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Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion

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1. EXECUTIVE SUMMARY

Purpose: *The purpose of this report is to provide background information on potentials, barriers, best practices, state of the art and measures of promotion of District Heating and Cooling to aid policy making.*

Preliminary assessments were performed on the likely cost and impact of adopting an EU wide approach to Combined Heat and Power (CHP) and District Heating- CHP-DH by studying three representative cities (Chapter 17). Looking at the maximum penetration in terms of fossil fuelled power stations it was estimated (Chapter 18) that a capital spend of €319 Billion on CHP-DH infrastructure will reduce heating costs by approximately €51.4 Billion per year and save 5.320 EJ of primary energy. (Subject to the constraints outlined in Chapter 18). This is almost half the EU27 primary energy demand for building heating. This would be greater if the waste heat from existing nuclear stations were considered as this option is feasible also[1].

Space and domestic water heating for buildings is currently one of the largest sectoral energy uses – about 43% of the total EU final energy consumption (excl. transport) - and is the most problematic to decarbonise[2]. Heating is currently mainly achieved with fossil fuel energy directly delivered to the buildings, creating local safety and emission issues. The cost of total energy imports into the EU in 2011 was €400 billion[3].

In 2008 the heat losses of the EU27 energy system before end use were in total 39.3 EJ. Valued with a crude oil price of 97 $/barrel these heat losses would have a market value of €480 billion per year[4,5]. Around 19 EJ of this loss is a by-product from electricity generating power stations[6] which is presently sent to cooling towers and water bodies and cannot generally be used to heat buildings economically as it is often at too low a temperature typically of around 30°C for large steam turbine power stations. This quantity is considerably larger than the low temperature heat demand for domestic and commercial buildings in the EU, of around 11 EJ[7] presently largely met with fossil fuel. The issue of these losses is explored further in Chapter 5 of this report.

This report addresses the practical way in which this unusable low grade heat can be upgraded to a temperature suitable to both heat and cool cities with the technique of Combined Heat and Power (CHP) and District Heating (DH) and District Cooling (DC) collectively termed CHP-DH. The effect of large steam turbine CHP is identical to that of an

[1] "Switzerland got 7.5 per cent of its heat from nuclear power stations in 2009. Within the EU, Slovakia got over 5 per cent of its heat from nuclear stations in 2009. Hungary and the Czech Republic also use nuclear heat. But in the EU's main nuclear players, such as France and the UK, the heat is simply expelled into rivers and seas". (Energy Efficiency: made in Denmark, exportable to the rest of the EU?- Stephen Tindale. April, 2012.

[2] See Chapter 5 page 35

[3] Philip Lowe, Director-General. European Commission.

[4] ECOHEATCOOL Work package 1. EU Intelligent Energy Europe Programme. 2005-December 2006.

[5] This costing is unrealistic in the sense that this heat has very little value due to its low temperature, however it indicates the potential value which can be unlocked with CHP which raises the temperature of waste heat at low energy cost..

[6] ECOHEATCOOL Work package 1. EU Intelligent Energy Europe Programme. 2005-December 2006.

[7] "Study on the European heat and cooling market and its technology mix" Under Energy Systems Evaluation Unit, Institute for Energy and Transport, JRC, European Commission. 2011.

electric heat pump[8] in that they both use electricity generated in a power station to upgrade the temperature of heat to a temperature at which it is usable for low temperature heating. Thus CHP has been termed a "Virtual Heat Pump"[9]. (Other forms of CHP using engines however reject heat at temperatures suitable to directly heat buildings.) In practice CHP-DH when compared in this way to a domestic heat pump is considerably more effective. The Coefficient of Performance – COP (the ratio of heat delivered per unit electricity used) - of existing CHP installations can be around 6 - 10, (with future higher COPs achievable where low temperature directly connected heat networks are developed – see 19.4). For a domestic sized electric heat pump its COP varies, higher in summer lower in winter but with average seasonal COPs around 3. (The term COP used for heat pumps, is identical in its description of the thermodynamic effect to the term Z factor as used for CHP plant – 19.4, 19.10). Thus the primary energy and CO_2 overhead (ie expended primary energy to deliver the energy) when upgrading heat from large scale base load power stations using steam turbines, via CHP to heat cities is extremely low compared to alternative heat sources[10]. This is discussed in 3.4 and 21.1.

