Decarbonizing the Heat Sector

Gordon Taylor

G T Systems

www.energypolicy.co.uk

October 2018

Decarbonizing the Heat Sector

Summary

Why Combined Heat and Power ?

The Importance of CHP Unit Size

Electric Heat Pumps

Large CHP-District Heating

District Heating is best for near-zero-carbon heat

Decarbonizing the Heat Sector

Context

Most progress on decarbonisation has been in the Electricity sector, still with ~ 26% of C emissions.

Solutions are emerging for the Transport sector, with ~ 33% of C emissions and quick turnover.

The Heat sector is ~ 42% and buildings have slow turnover so need near-zero-carbon heat carriers.

Options for Space and Water Heating

In the UK, ~ 80% is from individual boilers using natural gas. These are typically replaced with condensing boilers.

One proposed option is a Micro-CHP unit with a typical output of 1 kWe and 3-4 kWth, with a backup boiler, both using natural gas.

A second option is an electric Heat Pump and a backup heater also using electricity.

A third option is District Heating with water at ~ 70 C. This can use heat cogenerated from Power Plants (CHP) and from renewable sources.

Space and Water Heating with Low-C H2

Another option proposed for the UK is to re-purpose the gas network to carry low-carbon hydrogen, despite the still poor exergy match.

Most hydrogen is produced by steam reforming of natural gas at an efficiency of ~ 70%. The CO2 would need vast CCS and reservoirs.

The gas network capacity would be reduced ~ 70% by CV and ~ 59% by plastic lining - I.e. by about 88% overall, which is not feasible.

All gas boilers etc would need modification or replacement to burn H2.

The above help explain why such H2 networks have not been adopted.

Why Combined Heat & Power ?

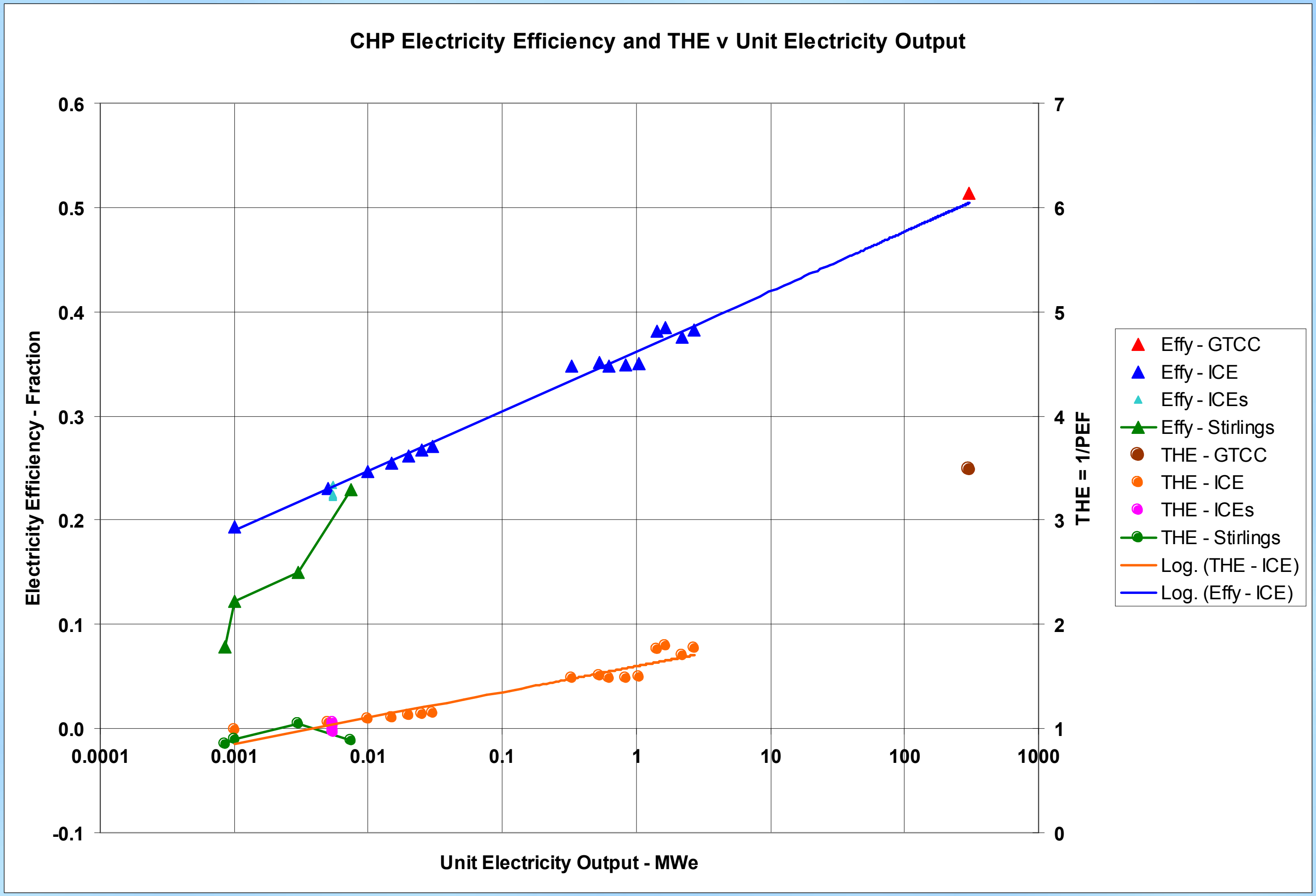
A Combined Heat and Power plant provides 'Thermodynamic' heat via a 'Virtual' Heat Pump, with no separate hardware or working fluid.

