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EXERGY & MARGINAL FUEL USE, AN ANALYSIS OF HEAT FROM CHP & HEAT FROM ELECTRIC HEAT PUMPS.

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1. OVERVIEW.

The paper presents a marginal cost and fuel use analysis, also an exergy analysis, to allocate fuel to the respective primary product electricity, and waste product heat, in thermal power generation.

The change in title follows the publication of an EU report Ref [I] for web download which contains two significant potential changes.
The reports title is “Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. SEC (2010) 65-SEC (2010) 66”.

It proposes to use “exergy” as a basis for allocation of emissions between electricity and heat in CHP.
Sample exergy factors for an EU assumption of a heat sink at 0C 273 K absolute are:-

Chemical exergy in fuel one.	Exergy--1.000.
Electrical energy, exergy in electricity one.	Exergy--1.000.
Heat energy in a gas flame at 1800C, exergy 0.860.	Exergy--0.860.
Energy as 100C heat to a building exergy, 0.265.	Exergy--0.265
Energy as heat rejected in electricity generation at 28C, exergy 0.090.	Exergy--0.090.
Energy as heat at 0C and reference for EU exergy calculations, zero.	Exergy--0.000.

Exergy signals the ability of heat above an ambient temperature of an environment to be converted into work, and is reflected in the “Carnot formula”.
The conversion of heat to work is covered by the second law of thermodynamics which dictates that to produce work from heat; some heat has to be rejected.

The efficiency with which heat can be converted to work in a heat engine is then dictated by the difference in temperature, between the source of the energy in the form of heat, and the temperature at which the same amount energy is either rejected or converted to power, in line with the first law of thermodynamics which dictates that energy is conserved. Exergy is a measure of the degradation of energy quality and utility to do work as the energy degrades to heat at ambient temperature.

The result is that the world is not short of energy thanks to the first law, but it is short of energy in a useful form, either warm enough to heat buildings or do work. Exergy is thus a measure of the usefulness of energy.

Recognition of the greenhouse impact of the actual CO2 emissions when dry wood 0.340 kg of CO2per kWh of energy in the fuel, and other biomass materials are burnt is the second significant issue. Coal in contrast, has CO2 emissions of 0.301 kg of CO2per kWh of energy in the fuel.

A cradle to final consumption analysis, replacing a cradle to grate analysis will optimise use of bio-fuels. The cradle to grate assumption does not encourage efficient use of bio-fuels in CO2 terms if it signals its emissions as being close to zero, whereas use of the actual emissions does. This approach if adopted more widely will encourage use of wood and it's by products to store its carbon in buildings and more optimal use of this scarce resource.

The purpose of this paper is to stimulate thinking about the analysis of CHP, and electric heat pumps in the UK and EU.

The merits of a high exergy electrical energy supply system, working with a low exergy piped heat supply system 75C flow 30C return, to meet the low exergy heat requirements of consumers can maximise fuel use and utilise heat, which under the second law of thermodynamics has to be rejected to the environment to convert heat to work.

This however can only occur if appropriate signals are given to encourage the development of CHP technology. A view that use of the waste product heat from power generation somehow can reduces emissions from the prime product electricity has hampered the use of waste heat by signalling fuel and emission overheads for the heat discouraging its use. The paper addresses these issues by a marginal cost and fuel use analysis, and exergy principles.

Electric Heat Pump "EHP" and Combined Heat and Power "CHP".

Heat from electric heat pumps is defined as renewable under current EU regulations. It is however different from solar thermal heat or heat from biomass, as the electricity to upgrade heat in the environment comes from fossil fuel sources. The heat has a fossil fuel overhead to raise the temperature of low-grade heat extracted from the environment. The ratio of the fossil fuel use per unit of heat is measured by the coefficient of performance (COP) of the heat pump. As an example, where an electric heat pump has a COP of 2.9, it delivers 2.9 units of heat raised in temperature from the environment at 0C to say 28C for one unit of electrical input.

The fossil fuel content of this heat depends on how much fossil fuel has been used to produce and deliver electricity to the heat pump. If the electricity has come from gas, and has a fossil fuel overhead of 2 then the fossil fuel overhead of the heat is 2, divided by 2.9 or 0.67 units of fossil fuel per unit of heat. If the electricity has come from coal, then the fossil fuel overhead is greater 2.7, divided by 2.9 or 0.96.

Heat from electric heat pumps is thus only renewable when the electricity itself is from a renewable source.

Heat pumps work by cooling the ground or air. These heat sources can be the ground at 8C or the air. For air, the source of heat varies from 15 C when people may first require heating in the autumn to conditions on the coldest day when temperatures may drop to minus 20C. They work best when as low a temperature as possible is used to heat the building with say air at 28C or under floor heating at 50C flow 43C return, with lower temperatures under part load. However return temperatures need to be above room temperature say 21C to transfer heat to the room. Heat pumps also need to meet domestic hot water loads where temperatures of over 60C are required a condition where their performance reduces compared to room heating.

Electric heat pumps suffer from what is known in England as “Murphy’s law” they are at their best on the hottest day in the summer and at their worst on the coldest day in winter.

Many existing UK heating installations fed by boilers are designed for 82C flow 72C return and are thus incompatible with retrofitting to electric heat pumps, as to achieve these temperatures the heat pumps will not hit the 2.9 COP target for renewable heat status, unless they have a higher temperature heat source than either ground, or air in winter.

