance requirement, Ground Source Heat Pumps (GSHPs) have become one of the main technologies considered to ensure new and major refurbishment building projects achieve the desired legislative and planning targets. Where the heat pumps are electrically driven, as is most common, and the electricity is sourced from the national grid it is important to review current and future projections of carbon dioxide intensity in the country.

In the vast majority of applications GSHPs remain more capitally intensive than conventional approaches and also versus other low carbon technologies. However, there is the possibility to recoup some of this additional cost due to the efficiency of the electric heat pump. Thus the relative ratio between gas and electricity prices becomes important.

For reference purposes, the instantaneous efficiency of a heat pump is typically measured by the coefficient of performance (COP), whilst the annual performance is analysed by the seasonal performance factor (SPF).

$$COP = \frac{\text{Power output from the heat pump}}{\text{Power used by the heat pump}} \left[\frac{kW_{th}}{kW_e} \right]$$

$$SPF = \frac{\text{Energy output from the heat pump}}{\text{Energy used by the heat pump}} \left[\frac{kWh_{th}}{kWh_e} \right]$$

Subscripts;
th = thermal power or energy
e = electrical power or energy

The typical COP reported by manufacturers can be over 4 but can be lower or higher depending on the geology, installation configuration and operational modes.

This paper will highlight the historical utility prices and carbon dioxide intensity for grid electricity. Using a mix of projections predicted by government departments and extrapolations by the author a number of future scenarios are used to demonstrate the variability of the economic and environmental outlook throughout the lifetime of a GSHP.

A case study is used to demonstrate the projected economic and environmental variability using these scenarios.

2 HISTORIC AND FUTURE UTILITY PRICES

Utility prices have recently started to increase in the UK, partially due to liberalised markets but mainly due to increasing worldwide fossil fuel prices. This recent trend is demonstrated in Figure 1 using the Retail Price Index.

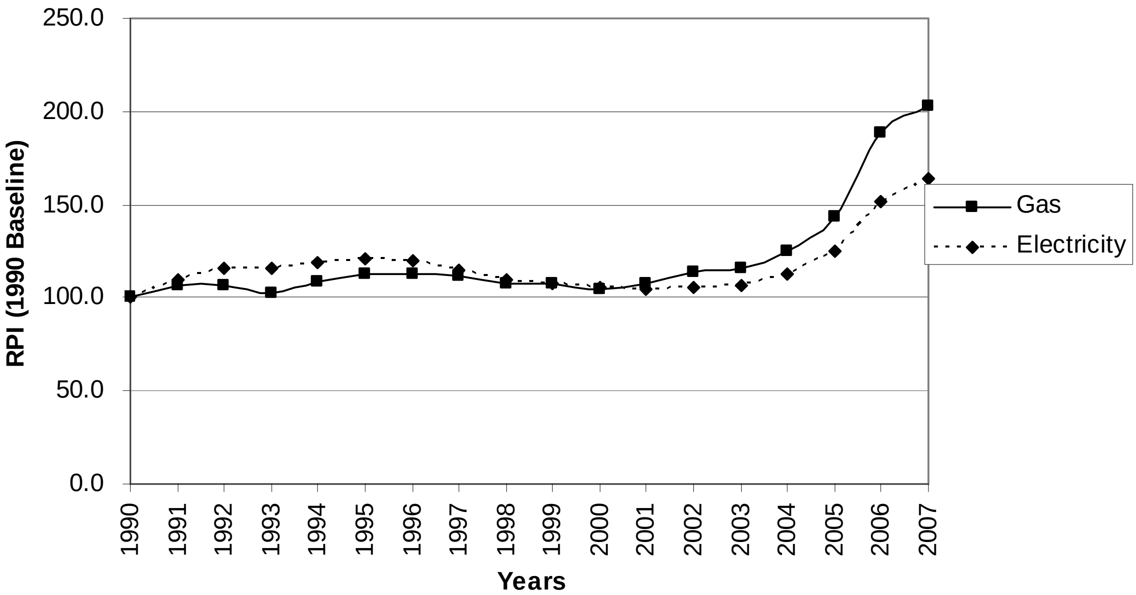

Figure 1: UK gas and electricity prices, 1990=baseline (BERR 2008)

As over 70% of the electricity in the UK is currently generated using fossil fuels, and over 30% specifically from gas (DTI 2007c), it is easy to see why there is a direct connection to not only fossil fuel prices but also gas. Hence, electricity and gas prices are not entirely interdependent although there is some flexibility in the generating grid to prioritise other power plants when certain fuels become relatively more expensive.

