Enabling the information society

Data Centre Energy Re-Use Metrics

A review of proposed metrics and a suggested new data centre metric:
Data Centre Source Energy Ratio (DC SER)

Contents

1. Abstract

One unavoidable fact about data centres, whatever we do to make them more efficient and no matter what efficiency improvement they provide elsewhere is that they consume a lot of energy. As data centre efficiency improves and further infrastructure efficiency gains become more difficult an area receiving an increasing amount of attention is re-use of the power that data centres turn into heat.

Clearly, if a data centre re-uses some or all of the consumed energy for some other purpose this should be recognised in efficiency metrics but how should we measure this? Of particular significance is the fact that the PUE of the data centre is likely to be worse in the heat re-use scenario due to the efficiency achievable by economised cooling systems which dump the heat to the atmosphere compared to the additional energy cost of heat pumps to raise the waste heat to a temperature where it is useful.

This document presents an example data centre with heat re-use and explores the options for how this could be represented in efficiency metrics. The main example is based on a UK site and one of the key issues which will arise during the analysis is that the level of energy saving and the applicability of metrics vary considerably with the local conditions.

1.1 Conclusions

This paper concludes that:

1. There is no simple method of incorporating data centre energy re-use into existing metrics such as PUE

2. The selection of the preferred method for energy re-use reporting is likely to depend upon the relative weightings given to energy efficiency versus carbon emissions as the level of source energy saving is only occasionally directly equivalent to the carbon saving.

3. Simple kWh subtraction of the energy re-used from the utility energy consumed by the data centre as in the proposed Green Grid ERE (Energy Reuse Effectiveness) metric is unrepresentative and misleading as the types of energy are frequently different and therefore cannot be usefully compared

4. To understand the efficiency improvements (if any) of the energy re-use system the metrics must use comparable values for energy. This requires the source energy consumption of the data centre and not just utility electrical kWh – a metric "Data Centre Source Energy Ratio" DC-SER is proposed as a working example

5. The different methods of calculating this DC-SER metric produce substantially different values for the example scenarios, the reader is invited to make their own determination of which method of calculation best combines practicality, portability and effectiveness of reporting

6. In contrast to metrics for other types of building the source energy efficiency and carbon intensity of the electrical supply to the data centre[1] must be considered to achieve a useful metric or comparative evaluation of efficiency

7. A metric such as Data Centre Source Energy Ratio would allow for the option to give renewable energy sources a weighting factor of < 1 to represent the perceived benefit of renewable sources

[1] Whether this is utility grid, onsite generation of a mix

8. The ideal metric considers the source energy or source carbon mitigated by the energy re-use, but for practical reasons an agreed approximation method as discussed in section 8 is likely to be necessary

2. Analysis method

In this paper a brief analysis of an example data centre both with and without a heat re-use system is used as an example with which to evaluate some proposed metrics for data centre energy efficiency and energy re-use.

2.1 Metrics

The key parameters which are tracked and assessed as indicators through the analysis are;

Overall source energy consumption and carbon emissions

The overall energy consumption (kWh of source energy[2] per annum) and carbon emissions (kg CO_2) of the entire system, data centre and heat re-use target are considered and the overall benefit of the heat re-use determined in energy and carbon.

PUE

The PUE of the data centre under each option, both as a simple electrical PUE and as a "modified PUE" which attempts to capture the heat re-use energy.

$$PUE = \frac{IT\ Load\ +\ Infrastructure\ Losses}{IT\ Load}$$

Data Centre Source Energy Ratio

The proposed metric which tracks the source energy consumed by the utility grid (or onsite cogeneration) to deliver each kWh of electricity to the IT equipment;

$$SER_{DC} = \frac{Primary\ Energy_{Power\ Station}}{IT\ Energy}$$

IT carbon intensity

The carbon intensity of the electricity delivered to the IT equipment, including data centre infrastructure losses but less any benefit from the heat re-use system. Note that this is essentially the Green Grid CUE metric.

$$IT\ Carbon\ Intensity = \frac{Total\ emissions\ to\ deliver\ power\ kg\ CO_2}{IT\ Energy\ Consumption\ kWh}$$

2.2 Note on the efficiency of the utility electrical supply

In some building efficiency metrics weightings are deliberately constructed to exclude the energy or carbon efficiency of the utility electrical supply to the building. For example from the EPA building benchmarks;

"EPA uses national average ratios to accomplish the conversion to source energy because ENERGY STAR is a national program and because the use of national average source-site ratios ensures that no specific building will be credited (or penalized) for the relative efficiency of its energy provider(s)."[3]

In the case of the data centre this is not desirable for a number of reasons;

[2] Source energy is the energy used at the primary fuel source, e.g. the coal consumed at the power station to produce the grid electricity delivered to the data centre

[3] http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs

When constructing a commercial building such as an office or retail premises there is no reasonable opportunity to choose a location with a different efficiency or carbon intensity of utility electrical supply. For the building to meet requirements it must be within a relatively small geographical area. This is not generally a constraint for data centres, most equipment in data centres is managed remotely, be that from 10 feet or 10,000 miles and with the exception of certain low latency requirements, relocating the data centre to another state or country to take advantage of higher efficiency or lower carbon utility electrical supply is quite practical. There is also a strong argument that, given the scale of energy use by data centres, the selection of sites based on utility efficiency or carbon intensity could influence the construction of cleaner and more efficient power stations.

Many consumers of data centre services will wish to be able to determine the overall energy efficiency or carbon intensity of the data centre(s) from which their services are delivered. To support this market in high efficiency or low carbon intensity services it is necessary to include within or preserve the ability to, apply the local utility or onsite generation supply efficiency and intensity data to data centre metrics.

3. Example data centre

To illustrate the options available for recognising energy re-use in metrics we will use an example data centre, first as a standalone building to establish the base case for comparison and then with a district heating system delivering the waste heat from the data centre to nearby residential housing.

Given that a data centre with heat re-use into a district heating system is likely to be a new build I will assume in all cases the modern technology and efficiency that would be expected in a new build. Comparing new build data centre technology with 20 year old domestic heating or data centre technology would not be useful. Both the data centre and domestic heating systems will be represented using relatively coarse annual averages for energy consumption and efficiency. Note that this makes the values for power and hourly energy consumption interchangeable.

The example data centre has an IT electrical load of 850kW, the infrastructure losses excluding the cooling plant are 150kW. The data centre is of modern design and uses a modest 23°C[4] air supply temperature from the CRAC units facilitating the use of economised cooling.

The residential housing requires an average over the year of 1,000kW for heating and hot water.

Four options will be explored to assess the efficiency and applicability of metrics;

A. Separate data centre and domestic heating
B. District heating system subtracting re-used energy from the data centre utility draw
C. District heating system considering re-used heat to be “free”
D. District heating system subtracting the saved energy from the data centre utility draw

Note that the specific numbers for data centre or heating energy consumption are not important, the numbers need only be representative as they are used only to evaluate the metrics. The data centre and domestic heating will be primarily evaluated using carbon intensity and source efficiency numbers for the UK.

[4] Whilst this is relatively low it is a realistic set-point for a contained air flow facility with a conservative IT environmental envelope

3.1 Case A – Separate systems

The first case is where the data centre and the nearby residential housing are separate systems; this provides the baseline case against which we can evaluate the energy efficiency improvement of the district heating system and compare how effectively the various metrics capture this.

Data centre

In this case the data centre is cooled by a set of modern free cooling chillers which operate in full or partial free cooling mode for much of the year. This free cooling system achieves an annual average CoP[5] of 10 and therefore requires an average 100kW of electrical power to deal with the 1,000kW of heat load presented by the data centre.

IT Load	Infrastructure losses	Cooling system losses	Overall utility draw
850kW	150kW	100kW	1,100kW

Table 1 Case A electrical delivery

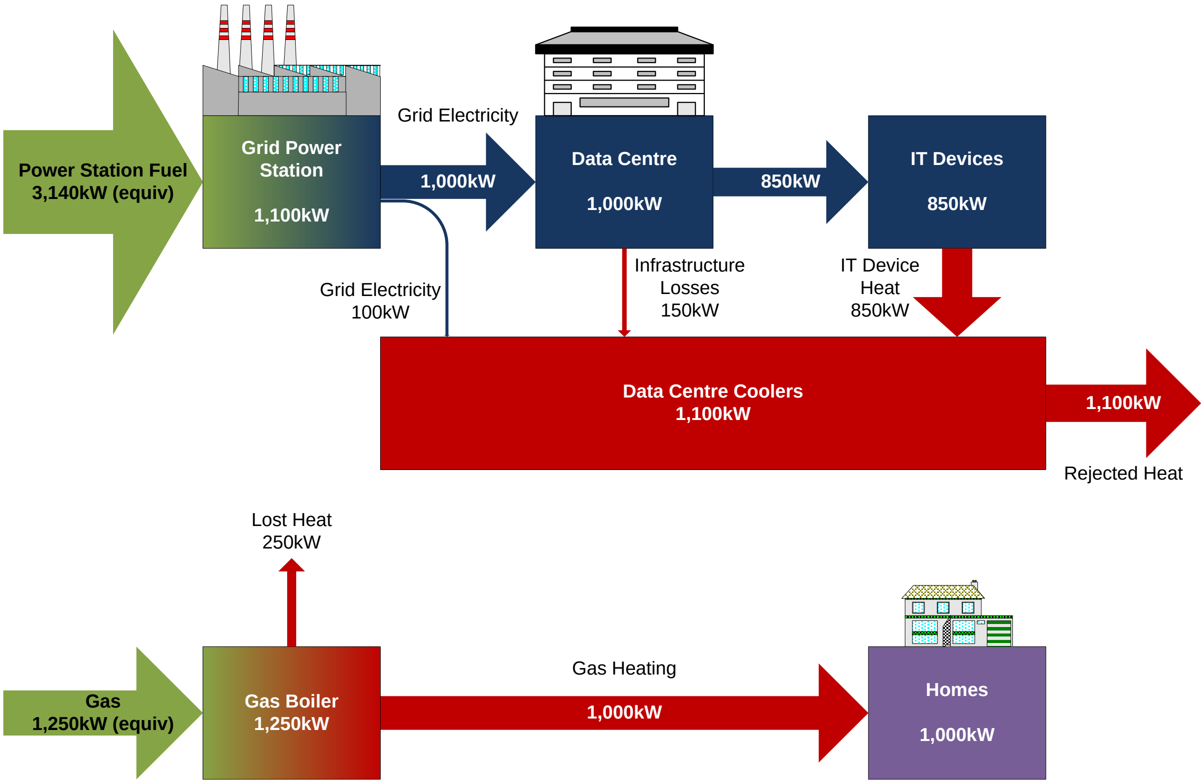

Figure 1 Case A - Separate systems

Housing

The hot water and heating for the housing is supplied by high efficiency condensing gas boilers[6]. These are assumed to achieve 80% efficiency converting their source energy to heat.