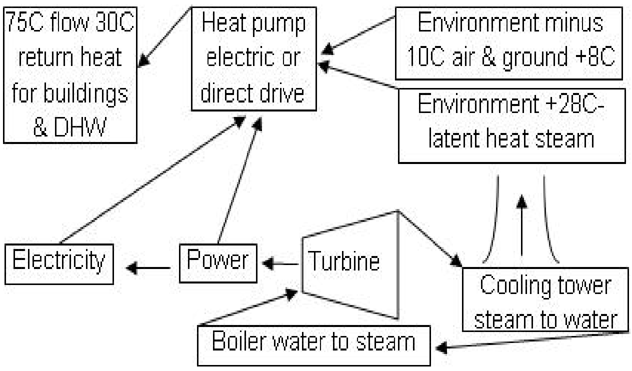
Waste heat from electricity generation can it be used economically?

Can heat normally rejected from say CCGT electricity generation from its chimney at 100C and from condensing the steam at 28C, be used in an economic way to heat buildings? If it can, no extra fossil fuel will be burnt. This heat will then perform a useful purpose as part of its degradation process to ambient temperature.

Clearly, the heat can be used locally for under floor heating or horticulture. However to pipe heat cost effectively a temperature difference between the heat flowing to a consumer and returning from the consumer, is usually at least 10C with district heating operating on temperature differences of 45C as at Odense in Denmark, 90C flow 45C return.

We illustrate two routes for capturing this environmental waste heat and delivering it at a higher temperature. First an electric heat pump at the cooling tower. The advantage is a large improvement in coefficient of performance (COP). This higher temperature waste heat source improves the (COP) of large electric heat pumps, particularly in winter, as cooling tower heat in the environment maintains its temperature summer and winter compared to ground or air sources. This improved COP more than compensating for heat and exergy losses in piping the heat to consumers from the electric heat pump.

The second is what is termed by Professor Robert Lowe of University College London as “a virtual heat pump”.[II]



This diagram shows how an electric heat pump or a directly driven gas engine heat pump can upgrade heat in the environment arising from the rejection of heat from electricity generation.

This option gives the heat renewable status in line with EU directives. In the UK, the heat will qualify for a subsidy under the proposals for Renewable Heat Incentives to meet EU renewable targets. For a domestic electric heat pump, a subsidy of £ 0.07 per kWh of heat will be given to stimulate private sector investment in the technology.

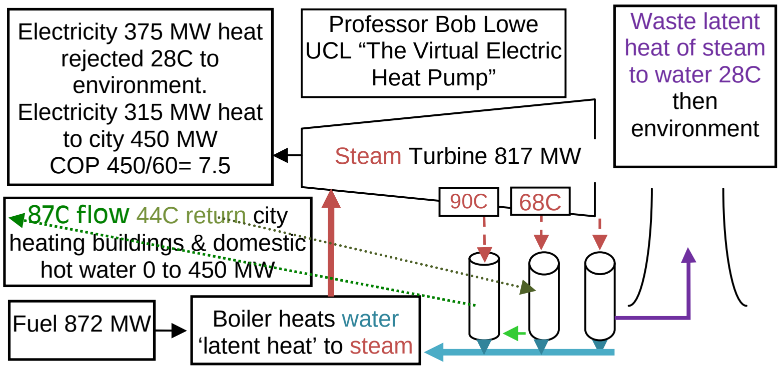
Directly driven heat pumps with the same conversion efficiency of fuel to power, will be superior to the electric heat pumps saving conversion losses in generating the electricity, then the power, losses in its transmission, and finally losses in conversion by an electric motor back to power.

The virtual heat pump CHP also uses electricity. Its use is more difficult to understand. I will try to explain it simply.

The heat that has to be rejected in steam turbines is the latent heat of steam. This is the heat used to turn liquid water into a gas, steam. For the cycle to work this heat has to be added by the boiler for the water to steam process, later condensed by the condensers after the steam has done its work and needs to be converted back to water.

If we condense the steam at a higher temperature, we do less work and produce less electricity.

The difference between the electricity we would generate when rejecting heat to the environment at 28C and the electricity we generate when rejecting the heat at 90C, reflects the electricity used in a virtual heat pump illustrated below.



Data from a 375 MW pass out CHP burning coal oil or gas illustrates the principle Ref[III]. The ratio of the electricity lost or used, for the heat gained can be calculated in exactly the same way as for an electric heat pump. In the case of the example given a COP of 7.5 is achieved. In CHPQA and other publications, this COP is referred to as the Z factor for the steam turbine.

The COP for the CHP heating at Odense in Demark significantly exceeds the EU benchmark of 2.9 for electric heat pumps. An analysis of the Vilnius 3 plant which has three stages for district heat extraction is similar and is described in Ref [IV]WRH Orchard Supplementary Paper, C479 IMechE 1993

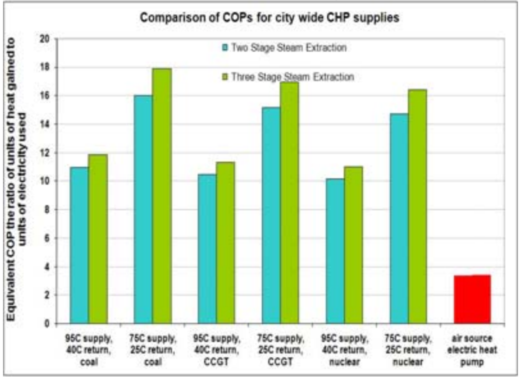
COPs in excess of twelve are achievable for low temperature city heating from CHP. [V].

We have adopted the same common principle to analyse heat from CHP and EHP's. Electricity used for heat gained, a ratio known as the coefficient of performance (COP).

The following chart illustrates the COP for different types of large-scale pass out CHP units and compares their COP to an air source heat pump.

The COP for industrial CHP where CHP meets higher temperature heat requirements for process heating in industry will be significantly lower than city CHP. Such temperatures are not normally met from electric heat pumps due to their even lower COPs to meet the same temperatures due to irreversibility's in the process.