Despite recent increases in gas prices the unit charges remain much lower than electricity, and also connection to the gas grid remains relatively easy and inexpensive with an extensive infrastructure through out the UK. However, the recent trend in rising gas prices relative to electricity prices is having a positive impact on the competitiveness of GSHPs versus conventional gas fired plant for space heating. For space cooling the GSHP system simply has to out perform conventional electrically powered chilling plant. Although electricity is more expensive than gas there are still possible operational savings due to the efficiency of heat pumps linked to adequately sized ground source configurations. Figure 2 shows the minimum COP required in heating mode over the last 3 years using average utility prices for gas and electricity. Over this short time span the minimum COP has varied between ~2.5 and ~3.5 which is certainly possible with current technology and design principles. However, the savings can be marginal if the ground configuration does not provide adequate flow rates and temperatures throughout the year. Certainly, air sourced heat pumps will struggle to provide operational savings versus gas fired plant although admittedly may still offer potential in “off-gas grid” sites where the competing fuel is LPG, oil or electric resistance heating.

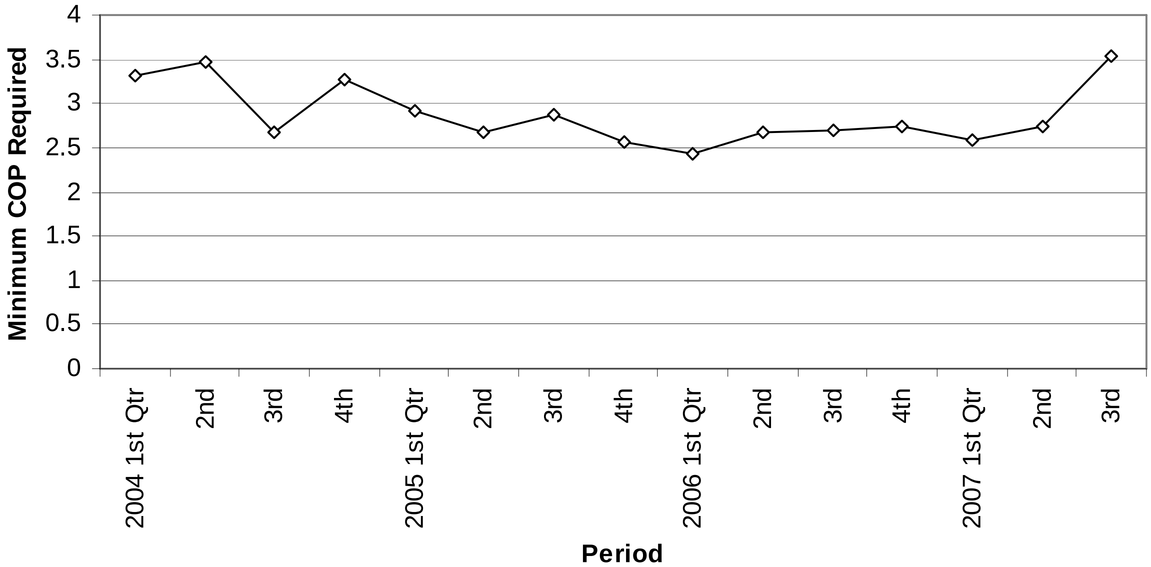

Figure 2: Coefficient of performance required for operational saving - GSHP versus gas fired heating

Looking further into the long term future of 20 years, i.e. over the expected lifetime of a heat pump, the price ratio between gas and electricity is very difficult to predict. Certainly, looking at short term trends, such as in Figure 2, there will be anticipated ongoing fluctuations although by analysing historical trends over longer periods, see Figure 1, it would seem that the ratio could continue to drop in favour of heat pumps and in particular GSHPs.

For the basis of this paper three scenarios have been compiled to show how rising utility prices will affect the operational competitiveness of GSHPs. This is important to consider due to current high capital price of GSHPs installations versus conventional systems in the majority of applications. All three scenarios show varying above inflation increases in electricity and gas prices.

The three scenarios are summarised in Table 1 and shown graphically in Figure 3:

Table 1: Energy price scenarios

Scenario 1	Equal above inflation increase for gas and electricity.	
	Electricity	+1% above inflation
	Gas	+1% above inflation
Scenario 2	Gas prices rise more so than electricity due to greater increase in imports; there is an impact on electricity prices but co-firing stations move to coal/ biomass/ oil and increase in nuclear and renewable energy technologies.	
	Electricity	+2% above inflation
	Gas	+4% above inflation
Scenario 3	Gas prices rise much more due to instability in gas supplying countries, again there is an impact on electricity prices but more so gas.	
	Electricity	+3.5% above inflation
	Gas	+7% above inflation