Heating load	Efficiency	Natural gas
1,000kW	80%	1,250kW (equiv)

Table 2 Case A heating delivery

[5] Coefficient of Performance, how many Watts of heat are removed for each Watt consumed by the cooling plant

[6] As required by current building regulations in the UK and much of Europe

Efficiency and source energy

Whilst we can calculate the electrical efficiency (PUE) of the data centre relatively easily this is of little use when we wish to compare the data centre electrical energy consumption with the natural gas consumed by the domestic heating systems. The issue is that we cannot usefully compare electrical energy with gas as these are different types of energy supply. In order to understand the energy savings of the heat re-use options we must supplement the electrical PUE with a measure which allows for comparison of the overall energy efficiency of the data centre system. To be comparable with the gas consumed by the heating system this will measure the energy input at the same point, the source energy consumed by the power stations which generate the electricity for the data centre. We will call this the Data Centre Source Energy Ratio (DC-SER)

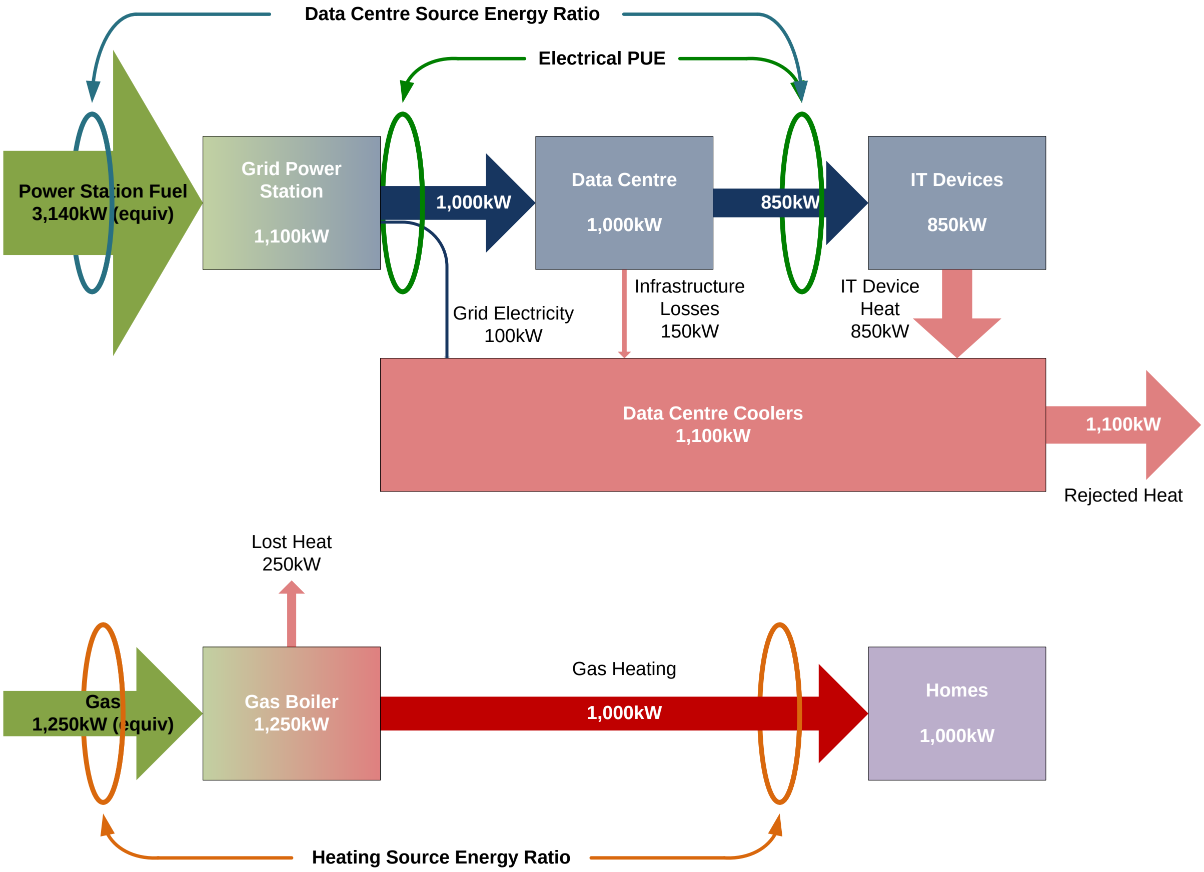

Figure 2 Case A - Electrical PUE and Source Energy Ratio

The PUE may be easily determined in the usual way by comparing the total utility draw with the power delivered to the IT equipment.

$$PUE = \frac{IT\ Load\ +\ Infrastructure\ Losses\ +Cooler\ Losses}{IT\ Load}$$

$$PUE = \frac{850kW\ +\ 150kW\ +\ 100kW}{850kW}\ =\ 1.29$$

To convert the utility electrical load of the data centre to the source energy required to deliver it the efficiency of the utility grid in converting source energy (fuels) to electrical power is taken to be 35%, thus a load of 1,300kW requires 3,140kW of fuel at the power station.

The Data Centre Source Energy Ratio can be easily calculated for the data centre and domestic heating as these are separate systems.

$$SER_{Data\ Centre} = \frac{Primary\ Energy_{Power\ Station}}{IT\ Energy}$$

$$SER_{Houses} = \frac{Primary\ Energy_{Boilers}}{Heating\ Energy}$$

$$SER_{Data\ Centre} = \frac{\left(\frac{1{,}100kW}{0.35}\right)}{850kW}$$

$$SER_{Data\ Centre} = \frac{3{,}140kW}{850kW} = 3.7$$

$$SER_{Houses} = \frac{1{,}250kW}{1{,}000kW} = 1.25$$

Again, all of the examples use annual averages so power may be considered interchangeably with hourly energy.

	Data centre	Domestic heating	Total
Load	850kW	1,000kW	1,850kW
Electrical consumption	1,100kW		
Electrical Efficiency (PUE)	1.29		
Source Energy Consumption	3,140kW	1,250kW	4,390kW
Source Energy Ratio (SER)	3.7	1.25	2.4

Table 3 Case A summary

The graph below shows how the total 4,390kW of primary energy is used by the power and heating delivery systems and the achieved efficiency. Note that the separate systems achieve an overall annual average 42% efficiency in converting source energy to IT electrical and domestic heating energy.

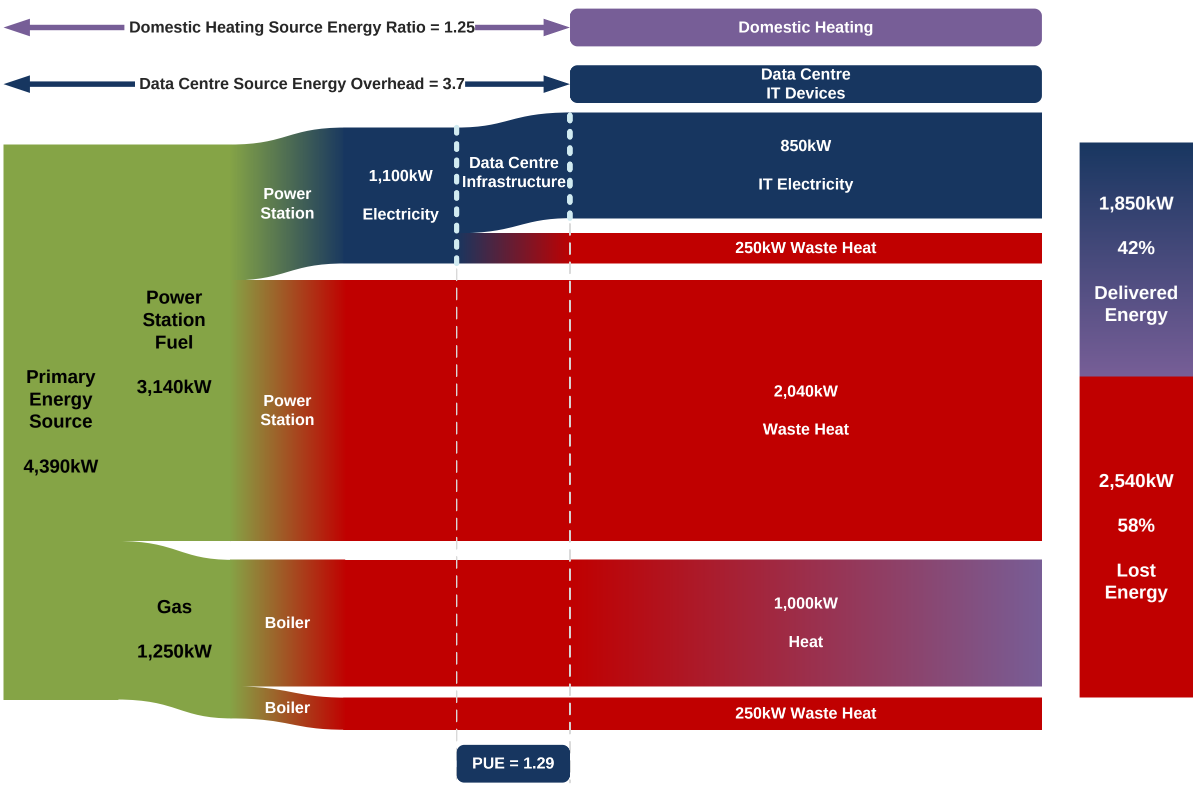

Figure 3 Case A - Energy paths and achieved efficiency

3.2 Case B – Subtract re-used heat

The remainder of the cases consider the data centre integrated with a district heating system. This makes the calculations slightly different as there is only one source energy input at the power station and this must be split and some fraction allocated to both the data centre and domestic heating systems.

The graph below shows how the 3,710kW of primary energy is used by the power station, data centre and domestic heating system represented in cases B, C and D. Note that in this case some of the delivered heating energy passes through the data centre IT electrical load.

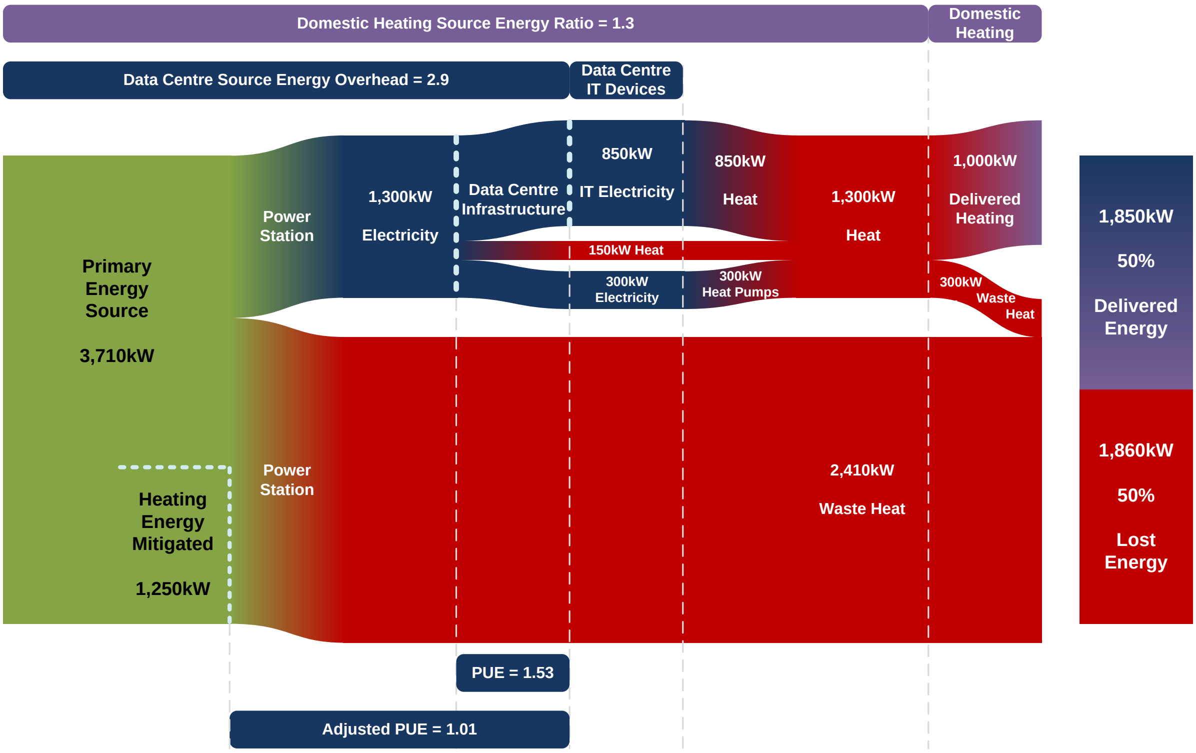

Figure 4 Cases B, C, D - Energy paths and achieved efficiency

Case B examines the metrics under the proposition that we should simply subtract the heating energy from the data centre utility electrical energy as currently proposed in the Green Grid ERE metric.