District Heating can meet much of the EU27 fabric heat loads, ventilation loads and domestic hot water load in a low carbon and energy-secure and cost effective (indigenous) fashion with the existing building stock. Conversely heat load reduction - by insulation etc (although strongly recommended where economic) is unlikely to achieve the same level of CO_2 reduction due to the domestic hot water and ventilation loads, which are difficult to reduce, and the cost and diminishing returns of high levels of insulation. CHP-DH is recommended as suitable for the very low energy Passivhaus designs by the leading Passivhaus Austrian proponent (6.3). Retrofitting and rebuilding of the existing buildings is likely to take too much time and money and be impractical for the legacy buildings found throughout Europe (6.3). Whilst District Heating necessarily delivers the same amount of heating energy kWhs, as any fossil fuelled boiler it may be replacing, if the heat is from CHP or renewable sources, the energy has a much lower fossil energy content (energy overhead) and carbon overhead and so the imperative to save these forms of low carbon energy is less compelling – heat energy from CHP is different in terms of its energy content and carbon footprint[11].

All heat, gas and electrical network solutions benefit from Diversity Factors. This is due e.g. to reduced occupancy and/or reduced room temperatures and hot water consumption that occur simultaneously in a *range* of buildings compared with the parameters used for design in *individual* buildings. So the total load seen by the network is less than the sum of all the design peak loads of all the various buildings. Moreover, large central plants cost less per unit of output. Conversely, options such as individual boilers, micro-CHP or heat pumps have to be sized for the full theoretical loads of the building and are also disproportionately costly.

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[8] "Exergy & marginal fuel use an analysis of heat from CHP and heat from electric heat pumps." http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf.

[9] Professor Robert Lowe, "Combined heat and power considered as a virtual steam cycle heat pump", Energy Policy 39 (2011) 5528–5534.

[10] Comparing a gas fired Combined Cycle Gas Turbine (CCGT) CHP unit, with a gas boiler, then every unit of heat from the CHP utilises 0.27 units of energy, whereas the boiler utilises 1.11 units, a factor of 4 higher. The heat pump utilises 0.66 units a factor of 2.44 higher. And electric heating utilises 1.98 a factor of 7 higher. Thus CHP heat is a very low energy / carbon content heat source. (Data from the example in Table 3.1)

[11] Confusion can arise due to a lack of consideration of the first law of thermodynamics that states that energy is always conserved, and an idea that all forms of energy are the same. Whilst progress has been made in awareness of the different amount of primary energy in electricity and heat the concept of the CO_2 footprint of energy is relatively new. This raises the question of how heat from CHP should be measured since a situation can be reached where the energy approaches zero CO_2 per kWh. If measured in the same energy units as gas and electricity consumers will get no signal about the environmental benefits of such a low CO_2 heat supply.

There are thus major benefits from the integration of heat, gas and electricity networks particularly due to the ability of heat networks to store heat to meet peak heat demands, absorb and smooth the variable output of renewable, and this ability can be readily extended using hot water storage tanks which are extremely cheap compared to electricity storage. See Chapter 10 for storage details Chapter 6 showing how CHP-DH with storage enables the integration of renewable energy.

DH is a highly reliable and resilient heating solution. The end user has only a simple consumer unit (with heat exchangers[12], pumps and valves), with no combustion chamber or flue requiring annual maintenance, or potentially hazardous on-site fuel storage or delivery. The service is run by professionals and has intrinsic storage in the network sufficient to cover brief CHP outages, while the peaking boiler plants may be run to cover any longer outages. Moreover, the supply of heat can evolve over time towards a mix of zero carbon indigenous sources without requiring any action by the building owner or occupier. It follows that district heating is a robust solution that is unlikely to be superseded. The human body temperature will always be 37°C, and thermal comfort will correspondingly always require room temperatures around 20°C to 25°C. To avoid Legionella, domestic hot water is raised to 60°C and circulated at 50°C. District heating with primary flow temperatures of 70 to 90°C are thus capable of providing a low exergy[13,14] carrier[15].