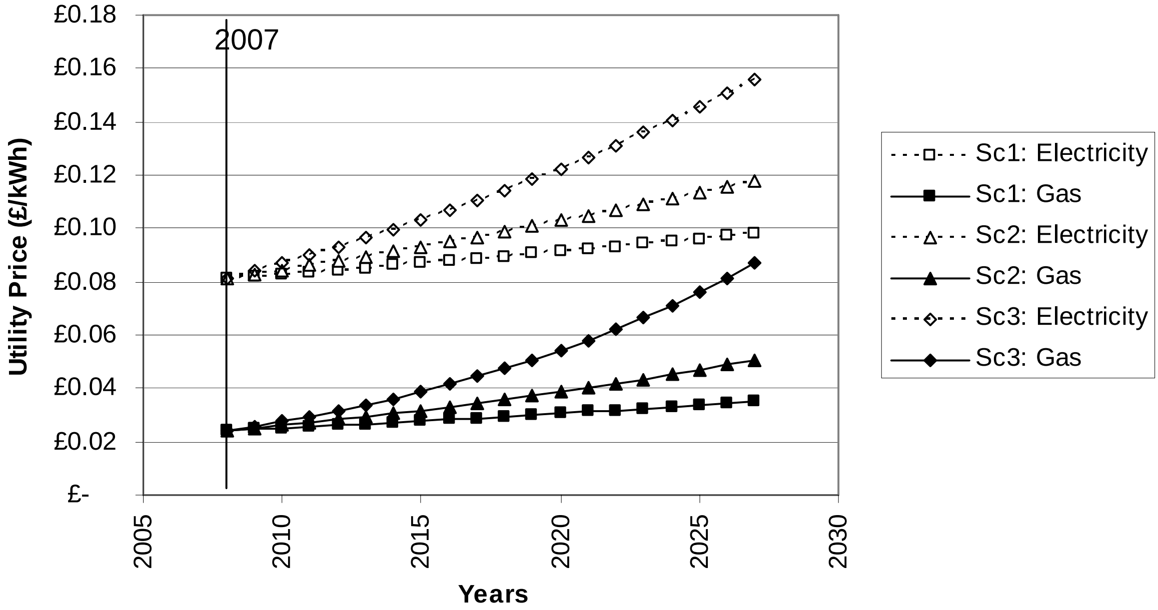

Figure 3: Projected utility prices to 2027 (2007=baseline)

Obviously this is a much simplified projection but in the absence of any suitable references for energy prices variation into the future, recent trends can be extrapolated to enable a demonstration of the impact on the competitiveness of GSHPs versus existing technology. In reality step changes in prices can often occur over very short time spans as markets react to changing legislation and the geo-political situation. The starting gas unit cost and electricity day rate is the average charged to “small” industrial users from 3rd quarter of 2006 through to the 3rd quarter of 2007 (BERR 2008).

It is still evident that for continuing conservative above inflation increases, scenarios 1 and 2, the resulting energy prices can still change significantly over the life time of any plant installed. Reviewing recent trends, Figure 1, even scenario 3 is certainly not unrealistic.

3 HISTORIC AND FUTURE ELECTRICITY CARBON DIOXIDE INTENSITY

Due to initiatives such as the Kyoto protocol and EU administered targets pressure is being exerted on the UK to reduce carbon emissions. As electricity generation is one of the major polluters (DTI 2007b) the UK government has over the last decade or so attempted to move to more efficient plant and less carbon sources of electricity. This is shown in Figure 4 where in 1990 the system average carbon intensity was greater than 0.75kg CO_2/kWh whereas in 2006 the figure dropped to ~0.55 kg CO_2/kWh.

