IMPLICATIONS OF A DECARBONISED GRID ELECTRIC SYSTEM FOR BUILDING EMISSIONS CALCULATION

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ABSTRACT

Achieving the UK Government's green house gas emission reduction targets require significant reductions in emissions from the electricity generation. This has implications for emissions from UK building stock as electrified building services will generate fewer emissions than their fossil fuel alternatives. In reviewing the National Calculation Methodology, which is used to show compliance with Building Regulations, it is found that the use of electrified building services are encouraged as are biofuel district energy systems.

This study considers how two case study buildings under different services arrangements performed in terms of their building emission rate (BER) when the carbon intensity of grid electricity reduces. It is found that the fully-electrified scenarios performed well at all carbon intensities and that at a value of 0.1kgCO2/kWh the fully-electrified scenarios have a lower BER than all others considered including biofuels. Perhaps more significantly it is also found that poorly performing buildings which offset emissions with onsite low/zero carbon generation such as combined heat and power (CHP) or photovoltaic generation are shown to perform far worse under decarbonised grid scenarios. In conclusion it is suggested that current assessment tools could do more to encourage consideration of the impending grid decarbonisation. This study omitted to consider domestic buildings, district energy systems or financial aspects of the design decision process leaving much scope for future investigations.

INTRODUCTION

The UK has committed to reducing greenhouse gas emissions to 80% below 1990 levels by 2050 as part of wider global efforts to tackle climate change. Achieving such dramatic reductions must necessarily involve political, social, economic, and technological change. The Committee on Climate Change (CCC) was established under the 2008 Climate Change Act to advise the UK Government and recommend reductions targets. Based on technical and economic modeling, the committee's scenarios for achieving these targets focus on the UK moving to a 'highly-electric' future in which electricity from low-carbon sources is increasingly used as the main source for heating, transport, power and lighting (Foxton, 2013). If these projections hold sway then the carbon emission factor for grid electricity will be logically reduced.

This emission factor is the average amount of green house gasses emitted from all sources, converted into an equivalent value of carbon dioxide, divided by the total amount of electricity generated. It is measured in kilograms of carbon dioxide equivalent per kilowatt-hour (referred to as $kgCO_2/kWh$ in this paper).

With a design life of 50 years and a useful life of around 25 years (Tse, 2010), non-domestic buildings being designed and built in the present, based on current emissions factors, will be sensitive to changes in this value. Assuming that the carbon emission factor for grid electricity continues to fall it has important implications for assessing not just the performance of a building but also its whole-life carbon emissions.

The carbon emission factor of grid electricity is used to calculate the emissions from buildings in the Standard Assessment Procedure (SAP) for dwellings, the Simplified Building Energy Model (SBEM), and Dynamic Simulation Modeling (DSM). It is also used in the production of Energy Performance Certificates (EPCs) and Display Energy Certificates which give buildings a recognisable and comparable energy performance rating from G (poor performance) to A+ (high performance) similar to that used for electrical appliances. In addition to these uses the factor is also commonly used by designers in dynamic thermal models to assess the impacts of design changes to the passive form and active systems.

Achieving low carbon emissions from buildings is increasingly becoming not just a legal requirement but also a client desire as building owner/operators seek to achieve their own environmental targets. Under such pressures the emphasis is on designers to advise the best combination of building form and services based on their knowledge and the performance information available to them.

This paper will review the role of building regulations in reducing emissions from buildings. We will then look at two case study non-domestic buildings under different building services design scenarios to see how variations to the grid electric carbon emission factor affect their emission rates. Finally this paper will discuss how application of variable emissions factors might affect design decisions

THE ROLE OF BUILDING REGULATIONS PART L IN REDUCING EMISSIONS FROM BUILDINGS

In England Part L of the Building Regulations sets out minimum energy performance criteria for new buildings and most buildings undergoing refurbishment. For new buildings other than dwellings, compliance with those parts of the regulations relevant to the conservation of fuel and power is met and evidenced by achieving five criterions that focus on the efficient performance of the building's building services and passive design and ensuring suitable provision for users to efficiently operate the building. These criterions are in line with the recommendations of the Climate Change Committee for reducing carbon emissions from buildings (CCC, 2012) and form part of a wider scheme (which includes the production of EPCs) to meet the European Energy Performance of Buildings Directive.