Data centre
As this example data centre operates at relatively low air supply and return temperatures the return water from the CRAC units is typically at 30°C. This is not hot enough to be useful for heating and therefore the temperature needs to be raised to 70°C – 80°C before it can be pumped out to the housing. These heat pumps are essentially the same as traditional mechanical chillers for the data centre cooling system but instead of being able to reject their heat at 40°C the chillers now need to achieve a condenser temperature of 75°C – 85°C. This requires that the chillers perform substantially more work and must operate all of the time.

This change in the data centre cooling system, although hopefully more efficient overall will result in a much lower average CoP than the economised cooling system in case A, for this example the CoP has been estimated as 3.3 resulting in an average electrical load of 300kW from the heat pumps.

IT Load	Infrastructure losses	Cooling system losses	Overall utility draw
850kW	150kW	300kW	1,300kW

Table 4 Case B electrical delivery

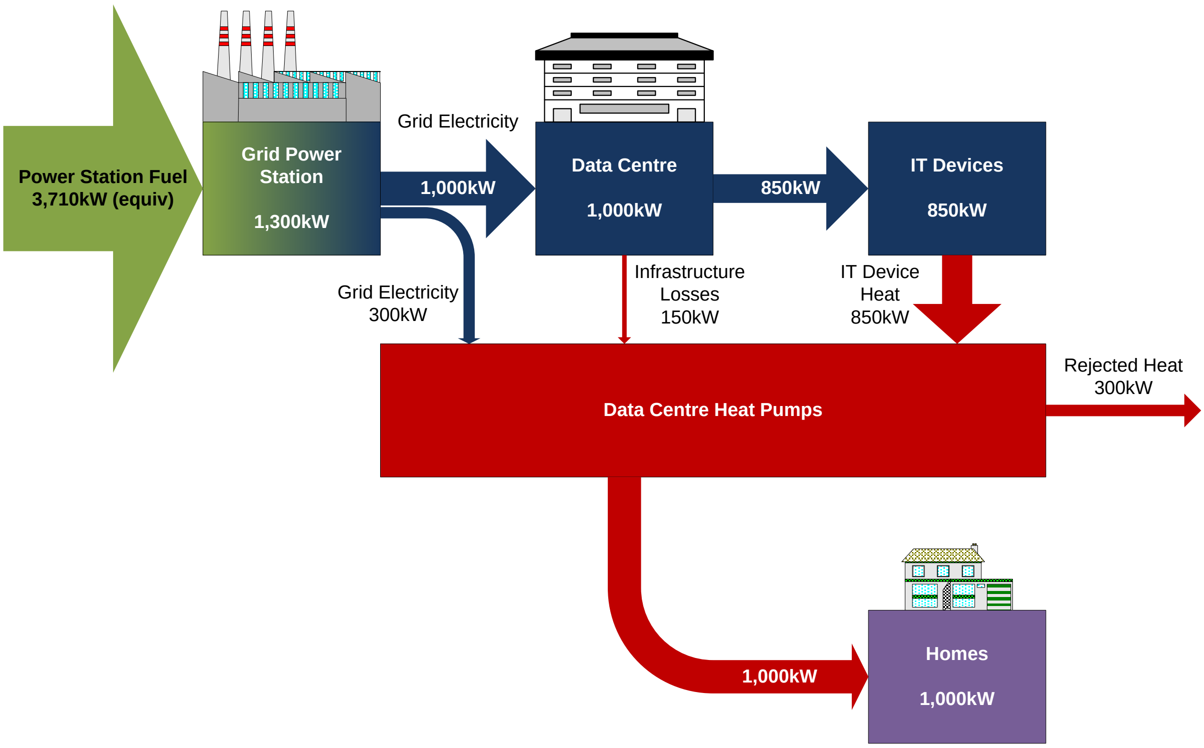

Figure 5 Cases B, C, D - District heating

Note that this example assumes that the entire thermal loss of the data centre is captured and made available in the heat re-use system, in practice this is unlikely and the heat recovery would be less effective.

Housing
In this case the housing receives heating and hot water from the data centre waste heat captured and delivered via the district heating system and therefore consumes no energy directly.

One issue with energy re-use through district heating is that the demand for heating varies seasonally with external temperature and therefore the full 1,000kW will not be required all year. To represent this seasonal variation it has been estimated that 77%[7] of the available heat is used by the district heating system over the year.

Heating load	Total available	Proportion used
1,000kW	1,300kW	77%

Table 5 Case B heating delivery

PUE
For case B the efficiency calculations will be based on subtracting the re-used heat from the data centre electrical power consumption.

$$Utility\ Draw_{adjusted} = True\ Utility\ Draw - Reused\ Heat$$

$$Utility\ Draw_{adjusted} = 1{,}300kW - 1{,}000kW = 300kW$$

As shown below there is a direct reduction in the overall source energy required by the combined data centre and domestic housing however the data centre "adjusted PUE" calculated using the adjusted utility draw is now less than one.

$$PUE_{adjusted} = \frac{True\ Utility\ Draw - Reused\ Heat}{IT\ Power} = \frac{1{,}300kW - 1{,}000kW}{850kW} = 0.35$$

[7] This specific value is chosen over the more obvious 75% to make the power delivery numbers easier to read and compare

Data Centre Source Energy Ratio

For our metrics to be meaningful we must account all of the energy consumed by the power station to provide electricity to the data centre.

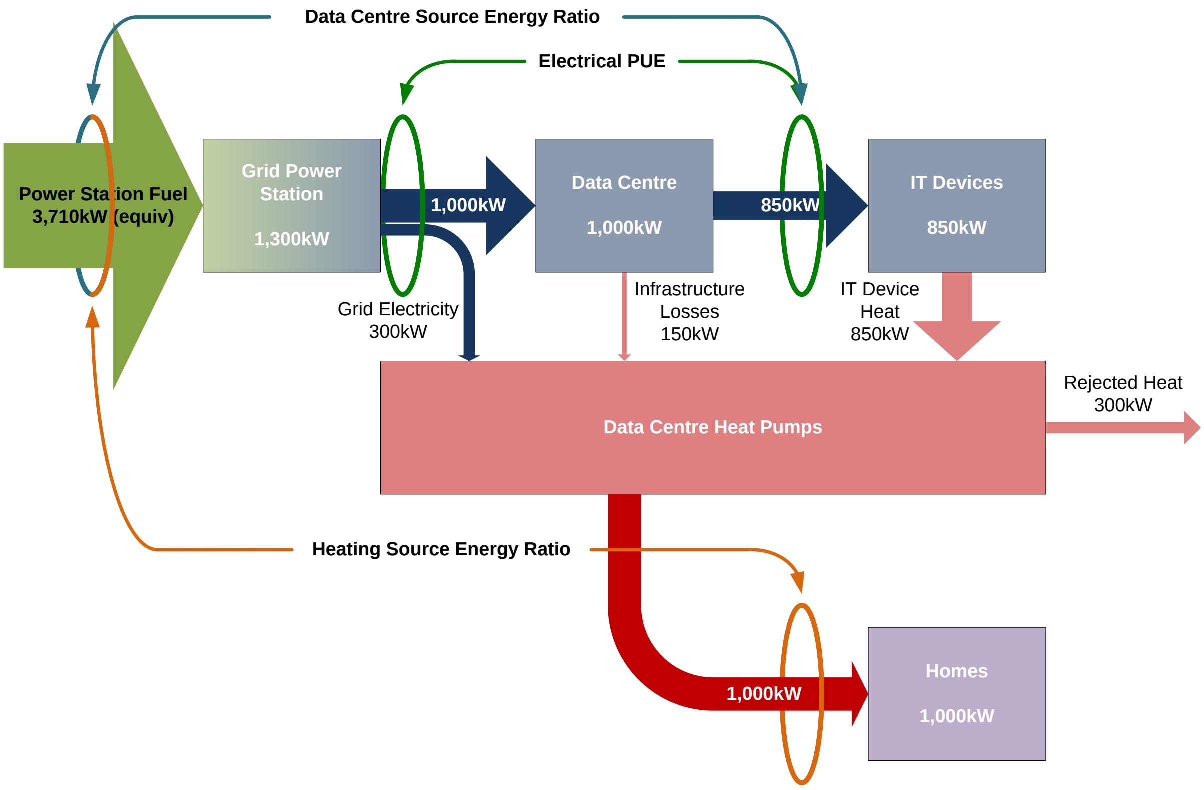

Figure 6 Cases B,C,D - PUE and Source Energy Ratio

If only 300kW of grid electrical power is accounted to the data centre then the remaining energy must be accounted to the domestic heating system. This needs to be performed using the comparable units of source energy. Under the case B proposition that re-used energy is subtracted from the utility draw;

$$Source\ Energy_{Data\ Centre} = \frac{True\ Utility\ Draw - Reused\ Heat}{Utility\ Source\ Efficiency}$$

$$Source\ Energy_{Data\ Centre} = \frac{1{,}300kW - 1{,}000kW}{0.35} = 850kW\ (source\ equiv)$$

To determine the allocation to the heating system we simply subtract the 850kW source energy allocated to the data centre from the overall source energy;

$$Source\ Energy_{heating} = Source\ Energy_{Total} - Source\ Energy_{Data\ Centre}$$

$$Source\ Energy_{heating} = 3{,}710kW - 860kW = 2{,}850kW\ (equiv)$$

As shown in the table below, allocation of the remaining 2,850kW source energy to the heating system results in the heating SER becoming substantially worse, from 1.25 with local boilers to 2.85 with the district heating system.

The overall SER has improved to 2.0 from 2.4 for the separate systems as the total source energy consumption has fallen from 4,390kW to 3,710kW providing a saving of 680kW source energy against the data centre and heating as separate systems.

	Data centre	Domestic heating	Total
Load	850kW	1,000kW	1,850kW
Electrical consumption	300kW		
Electrical Efficiency (PUE)	0.35		
Source Energy Consumption	860kW	2,850kW	3,710kW
Source Energy Ratio (SER)	1.0	2.9	2.0

Table 6 Case B summary

3.3 Case C – Re-used heat is "free"

In this case the heat re-use system from case B is examined again but this time we consider the heat provided to the domestic heating system by the data centre as being a free by product of the data centre and therefore having no source energy consumption[8].

Efficiency

Under the case C proposition, the full burden of the energy consumption is placed on the data centre. The first key point to note is that the electrical PUE rises from the 1.29 of the economised cooling system to 1.53 with the overhead of running the heat pumps for the district heating.

$$PUE = \frac{850kW + 150kW + 300kW}{850kW} = 1.53$$

The heating system no longer has a defined efficiency as it apparently consumes no energy which is reflected in the zero SER value for the heating system. The data centre now has a much higher SER of 4.4 whilst the overall system SER is the same for cases B, C and D at 2.0.

$$SER_{Data\ Centre} = \frac{3{,}710kW}{850kW} = 4.4$$

	Data centre	Domestic heating	Total
Load	850kW	1,000kW	1,850kW
Electrical consumption	1,300kW		
Electrical Efficiency (PUE)	1.53		
Source Energy Consumption	3,710kW	0kW	3,710kW
Source Energy Ratio (SER)	4.4	0	2.0

Table 7 Case C summary

[8] This will equate to zero carbon intensity.

3.4 Case D – Subtract the energy saved from the data centre utility draw

The final case tries to strike a balance between the extremes of cases B and C. By determining the source energy efficiency of the utility power grid feeding the data centre and the energy which would have been consumed by the housing if district heating was not used it is possible to determine the overall energy saving. This overall saving may then be applied to the data centre efficiency calculation to mitigate the increase in PUE due to the design changes required for the district heating system.