The COP for heat from nuclear and coal-fired plants is affected by two factors one the lower fundamental electrical efficiency of the steam cycle, as coal nuclear and biomass are not suitable for combustion in higher efficiency power generation cycles, such as the diesel and CCGT. These cycles have similar COPs for heat as heat from CCGT. This is due to the much greater amount of reject heat in these power generation cycles with relatively low electrical efficiencies.



EU Policy and incentives for CHP and electric heat pumps.

The EU recognises the contribution that heat pumps and CHP can make to decarbonising the heat sector.

Having discussed the differences in treatment of CHP and heat pumps, with experts on the formulation of EU policies and their time scales, there appear to be two ways forward within the EU to bring the technologies to a common basis.

One option is to classify heat from CHP also as renewable where it demonstrates a COP greater than 2.9 the benchmark set for electric heat pumps.

A second option is to classify heat from both electric heat pumps and CHP as low CO2, then extend the definition of renewable heat to include low carbon heat from CHP, electric heat pumps and other low CO2 sources such as biomass and other renewable fuels.

The fossil fuel element of the heat from electric heat pumps, means that where the electricity that drives them with a COP of 2.9, comes from coal, they emit more CO2, 0.32 kg/kWh, than an 86% efficient (GCV) condensing gas boiler, 0.22 kgCO2/kWh.

Some people reason, that any increase in global electricity demand from adding electric heating to global systems, inevitably results in further investment in coal fired plant somewhere in the world. They would reason that incentives to add electric heating with its direct effect in the UK of increasing the peak demand for electricity and reducing its overall load factor is inappropriate in any form.

This would include the use of electricity in electric heat pumps. They would reason that global electricity networks mean that electricity from coal is at the global carbon margin. The CO2 impact of installing electric heat pumps thus needs to be assessed against this CO2 emission factor instead of local average CO2 emissions for specific countries, with their mix of high and low carbon electricity sources.

Reclassification of heat from electric heat pumps as a low CO2 source of heat is technically the most appropriate way forward.

It will allow the CO2 footprint of its heat from electric heat pumps to be linked to the fossil CO2 footprint of electricity driving the heat pump or renewable electricity sources.

In the case of renewable electricity sources, the appropriate comparison for use of their electricity to minimise g CO2 emissions globally is to decide whether it is best degraded to low quality heat in an electric heat pump or is displaces electricity from coal-fired plant somewhere in the world.

UK national energy sector policy for CHP and Electric Heat Pumps.

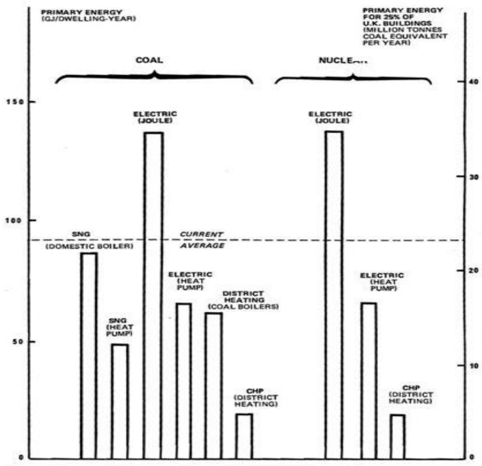


Figure 17 page 48 Energy Paper 20 (1977) Primary Energy Requirements for long term (post 2000 alternatives) ISBN 011410603 7

The relative merits of heat from electric heat pumps, gas fired directly driven heat pumps and heat from CHP are analysed in CP 56/75 BRE, and Energy Paper 20 1977, 35 and 53. These reports concluded that it was in the interest of the UK to copy the Danes and retrofit district heating to UK cities to replace heating by gas, electricity and other fuels.

Dependency on imported gas and its balance of payment effect means the CHP city wide heating is likely to be of more benefit to day, particularly because of the work it generates in cities, using UK based skills and materials.

In 1976 the gas and electricity supply industries offered the alternatives to district heat of domestic electric heat pumps, synthetic natural gas boilers; synthetic natural gas fired heat pumps. District heating threatened their established domestic captive market which can cross subsidies competitive industrial markets. The adjacent chart compares the relative merits of the different options as evaluated by the Marshall committee.

The current emphasis on bio and a nuclear future makes this 1977 work relevant today. Biomass, coal and nuclear power generation use similar thermal power cycles to 1977, with inherently lower electrical efficiencies than gas fired CCGT.

Biomass boilers and geothermal heat require heat networks to achieve economies of scale and to address control and emission issues, a further benefit of retrofitting UK cities with low temperature pipe heat supply infrastructures.

Nuclear CHP offers the lowest CO2 footprint for heat. The nuclear citywide CHP option and coal fired CHP co fired with biomass offer major opportunities to decarbonise the heat sector. Particularly if subsequently retrofitted with carbon capture and storage, an equally important technology for biomass, to reduce its CO2 emissions when burnt the prospect of negative CO2 emissions using sustainable products is possible.

The CO2 footprint for heat from CHP can be compared to the CO2 overhead for energy in different fuels. Measured in kgCO2/kWh these are 0.301 for coal, 0.191 for gas, and 0.340 for dry wood. The figures can be compared to 0.080 kgCO2/kWh for CHP heat from coal.

Coal fired CHP heat thus offers heat sector savings of over 0.11kgCO2/kWh when displacing natural gas burnt in boilers.

Whilst it may seem counter intuitive, building coal fired CHP results in greater CO2 savings in the heat sector than the installation of new gas boilers. Coal fired CHP thus offers a means to reduce CO2 emissions from coal today, to decarbonise the heat sector in parallel with work on CCS to decarbonise all fossil fuels when burnt in the future.