A Micro-CHP unit provides some electricity and the cogenerated heat, with more heat from a backup boiler.

A Combined Heat and Power plant with a District Heating network replaces a Power-Only plant and Cooling Towers.
So it uses the Power Plant reject heat, which is otherwise wasted.
In the UK, this is about 15% of all Primary Energy consumption.

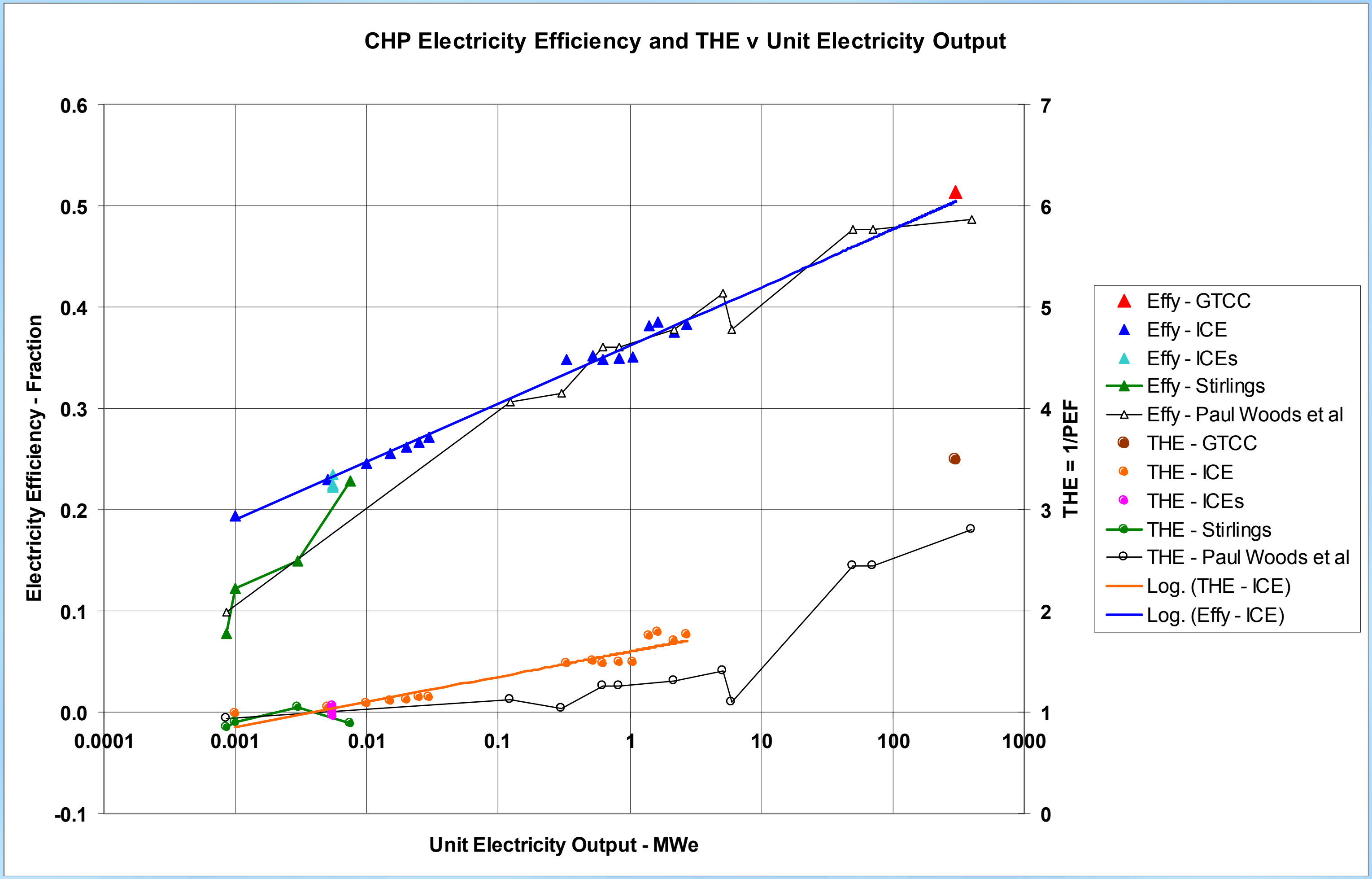
The Importance of CHP Unit Size - 1

Electricity Efficiency & Thermodynamic Heating Efficiency vs Size



The Importance of CHP Unit Size - 2

With data from Paul Woods et al, as amended



The Importance of CHP Unit Size - 3

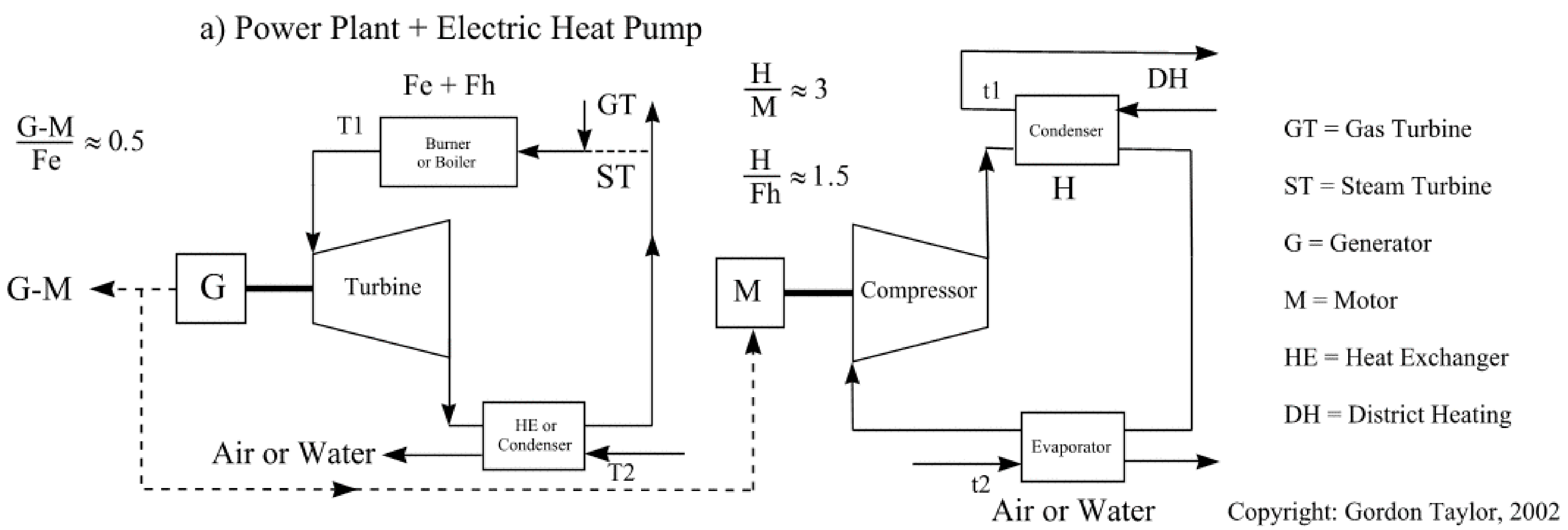
Micro-chp units of ~ 1 kWe have a Thermodynamic Heating Efficiency of less than 100%.

A micro-chp unit has a heat output too small for most space and water heating loads, so needs a backup boiler.

Most test data is measured under steady-state conditions, whereas real use is dynamic, which is less efficient.

Compared with a condensing gas boiler with an annual average efficiency of 96%, a micro-chp system offers no fuel and CO_2 saving.

Power Plant + Electric Heat Pump - 1



Power Plant Effy 50% x HP COP 300% = Thermodynamic Heating Effy 150%

Power Plant + Electric Heat Pump - 2

The Thermodynamic Heating Efficiency = Heat Out / Incremental Fuel. This is the reciprocal of the 'Primary Energy Factor' used on the Continent.