Although it is anticipated to steadily decrease, fossil fuel energy is likely to be a significant fuel for power generation for many decades, due to the slow rate at which new power stations can be built and replaced, and the need for firm capacity to support variable output renewables. Biomass is also expected to continue to be combusted in power stations. The report provides background support to the case that District Heating – DH and District Heating and Cooling DHC (DH is used to mean DHC hereafter) - networks fed by waste heat from these fossil / biomass fuelled power stations in the short term, and renewables (and other low/non-fossil heat sources) in the long term, but with the CHP retained to provide both heat and electrical power back up, are likely to be the key component of a low carbon and more energy-secure Europe. This is due to its cost competitiveness (Chapter 17) compared to other options, its flexibility in terms of its ability to use various non-fossil heat sources such as wind energy, solar heat,[16] and industrial waste heat, geothermal heat and heat from waste combustion which are becoming increasingly integrated into heat networks. These low temperatures heat sources can be readily integrated into a DH network which is not the case for an "all-electric" future.

Building heat load is unlikely to shrink significantly (Chapter 6) due to the difficulty and cost of retro-insulating existing buildings and the slow turnover of the building stock. Heating the

[12] Not in all cases – ie Odense which is directly connected to buildings.

[13] In thermodynamics, the **exergy** of a system is the maximum useful work possible during a process that brings the system into equilibrium with the environment. Thus exergy is for our purposes a measure of the usefulness or value of energy. It is inappropriate to use high exergy energy for example gas, for uses which require low exergy heat, such as heating which can be met with low temperature waste heat.

[14] "Exergy & marginal fuel use an analysis of heat from CHP and heat from electric heat pumps." http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf.

[15] Technologically, it should be possible (using floor heating instead of radiators) to lower the required DH forward temperature to maybe 40 °C The problem of Legionella must then be dealt with either using electricity directly or by a heat pump – Professor Niels Houbak.

[16] "Solar energy contributes to cleaner district heating" Mr. Lars Gullev, managing director, Veks, and chairman of DBDH Hot:Cool. Energy and environment

current building stock in cities by renewable electricity delivered through the electricity network (either to individual heat pumps or direct resistance heating) faces practical difficulties due to the cost of upgrading distribution networks[17] and increasing power station capacities to deal with the resultant cold weather peak electrical loads[18]. (See Chapter 3.6) Domestic electric heat pumps are connected to the low voltage grid and thereby incur very high marginal losses particularly[19] during peak cold winter periods when they are necessarily less efficient as measured by a low coefficient of performance at this time; this in turn imposes very high peak demand on the distribution grid. Cold snaps have recently caused this kind of problem in the French electricity network[20]. Solutions to this issue are combining the electric heat pump with a fossil source of heat to meet peak loads. A more satisfactory solution is likely to be the integration of larger more effective electric heat pumps in the HV grid and with low temperature heat networks.

Large scale electricity storage if it is intended to allow stored renewable electricity to be used for building heating and cooling implies extremely costly long term electricity storage for dealing with the variability (also called intermittency) of renewable energy, and again there is the issue of distributing it to the final user via the distribution grid which will need upgrading in many cases. These issues are avoided if readily available and much cheaper thermal storage and District Heating is used. Similarly in the Southern countries, ice storage with District Cooling is a method of storing energy and distributing it cost effectively. Both can be applied inter-seasonally whereas it is unlikely that economical bulk inter-seasonal electricity stores will be available in the foreseeable future. Waste heat via absorption chillers can contribute to district cooling when working with other forms of chilling and thus can provide heat loads for CHP in the Southern Countries. Surplus wind can be stored as ice and potentially interseasonally. It was found that Barcelona could be cost effectively heated and cooled using CHP-DH (Chapter 17).

Part of our work involved cooperation with partners of the EU funded project Ecostiler[21] which explored the benefits of lower temperature heat networks and CHP designs. These offer significant savings compared to standard CHP-DH designs which are not optimised for heat supply. The Ecostiler calculations signalled that the potential for heat production from these low temperature systems could have a COP of 14 to 16 offering up to twice the savings compared to most normal DH networks which operate at 120°C (flow) - 70°C (return) and four times the savings of heat pumps with a COP of only 4. This is looked at in detail in Chapter 19.4.