Sustainable Energy without Hot Air Professor David JC Mackay.

Professor David JC Mackay's excellent book "Sustainable Energy-without the Hot Air" [VI] has stimulated discussion in the UK about the relative merits of electric heat pumps or CHP to decarbonise the UK heat sector. His conclusions differ from Energy Paper 20 (1977) [VII] that recommended conversion of cities to large scale CHP on the Odense model. He favours an all-electric heat pump solution.

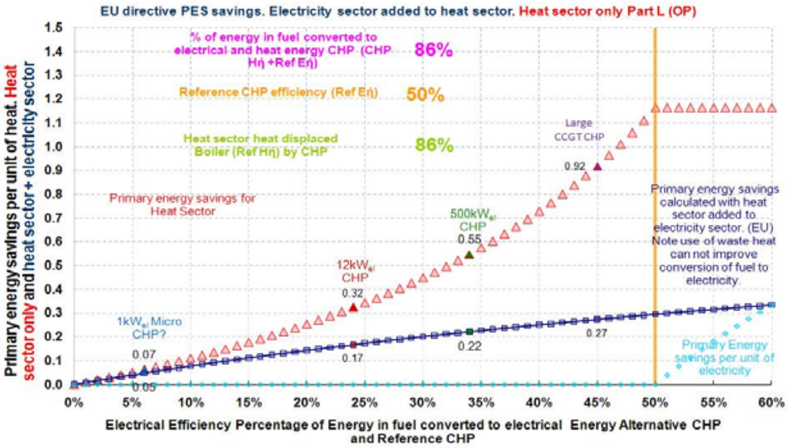
His analytical work for heat pumps and CHP concentrates on gas fired electricity generation.

His examples of CHP performance in the UK are mainly in the industrial sector needing higher temperature heat. UK performance of CHP is restricted by a cut off in incentives per unit of electricity produced when the CHP reaches an overall efficiency for production of electricity and heat of around 60% when the potential is 86%. This is due to the CHPQA method to incentivise use of heat from CHP through a subsidy on electricity. This effect is analysed in [VIII]CHPA-Critique.doc

The author agrees with Mackay's view that electricity and heat are quite different products with different values and that adding efficiencies for such differing products is not a helpful concept.
The following chart analyses the effect of using heat from CHP on the heat sector, and its primary energy saving impact on that sector. It uses reference electricity generation from 50% efficient CCGT for comparison in the electricity sector, against lower efficiency electricity generators.

The principle behind the analysis is that the fuel use per unit of electricity stays the same as the electricity from the reference generator, for all CHP's. Where the CHP's electrical efficiency is lower, we allocate fuel to the heat to raise the efficiency of the electricity from any CHP to the same electrical efficiency as the reference CHP.

The chart compares primary energy savings from lower electrical efficiency CHPs to a 50% efficient reference CCGT. The overall efficiency for the CHP and heat from a boiler treated as the alternative source of heat in the heat sector in the diagram is 86%.



When we use reject heat from CHP for horticulture at 28C our primary saving is all the fuel that would otherwise be burnt either in a boiler, or burnt to provide electric or other forms of heating.

When the CCGT moves to operation as virtual heat pump with less electricity generated and heat rejection at a temperature suitable for district heating, this electricity use is reflected by the lower electrical efficiency shown on the diagram by the change from 50% to say 45%. Now the saving is lower at 0.92 units of primary energy compared to when all the fuel for the boiler is saved reflecting 1.16 units of primary or fuel energy.

The blue curve shows overall savings calculated by adding heat as a product to electricity as a product. It illustrates how adding different products together misleads. It illustrates the benefit of CHP to the country as a whole but underestimates the impact and importance of CHP for the heat sector particularly for large scale CCGT CHP.

The curve illustrates a further area of agreement with professor Mackay. The very low primary energy savings from micro CHPs tested by the Energy Savings Trust signal electrical efficiencies on a GCV basis of between 6 and 12 %. The difference in performance between micro CHP and large-scale city wide CHP becomes very clear when the effects of heat from CHP are analysed for the heat and electricity sectors on their own.

The blue curve commonly used for assessing savings from CHP obscures the benefits of the higher electrical efficiency CHP for the heat sector.
In agricultural terms, the blue curve is similar to adding information about strawberries to information about watermelons on the basis that both are fruit, then estimating savings for the watermelon strawberry mix.

We also agree that burning gas to convert it to low grade heat in a boiler is not good utilisation of the exergy in the gas. Particularly when it can be converted to high exergy electricity and low exergy heat in CHP.

In the heat sector, other fuels such as biomass, sustainable but more difficult to convert to electricity with high efficiency; are well suited to low temperature CHP district heating with its low maintenance costs compared to gas boilers on account of annual safety and other inspection costs for gas appliances in buildings in the UK.
The book suggests the UK should consider leapfrogging the gas fired CHP option and move directly to electric heat pumps, as a result of his analysis of small scale and industrial CHP.

Citywide district heating using condensing CHP designed to serve low temperature citywide district heating at 75C flow 30C return is different. When analysed the higher electrical efficiency and lower temperature of heat supply tip the balance to the city wide heating option recommended in energy paper 35 particularly when the analysis is extended from use of gas as a the fuel, the assumption in the book, to other fuels coal, biomass, nuclear which can not be converted so efficiently to electricity.

It is practical to retrofit current UK heating systems designed for 82C 72C to connect to a new heat network in a way that can access low exergy heat from CHP fired by any heat source including nuclear condensing CHP as well as solar thermal and geothermal heat. Such networks offer potential for more effective use of heat from all forms of heat pumps with access to higher temperature heat sources than very cold air, offering a way to obtain optimal use of electric heat pumps and CHP.