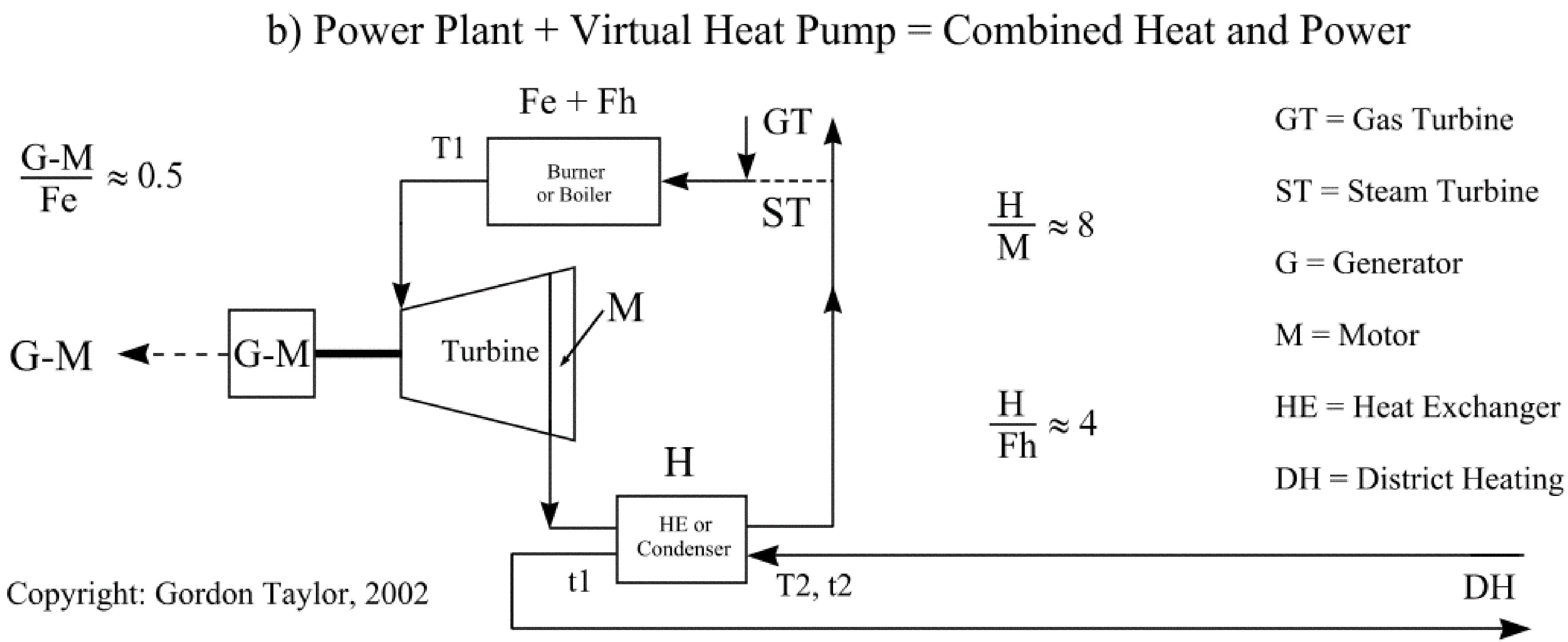
Thermal power plants and individual electric heat pumps have a Thermodynamic Heating Efficiency of less than 150%.

Compared with individual condensing gas boilers with efficiency of 96%, the fuel and CO_2 saving is less than 30%.

Building heat loads are uncertain and vary with occupant number and behaviour. So the heat pump may be oversized and run inefficiently, or undersized and require more use of the backup heater. Thus the fuel and CO_2 saving is often less, as shown by field trials.

Widespread use of electric heat pumps would require very costly upgrading of electricity generation, transmission and distribution.

Large CHP-DH - 1



Power Plant Effy 50% x Virtual HP COP 800% = Thermodynamic Heating Effy 400%

Large CHP-DH - 2

The Thermodynamic Heating Efficiency = Heat Out / Incremental Fuel.
This is the reciprocal of the 'Primary Energy Factor' used on the Continent.