Efficiency

For this proposition we need to determine the energy saving of the district heating system. We know from Case A that the domestic boilers would consume 1,250kW of source energy so we will subtract this from the total 3,710kW source energy at the power station.

$$Source\ Energy_{Data\ Centre} = Source\ Energy_{Total} - Source\ Energy_{Heating\ -\ Case\ A}$$

$$Source\ Energy_{Data\ Centre} = 3{,}710kW - 1{,}250kW = 2{,}460kW\ (equiv)$$

To determine the adjusted utility draw of the data centre for a PUE calculation the source energy reduction must be converted into the equivalent electrical power delivery based on the 35% efficiency of the power station resulting in an equivalent saving of 438kW of electrical power.

$$Reuse\ Saving = 1{,}250kW\ (equiv) * 0.35 = 440kW$$

$$Utility\ Draw_{adjusted} = True\ Utility\ Draw - Reuse\ Saving$$

$$Utility\ Draw_{adjusted} = 1{,}300kW - 440kW = 860kW$$

	Data centre	Domestic heating	Total
Load	850kW	1,000kW	1,850kW
Electrical consumption	860kW		
Electrical Efficiency (PUE)	1.01		
Source Energy Consumption	2,460kW	1,250kW (est)	3,710kW
Source Energy Ratio (SER)	2.9	1.25	2.0

Table 8 Case D summary

Note that in this case, by design, the domestic heating SER is exactly the same as in Case A and all of the energy savings have been attributed to the data centre. In this case the adjusted PUE falls to 1.01 and the SER of the data centre falls to 2.9.

4. Comparison of cases A-D

To review the three options for re-use metrics presented so far it is useful to summarise the results.

4.1 Annual Energy Consumption

The annual energy consumption of the four cases is shown below;

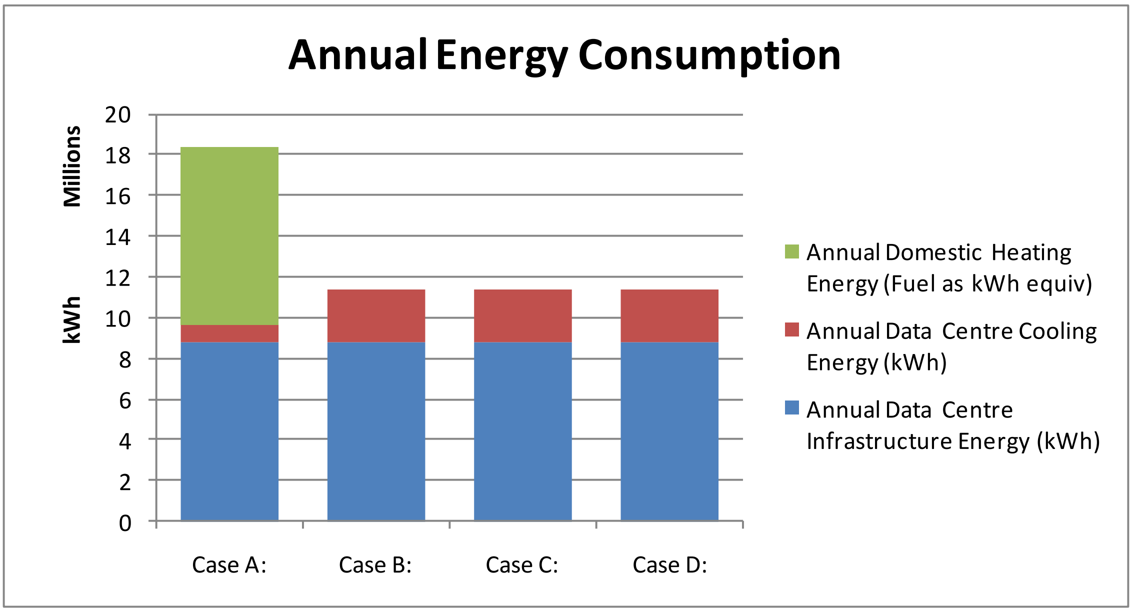

Figure 7 Annual energy consumption Cases A-D

In Figure 7 it appears that the district heating system in cases B-D saves a significant proportion of the overall energy but this is misleading as the data centre consumes electricity whilst the domestic heating consumes gas and these two energy sources are not comparable on a kW per kW basis.

The four cases are;

A. Separate data centre and domestic heating
B. District heating system subtracting re-used energy from the data centre utility draw
C. District heating system considering re-used heat to be “free”
D. District heating system subtracting the saved energy from the data centre utility draw

Converting the data centre electrical energy consumption to source energy consumption so that it is comparable with the gas used for heating provides the chart Figure 8 below. As shown when the total source energy consumed by the system is considered the efficient domestic gas boilers make up a much smaller part of the overall energy consumption and the difference between the separate systems in case A and the combined systems in cases B, C and D is much smaller.

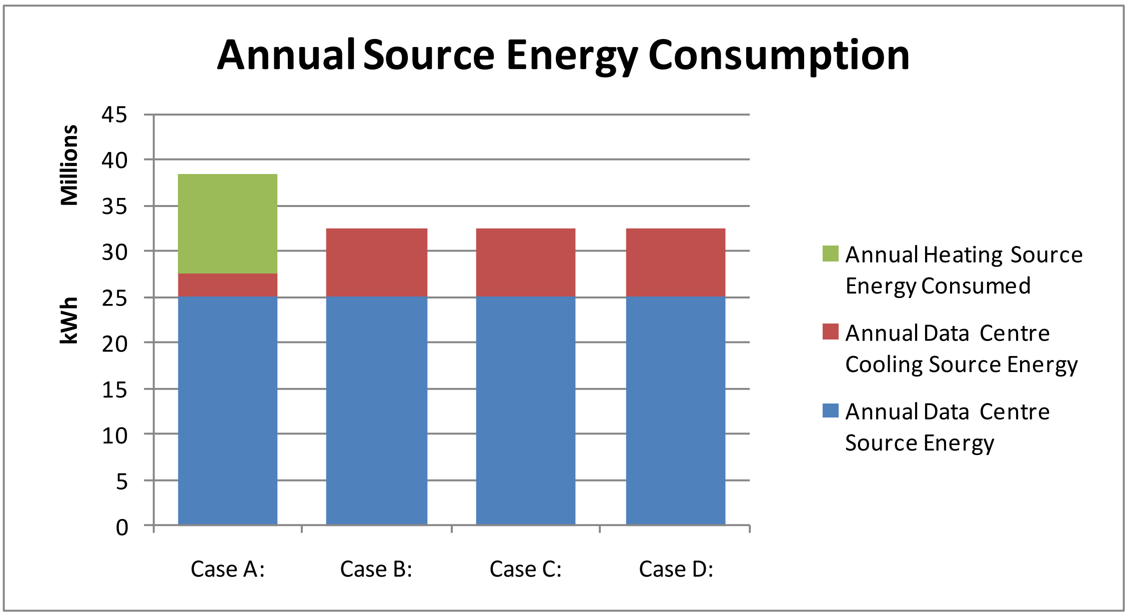

Figure 8 Annual source energy consumption Cases A-D

4.2 PUE

In case A the PUE of the standalone data centre was 1.29 whilst in cases B, C and D the electrical PUE of the data centre including the heat pumps for the district heating system was 1.53. Cases B, C and D explored different ways of adjusting the PUE to represent the energy re-use of the district heating system.

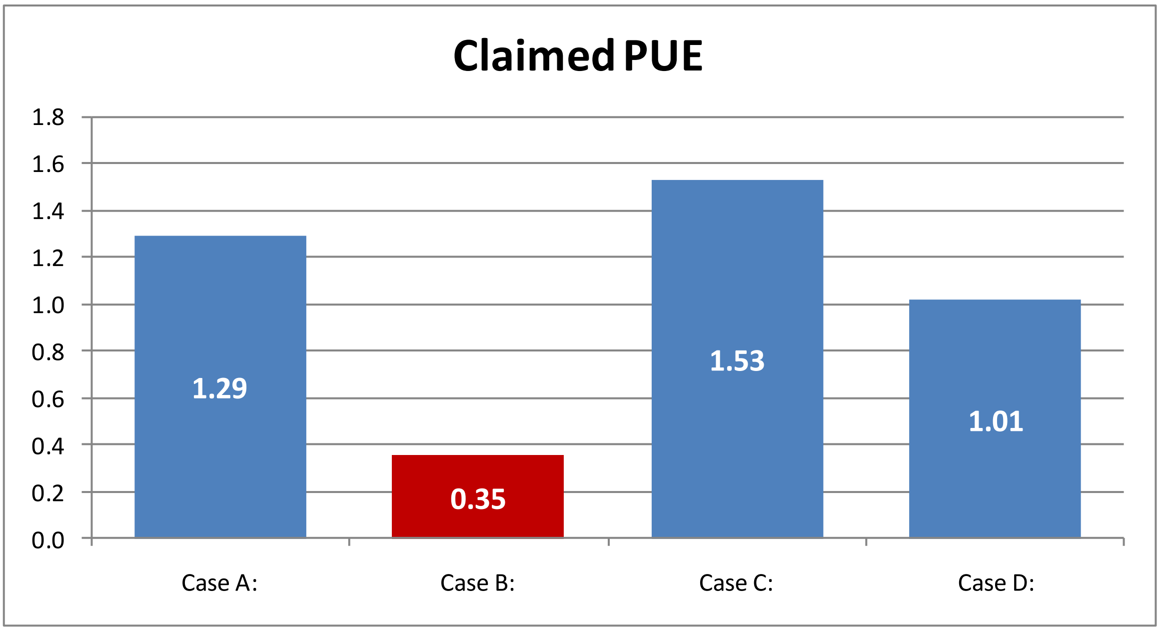

Figure 9 Claimed PUE Cases A-D

As shown in Figure 9 the three different methods of adjusting the PUE produce substantially different results with case B standing out immediately because it produces a PUE of less than one although case D is also capable of this given certain combinations of source efficiency and energy re-use. Case C seems unfair given that the district heating data centre of cases B-D is more efficient overall than Case A. The manipulation of PUE to capture re-used energy appears to generate confusion rather than provide additional information.

4.3 Source energy ratio

Extending the electrical PUE scope back to the source energy supply the Source Energy Ratio provides a clearer view of the overall and comparative efficiency as shown in the table and graph below;

	Case A	Case B	Case C	Case D
Data Centre SER	3.70	1.01	4.37	2.90
Domestic Heating SER	1.25	2.86	0.00	1.25
Overall SER	2.37	2.01	2.01	2.01

Table 9 Annual Source Energy Ratio Cases A-D

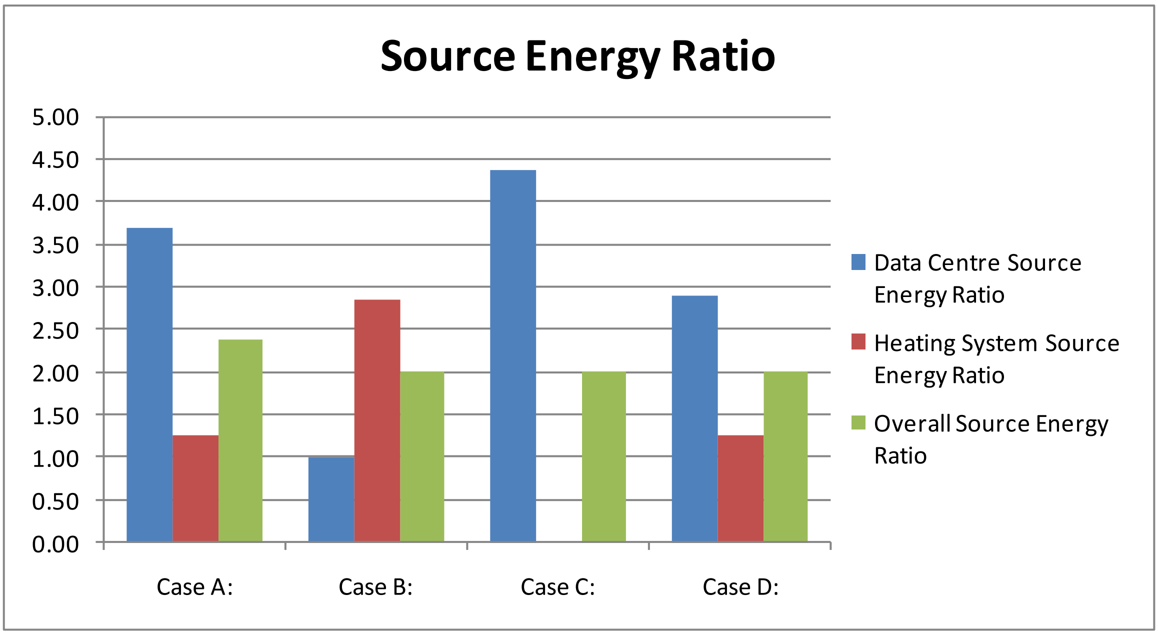

Figure 10 Annual Source Energy Ratio Cases A-D

As shown in Table 9 and Figure 10 the overall SER provides a good indication of the comparative efficiency of the standalone and combined systems. Note that the overall SER is the same in cases B, C and D. Cases A and D seem to be the more informative and comparable, the domestic heating system maintains its original SER whilst the heat recovery equipped data centre gains the benefit and reduces its SER from 3.7 in case A to 2.9 in case D.