Analysis of relative merits of CHP's and EHP's taking into account average and marginal network losses.

The fundamental methodology for analysis is set out in "the Orchard Convention". [IX]

We also use "Exergy" analytical principles based on the first and second laws of thermodynamics

We evaluate the effect of average and marginal losses for heat and electrical networks for the two different technologies.

We evaluate three locations for CHP's. **1**) City scale units, suitable for burning any fuel coal, biomass, oil, gas, nuclear. **2**) 500kW CHP sited at local transformers'. **3**) CHP at consumer's premises.

Average distribution losses electricity, central generation	8%
Marginal distribution losses electricity, central generation	16%
Average distribution losses electricity, local generation	3%
Marginal distribution losses electricity, local generation	6%
Average distribution losses modern heat city wide CHP	15%
Marginal distribution losses heat city wide CHP	2%
Average distribution losses heat, local generation LV side 500kVA transformer	8%
Marginal distribution losses heat, local generation	1%

The list of loss assumptions is preliminary, for comment and refinement.

As an example, vacuum technology and nano insulation materials have the potential to improve insulation for buildings, windows and pipes. Cryogenic super conducting developments promise reduced electrical losses.

The nature of electrical and heat losses.

The nature of losses from heat and electricity networks, are fundamentally different.

Heat losses.

For heat, average losses are linear. A function of the surface area of the pipe, and the difference in temperature between the pipe, its insulation, and its environment. Losses from a pipe with a constant flow and temperature are thus independent of the heat energy delivered. This is a

function of the mass flow of the liquid and the temperature difference between flow and return. Losses are similar in summer and winter, particularly for pipes in the ground. The losses per unit of heat delivered are thus highest in the summer, and lowest in winter.
Marginal losses to deliver more heat at times of peak demand require a higher mass flow. Where there is no change in flow temperature, flow line losses do not change. Marginal losses on the flow line thus tend to zero.

In EU exergy terms a loss of 10% for heat at 100C in a heat network amounts to 0.0265 units of exergy. The same 10% loss on an electrical network amounts to an exergy loss of 0.1 units of exergy. This factor of four difference, is a reason why losses from a heat network of 20% reflect a smaller primary energy loss than an electricity network with a loss of 10%.

Electrical losses and impact on transformers and electrical network for electric heat pumps.

Marginal electricity losses in contrast rise steeply with demand, as most loss mechanisms are a function of the square of the power delivered. High marginal electrical losses coincide with times when the COP of an electric heat pump is at its lowest, on the coldest days. These impact on electrical network design, and its capacity to absorb peak electric heat pump loads.

The impact on local transformers from conversion of dwellings to electric heat pumps may be underestimated. Many individual dwellings in the UK have a single-phase 60 amp or 100-amp 240-volt supply, giving them a peak capacity of twenty four (24) kW. This peak when diversified at the local area transformer, due to consumers using electricity at different times, is typically less than one (1) kW per dwelling.

If we reduce domestic hot water and heat loads to three or six kW per existing dwelling, we can estimate the effect on the local transformer. If the electric heat pump has a COP of three on the coldest day, we add a further 1kW to 2kW of load per dwelling.

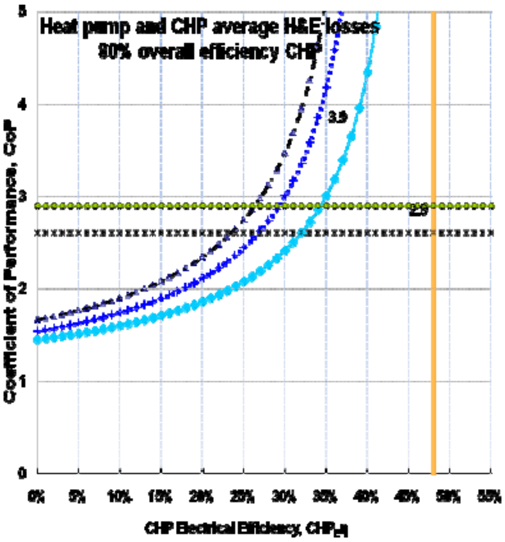
The transformer capacity will have to increase by a factor of two or three, with major knock on effects on investment in new generating capacity and HV networks to meet loads. There will also be disruption to our streets to install the larger service.
There is almost no diversity on heat loads, except insofar as record low temperatures during a very cold spell affect individual cities and do not tend to affect the whole UK at once.

Analytical principles for comparing electric heat pumps and CHP.

The principles are similar to those used in Part L of the building regulations and by the EU to evaluate CHP.

A vertical line on the right of the charts defines a 48% (GCV) for CCGT reference generator.

The charts plot the COP of heat for CHPs of different electrical efficiencies at different locations using three curves.



Two horizontal lines reflect the COP of electric heat pumps (EHP's). A COP of 2.9 reflects the benchmark for renewable status for heat from EHP's

The electrical efficiency of different CHPs are signalled on the x axis from 0% to 55%

All CHP units in the charts have an overall heat and electrical efficiency of 80%.

Lower electrical efficiency CHPs are compared to 48% efficient reference CCGT average H&E losses.

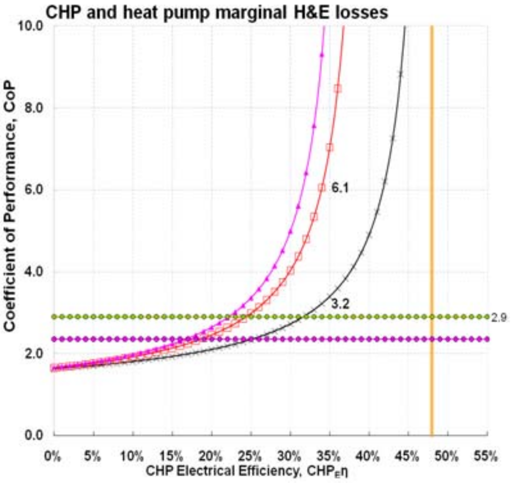
The curve to the left reflects the COP of heat from CHP at points of consumption.