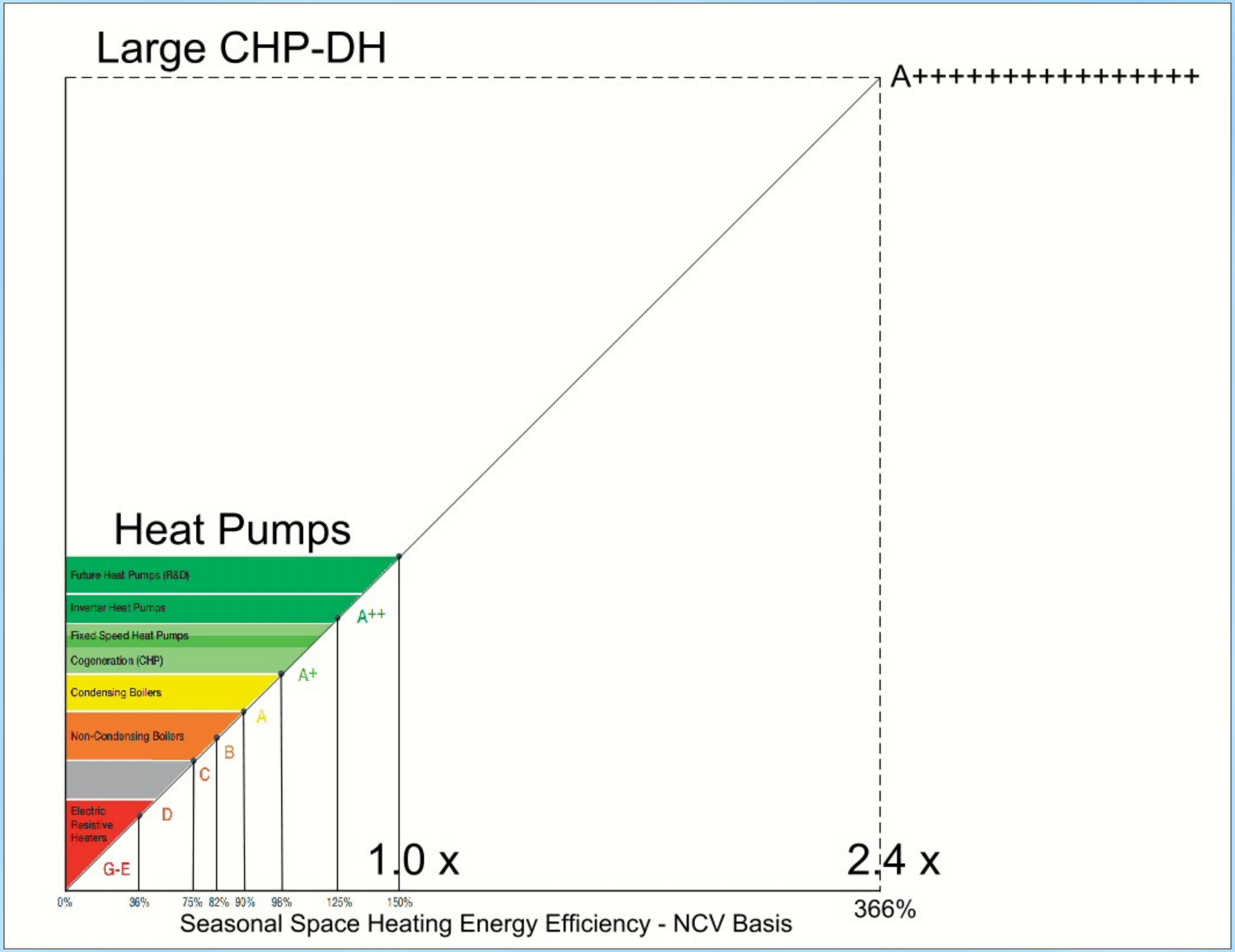
Large gas-fired CHP plants have a THE at the plant gate of about 400%.
Some heat is from Heat-Only Boilers and the DH network has heat losses.
So the Thermodynamic Heating Efficiency of Large CHP-DH is about 330%.

Compared with individual existing gas boilers with an annual average efficiency of 65%, the fuel and CO2 saving is about 80%.