We have had discussions with suppliers of the dominant European prime mover, the combined cycle gas turbine (CCGT) who accept that much lower cost heat and with a lower CO_2 overhead can be produced for heat networks operating at 75°C (flow) and 30°C (return) but currently they report there is no demand for such CCGTs which illustrates the lack of

[17] A report on a study for the Energy Networks Association Gas Futures Group, November 2010. Redpoint Energy Ltd.

[18] The French power demand is extremely temperature sensitive, some 2-3 GW per degree centigrade, with only one third of houses electrically heated, and has to rely heavily on electricity imports from Germany at peak winter periods.
http://www.claverton-energy.com/wp-admin/post.php?post=4182&action=edit&message=1

[19] Electrical network losses are generally proportional to the square of the power transmitted, thus double power will quadruple losses.

[20] Karolin Schaps (Feb 14, 2012). "Germany powers France in cold despite nuclear u-turn". Reuters. http://www.reuters.com/article/2012/02/14/europe-power-supply-idUSL5E8DD87020120214.

[21] http://concerto.eu/concerto/concerto-sites-a-projects/sites-con-projects/sites-con-projects-search-by-name/ecostiler. Orchard Partners London Ltd are one of the Partners

awareness of the possibilities. Future studies into CHP-DH where possible should not be based upon the traditional higher temperatures (120 °C flow) which significantly diminish the apparent cost effectiveness and instead take into account the possibility of these much lower operational lower temperatures. These lower temperature networks are also much more compatible with other renewable heat sources such as solar energy, heat pumps industrial waste heat, geothermal etc. It is important that the market becomes aware of these options and explores them in more detail so that interest and demand can be stimulated[22].
The Ecostiler project continues to evaluate the practical issues in optimising the design of CCGT CHP and other electricity generating plant to supply heat networks designed for 70-75°C flow for base load heat from steam turbines for most of the annual heat load with the heat supply temperature raised locally with engine based CHP to a maximum of 90-95°C .A table of relative CO_2 footprints per unit of heat delivered (Chapter 21.4) indicates the powerful decarbonising effect of DH networks as a means to supply heat sector needs for the existing building stock in EU cities. Note that CHP-DH readily decarbonises the ventilation and domestic hot water heat loads which are not so easily tackled by insulation.

There are many examples of how countries minimise their dependency on imported fuels of all types through CHP-DH. Denmark (Chapter 6) is one example of high penetration of low carbon piped heat networks and since the oil crisis of 1973 has lowered its fuel imports as a result and has one of the lowest per capita primary energy consumptions in Europe. The Odense scheme is often held up as an example of an efficient system (Annexe 6). It is worth noting that the specific energy demand for buildings in the Nordic countries is often lower than in more Southern Countries due to the higher insulation levels (4.1) – it is not the climate which makes CHP-DH attractive in these countries.

CHP-DH stations whose operational hours will be reduced by the use of the other non-fossil fuel sources cited earlier will not become obsolete but will increasingly offer back-up and load following services for fluctuating renewable energy sources. This ability to operate during a prolonged period of low wind for example, which can last for several weeks, reduces the capacity needed for large and expensive electrical or other energy storage and the provision of otherwise infrequently used and inefficient back up generators.

CHP-DH networks already provide very large heat storage capacities at low cost in existing district heating accumulators (Chapter 10). These heat stores are significantly cheaper than electricity stores, and can be built on a scale needed to allow the storage of surplus wind energy as heat using large central heat pumps (9.13). One study simulated the possible interaction between a power system and a DH system. In a Danish case with 50% wind energy (in 2020 or 2025) it demonstrated that the Danish DH systems will be able to absorb a considerable part of the wind power variations[23].The DH networks also provide a viable means of delivering this heat to buildings meaning that wind energy can make a significant cost effective contribution to de-carbonising European heating by displacing the present use of directly delivered fuels. As already outlined this will be difficult to achieve by delivering wind energy through electric cables due to the costs of upgrading the power network[24] .

[22] Incentives applied to current higher temperature heat networks to assist consumers to reduce the return water temperatures from consumers will allow networks to operate at lower temperatures extending their life. Network temperatures historically were determined by cost and the CO_2 footprint of heat from boilers where the fuel use per unit of heat is *not* a function of the heat supply temperature as for CHP.