Compliance with Criterion 1 for non-residential buildings is proven using either the Government's approved Standard Building Energy Model (SBEM) or Dynamic Simulation Modelling (DSM), which both follow the National Calculation Method (NCM). This calculates the annual emissions rate per m^2 value for the actual building (the building emission rating or 'BER') and compares it to a target emission rating (TER) derived from a notional building of the same type and scale.

The NCM sets out emission factors to use when calculating the TER. The values are given in the NCM guidance as $kgCO_2/kWh$ and as of 2012, the values are weighted to account for the effects of the associated nitrous oxide and methane and include for upstream transport emissions and emission sources outside of the UK (BRE, 2011). Both the TER and BER values are given as a kgCO2/m2·annum value, this incorporates the energy consumed by building systems multiplied by a 'primary energy factor', a measure of the primary energy required per unit of energy delivered. Electricity currently has the highest emissions factor of any fuel but the regulations do not specify which active technologies should be used to meet the TER; because both the Notional and the Actual building models use the same fuel sources compliance can be achieved with an entirely electric building, however conventions in the methodology mean that this can only be achieved through use of heat pumps or similarly efficient technologies.

In the 2013 edition of the NCM fuel use in the Notional building is set to match fuel use in the Actual building. To ensure electricity is used efficiently heat pumps and direct electric heating are treated differently. The emissions factor for grid electricity in the Notional building is much lower than that for the actual building meaning that to match the emissions an efficiency of 133% would be required.

Similarly to heat pumps, the use of district heating systems fuelled by either biofuels or waste heat are encouraged; the equivalent efficiencies required of these systems in the Actual building are much lower than the efficiencies that would be required of a similarly fuelled boiler or CHP. This is due the Notional building's emission factor for district heating having a floor of $0.15kgCO_2/kWh$ when heat supplied to the Actual building has an emission factor below $0.15kgCO_2/kWh$; biogas, biomass and waste heat all have a factor below this figure ($0.098kgCO_2/kWh$, $0.031kgCO_2/kWh$ and $0.058kgCO_2/kWh$ respectively). The resulting effect is that to match the notional building's 63% efficient biomass burning plant the actual building need only achieve an efficiency of 15%.

Another amendment incorporated into the 2013 edition of the Building Regulation, regulation 25A, introduced a requirement on the person responsible for carrying out the construction of a new building to show evidence that the technical, economic and environmental feasibility of high-efficiency alternative systems have been considered. The technologies listed coincide with the CCC's 2012 conclusions on how to reduce emissions from buildings, namely heat pumps, bioenergy and district heating (CCC, 2012).

Alongside the need to ensure compliance, environmental aspirations of building owner/operators can influence design decisions. BREEAM (the Building Research Establishment Environmental Assessment Methodology) is a widely recognised voluntary rating system that scores buildings against a set of sustainability criteria. The ability of the building design to improve upon the TER (and other performance aspects of the Notional building) is a key factor in achieving a high BREEAM rating. Achieving prescribed levels of compliance with BREEAM is increasingly written into building owner/operator employer's requirements including the British Government who as of 2011 requires all their new buildings to achieve as a minimum a BREEAM 'Excellent' rating (DEFRA, 2011).

BREEAM criteria cover a wide range of sustainability issues including the way construction is managed, the health and wellbeing of building users, water conservation, materials used, waste at all stages of the building life, impacts on local ecology, transport and building location, pollution and of course energy (BRE, 2014a). Many of the energy credits within the BREEAM scheme target the use of efficient equipment and controls or energy monitoring, such improvements will improve the overall performance of the building regardless of its primary fuel source. BREEAM energy criteria 'Ene 01' and to a lesser extent 'Ene 04' are concerned with emissions from the building:

Ene 01 weighs the performance of the actual building against that of the notional building using an Energy Performance Ratio.