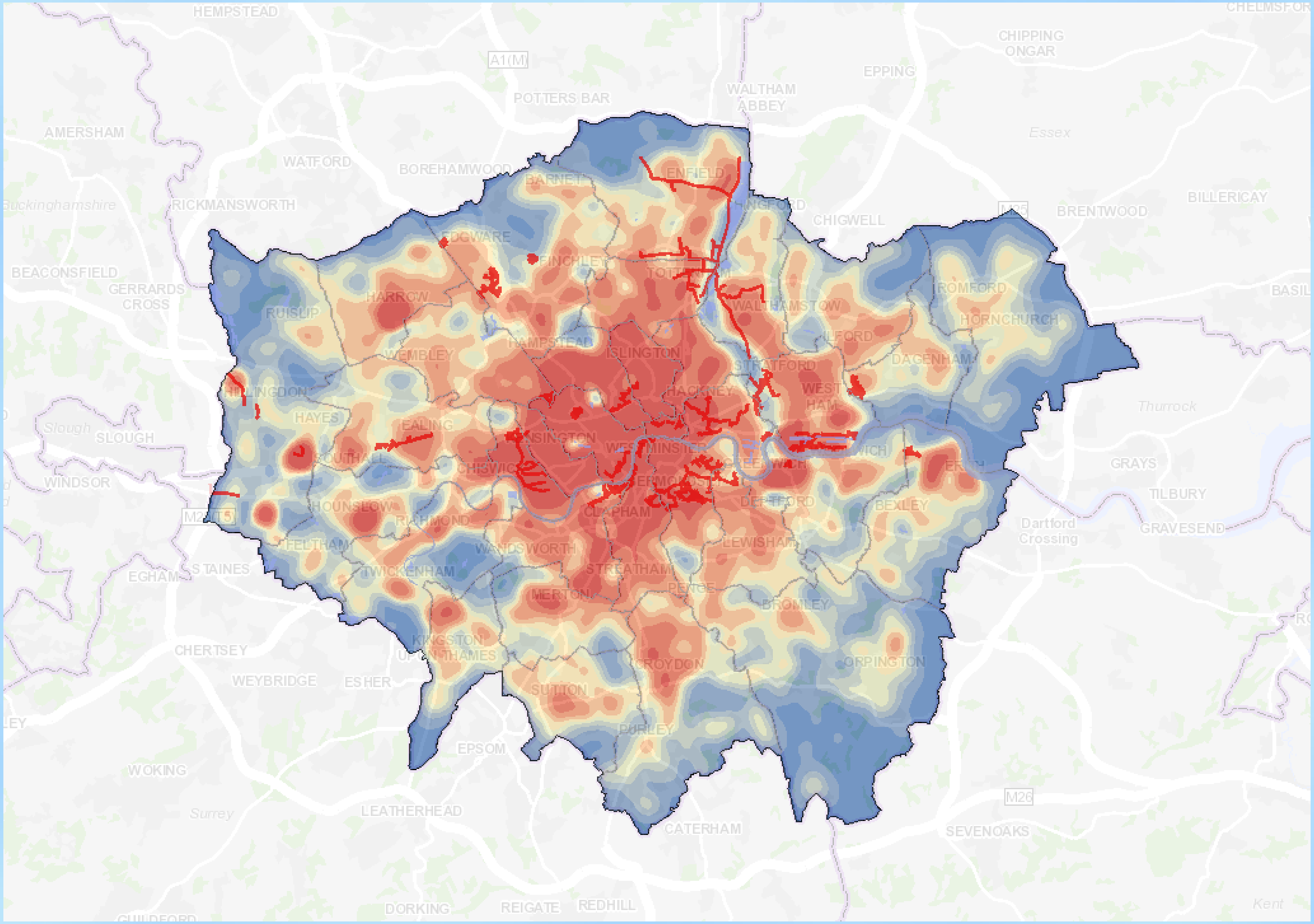
Building heat loads are uncertain and vary with occupant number and behaviour.
But these are averaged, so have little effect on the THE and CO2 saving.

Modern DH systems vary the flow temperature over the year, so reducing losses and providing primary 'outside compensation' control. They also include individual water flow or heat meters, so avoiding waste.

Heat Pumps vs Large CHP-DH



London Heat Map



Deploying District Heating

The Heat Load Density varies across all cities - being highest in the centre and lower in the suburbs.

So District Heating networks should be built from the centre, capturing the largest heat loads first to improve the cash flow.

City centre buildings often require cooling. These loads can be met with separate District Cooling networks or with District Heating networks driving heat-driven chillers with surplus heat in summer.

Heat Interface Units are smaller than existing gas and oil boilers. So District Heating often releases valuable city centre floor space.

District Heating avoids Nox emissions from gas-fired boilers and chillers. This especially benefits city centres with high-rise buildings.