[23] Published in "EuroHeat & Power", Paul F.Bach English Edition IV/2011. The article is also available:
http://pfbach.dk/firma_pfb/forgotten_flexibility_of_chp_2011_03_23.pdf

[24] A report on a study for the Energy Networks Association Gas Futures Group, November 2010. Redpoint Energy Ltd.

CHP-DH also has a major contribution to local emission reductions and safety since a potentially hazardous fuel is no longer delivered to individual buildings and can be burnt safely and cleanly in large central stations which can afford more complete abatement technology. These additional cost savings were not included in the analysis in Chapter 17.

Whilst the report identifies that heat from fossil fuel fired CHP has generally a lower CO_2 footprint than heat from electric heat pumps driven by electricity from the same generation unit (Chapter 23), both technologies are probably essential to optimise scarce resources. For example it is possible for cities to use large scale heat pumps, fed by surplus wind for example, linked to heat storage feeding heat into the DH network. (One example is the 2 x 90 MW Helsinki heat pumps – Chapter 9.13). These large heat pumps are in the high voltage network and do not incur the high distribution losses of smaller units). For the building heat load that is beyond the DH networks, the solution may involve energy savings with individual domestic electric heat pumps (for smaller loads) and biomass district heating or small (0.1 – 3 MW) modern gas engines for larger loads (See 9.12 and 14.7).

Clearly there is a limit (best expressed as load per km, not the usual method of load per km^2, according to Professor Sven Werner) for the DH network. However – having already reached 60% of heat supply in Denmark – at full deployment, DH should ultimately account for perhaps 80% of national heat supply. Moreover, Denmark is continuing to research solutions for lower heat load densities. In warmer Southern climates District Cooling loads can substitute for District Heating loads as was found to be the case in Barcelona (Chapter 18).

Investigations reviewed the effect of the sequence of investment with low CO_2 DH being installed first and then the effect of that decision on incremental demand side measures (Chapter 15). These decisions change when analysed on the basis of CO_2 footprint and primary energy content for heat supply and any associated fiscal benefit compared to standard energy supply models (which do not differentiate between either the energy overhead of the energy reflected in its temperature or its CO_2 footprint per kWh of energy[25]).

This alternative type of analysis shows that beyond a certain quite modest point, diminishing returns set in with insulation and more primary energy and carbon savings are achieved per unit spend with CHP-DH than energy conservation measures. Similarly, diminishing returns almost certainly occur when trying to optimise large heat using processes such as steel, cement and glass etc. It may be more cost effective to capture the waste heat and use it for heating rather than seeking to make the process itself more efficient. In Sweden around 10% of DH energy is recaptured from industrial processes. (Table 9.4).

The modern technology of large (MWe range) efficient gas engine CHP units (Chapter 9.12. 14.7), located within the distribution network are a reasonable interim solution during the 'build-up' phase of deploying DH and lower the otherwise costly supply of boiler-only heat. (They are less suitable as final solutions alone, because they have higher operating costs than CCGT plants - due to the lower efficiency (43% compared to 58% LHV) and somewhat higher maintenance (0.01 EUR / kWh compared to 0.003 EUR / kWh) - and still require gas, most of which is depletable and carbon-intensive). The small build-up phase networks can ultimately be connected to large networks and to large CHP power stations – either new

[25] Comparing a gas fired Combined Cycle Gat Turbine (CCGT) CHP unit, with a gas boiler, then every unit of heat from the CHP utilises 0.27 units of energy, whereas the boiler utilises 1.11 units, a factor of 4 higher. The heat pump utilises 0.66 units a factor of 2.44 higher. And electric heating utilises 1.98 a factor of 7 higher. Thus CHP heat is a very low energy / carbon content heat source. (Data from the example in Table 3.1)

purpose built stations or ones that may have been converted at some point in their life-cycle. The engines can be retained at low cost to offer back up and redundancy in the distribution network there being increasing concern about the vulnerability of power networks to disruption by various causes such as e.g. copper theft

These engined chp units may have a significant part to play in meeting heat load whilst they may have a lower electrical efficiency they are ideal for peak lopping and load following. The heat they reject is at a high temperature allowing local network temperatures to be topped up from the units without affecting the low cost low temperature heat supply from the large steam turbine CHP. This capability is particularly relevant when they are used to develop initial CHP networks as part of a cities planned heat infrastructure development.