Ene 04 encourages the designer to consider how energy demand may be reduced through passive design and the use of free cooling. It also encourages the consideration of low and/or zero carbon (LZC) technologies (though does not enforce their use). This reinforces the regulatory requirement to carry out a feasibility study however the legal obligation is only for this to be conducted 'before construction'. The purpose of Ene 04 is 'to encourage the study to be done early in the project, not just before construction starts, so that the most appropriate solutions can be adopted' (BRE, 2014a). The important thing to note is that the basis of the feasibility study in both BREEAM and the building regulations is a comparison of carbon emissions from different scenarios. These scenarios are based on current emission factors and do not necessarily consider future changes to these values. It is because of this that a building which currently out performs alternatives might perform worse in the long term from an emissions perspective as a result of a decreasing grid electricity carbon intensity (GECI). This has not gone unnoticed by the BRE, who advised on values for the NCM; alongside the emissions ratings used for the SBEM calculations they have published emissions factors for a 15-year projection (2013-2027) which they suggest "*may be relevant to consideration of longer term impacts*" when calculating emissions (BRE, 2013; BRE, 2011). It is this issue of how a changing grid carbon intensity will affect building emissions which lies at the heart of the second half of this report and will be explored in the following sections in more detail.

METHODOLOGY

In order to show how the changing carbon intensity of the grid electric system will affect emissions from buildings we will consider two models based on real buildings under different building systems arrangements and compare these based on:

- the margin by which their BER meets or exceeds the building TER;
- the as-designed EPC score and building asset rating

A sensitivity analysis will then be carried out on the BER to see how each case performs under a range of grid carbon intensities by varying this value and again comparing the BER ratings for each case. This will be carried out using Microsoft Excel.

A note on the Notional building

Within the UK, devolved administrations operate different building regulations for energy and although they use the same methodologies and approved calculation software, they have different definitions for the 'Notional' building and set different levels of baseline performance (BRE, 2014a) the methodology used in this paper is based on the 2013 Building Regulation for England.

Building compliance calculations

Using the UK Compliance module of IES VE the buildings will be assessed based around a common passive building and lighting design with the only variables being the active services systems for heating, cooling and domestic hot water (DHW).

Systems within the two case study buildings will then be set up in line with the scenarios described in the case study section.

For each scenario, a Building Regulation Part L Compliance (BRUKL) report and an EPC will be produced giving a comparable result for each building and showing that the designs are compliant with regulations. The EPC ratings give an indication of how the building's performance is perceived under current conditions. Details of how the EPC ratings are calculated are given in brief later in this section of the report.

The UK Compliance module of IES VE is an approved software for the calculation of building emissions to show building regulations compliance and follows the NCM. The software calculates an emission rating for the 'Actual' building (BER) and an emissions rating for a 'Notional' building (TER). Both the Notional building and the Actual building use the same user defined model geometry. For the purpose of the NCM the model geometry should be as close as possible to the real building geometry.

Under the 2013 edition of the building regulations the TER for a building is equal to the emissions rating from the Notional building as calculated using the (NCM) with no further adjustments being made. To comply with Part L of the regulation the BER of the Actual building must be equal to or less than the TER

The Notional building represents the minimum acceptable standard for a building covered by the regulations in terms of passive design and active systems specification. To allow accurate comparison between the Actual and Notional building certain operating parameters for both models are fixed and defined by the NCM:

- The systems for both buildings operate on a pre-defined schedule as set out in the NCM.

- Internal gains for both buildings will use pre-defined values from the NCM.
- The weather data used to assess Criteria 1 is the test reference year (TRY) which is incorporated into the IES compliance module. TRY weather data sets are available for a number of locations around the UK and the nearest available location to the actual location is used.

The Notional building varies from the Actual building in its construction and system performance parameters:

- Systems in the Notional building will be based on the user selections for the Actual building but with pre-defined NCM performance values. The performance values for the Actual systems are user defined and should improve upon those of the Notional building.
- The construction elements of the Notional building will be based upon values set-out in the NCM.