This can, of course, also be plotted as a percentage efficiency if case C is eliminated, this is shown in Figure 11.

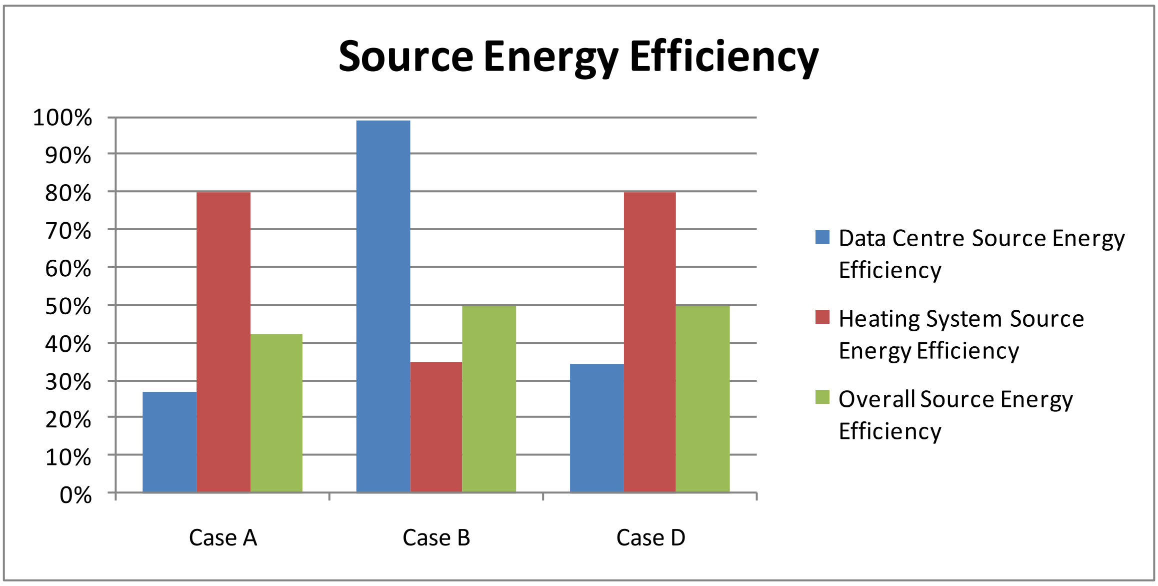

Figure 11 Annual Source Energy Efficiency Cases A, B and D

5. What about carbon?

A very similar analysis can be performed for the carbon due to the electricity and gas consumption. Two carbon intensity numbers are of interest here, the carbon intensity of each delivered kWh of electricity to the IT equipment and of each delivered kWh of heating.

5.1 Case A

For case A we will use the efficiency data for the boilers and a composite grid carbon intensity (this needs to be a composite because of the mixed fuel sources on the utility grid).

Source	Carbon intensity	Local conversion efficiency
Gas	0.184 kg CO_2 / kWh	80%
Electricity	0.544 kg CO_2 / kWh	100%

Table 10 Carbon intensity of fuels

Using the direct electricity consumption of the data centre and gas consumption of the domestic heating in case A it is relatively easy to determine the overall annual carbon.

Source	Energy consumption	Annual CO_2
Gas	8,760,000 kWh	2,014 Tonnes
Electricity	9,636,000 kWh	5,242 Tonnes

Table 11 Case A annual carbon

5.2 Case B

For case B the assumption was that we could subtract the kWh of re-used heat from the data centre's drawn electrical kWh. In this case we have a total annual CO_2 for the electricity delivered which we need to allocate which is the sum of the data centre and heat pump electricity consumption.

Source	Energy consumption	Carbon intensity	Annual CO_2
Electricity	8,760,000 kWh + 2,628,000 kWh	0.544 kg CO_2 / kWh	6,195 Tonnes

Table 12 Total annual CO2 for cases B-D

To allocate this for case B we determine the proportion of the energy that was re-used.

	Total	Share	Allocated
Data Centre	6,195 Tonnes	300 / 1,300	1,430 Tonnes
Domestic heating	6,195 Tonnes	1,000 / 1,300	4,765 Tonnes

Table 13 Case B annual allocated carbon

5.3 Case C

As for case B we need to allocate the total carbon between the data centre and the domestic heating. In Case C the assumption is that the domestic heating energy was "free" and therefore the entire carbon is allocated to the data centre.

	Total	Share	Allocated
Data Centre	6,195 Tonnes	1,300 / 1,300	6,195 Tonnes

Table 14 Case C annual allocated carbon

5.4 Case D

In case D we subtracted the energy saved on the domestic heating from the data centre energy. To apply this to the annual carbon we need to apply the same rules, we know from the SER analysis that the total source energy of the combined data centre and heating is 3,710kW and that 2,460kW of this is allocated to the data centre with the remaining 1,250kW allocated to the domestic heating;

	Total	Share	Allocated
Data Centre	6,195 Tonnes	2,460 / 3,710	4,107 Tonnes
Domestic heating		1,250 / 3,710	2,087 Tonnes

Table 15 Case D annual allocated carbon

5.5 Comparison of carbon allocation in cases A-D

The chart below shows the data centre, domestic heating and overall carbon in each of the four allocation regimes. As for the Source Energy Ratio charts the two which seem to be reasonable and comparable are cases A and D. Both cases B and C substantially distort what we know to be the actual underlying case.

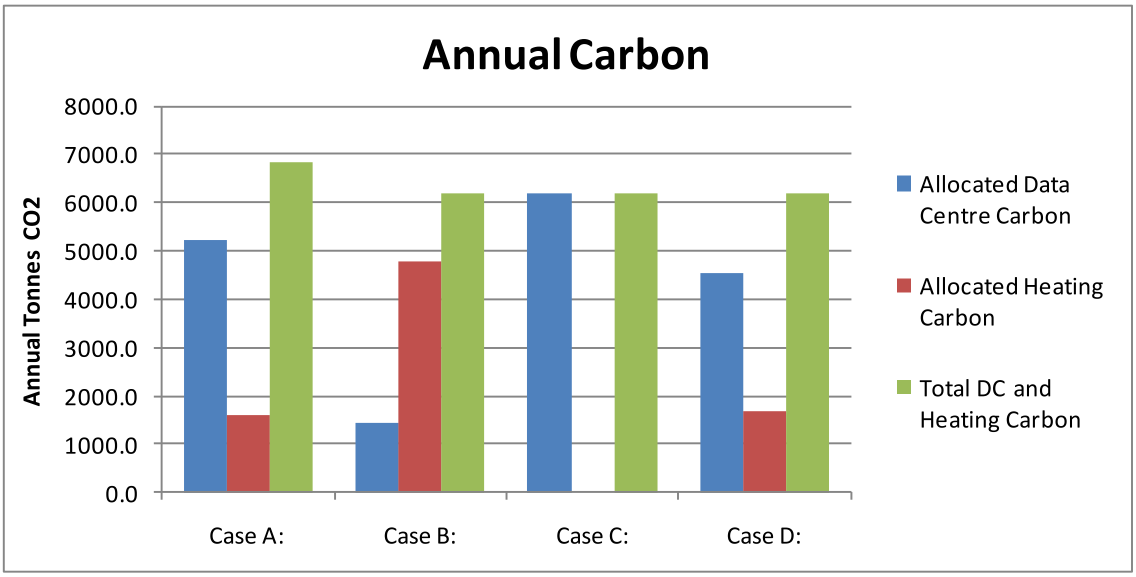

Figure 12 Cases A-D annual carbon

5.6 Determination of a CUE type metric

Given that we know the kWh delivered to each of the data centre and the domestic heating we can use the total annual carbon data to provide a carbon intensity of delivered energy.

As an example we can determine the carbon intensity of the delivered IT energy in Case D by;

$$Carbon\ Intensity_{Data\ Centre} = \frac{Allocated\ Carbon\ kg}{Delivered\ kWh} = \frac{4{,}181{,}000}{850.365.24} = \frac{4{,}181{,}000}{7{,}446{,}000} = 0.56\ \frac{kgCO_2}{kWh}$$

	Overall	Data centre	Domestic heating
Case A	0.45	0.7	0.23
Case B	0.38	0.19	0.54
Case C	0.38	0.83	0
Case D	0.38	0.55	0.24

Table 16 Cases A-D annual kg CO2 / kWh delivered

Considering the Green Grid CUE metric, we would need to choose whether to modify the metric at all for this data centre and if so, which of the modified values to choose. In case A the CUE is 0.45 kg CO_2 / kWh. As before case D seems to provide the most realistic view of the improved overall carbon intensity.

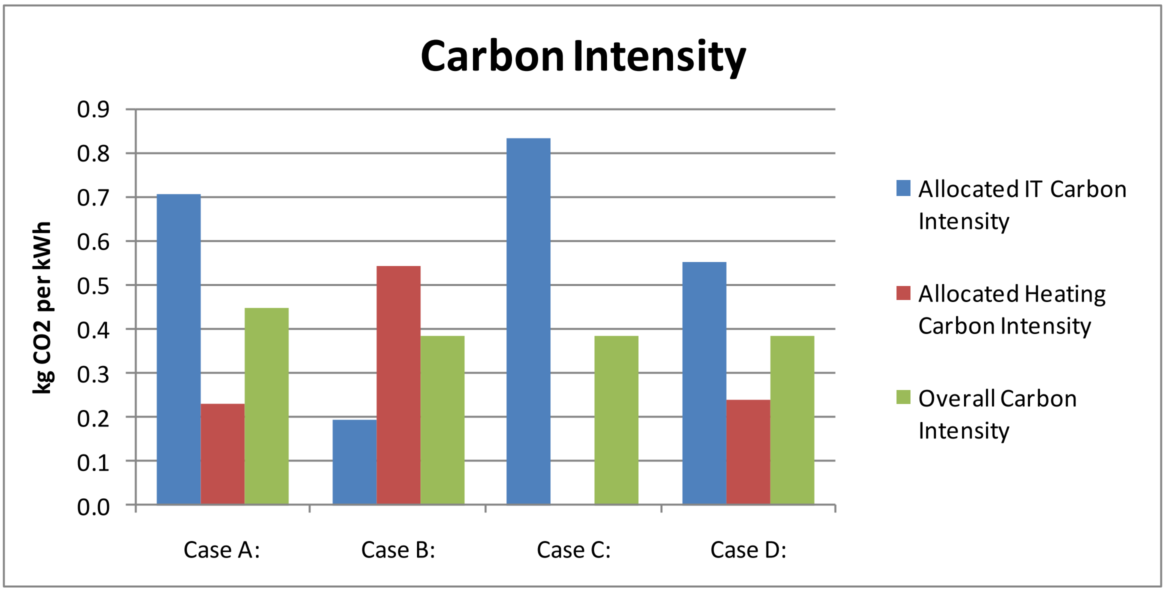

Figure 13 Cases A-D allocated carbon intensity

6. The same data centre in France

We cannot properly evaluate these metrics under only UK conditions. To test how they respond to an alternative type of power generation and domestic heating they have also been evaluated using numbers more typical for France.