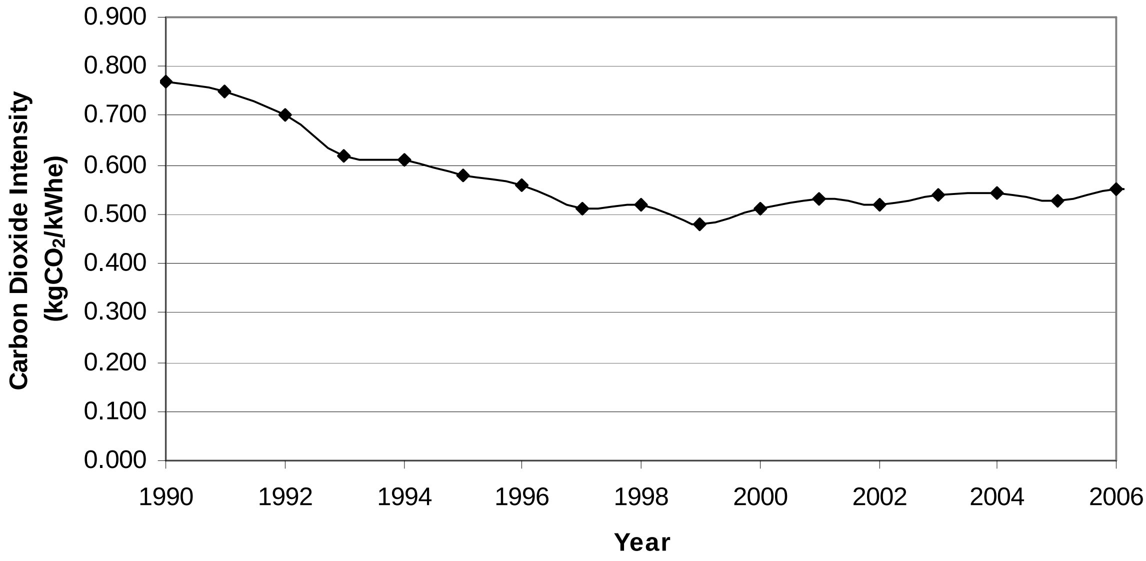

Figure 4: Historical carbon dioxide intensity of electricity in the UK

Gas fired plant assuming a seasonal efficiency of 85% emits ~0.228kgCO_2/kWh_{th} (ODPM 2006) so again there is a need to review the minimum performance of the heat pump to ensure comparative improvements versus conventional heating methods. Figure 5 reviews the corresponding minimum COP required in heating mode to ensure a carbon saving versus the baseline technology. These efficiencies are again possible but in order to maximise the carbon saving systems still need to be optimised. In the 1970's the carbon intensity was much higher, ~1kgCO_2/kWh_e, and it is easy to see in these circumstances the carbon dioxide emissions could be much greater for GSHPs than convention.

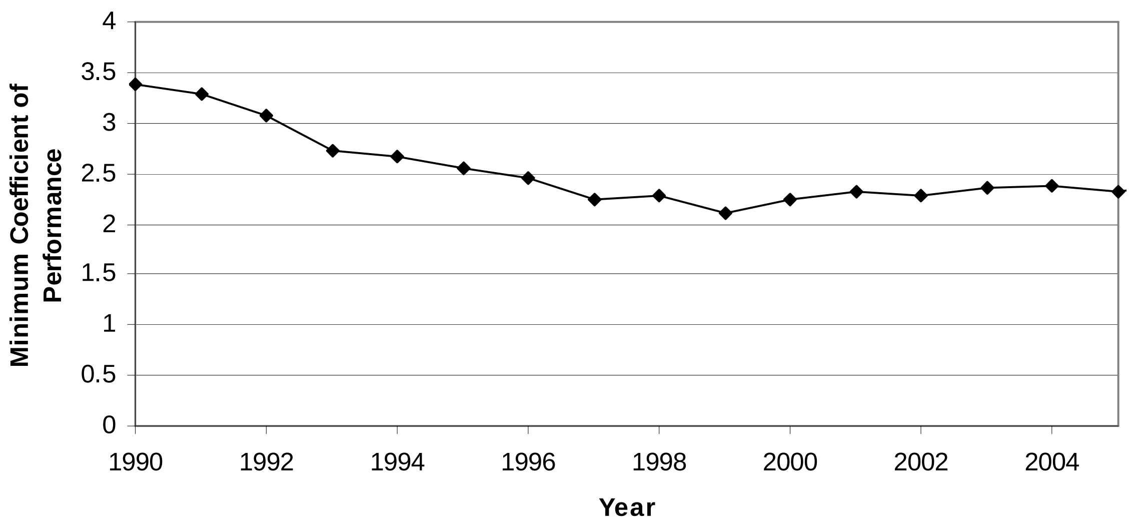

Figure 5: Minimum heat pump COP - GSHPs versus gas-fired heating

For compliance building designers are instructed to use fixed carbon dioxide factors referenced from the latest building regulations for both electricity and gas when analysing new strategies (ODPM 2006). Whilst this avoids different parties using different figures according to their respective agendas there is still some ambiguity regarding the accuracy and bias for certain technologies. Gas heating coefficients are likely to remain relative constant whilst electricity coefficients will ultimately change as new cleaner technology is used but the extent of which is still difficult to judge over the GSHP lifetime of 20 years. The latest figures reported by the Building Regulations are actually lower than the current system average so as to reflect the changes up to the chosen end point, 2020, but different technologies have different life spans so hence the static averages can easily under or over estimate cumulative carbon dioxide savings.