Diversity Factor vs Number of Loads

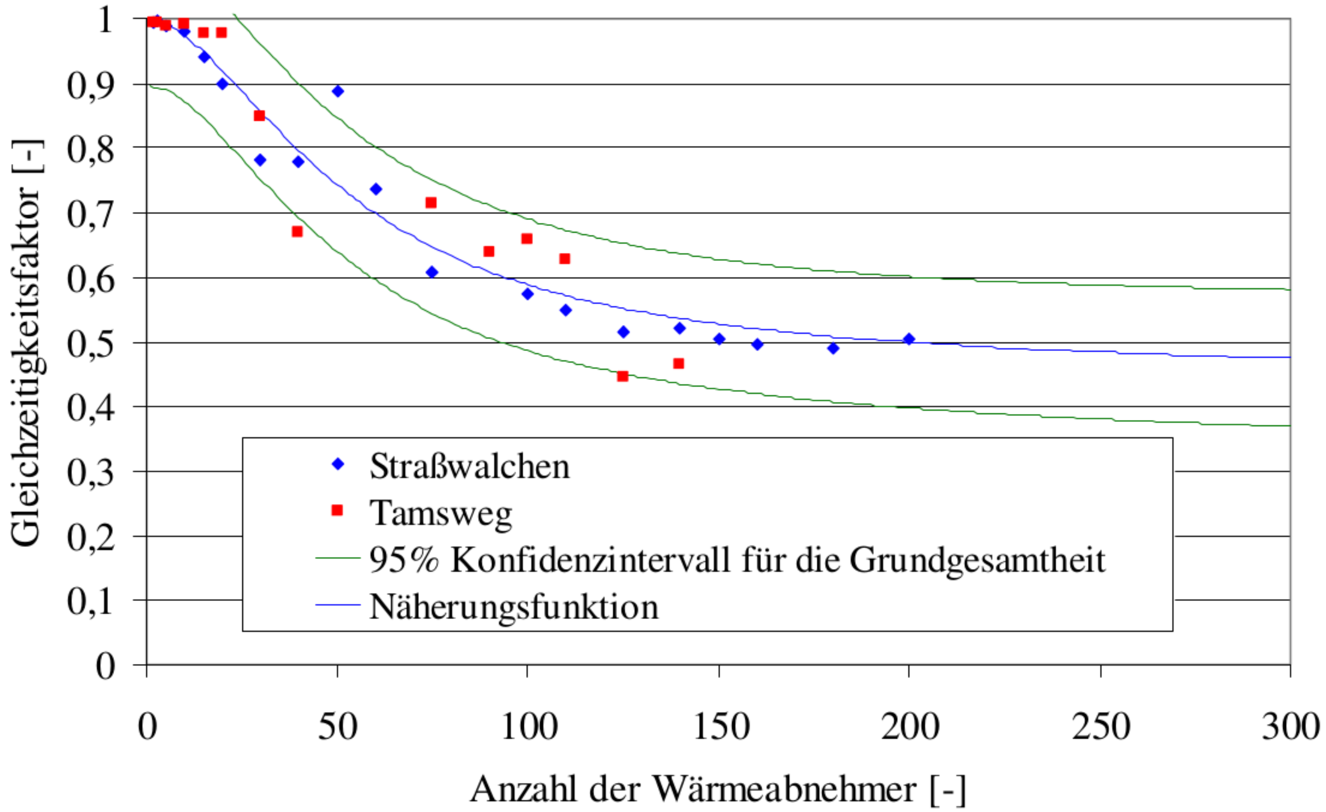


Abbildung 6-2: Näherungsfunktion für den Verlauf des Gleichzeitigkeitsfaktors in Abhängigkeit der zu versorgenden Abnehmerzahl

Figure 6-2: Trend of the suggested approximative equation for calculating the simultaneity factor depending on the number of consumers

Further Merits of District Heating - 1

In large networks, diversity reduces the maximum load to ~ 0.5 times all the individual loads, so the central plant is smaller and less costly.

Large central plants are installed and run by professionals ensuring reliable service, low emissions, energy efficiency, water quality and good maintenance, so have long lives.

But small distributed plants are often poorly installed, run by end-users, and poorly maintained, so have short lives.

Further Merits of District Heating - 2

Compared with electricity and gas, District Heating at ~ 70 °C or less gives the best possible exergy match for space and water heating.