EPC Calculation

The EPC calculation is another integral function of IES VE Compliance. The EPC gives the following data:

- Asset rating = 50xBER/SER (Standard Emission Rate (SER) based on 'Reference' building)
- A rating between G and A+ based on the asset rating, with 'A+' being the highest performance
- Comparable data for 'performance of typical building' based on a building built to 1995 Part L standard

CASE STUDY BUILDINGS

Brine Leas School

Brine Leas Sixth Form is located in Nantwich, England. Space heating is provided using gas-fired boilers distributed using a central air handling unit (AHU). Where required air conditioning is supplied using 'split' units. Domestic hot water (DHW) is preheated using solar thermal panels supplemented by stand-alone hot water heaters(Xie, 2012).

Case 1 – Space heating is provided by a high-temperature air source heat pump (ASHP) via a wet distribution system with radiators. Where cooling is required this is provided with reversible 'split' unit systems which also provide heating.

Case 2 – All rooms are served using a centralised variable refrigerant flow (VRF) system. The building benefits by offsetting rooms that need cooling against those that need heating resulting in a high seasonal efficiency.

Case 3 – Space heating is provided by a condensing gas boiler via a wet distribution system with radiators. Where cooling is required this is provided with reversible 'split' unit systems which also provide heating.

Case 4 – As Case 3 but with a wood-pellet fuelled boiler.

Case 5 – Space heating and DHW are provided by a low-efficiency gas boiler (LEB) via a wet distribution system with radiators. Where cooling is required this is provided with reversible 'split' unit systems which also provide heating. The flat roof of the building is used to install a photovoltaic (PV) electric generation system. Based on the scenario of the building having an existing boiler which the owner wishes to retain, this case allows us to explore a scenario in which compliance is met only through the use of ad-hoc low/zero carbon generation technologies. For this case a model will be run both with and without the PV array (Case 5a and 5b respectively) to show the performance improvement due to PV.

Worthing Pools

The Worthing Pools project was a landmark leisure centre on the West Sussex coast. The building was designed by Wilkinson Eyre Architects who worked collaboratively with AECOM. The original services design incorporated a large ground source heat pump (GSHP) system providing cooling and low temperature heating whilst a CHP combined with condensing boilers provided high temperature heat for pool water and air heating.

It is worthy of note that the SBEM and the NCM do not have provision to allow for swimming pool loads. In the 2013 revision of the NCM swimming pools are not drawn in the model geometry and instead the surface area is treated as though it was an exposed ground floor although recommended maximum U-values for the pool enclosure are given(BRE, 2014b).

In practice a swimming pool often represents a good financial case for the use of a combined heat and power (CHP) generator. The plant is sized to supply the base heat load of the pool water and the building benefits from electricity that is produced as a side-product. The emissions 'pay-off' for a CHP is analogous to the financial one, additional emissions from increased gas consumption are offset by the equivalent emissions reduction from displaced grid electricity(B&ES, 2015).

Case 1 – Space heating, and cooling are served by a ground source heat pump (GSHP), taking advantage of the buildings simultaneous need for both heating and cooling. DHW supplied by high temperature ASHP. The pool water heating load is not considered but given a sufficiently sized system the demand could also theoretically be met by an ASHP.

Case 2 – Heating and DHW served by a high efficiency condensing gas fired boiler, cooling supplied by electric fuelled, air-cooled chiller. Distribution via both wet and air systems.

Case 3 – 10% of space heating and 100% DHW supplied by a natural gas fired CHP combined with a high efficiency condensing gas fired boiler.

Case 4 – 10% of space heating and 100% DHW supplied by a biomass (wood pellet) fuelled CHP combined with a high efficiency condensing gas fired boiler.

RESULTS, ANALYSIS AND DISCUSSION

Brine Leas

Table 1 TER, BER fuel consumption and EPC rating results for Brine Leas scenarios from IES VE Compliance modelling

Scenario	TER ($kgCO_2/m^2$)	BER ($kgCO_2/m^2$)	Gas (kWh/m^2)	Biomass (kWh/m^2)	Electricity[1] (kWh/m^2)	EPC Band/ Asset Rating
Case 1	14.7	12.8	0.0	0.0	25.4	A/25
Case 2	16.1	11.1	0.0	0.0	21.9	A/22
Case 3	15.5	15.2	29.0	0.0	17.7	B/30
Case 4	11.8	9.7	0.0	37.4	17.1	A/19
Case 5a	15.5	9.5	34.3	0.0	17.7	A/16
Case 5b	15.5	26.3	34.3	0.0	17.7	B/32

Table 1 shows results for the five Brine Leas scenarios. The low efficiency boiler with PV scenario has the lowest BER closely followed by the biomass boiler. The ASHP and VRF scenarios perform better than the gas boiler scenario. The biomass option consumes more energy than the gas alternatives due to the lower thermal efficiency of the wood pellet burning boilers however the low emissions factor for biomass means it still achieves a lower BER than most other scenarios.