Due to an ongoing requirement for the government to plot a path to reducing carbon emissions in the UK the latest updated energy projections report on a number of different scenarios leading up to 2020 (DTI 2007b). From this information it is possible to calculate the corresponding year on year carbon dioxide emissions for each scenario.

Added to the ongoing changes in generating plant and resulting annual system average is the variation throughout the day as a result of different plant coming on line. Generally, less efficient and more carbon intensive plant is only used during peak times with nuclear and more efficient plant being used for the base load (Bettle R. et al 2006). These peak times happen to coincide with certain periods during the day when heating and cooling is needed. This leads to the consideration of a further so called marginal carbon dioxide coefficient.

In summary the scenarios used for analysis in this paper are outlined in Table 2 and shown graphically in Figure 6. The projections used for scenarios 3-6 only provide data up to 2020; therefore, to enable savings throughout the presumed lifetime of the heat pump, the data has been extrapolated up to 2030. This was completed using the yearly marginal differential for the period 2015-2020 for each respective scenario.

Table 2: Electricity carbon dioxide emission scenarios

Scenario	Description	Reference
Sc 1	Building Regulations 2006	(ODPM 2006)
Sc 2	Static 2005 System Average	(DTI 2007a)
Sc 3	Dynamic Low CO_2 Savings Projection – System Average	(DTI 2007b)
Sc 4	Dynamic Medium CO_2 Savings Projection – System Average	(DTI 2007b)
Sc 5	Dynamic High CO_2 Savings Projection – System Average	(DTI 2007b)
Sc 6	Dynamic Medium CO_2 Savings Projection to 2030 – Peak Marginal Average	(MTP 2007)

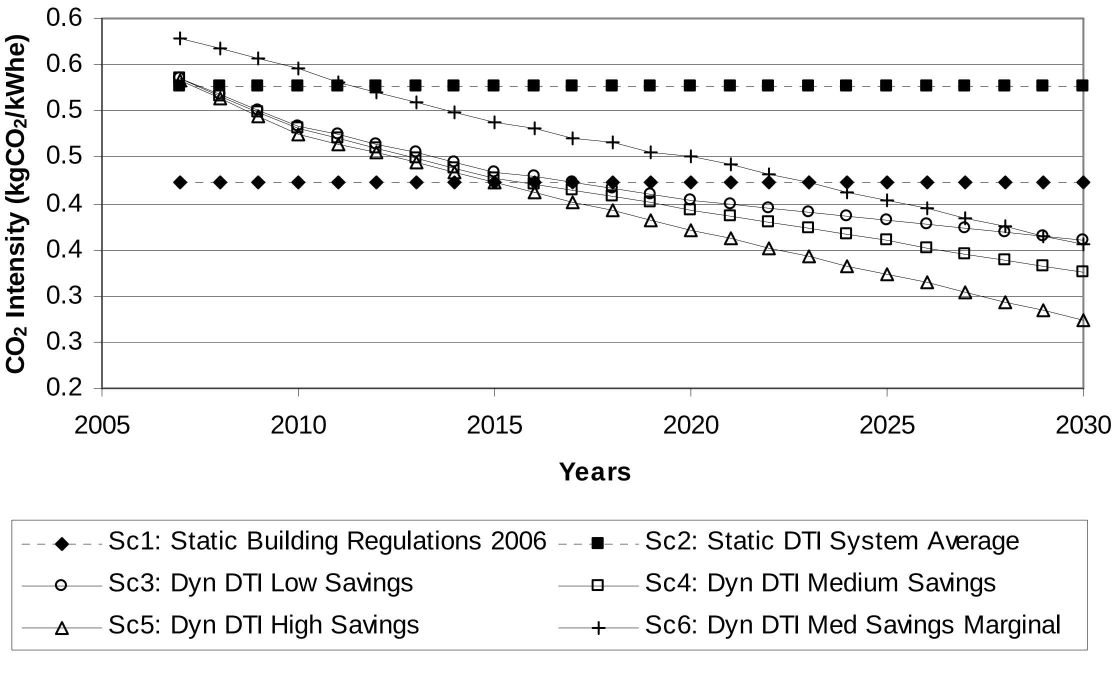

Figure 6: Electricity carbon dioxide emissions scenarios to 2030

From reviewing Figure 6 it easy to understand how differing coefficients can affect the carbon dioxide reduction reporting throughout the lifetime of a GSHP system versus conventional or alternative systems.

4 CASE STUDY

The case study is a new museum in the North West of Scotland. Due to the anticipated delicate nature of some of future exhibits space conditioning was required 24 hours a day. A thermal analysis of the building was completed using the IES[1] software package. The corresponding heating and cooling loads are shown in Figure 7 and Figure 8.