In France it is quite common for domestic heating to be powered from the utility electrical supply rather than local gas boilers. The carbon intensity of utility electrical power is also much lower due to the very high proportion of nuclear power in France.

6.1 Values used for France

For France the following values have been used to determine the metrics;

Parameter	UK	France
Carbon intensity of utility electrical energy	0.54 kg CO_2 / kWh	0.1 kg CO_2 / kWh
Carbon intensity of domestic heating energy	0.184 kg CO_2 / kWh	0.1 kg CO_2 / kWh
Source energy efficiency of utility electrical power	0.35	0.35
Source energy efficiency of domestic heating	0.8	0.35

Table 17 Comparison of calculation values for UK and France

Note that there is in reality a small difference between the source energy efficiency of the French and the UK utility electrical supply.

6.2 Annual energy consumption

The annual energy consumption is the same in France as in the UK;

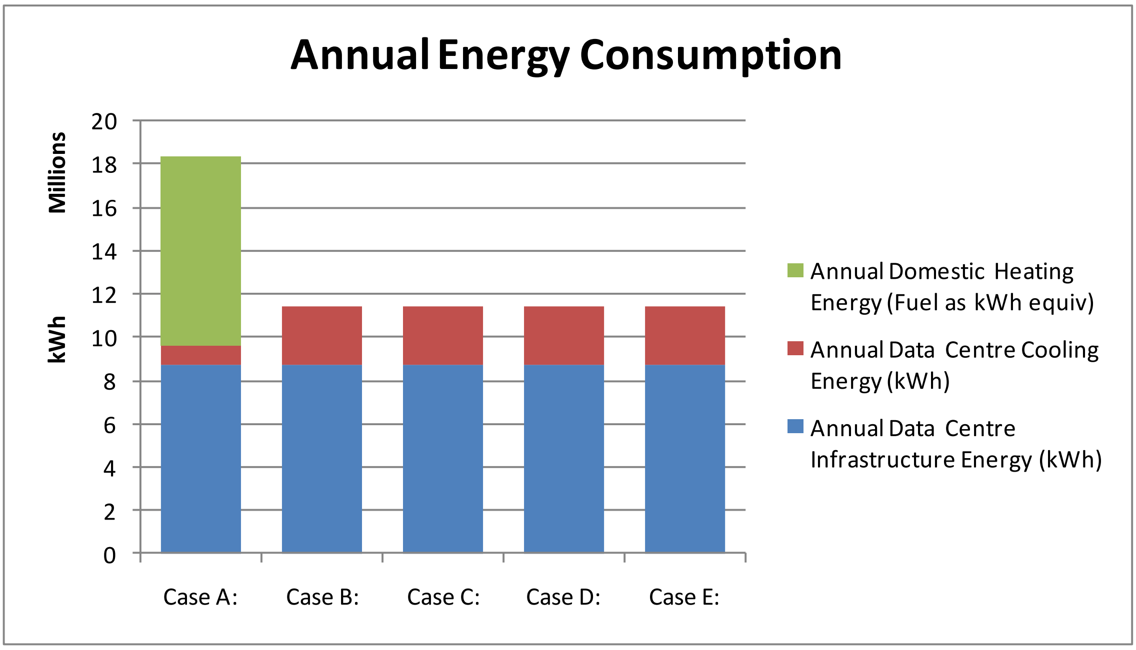

Figure 14 Annual energy consumption cases A-D

The source energy consumption is however notably different, as in France the domestic heating is considered to be electrically powered. Therefore all the inefficiencies of converting heat to electricity and then distributing that over a transmission grid must be considered;

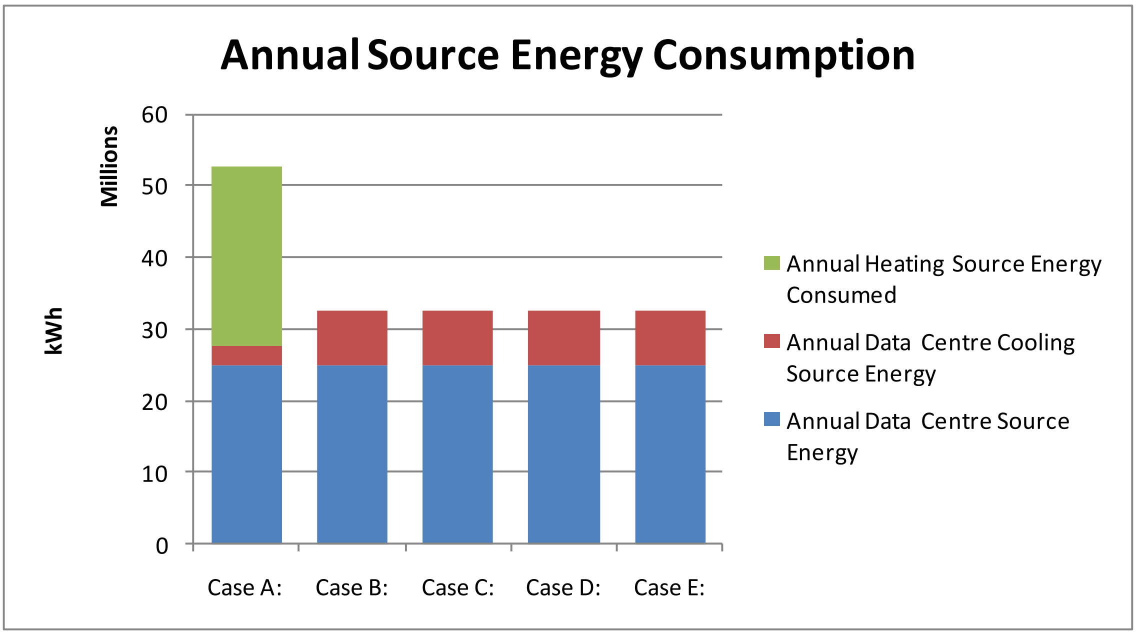

Figure 15 Annual source energy consumption in France - Cases A-D

As shown in the graph above the overall source energy consumption in case A is much larger where the domestic heating and hot water is electrically powered, leading to a much larger saving in source energy when the systems are combined.

6.3 PUE

Using the same methods to calculate a PUE we see that now case D also exhibits a PUE of less than one, this is due to the much higher source energy of the electrically powered domestic heating systems.

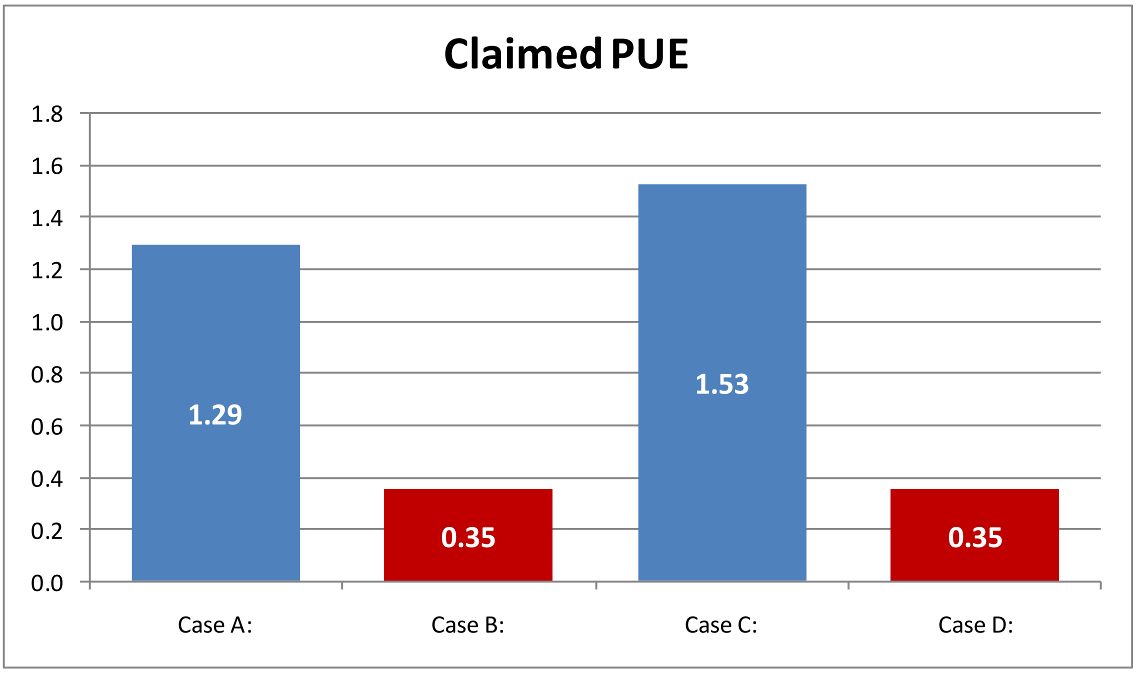

Figure 16 Claimed PUE Cases A-D in France

Again, modifying the PUE to account for energy re-use results in confusing and misleading values.

6.4 Source energy ratio

As for the UK, extending the electrical PUE scope back to the source energy supply (the Source Energy Ratio) provides a clearer view of the overall and comparative efficiency for the French system as shown in the table and graph below;

	Case A	Case B	Case C	Case D
Data Centre SER	3.70	1.01	4.37	**1.01**
Domestic Heating SER	**2.86**	2.86	0.00	**2.86**
Overall SER	**3.24**	2.01	2.01	2.01

Table 18 Annual Source Energy Ratio Cases A-D in France

As shown in the table and graph the calculated source energy ratios for cases B and C are the same as for the UK whilst the heating and overall SER are higher in case A. In case D the heating and data centre have exchanged places with the heating taking the majority of the source energy and the data centre SER being close to one.

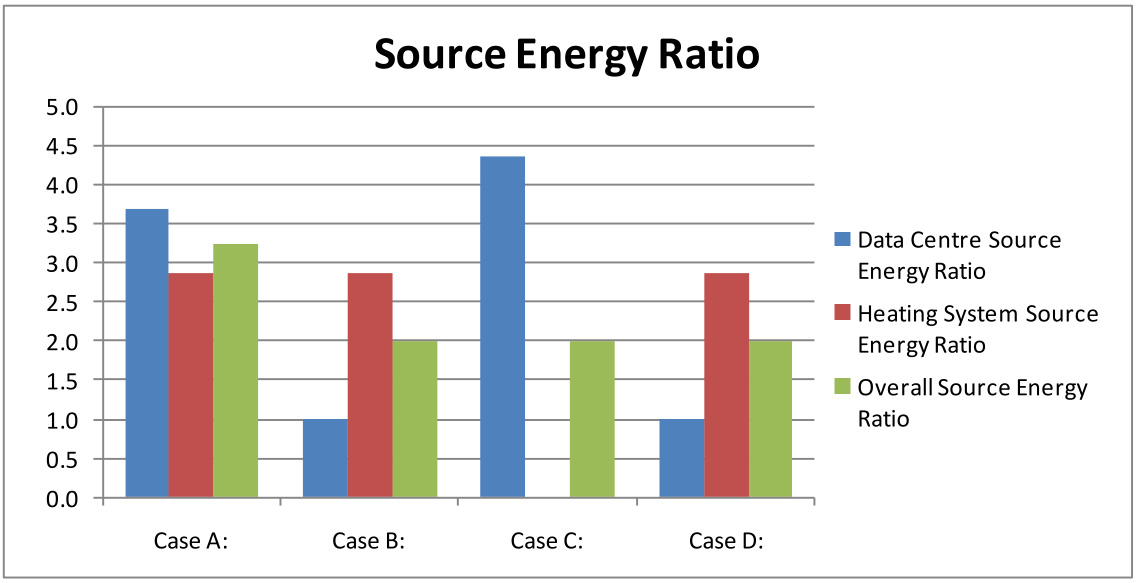

Figure 17 Source energy ratio cases A-D in France

As for the UK analysis cases A and D appear to provide a reasonable comparison of the two systems.