Thus CHP fits into overall security of supply for the EU particularly the integration of heat and electricity networks and gas networks to optimise use of scarce resources where competition between alternative network investments may not be the optimal solution to meet 2050 targets. . They may also have a role dealing with the anticipated electric vehicle battery charging peaks.

As a guide to how DH can achieve its full potential the Danish experience is useful. Since about 1980, Denmark has required every local authority to prepare a 'Heat Plan'. This involves dividing the built-up areas into 'gas' and 'DH' zones. Moreover, DH is accepted as the final solution, so even 'gas' zones are for limited periods, such as 15 years. This is long enough to recover gas investments but not so long as to block the evolution to DH. In Scandinavia, the heat utilities are usually owned by the local authority. However, elsewhere in Europe, they may be owned by Energy Service Companies (ESCOs). Each is successfully delivering the transition to DH. See for example[26].

To be able to make its full contribution CHP-DH scheme developers would benefit from the same sort of quasi-governmental powers as are enjoyed by gas, water and power networks. These include pre-granted planning permission, the ability to compulsorily purchase land, road breaking and land crossing rights and market / planning mechanisms to ensure high heat take up rates in designated areas. These rights lower market risks significantly enabling access by developers to capital at low rates increasing their appetite for investment (See Annex 5).

It is essential that all economic assessments of CHP-DH are carried out using an appropriate discount rate for infrastructure, which could be 3.5%, and that modern designs with low DH supply temperatures are assumed otherwise misleading results may be obtained. For more details see sections 19.4, 24.1 and 4.6 of this report.

[26] http://www.copenhagenenergysummit.org/Low%2520Carbon%2520Urban%2520Heating,%2520Heat%2520Plan%2520Denmark%2520paper.pdf
A paper by Anders Dyrelund. Slide 5 referring to the 'municipal heat supply planning'

2. SUMMARY OF CONTENTS

This document is prepared in such a way that the main conclusions are summarised in the **Executive Summary** and the readers may then if they wish focus on individual Chapters for detailed information. These Chapters can be read independently and are to a large extent self-contained, so there is a certain amount of duplication of some points, Chapter to Chapter.

Chapter 3 Overview and General Concepts – CHP-DH In Europe – How it Saves Energy comprises a general overview of the reasons why CHP-DH is an attractive technology. It covers the energy savings achievable pointing out that CHP is a very low-carbon content source of heat compared to other sources. It compares CHP to a heat pump and considers the prospects for city heating of CHP-DH compared to individual heat pumps. It notes two methods of expressing the energy and carbon savings from CHP-DH each with different benefits.

Chapter 4 Is CHP-DH Economic Compared To Separate Production? reviews a number of studies on the economics of CHP-DH including a JRC analysis presented in Chapter 17). Six other independent studies are cited which indicate that CHP-DH is likely to be the lowest cost heating option for large parts of Europe. (Chapter 25 discusses the locations of power stations in Europe and their proximity to suitable city heat loads. Chapter 19 discusses the conversion of existing power stations to CHP indicating it is quite practical, and Chapter 23 gives examples of where this has been done including very long transmission pipelines up to 140 km).

Chapter 5 The Conversion of Fuels to Electricity in Electricity-Only Power Stations Wastes Large Quantities of Energy discusses the energy losses from power stations which are potentially available for District Heating in Europe. It indicates that a large part of the present heating sources such as gas and electricity could be replaced by low-carbon content heat from CHP stations since the total present losses are 19 EJ compared to a low temperature building heating demand of 11 EJ.

Chapter 6 Long term prospects for CHP heat loads – discusses the Danish view of CHP-DH which is seen as applicable to much of Europe. This view sees CHP-DH as an essential technical partner to large penetrations of fluctuating wind energy, due to CHP stations' ability to provide very fast balancing and replacement of electricity during low wind periods, the ability to absorb large quantities of surplus wind energy and store it in district heating energy stores. This heat can be subsequently delivered to consumers (along with industrial waste heat, geothermal and other sources of heat) without the need to expensively upgrade electrical distribution grids. Fossil fuel in these CHP stations will to a large extent be replaced by biomass and waste energy sources. Information is given which shows that the building heat load for CHP is unlikely to shrink significantly.