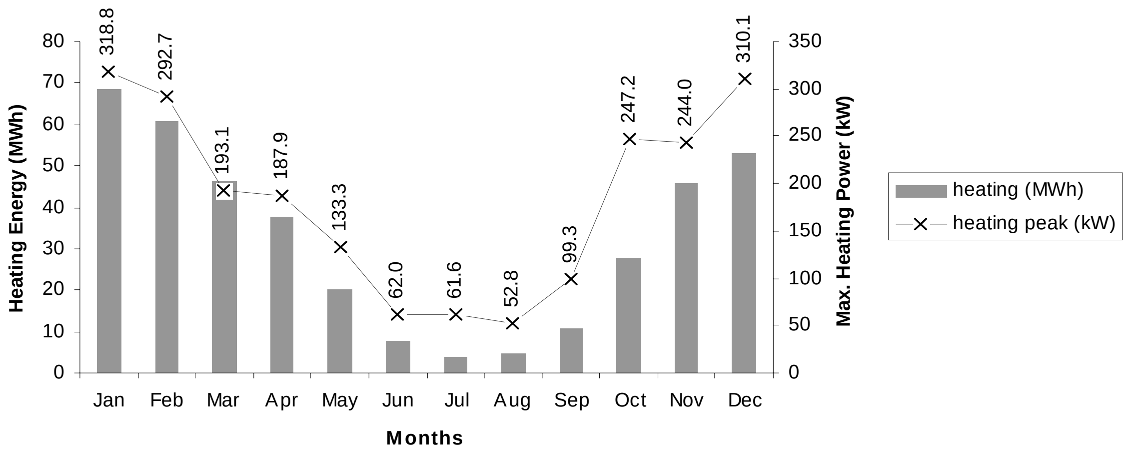

Figure 7: Case study heating loads (MWh/yr and kW)

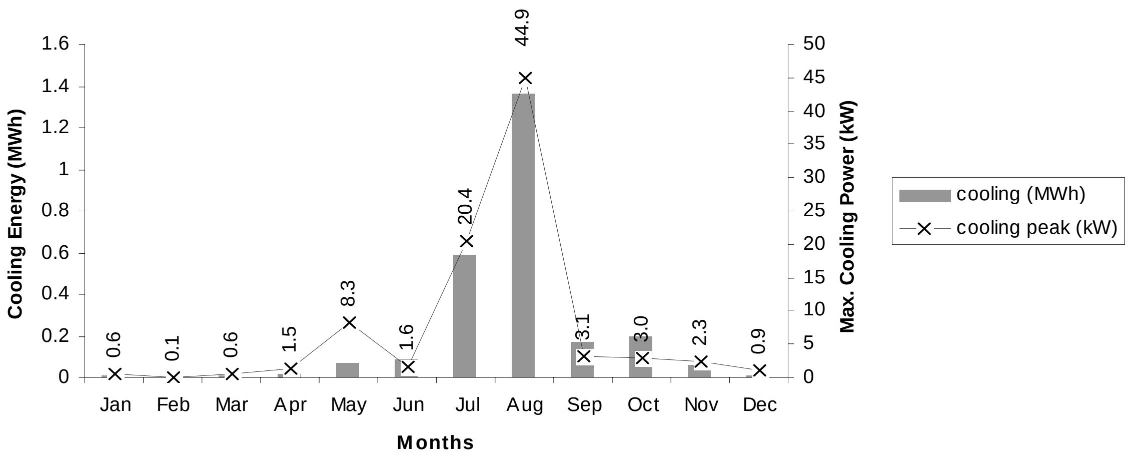

Figure 8: Case study cooling loads (MWh/yr and kW)

It can be deduced that the heating loads, both in maximum capacity (kWs) and energy terms (MWhs), are much greater than the respective cooling loads. This was inherently linked to the location. However, due to the strict minimum and maximum humidity limits, ventilation rates need to be higher than normal leading to increased heat loads for this size of building. Low cooling loads are additionally linked to passive measures such as exposed thermal mass and extensive solar shading, designed into the building.

[1] IES – Integrated Environmental Solutions – www.iesve.com

Following a feasibility of a number of technologies, GSHPs were chosen as the preferred option in order to minimise carbon dioxide emissions and also provide operational savings for the museum trust. Due to the low cooling loads and for practical reasons the cooling loads are likely to be provided using conventional technology. Therefore, the following analysis only considers the corresponding heating loads for the new building.