The middle curve reflects the COP CHP at 500 kVA transformers.

The curve to the right reflects heat from large-scale citywide CHPs.

The top horizontal line is EHP with no electrical losses i.e. close to CCGT.

The bottom horizontal line illustrates the reduction in COP for EHP's due to electrical losses to consumer's premises.



The COP of 3.9 on the middle curve reflects heat from a 500kW CHP at the local transformer.

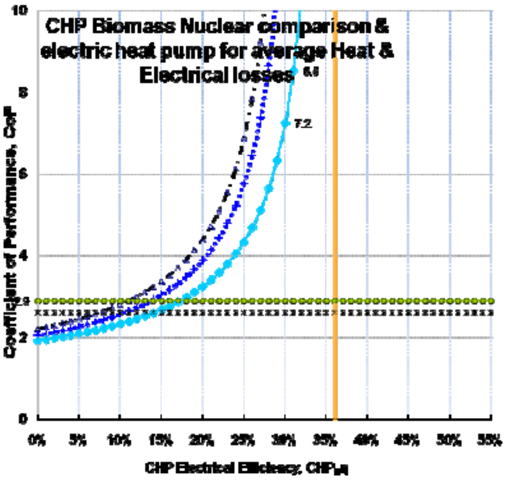
The crossing point for the right hand curve and the 2.9 COP line shows how much the electrical efficiency of a CCGT can reduce to deliver heat at a higher COP than a heat pump.

The benefit of higher electrical efficiencies of larger scale CHP compared to micro CHP are evident from the crossing point of the curves and horizontal lines.

Comparison with 48% efficient CCGT marginal H&E losses.

Marginal losses signal the benefit of local electrical generation capacity compared to central capacity. The COP of heat from the 500kW CHP rises from 3.9 to 6.1 and the effective COP of the electric heat pump drops to 2.4.

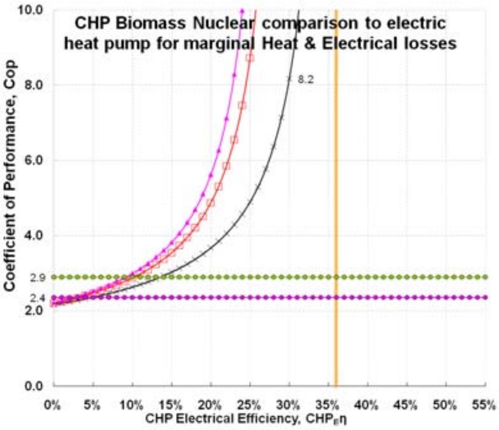
Central 48% efficient CCGT's changing to CHP mode can drop their electrical efficiency when producing heat to 25% to deliver heat to consumers for the same COP as the local electric heat pump. Signalling advantages of CCGT CHP meeting peak heat demands compared to electric heat pumps.



Electricity from Coal Nuclear and Biomass average losses heat and electricity.

When we produce electricity from biomass or coal, the efficiency of conversion of fuel to electricity is low in comparison to gas fired CCGT.
This results in more reject heat available for CHP.
The Energy Paper 20 and 35 analysis is based on nuclear and coal generation and thus more closely reflects our long term future thermal generation from biomass and nuclear.
Energy Paper 20 signals similar results to the charts. Biomass CHP operating at 30% electrical efficiency on the coldest day delivers heat to consumers with a COP of 7.2.

Electricity from Coal Nuclear and Biomass marginal H&E losses heat.



The marginal loss effects are more pronounced as shown in this chart signalling the potential for heat from CHP to meet heat sector demands on the coldest day when heat rejected by generation is greatest.

Optimal temperatures for heat networks.
Condensing operation for boilers and CHP to increase their overall efficiency, only takes place if the water returning to be reheated is below 50C. Higher water temperatures cannot condense the water vapour in the exhaust gases.
Danish “directly connected” practice in the city of Odense with a heat supply temperature of 90 to 95C and heat return temperature of 45C encourages condensing operation.
The lower the flow and return temperatures, whether heat comes from heat pumps, or CHP the better the COP.

We consider 75C flow and 30C return as an achievable technical target to retrofit UK housing stock and to modify most existing low temperature heating systems in buildings. A flow temperature of 75C is sufficiently high to meet the current requirement to heat domestic hot water to 60C, to combat Legionella bacteria and Legionella disease. We can readily achieve return temperatures lower than 30C when preparing domestic hot water and heating incoming air.

Low temperature, directly connected heat networks, will be compatible with heat from large electric heat pumps, seasonal heat storage and heat from large-scale solar thermal collectors. The Marstal district heating installation in Denmark and others demonstrate the benefits of solar thermal and district heat. Economies of scale give considerable savings compared to solar panels on individual roofs. Apart from lower costs, a benefit is that all the heat from the panel gets into the communal system and its heat storage, compared to individual dwellings where heat from the panel depends on use of the hot water system. Methods to prevent over heating of domestic hot water have to be included as part of the design of individual solar systems.

EU Exergy formula for the analysis of CHP.

The EU propose a new “Carnot Efficiency” allocation method in their report entitled “Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. SEC (2010) 65 SEC (2010) 66.

In an excel spreadsheet which is on the CD with this paper we have analysed the effect of the assumptions in the formula and their effect on the allocation of fuel to electricity and heat in the formula.