Chapter 7 Potential Growth Rates of CHP-DH, Price Levels In Europe and Penetration discusses the historical growth rate of CHP-DH which can be quite rapid – 17% /y in with a 12 fold increase in 18 years in China for example, and gives details of the cost of DH heat in various countries and the present usage rates of DH.

Chapter 8 Smart Cities Heat and Power Grids briefly reviews smart heat grids and

smart cities citing Copenhagen as a good example of a smart city.

Chapter 9 District Heating Technology - Sources of Heat reviews the sources of heating and cooling for DH, covering power station waste heat including nuclear power stations (not discussed in detail in these chapters), solar heat, waste industrial heat, heat pumps, small gas engines, temporary boilers, waste incinerators (14.1 indicates the proportion of heat that can come from a typical waste plant), biomass and heat only boilers. These sources are all seen as complementary to CHP-DH. Data is given for the present sources of DH heat in Europe which is predominantly CHP stations.

Chapter 10 Thermal Storage in Accumulators in DH Schemes discusses heat storage in large thermal water tanks which are standard practice in many existing DH schemes. Their use enables the absorption of surplus wind energy via heat pumps or resistance heating, and its subsequent onwards transmission to customers in DH pipes. Storage also permits the CHP station to generate during low wind periods and store the waste heat until it is needed. This maximises the economic benefits. The storage times are typically several days currently but storage solutions are being developed with several months heat capacity. Thermal storage costs are significantly less than a typical Pumped Hydro Electricity Storage Plant (PHES). Furthermore large electricity storages imply a significant and expensive upgrade of electrical distribution in order to deliver stored electrical energy to dwellings if it is to be used for heating; this is not the case with electricity stored as heat in thermal stores. Ice storage for District Cooling energy storage is also mentioned.

Chapter 11 District Cooling discusses the technology of District Cooling, how it can be part of a District Heating scheme and the historical rates of growth. Compressor-driven chillers driven by electricity, are compared with absorption chillers driven by waste heat which provide a sink for power station waste heat in hotter countries.

Chapter 12 Bulk Heat Transmission Technology discusses how heat is transmitted and, the likely costs of such transmission. It gives examples of the longest transmission mains which are over 140 km in length and indicates that it is likely to be economical to transmit very large quantities of heat up to 140 km.

Chapter 13 Heat Distribution in Modern DH Schemes discusses how heat is distributed using pipes, individual heat storage, the likely costs of distribution, heat metering vs. water metering, the benefits of low return water temperatures, health aspects, and connections to dwelling – direct vs. indirect.

Chapter 14 Load Profiles and Sizing of CHP Plants, Size of Schemes discusses heat load profiles and heat duration curves. The sizing guideline is introduced which states that if the peak output of the CHP plant equals half the maximum heat demand on the system then the CHP will provide 90% of the total heat delivered in a year. The rest of the energy will come from heat-only boilers or other sources. It discusses minimum viable heat load density, the inappropriateness of using kW/m^2 as a measure of heat density compared to kW/m of frontage when discussing heat loads, and gives some examples of very small CHP-DH schemes. Danish heat load planning guidelines are mentioned.

Chapter 15 Insulation and Energy Conservation Compared to CHP-DH discusses the issue of insulation and energy conservation versus CHP-DH. This indicates that in some cases CHP-DH is a better option. This is because beyond a certain point incremental insulation becomes more expensive than providing low carbon heat from CHP. In other

words over the life of a scheme of 30 - 60 years, a greater carbon reduction may be obtained by investing in CHP-DH than insulation and other conservation measures.

Chapter 16 Best Practice for DH discusses Best Practice for DH mentioning the Odense scheme in Denmark as a good example– see also Annex 6.

Chapter 17 Total System Cost Assessment of Heating and Cooling Supplied from Converting Existing Thermal Stations to CHP provides a total system cost comparison carried out by the JRC comparing individual heating by gas and electricity with the alternative of CHP-DH for 3 representative cities; Barcelona, Liverpool and Cologne. Assuming that all potential dwellings were connected to a given district heating network the required infrastructure investments would in most cases be paid back within 4-10 years, from the point of view of total cost savings.