The GSHP software package, GLHEPro, was used to simulate and size the system (Spitler J.D. 2000). By attributing the performance of a commercially available heat pump to the performance of the ground system it is possible to calculate the required electricity for the system over the operational lifespan and, hence, estimate the respective operational energy costs and carbon dioxide reduction. Figure 9 and Figure 10 show the corresponding projected year on year operational savings and carbon dioxide emissions over the assumed 20 year lifetime for heat pumps.

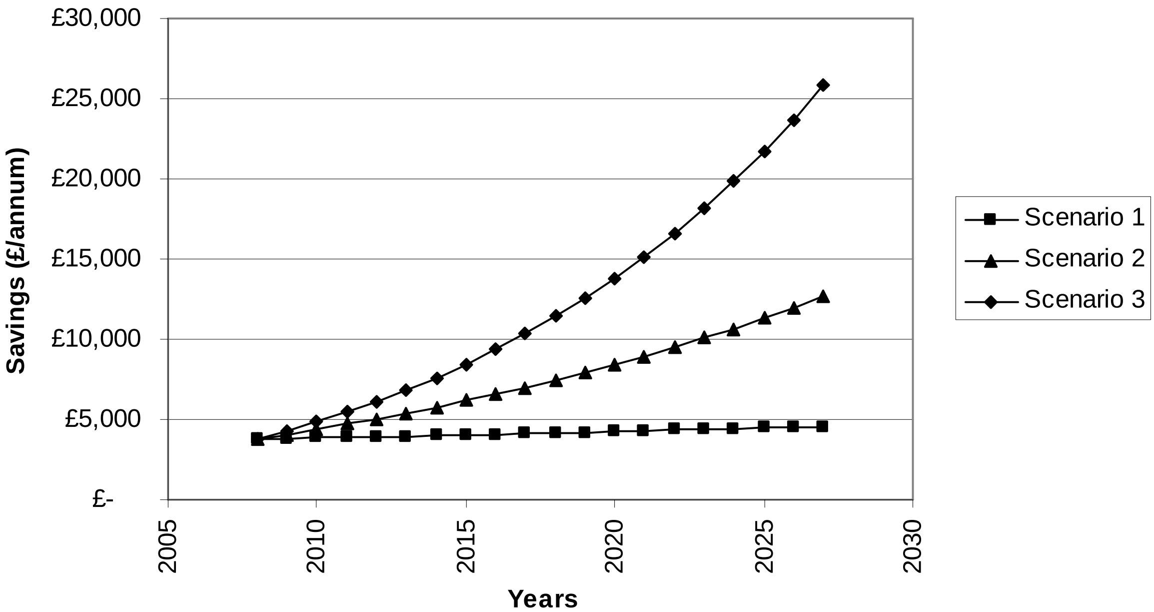

Figure 9: Projected year on year operational savings - GSHP versus gas fired plant

Figure 9 highlights the sensitivity of the economic case to future energy prices with cumulative savings up to 2027 varying from ~£81,000 for scenario 1 to ~£246,000 for scenario 3. The presentation of this scenario analysis becomes particularly relevant when considering the additional cost attributed to the GSHP versus conventional technology. A net present value study is being completed to review the projected payback considering the different scenarios and the anticipated cost of the installation. This may ultimately lead to the consideration of a duel fuel system with less expensive conventional plant to cover peak loads and areas within the building with lower occupancy throughout the year.