We have selected a CHP with an electrical efficiency of 35% and an overall efficiency for heat and electricity of 86% for illustration. It represents a 500kW dual fuel engine CHP burning either natural gas and oil or bio methane and bio oil.

The table shows two effects of the formula for discussion the first is the effect of rejecting heat at higher temperatures on emissions for electricity and the heat, the second the effect of the base temperature assumption.

Temperature of heat rejection C	Base temperature 0C	Base temperature 0C	Base temperature 30C	Base temperature 30C
	ECel Fuel per unit electricity	ECh Fuel per unit heat	ECel Fuel per unit electricity	ECh Fuel per unit heat
0.00	2.86	0.00		
20.00	2.60	0.18		
30.00	2.50	0.25	2.86	0.00
40.00	2.41	0.31	2.44	0.28
60.00	2.26	0.41	2.30	0.38
80.00	2.15	0.49	2.19	0.46
100.00	2.05	0.55	2.10	0.52
120.00	1.98	0.60	2.02	0.57
140.00	1.91	0.65	1.96	0.62
150.00	1.88	0.67	1.93	0.64
160.00	1.86	0.69	1.90	0.66

Base Temperatures.

The calculations change as the base temperature is changed. Is 0C an appropriate base?

One would expect heat rejected at 30C in large central power stations to be signalled as having zero emissions to encourage its use and heat at 100C from chimneys.

The result in the formula depends on the base temperature. Given the practical constraints in a steam cycle of rejecting heat at 0C the paper recommends changing the base to 30C.

It should also be noted that the average ambient temperature in the countries of central and north-west Europe is 10C, not 0C.

District heating flow temperature assumption.

The second issue is that where CHP serves community or district heating a temperature of 150C and Carnot efficiency for heat of 0.3546 has been set as a standard independent of the actual temperature of heat rejection. The influence of the temperature of heat rejection is shown in the table.

Various concerns arise, one is the arbitrary temperature will discourage maximising the utilisation of fuel and generation of electricity by rejecting heat to district heat at the lowest practical temperature to achieve the highest actual electrical efficiency and production of high exergy electricity.

A further concern is how to ensure that heat rejected at a high temperature is actually utilised at that temperature to produce further work as the logic behind the methodology appears to be that the heat at a higher temperature could be used to produce further work before being rejected at zero C. This is a questionable assumption, due the practicalities of converting low temperature heat to work.

Thermodynamic logic signals use of the actual temperature of heat for the district heating in the formulas, we can see no reason for not using this signal.

If we compare the emissions signal for district heat at 80C compared to district heat at 150C, for a base temperature of 0C and a practical base temperature of 30C, we can assess the impact of the limit on emissions signal to the heat sector and the inherent cross subsidy to the electricity sector.

Emissions per unit of heat reduce from 0.67 to 0.49 with no change in base and from 0.67 to 0.34 with a base change to 30C.

This is a significant overall change in emission signal to the heat sector of 0.33 units of fuel per unit of heat.

The formula has only been recently issued and we have not assessed all its implications however we have noted the gap between the theoretical efficiency for electricity generation in the formula of 88% compared to practical thermal electricity generation efficiencies ranging from 35% to 50% (HCV basis) depending on the fuel.

The author is concerned that the formula will discourage investment in citywide heating, and the use of reject heat from CHP for horticulture and other low exergy applications and investment in piped heat supply systems essential for effective use of biomass. It is possible the formula will increase emissions due to its effect of significantly increasing the efficiency of the conversion of fuel to electricity in its emission calculations for electricity.

The author is also concerned that it will allocate emissions to heat in situations where the marginal fuel burn for the heat in practice is zero and use of the formula may affect and distort this cost signal.

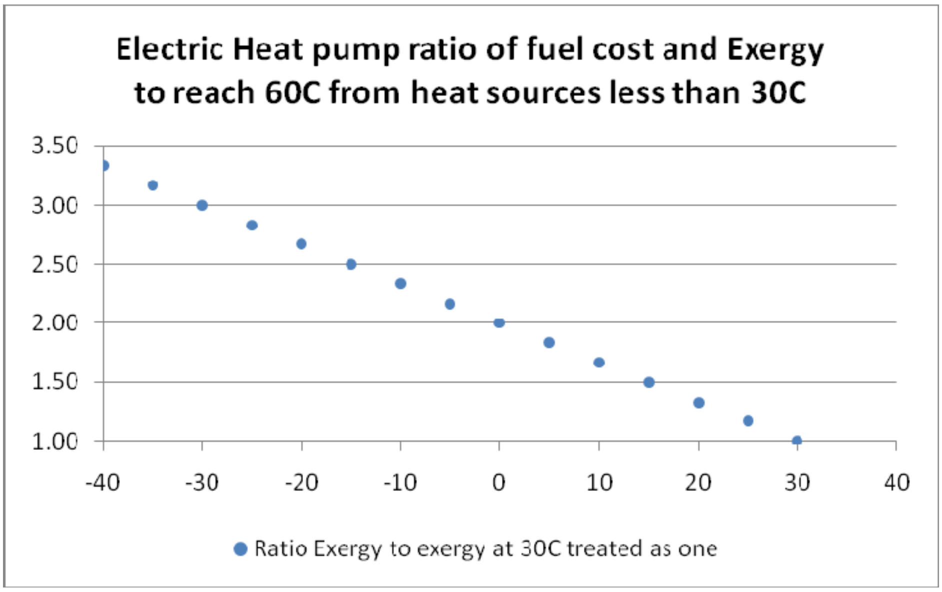
The author reasons that use of heat from CHP can only gives significant savings in the heat sector. If it can give savings in the electricity or power sector, one could argue that encouraging motorists to run their car heaters summer and winter will give significant fuel savings for the transport sector.