The scenarios in Cases 1, 2, 4 and 5a all achieve an EPC A rating. The high efficiency condensing gas boiler performs the worst out of all scenarios in terms of BER and EPC rating.

As would be expected the two full electric scenarios (Cases 1 and 2) both benefit significantly from any drop in GECI. As the GECI falls the emissions offset by the PV in the LEB+PV (Case 5a) scenario become far less significant and the system quickly becomes one of the worst performing. As the GECI value approaches 0.1$kgCO_2$/kWh, which is the value set by the DECC as a target GECI by 2030(DECC, 2014) the LEB+PV (Case 5a) becomes the second worst performing scenario. Coincidentally this is the same value at which the high-temp ASHP (Case 1) begins to outperform the biomass option (Case 4) (see figure 1).

Why the low efficiency boiler with PV scenario passes and why it fails

With a low efficiency boiler (relative to the Notional building) the building's BER exceeds the TER and fails Criterion 1 (see table 1), however as long as services meet minimum efficiencies set out in Criterion 2 designers are free to off-set the emissions by improving other elements of the design, for example by reducing U-values or air leakage. This convention also means that high emissions can also be offset by installing zero-carbon electric generation technologies such as PV. In this scenario, by installing a relatively large system the resulting building not only passes but outperforms the other scenarios. However, as the GECI falls the emissions offset by the PV system have less of an impact on the BER and the building's underlying performance becomes more apparent. Without PV, grid electricity is still a significant contributor to total building emissions and the falling GECI has a sharper impact on reducing the BER.

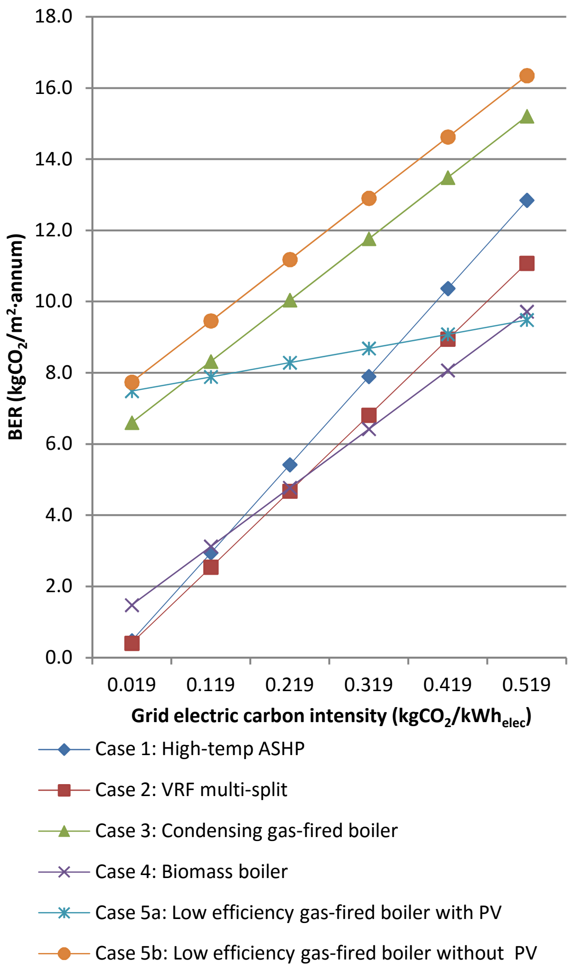

Figure 1 Brine Leas BER values under changing grid carbon intensities

[1] Value is consumed electricity only, grid displaced electricity is not shown however this value is incorporated in the graph in figure 1.