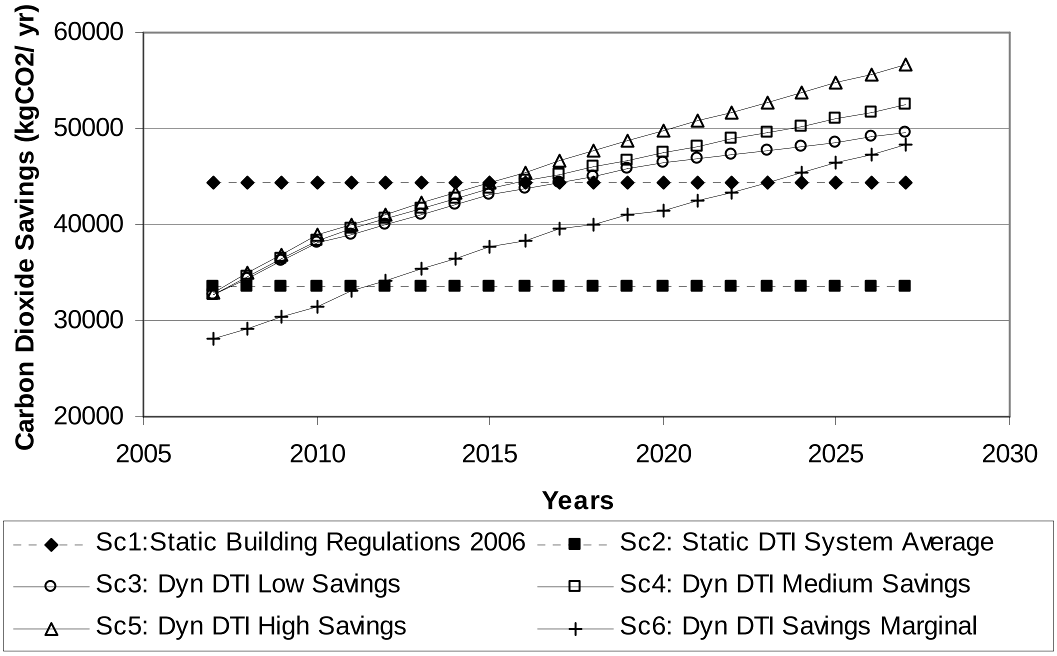

Figure 10: Case study year on year savings

Figure 10 also shows the projected year on year variation using different scenarios. The cumulative savings varies from 735 to 969 tCO_2/yr up to 2027. In parallel to the economic review it may become apparent that a duel fuel approach may be more cost effective considering the equivalent kg CO_2 saved per kW installed. Higher loads are more infrequent so sizing the GSHP system to for example, 30% of the peak capacity (kW), will deliver a much greater percentage of the yearly energy loads (kWh).

5 CONCLUSIONS

This paper has demonstrated the future variability of economic and environmental performance of GSHPs in the context of the UK by reviewing two key parameters, the unit energy prices and carbon dioxide coefficient. By using scenario analysis it has been possible to demonstrate the robustness of the technology in to the long term from an economic and carbon dioxide reduction viewpoint. All the scenarios suggest savings versus conventional technologies.

Although it is essentially impossible to exactly predict future utility prices over the lifespan of a GSHP system or indeed any other comparable technology, scenario analysis can highlight the differing outcomes using considered judgement and short and long term historical data. The development of such an economic model allows the building designer to present financial risk to building developers. This maybe a more complicated model than is usually used for technology appraisal but can be justified as energy prices increase further and when investment decisions can be rolled out across a portfolio of similar projects by a building procurement team, or, in the wider policy context, to drive legislation.

The range in carbon dioxide savings attributed to the adaption of a GSHP in the case study showed that whilst there is still a need for an accepted electricity coefficient for all building designers to use there is also a need to consider how differing scenarios can alter the results significantly. With the adaption of zero or near zero carbon emitting technologies, such as wind, photo-voltaics and biomass heating the incidence of savings are generally less contentious, although the absolute values remain inherently linked to the future generation mix. However, with certain technologies such as heat pumps, particularly air source heat pumps, and gas fired CHP the savings can be marginal and hence scenario analysis is a method to help set limits on respective installation and design practices. For example a minimum COP for GSHPs or a minimum utilisation factor for CHPs can be set to ensure that in all scenarios savings can be realised.

There are a number of areas that remain integral to the optimisation of any technology in the built environment which have not been covered within this paper. These include but are not limited to:

- *Comparisons to other alternatives such as Biomass and CHP and further passive technologies.*
  This is concurrent with the work of Lovins to ensure that the optimum complete building solution is developed rather than an imbalanced focus given to one or a limited number of technologies (Lovins A.B. 1996).

- *A further extension to the GSHP optimisation to consider heat and coolth storage.*
  From an economic viewpoint much lower electricity rates are often available between the hours of 12AM and 7AM. Equally, and as indicated by scenario 6 of the carbon dioxide factor analysis, using electricity to during off-peak periods can reduce carbon emissions. This would need the adaption of different intensity coefficients for each period of the day.

- *Climate Change*.
  A sensitivity analysis of how climatic changes may alter resulting heating and cooling loads over the lifetime of the building.

Whilst there is a reasonable understanding of how well conventional technologies perform in-situ there is still a lack of information regarding the performance of systems that are either immature or new to the UK context. Building designers are forced to use manufacturer's data which may only reflect performance in test laboratories and on day one of installation. Therefore, there is a need to use not only post occupancy evaluation of building performance but also that of the technology. One of the key sets of parameters for GSHPs is the heating and cooling load forced on the ground system. Therefore, as there is uncertainty regarding the building energy requirements there is linked effect to the ongoing performance of the GSHP. An equally important set of parameters is the geological thermal properties which vary throughout the UK and hence can change the relative performance of the GSHP at different sites. The author is continuing research into these areas by using empirical, as well as theoretical data, from a number of installations in the UK and Holland.

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