The author is however on learning curve on exergy and is grateful to both Professor Robert Lowe and David Olivier for assisting him in his understanding of the concept to date. The views expressed are to stimulate discussion and increase the authors understanding of the use of exergy as the basis for allocations in CHP.

Electric Heat pump and Exergy analysis.

The following chart uses exergy principles to evaluate the theoretical effect of the exergy required for an electric heat pump using heat sources at different temperatures to raise domestic hot water to 60C by comparing a waste heat source of 30C from electricity generation to air sources at lower temperatures.
The purpose, to evaluate the difference in fuel requirement for a heat pump using reject heat from power generation as its heat source compared to air or ground sources at temperatures down to minus 40C.

The following chart plots the relative exergy or electricity consumption to raise heat to 60C from lower temperature sources in the environment.



It signals the benefit of using higher temperature sources of heat for heat pumps and the relative cost of reaching 60C with a source of heat at 30C cost index one, source of heat 0C cost index 2.

Long term UK thermal electricity generation can be large scale CHP burning bio fuels or nuclear CHP, demonstrated in the UK at Calder Hall, and in Lithuania at Ignalina. As use of gas and other fossil fuels is reduced signals to encourage use of low temperature heat in these cycles are essential if the CO2 displacement potential of reject heat from electricity generation is to be realised.

CONCLUSIONS.

The main vulnerability for consumers and our cities is loss of electricity supplies. Normally this loss in winter is due to failure of power lines, the most vulnerable part of any modern country's infrastructure. A more serious threat is economic damage when such systems are intentionally disrupted.

A 500kW distributed condensing CHP scenario using dual fuel engines burning gas with oil as a standby fuel, sited at most 11kV to 415V transformers in UK cities can prevent loss of supply and associated economic damage. An all-electric heat pump scenario in comparison will increase consumer vulnerability.

Energy papers 20 and 35 identified CHP district heating as a better solution than electric heat pumps in every home. Electric heat pumps optimally will feed heat into low temperature heat networks allowing them to access higher temperature ground heat stores and other heat sources.

A DECC heat sector study addressed some aspects of city heating but did not cover the range of issues analysed in Energy Paper 35. The study recommended further work, we suggest the work include:-.

- Hard to heat housing and a relative cost analysis of the alternative of higher costs insulation measures to code level 4, after the low hanging fruit of cavity fill and roof insulation have been picked, compared to low CO2 piped heat supply that decarbonises ventilation and domestic hot water loads as well as fabric loads.
- Balance of payment benefit.
- Security of supply.
- An analysis of the relative disruption for consumers for retrofit insulation, ground source heat pumps, upgrading the electrical infrastructure, further replacement of old local gas infrastructure, as well as installation of a new low CO2 piped heat supply system running at the edge of pavements under the kerbs between pavement and road, a route clear of other services.

The paper has compared CHP and electric heat pumps using “Orchard Convention” principles by analysing the heat and electrical average and marginal loss effects on the two technologies.

Fuel saving benefits with large scale district heating and CHP feeding low temperature heat networks prove superior to all electric heat pump scenarios.

CHP’s with low electrical efficiencies such as micro Stirling engine gas fired CHP’s, can not optimise exergy on account of their low conversion of the exergy in the fuel to electricity and are inferior to electric heat pumps.

Gas is identified as fuel which can be converted at high efficiency to electricity and heat in CHP. Use of gas boilers and small scale CHP where the exergy in the fuel is mainly degraded to low temperature heat, is suboptimal use the fuel.

The author finds no difference in principle between heat from electric heat pumps and heat from CHP. He recommends both products are put on the same footing for UK and EU incentives for reducing CO2 emissions.

To achieve this we suggest an extension to the EU definition of renewable heat to include a next best option category low CO2 heat.

We propose that heat from electric heat pumps are then classified as low CO2 heat instead of renewable to reflect their fossil fuel overhead, putting electric heat pumps on the same footing as CHP “virtual heat pumps”.

The CO2 overhead for heat and electricity will change depending on whether the source of the electricity is viewed as coming from the world’s marginal CO2 electricity from coal, or electricity from a renewable sources.

The review of new EU formula allocating benefits between electricity and heat based on exergy raises concerns that the formula could increase CO2 emissions and discourage use of low temperature heat district heating by setting an arbitrary figure of 150C for all heat to district heating when many current and future systems operate at lower temperature with future systems proposed for 75C.

The paper recommends use of the actual temperature of the heat supply to the district heating. It will encourage greater production of the high exergy product electricity from the available heat. There is a need to stimulate development of piped heat networks to distribute, and the use the very large resource of low-grade reject heat from electricity generation heat in district heating.
This requires incentives mainly on heat the waste product, instead of electricity the prime product.

The base temperature of 0C is an impractical temperature for heat rejection from steam turbines the paper recommends raising it to 28C to 30C to reflects the level of temperature for heat rejection for many large steam turbines currently generating electricity. Or at a minimum it should be raised to the mean ambient temperature in a country (10 C in England and Wales, 8 C in Scotland)

In the UK, the total heat rejected in CCGT and other electricity generation, in energy terms amounts from cooling towers and chimneys is estimated at 480 TWh of energy made up of 137 TWh from chimney heat at over 80C and 343 TWh from cooling systems rejecting heat to the environment. This exceeds the total supply of gas to UK domestic consumers of 334 TWh which assuming an average efficiency for conversion to heat amounts to 267 TWh of delivered heat. This indicates the potential that exists in the UK to copy the retrofitting of Odense with low temperature piped heat supplies, as recommended in Energy Paper 35 in 1977.

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