6.5 Carbon intensity

Using the same calculation approach as before the total carbon and carbon intensity can be determined. For France however the overall carbon and intensity are much lower due to the extensive use of nuclear power.

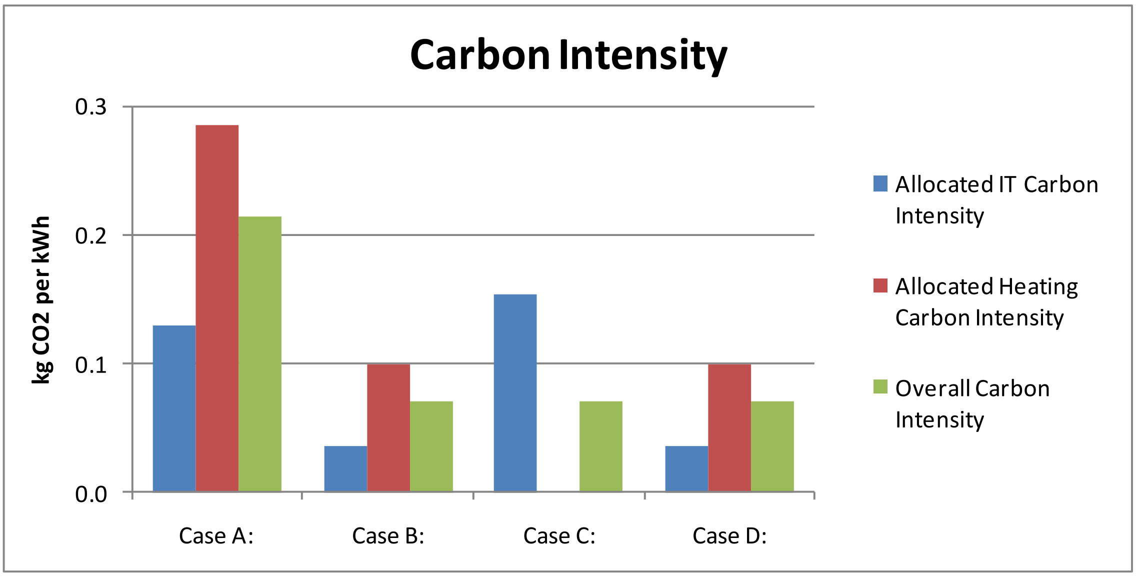

Figure 18 Carbon intensity cases A-D in France

Note that the overall carbon intensity of the combined data centre and district heating system is one fifth that of the UK example.

As before cases A and D appear to provide a good and consistent comparison of the two systems.

7. Subtract the carbon saved

If the user of the metric is more concerned with carbon emissions than energy efficiency then there is a valid argument that the basis of the savings calculation used in case D "Subtract the source energy saved" should be used but in place of the source energy saving the carbon saving should be the basis of the evaluation.

Performing the evaluations as before but for Poland is a good example of where calculating on carbon rather than source energy savings gives a substantially different result.

The table below provides the assumed data for electricity grid carbon intensity and the intensity of heating gas.

Source	Carbon intensity	Local conversion efficiency
Gas	0.184 kg CO_2 / kWh	80%
Electricity	1 kg CO_2 / kWh	100%

Table 19 Carbon intensity of fuels

7.1 Case E

Using the direct electricity consumption of the data centre and gas consumption of the domestic heating in case A but with the values for Poland it is relatively easy to determine the overall annual carbon.

Source	Energy consumption	Annual CO_2
Heating gas	8,760,000 kWh	2,014 Tonnes
Data centre electricity	9,636,000 kWh	9,636 Tonnes
Combined heat re-use	11,391,000 kWh	11,391 Tonnes

Table 20 Case E annual carbon

Given this annual carbon of directly heating the houses we can perform the subtraction from the data centre electricity in the same manner as for the source energy in case D.

$$CO_{2\,Data\ Centre} = CO_{2\,Total} - CO_{2\,Heating - Case\ A}$$

$$CO_{2\,Data\ Centre} = 11{,}391\ Tonnes - 2{,}014\ Tonnes = 9{,}377\ Tonnes$$

Source	Total annual CO_2	Allocated annual CO_2
Data centre	11,391 Tonnes	9,377 Tonnes
Domestic heating	11,391 Tonnes	2,014 Tonnes

Table 21 Case E annual carbon

To determine the adjusted utility draw of the data centre for a PUE calculation the carbon reduction must be converted into the equivalent electrical power delivery based on the 1 kg / kWh carbon intensity of the utility grid resulting in an equivalent saving of 438kW of electrical power.

$$Utility\ consumption_{\ adjusted} = \frac{9{,}377{,}000\ kg\ CO_2}{1\ kg\ CO_2/kWh} = 9{,}377{,}000\ kWh$$

$$Utility\ draw_{\ adjusted} = \frac{9{,}377{,}000\ kWh}{8{,}760\ h} = 1{,}070\ kW$$

Note that due to the high grid carbon intensity the carbon saving is small in comparison to the data centre carbon and therefore the compensated utility draw is only slightly lower than the standalone data centre.

7.2 Case D

Using the same calculation method as for the UK case D with the figures for Poland gives the same SER as we have not changed the source intensity of the grid power, just the primary fuel source and therefore the carbon intensity. We can therefore use the same adjusted utility draw values with the carbon intensity for Poland to determine the allocated carbon based on subtracting the source energy mitigated.

	Total	Share	Allocated
Data Centre	11,391 Tonnes	2,460 / 3,710	7,559 Tonnes
Domestic heating	11,391 Tonnes	1,250 / 3,710	3,833 Tonnes

Table 22 Case D annual allocated carbon - Poland

7.3 Comparison of cases D and E

Having calculated the carbon saved version of case D we can see that in the case of Poland, with a high grid carbon intensity there is a substantial difference in the allocated energy and carbon to the data centre and domestic heating. The calculated SER is shown below;

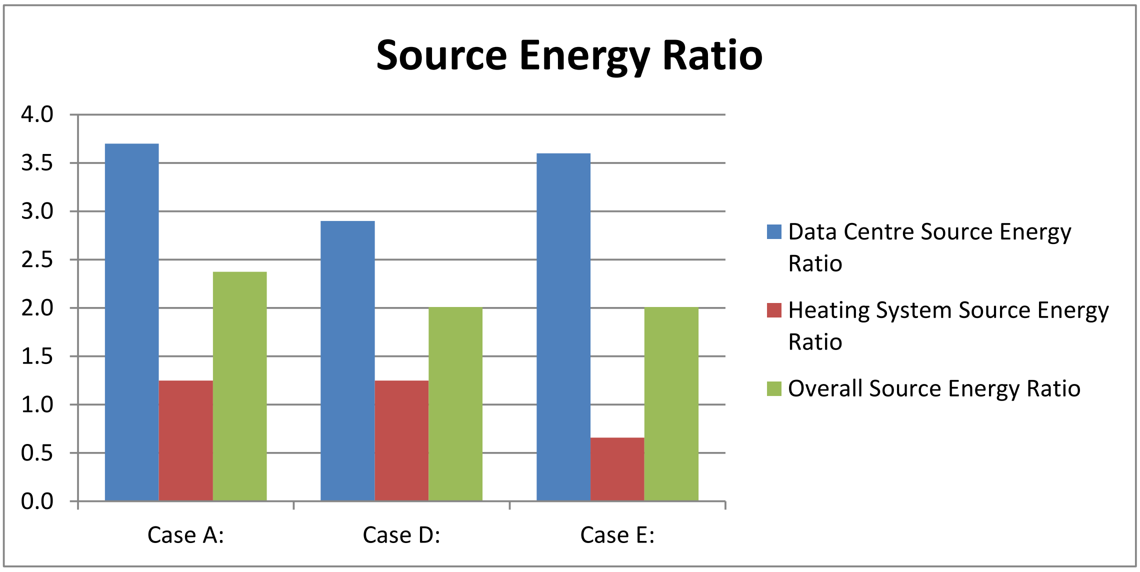

Figure 19 SER comparison cases A, D and E in Poland

Note that in this case the SER of the heating system is less than one due to the comparatively low carbon intensity of the gas fuel for the boilers.

Plotting the allocated carbon intensity also shows a distinct difference between the methods with the carbon allocated to the domestic heating in Case E being based on the saving the carbon allocated to the data centre rises very close to the base carbon intensity in Case A. From a carbon perspective this is a more realistic report as there is very little overall carbon saving as shown by the green bars of overall carbon.

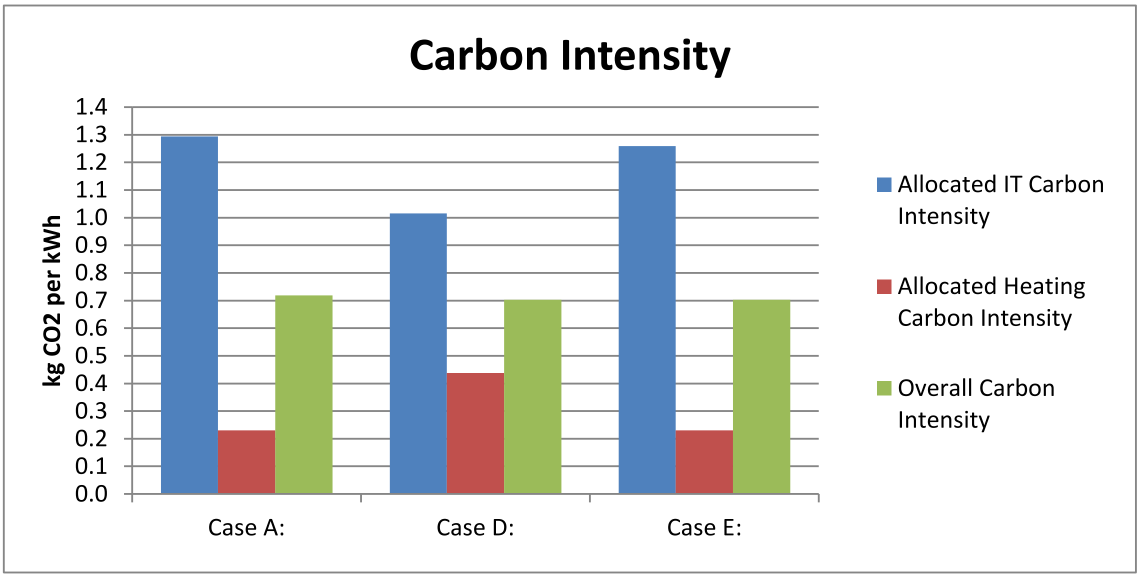

Figure 20 Carbon intensity comparison cases A, D and E in Poland

8. Practical calculation of Source Energy Ratio

The source energy ratio values provided thus far in this paper have taken advantage of the tightly defined comparison and the pre-calculation of the energy used by the target of the data centre energy re-use when operating as standalone systems. There are two substantial issues with performing this trick;

- It will not always be easy or practical to calculate the “energy which would have been used” for real data centres and heat re-use targets
- It would be difficult to effectively cover all of the potential types of energy re-use in a description of the calculation methodology, leading to miscalculation of the values and the SER becoming no more than a marketing number as is currently happening with miscalculation of “partial PUE” and PUE values lower than one

Given these issues it will be necessary to provide an agreed approximation mechanism which is both simple enough to use and largely fair.

8.1 Calculating SER from harmonised PUE weighting factors

There is already a set of weighting values for different fuels defined for data centres in the harmonised PUE calculation method;

Energy Type	PUE Weighting Factor	SER multiplier
Electricity	1.0	1 / 0.35 = 2.86
Natural gas	0.35	0.35 / 0.35 = 1
Fuel oil	0.35	0.35 / 0.35 = 1
Other fuels	0.35	0.35 / 0.35 = 1
District chilled water	0.4	0.4 / 0.35 = 1.14
District hot water	0.4	0.4 / 0.35 = 1.14
District steam	0.4	0.4 / 0.35 = 1.14

Figure 21 Harmonised PUE fuel weighting factors

It would be possible to use these published factors to generate reasonable estimations of the data centre and overall SER. It would be more effective to replace the electricity value with the local utility grid electricity source efficiency which can be determined from the fuel mix information used to calculate the carbon intensity of the local or national grid

The SER multiplier shown in the table could be applied to the fuel source that the target of the data centre heat re-use would use if not provided with heat from the data centre.