WORTHING POOLS

For the Worthing Pool scenarios it is an all-electric system (Case 1) that achieves the lowest BER and is the only building to achieve an EPC A rating (see table 2). Both the gas-fired and biomass CHP scenarios (Cases 3 and 4) show only a small improvement over the gas boiler (Case 2) but this may be an unfair representation of the CHP due to the low load apportioned to it (see figure 2).

Table 2 TER, BER fuel consumption and EPC rating results for Worthing Pool scenarios from IES VE Compliance modelling

Scenario	TER ($kgCO_2/m^2$)	BER ($kgCO_2/m^2$)	Gas (kWh/m^2)	Biomass (kWh/m^2)	Electricity[1] (kWh/m^2)	EPC Band/ Asset Rating
Case 1	105.4	79.6	0.0	0.0	157.3	A/21
Case 2	126.5	123.2	411.8	0.0	67.6	B/33
Case 3	126.5	122.5	416.3	0.0	67.6	B/33
Case 4	124.6	117.6	407.8	11.3	67.6	B/31

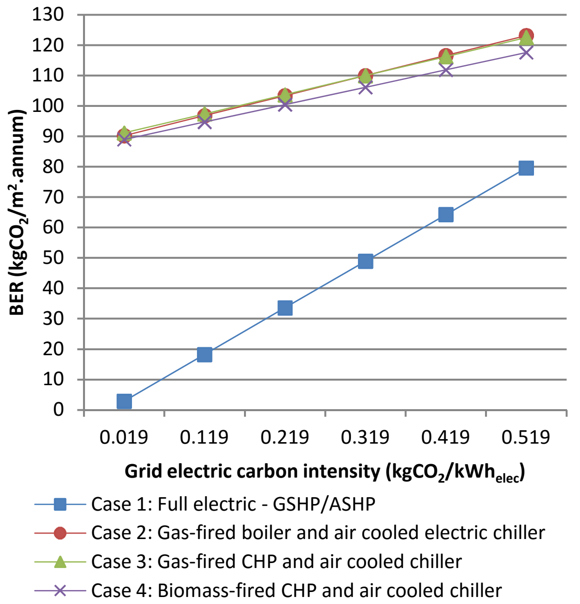

Figure 2 Worthing Pool BER values under changing grid carbon intensities

The building's heat and DHW lead demand mean that the fuel for this has the most significant impact on emissions. In the Gas Boiler, Gas CHP and Biomass CHP scenarios electricity plays a small role in overall emissions meaning a changing GECI is slow to impact and a 90% reduction in its value results in only a 27% / 26% / 24% reduction in overall emissions respectively (see figure 3). Under the all-electric scenario emissions are directly proportional to GECI and at 0.1$kgCO_2$/kWh achieves

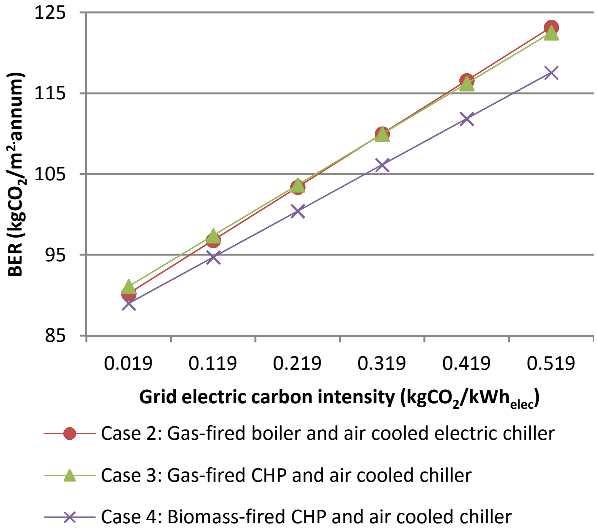

Figure 3 Emissions factor for CHP heat relative to grid electricity emissions factor

an 81% reduction in building emissions relative to current levels.