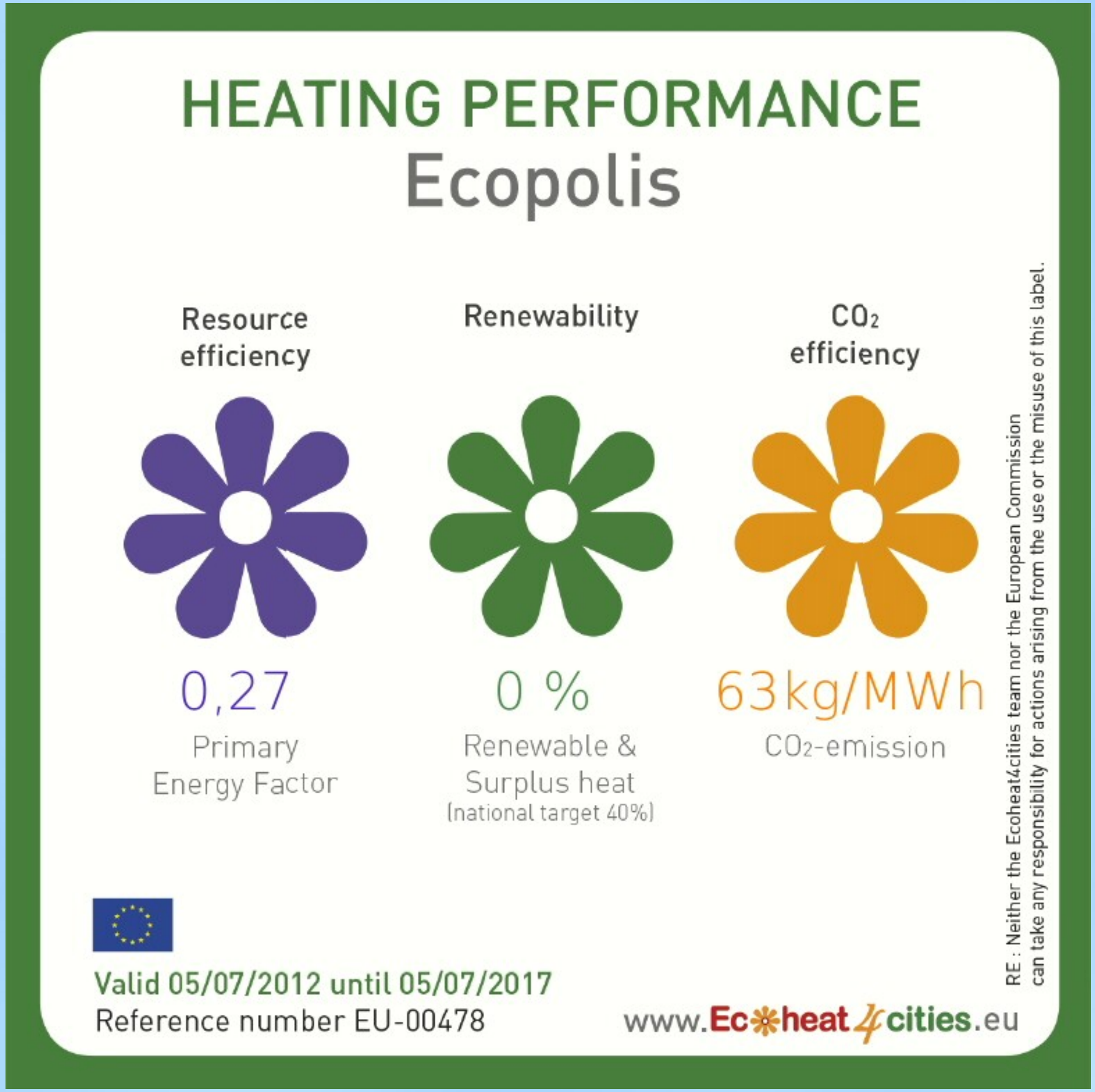
So it is completely future-proof and easy to finance over long periods.

DH networks use power and industrial reject heat and renewable heat.

The latter sources include municipal waste, biomass, large solar heat arrays, excess wind electricity, and deep geothermal heat.

By such means, space and water heating in Copenhagen is on track to be near-zero-carbon by 2025.

DH System Energy & Emissions Label



Conclusions on Decarbonizing Heat

Refurbishment of buildings to Passive House standards would be too slow and costly, and unacceptable for heritage buildings.

Micro-chp offers no fuel or CO_2 saving over condensing boilers.

Large CHP-DH gives much greater fuel and CO_2 savings than individual electric heat pumps.

District Heating is the best means of using low-carbon sources such as power and industrial reject heat, municipal waste, biomass, solar heat, excess wind electricity, and deep geothermal heat.

DH with Large CHP and such sources offers a smooth transition to near-zero-carbon heating of buildings in towns and cities.

Decarbonizing the Heat Sector
‘1000 Cities Cannot be Wrong’

Gordon Taylor, M.I.Mech.E.

G T Systems

email: gordon@energypolicy.co.uk

More presentations and papers on energy are at:
http://www.energypolicy.co.uk/