Determine the source energy

The total source energy may be determined by multiplying the total supplied energy by the SER multiplier for the data centre fuel;

$$Source\ Energy_{total} = Total\ energy\ * SER\ multiplier_{data\ centre\ fuel}$$

The re-use source energy may then be determined by multiplying the re-use energy supplied by the SER multiplier for the fuel that the re-use target would have used if energy was not delivered from the data centre;

$$Source\ Energy_{re-use} = ReUse\ energy\ * SER\ multiplier_{other\ fuel}$$

Determining SER

Given the total and re-use source energy it is simple to determine the SER values, for the re-use energy this is simply the SER multiplier for the selected fuel source;

$$SER_{re-use} = \frac{ReUse\ energy\ * SER\ multiplier_{other\ fuel}}{ReUse\ energy} = SER\ multiplier_{other\ fuel}$$

For the data centre the SER is the source energy not allocated to re-use divided by the delivered IT energy, similar to the PUE calculation;

$$SER_{data\ centre} = \frac{(Source\ Energy_{total} - Source\ Energy_{re-use})}{delivered\ IT\ energy}$$

The overall SER is simply the total source energy divided by the delivered IT energy plus the re-use energy. Note that the sum in the denominator of this fraction may exceed the total electrical kWh delivered to the data centre as some energy may pass into the IT equipment as electricity and then be captured as heat for re-use;

$$SER_{overall} = \frac{Source\ Energy_{total}}{delivered\ IT\ energy + ReUse\ energy}$$

Whilst these values will not be as “accurate” as the full calculation of the energy which would have been used by the energy re-use target they are easier to perform and harder to manipulate.

8.2 Assume that all re-use energy has an SER of 1

From the UK example it appears reasonable to perform the calculations by assuming that all re-use energy is weighted as having an SER of one. This approach has the advantage of being very easy to calculated but, as shown in the example for France below this method is not particularly consistent across different regions.

UK

Including a Case G where the re-use energy is considered to have an SER of one provides the following comparison with cases A and D.

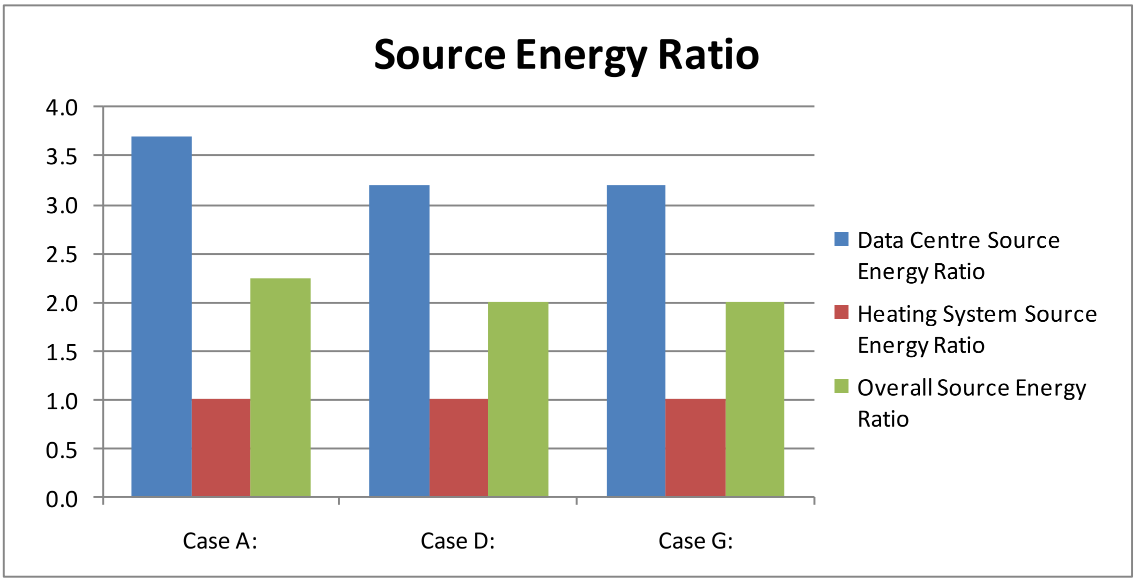

Figure 22 UK Source energy ratio - re-use has an SER of one

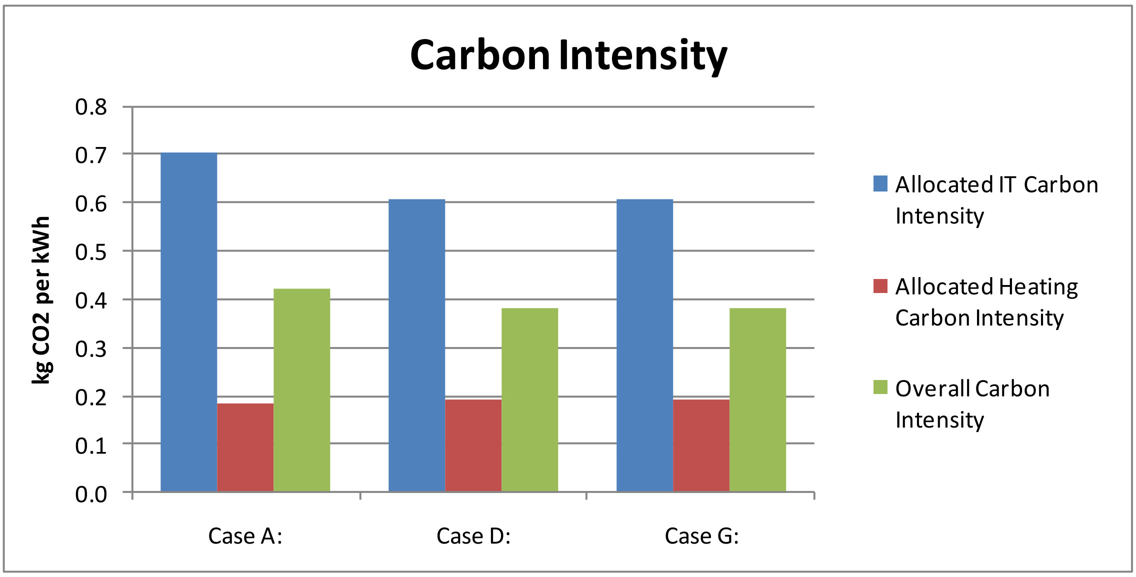

Figure 23 UK carbon intensity - re use has an SER of one

In the UK case there is no change in the allocated source energy ratio or carbon intensity between the full case D “subtract what the re-use target would have used” method and the re-use SER of one method.

France
Performing the same analysis for case G using the data for France provides the output below;

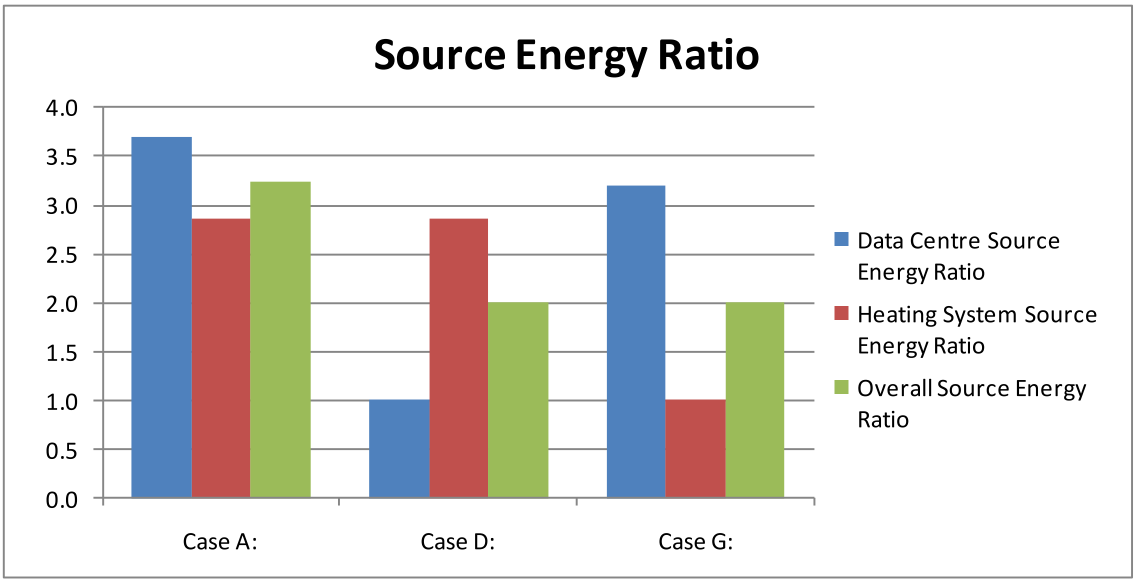

Figure 24 France Source energy ratio - re-use has an SER of one

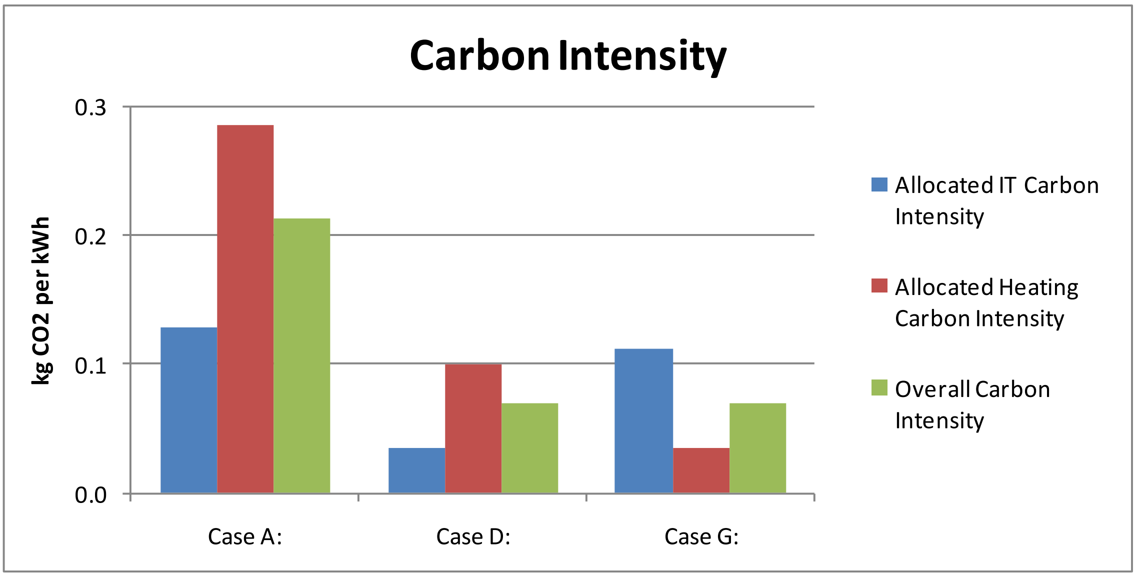

Figure 25 France carbon intensity - re-use has an SER of one

It is immediately notable that in the French case there is a substantial change when using the re-use SER of one. It is left to the reader to determine whether this appears to be a reasonable representation of the improved efficiency of the combined system.

8.3 Other standards for determining the re-use energy

There are many local standards for determining the energy use of likely targets for data centre heat re-use. In the UK for example BRE define the method for calculation of the "SAP rating" for buildings http://www.bre.co.uk/sap2009/page.jsp?id=1642 .

9. Document Information

Version History

Version	Description	Version Updates	Date
0.1.0	DCSG Review	Added section 7 subtract the carbon saved	24 March 2011
0.0.9	DCSG Review	Paul Latham comments	23 March 2011
0.0.8	DCSG review		20 March 2011

Version History

Release History

Version	Description	Authoriser	Date

Release History