In figure 2 the all-electric scenario (Case 1) performs so well that it makes it difficult to compare and contrast the other scenarios. Figure 3 shows the results for the gas boiler, CHP and biomass CHP scenarios only (Cases 2, 3 and 4). As GECI reaches 0.3$kgCO_2$/kWh the gas-fired boiler (Case 2) BER drops below that of the CHP scenario (Case 3) (though the biomass CHP (Case 4) out performs both scenarios). To understand why this happens it is necessarry to look at how emissions from the CHP are calculated.

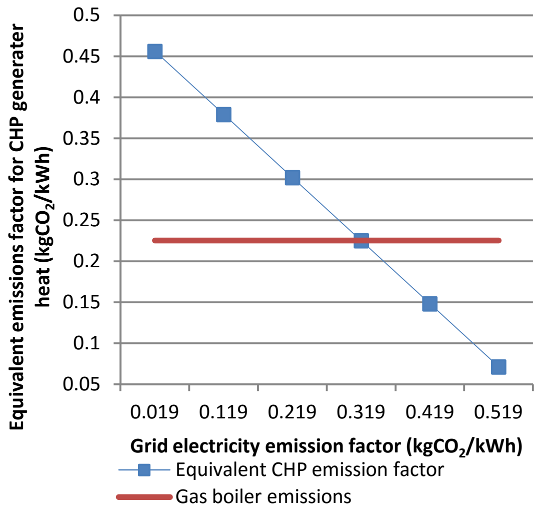

Figure 4 Equivalent emissions factor for heat generated by a gas fired CHP compared to condensing gas boiler

Figure 4 shows equivalent emissions factor for CHP generated heat relative to GECI compared to emissions for a condensing gas fired boiler with a season coefficient of performance (SCoP) of 95.75%

based on equation 1. The carbon intensity of CHP generated heat is inversely proportional to the GECI value. The low thermal efficiency of the unit (36%) results in almost twice as much fuel consumption compared to the boiler but this is offset by the higher emissions rating of displaced grid electricity. As with the LEB & PV scenario for Brine Leas, when value of the emissions offset by displaced grid electricity fall the systems underlying thermal efficiency becomes apparent.

$$CHP\ Emission\ Factor = \frac{1}{H} \times (F \times CO_{2F} - E \times CO_{2E}) \quad (1)$$

Swimming pool heating loads have not been included in either the plant loads or the energy demand calculations as the software does not include a suitable facility for this and therefore the associated emissions are not shown. For the purpose of this study it does not pose a significant problem as the load can be considered akin to an equipment load i.e. its presence would proportionally increase the energy consumption of all models.

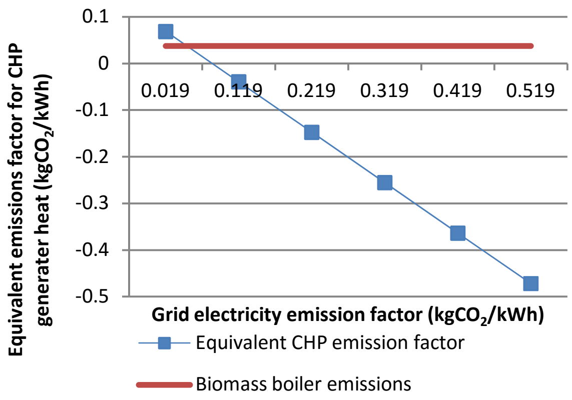

Figure 5 Equivalent emissions factor for heat generated by a biomass CHP compared to biomass boiler

DISCUSSION

For both the Brine Leas and Worthing Pool case studies, the all-electric scenarios perform well, with the GSHP (Case 1) showing the lowest BER for Worthing Pools under current emissions values. As they are entirely electric fuelled they logically benefit from any decrease in GECI and continue to outperform other scenarios under decreasing values of GECI. It is worth noting that the all-electric scenarios employ relatively high performance energy sources and this is a considerable contributing factor towards their low BER ratings. These results are in line with earlier work by James and Edwards (2009) who explored the performance of electric heat pumps compared to gas fuelled alternatives under a decreasing GECI for domestic heating. They found that by switching from an efficient gas boiler to a heat pump emissions reductions of around 60% could be achieved by 2020 if the carbon intensity of grid electricity was reduced to 0.294kgCO_2/kWh.

For the case study a gas fired CHP does not represent the best option under a decreasing GECI scenario but the same cannot be said for the biomass CHP. Figure 5 shows how a biomass CHP with a system efficiency of 87.0% performs against a biomass boiler with an efficiency of 83.03%. Biomass already offers a low-carbon fuel source; by offsetting this against grid electricity the technology effectively offers heat with a negative emission factor. Even at a GECI of 0.05kgCO_2/kWh the equivalent emissions factor for heat generated by the biomass CHP remains slightly below that of a biomass boiler.

Both the Worthing gas-fired CHP and Brine Leas LEB & PV scenarios highlight the impact a decarbonised grid electricity supply has for the way building performance is measure. Those buildings which offset poor underlying performance through the use of on-site generation perform far worse under GECI values which are already being set as near-term targets for the generation sector (DECC, 2014).

How then might the impact of future reductions in the GECI be better demonstrated to designers and building owners using existing tools? One way might be to use the existing feasibility study requirement of the building regulations and BREEAM scheme. By including a requirement for a whole life study which incorporates an annual GECI decrease factor. By giving an additional BREEAM credit for carrying out feasibility studies incorporating this factor at an early stage, design teams might be encouraged to pursue this as an easy target. Design teams armed with this information might be able to make better informed design decisions.

Another way BER sensitivity to emission factors might be made clearer is though the addition of simple table on EPCs as illustrated in figure 6. The data in figure 6 is based on the gas-fired CHP scenario for Worthing Pools, for this case the BER improvement over the TER increases as the GECI falls.

CONCLUSIONS

This study has shown that the current building regulations mean it is easier to improve a building heated with an efficient electric heat pump than one heated with an efficient gas fired boiler due to the Notional building's gas-fired plant being very highly specified relative to the natural efficiency limit of such systems. This leaves designers to choose either CHP or bio-fuels to overcome this barrier or to invest in improving the passive building performance (for example by trying to better the already challenging Notional permeability value of 3m^3/m^2·hr@50Pa).

For buildings trying to achieve a high BREEAM rating which depend on the Ene01 criteria and require a large margin of difference between the BER and TER, the availability of theoretically very high performing heat-pumps (relative to 2013 Notional efficiency values) means that electricity alongside biofuels offer the best option for designers, builders and clients.

Consideration of the long term impact of a decarbonised grid and changing emissions factors could feasibly be incorporated into the current Building Regulation assessments, or into the BREEAM scheme to incentivise designers by making this an 'easy win' target point within the existing scoring system which might bring knowledge of the long term performance of building services under different future energy scenarios to the attention of building owner/operators and other interested stakeholders at an early enough stage to influence final building services selections.

This study has omitted to consider several key aspects affecting the future of UK building stock leaving much for future research; in particular a wider range of services systems and building types should be reviewed including the domestic sector and the effect of financial considerations on design decisions should be explored.

<table>
<tr><th colspan="3">WORTHING POOLS</th></tr>
<tr><td colspan="2">Under current Emission factors the building BER is:</td><td>122.5 kgCO2/m2·annum</td></tr>
<tr><td colspan="3">However emissions associated grid supplied electricity are expected to fall in the near future. Under these circumstances the BER would be as follows:</td></tr>
<tr><td>Electricity emission factor (kgCO2/kWh)</td><td>BER (kgCO2/m2·annum)</td><td>TER (kgCO2/m2·annum)</td></tr>
<tr><td>0.4</td><td>115.1</td><td>120.5</td></tr>
<tr><td>0.3</td><td>108.8</td><td>115.5</td></tr>
<tr><td>0.2</td><td>102.5</td><td>110.4</td></tr>
<tr><td>0.1</td><td>96.2</td><td>105.4</td></tr>
</table>

Figure 6 Example of a simple table that could be added to EPCs to show sensitivity of BER to grid electricity carbon intensity

NAMENCLATURE

H, Useful heat (kW)

F, Fuel consumed (kW)

CO_{2F}, Emission factor for fuel (kgCO$_2$/kWh)

E, Electricity Produced (kW)

CO_{2E}, Emission factor for grid electricity (kgCO$_2$/kWh)

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