Chapter 18 Calculation Of The Potential Contribution From CHP District Heat (CHP-DH) In The EU. In order to place the possible costs and energy savings calculated for the 3 cities studied in Chapter 18 in context, this chapter assumes a target (in the model), such that close to 75 % of the domestic and commercial low temperature heat load in the EU27 could be provided by waste heat from CHP-DH. This is then compared country by country with the available heat if all combustion power stations were converted to CHP-DH. In approximate terms a capital spend of €319 Billion on CHP-DH infrastructure could reduce heating costs by approximately €51.4 Billion per year and save 5.320 EJ of gas. (Subject to the constraints indicated)

Chapter 19 Combined Heat and Power and Steam Turbine / Combined Cycle Power Stations - Background and Concepts. Conversion of Existing Stations to CHP. Comparison of CHP with Heat Pumps discusses the thermodynamics of steam cycle CHP power stations. It introduces the concept of the Z factor and the Iron Diagram for a steam cycle power station. The possibility of converting existing power stations to CHP is discussed and examples are given where this has been successfully done. It indicates that there is a strong possibility that over their lifetimes many existing power stations can be converted to CHP-DH. It is demonstrated that from a thermodynamic point of view CHP is equivalent to a heat pump. A comparison is made between CHP and the performance of heat pumps which indicates that CHP-DH is superior in terms of energy performance.

Chapter 20 Types of Power Plants that can be obtained as Electricity only or CHP discusses the technology of Combined Heat and Power, including the different kinds of power stations such as steam turbines, gas turbines combined cycles and gas engines which may be used. It discusses the modifications that would be made to convert an existing electricity-only power station or prime mover to CHP and cites examples where this has successfully been done.

Chapter 21 Methods of Allocation of Carbon Saving and Fuel Saving in CHP Processes discusses further the allocation of extra fuel burn to CHP heat - the method used in Denmark and the Orchard Convention proposal. It gives a table showing the carbon content of various heat sources calculated using this method.

Chapter 22 Capital Costs of New Power Stations, CHP Power Stations and the Cost of Conversion of Power Stations to CHP discusses the likely cost of ordering new stations, or converting existing power stations to CHP. Various studies and examples indicate that the costs of conversion are likely to be modest – in the range of 10 – 20% of the cost of a new

station, particularly if conversion is carried out on the best candidates and at times of refurbishment.

Chapter 23 Examples of District Heating and CHP-DH Schemes particularly where Existing Stations Have Been Converted gives examples of CHP-DH of various sizes, in particular where existing power stations have been converted to CHP including Flensburg, Germany (conversion), Prague, Czech Republic (conversion plus 60 km pipeline), the Amercentrale plant in the Netherlands (partial conversion), Canavese, Italy (gas engine / heat pump) and Polderwijk the Netherlands (bio-gas engine).

Chapter 24 Financial and Institutional Barriers to CHP-DH and Measures of Promotion discusses financial and institutional barriers to CHP-DH. It points out that there are no technical barriers and that overall CHP-DH is generally economic if assessed at a national level and that the reason for its failure to progress significantly is due to institutional barriers. Chief amongst these is that CHP-DH developers do not have the full range of statutory powers to create market conditions suitable for the private sector as enjoyed by other network operators such as oil and gas. Statutory powers include those for compulsory land purchase, land entry, pipe laying and pre-granted planning permission, enhanced market access for the provision of heat in DH areas. The lack of these powers increases market risk and raises the cost of capital to private sector developers.

Chapter 25 Locations of Power Stations Potentially Suitable for Conversion to CHP Stations and Their Proximity to Large Cities contains an analysis of the locations of existing large power stations and their proximity to available large cities able to take the heat if in due course they were converted to CHP-DH. It indicates that the majority are likely to be within an economical distance to enable connection, although this would have to be verified on a case-by-case basis.

ANNEX 1 contains an article about the conversion of Flensburg Power Station and the city to CHP-DH. This is an interesting example because it is a historic city with narrow streets and not laid out in an optimal manner for a DH grid.

ANNEX 2 discusses the differences between the HCV and LCV efficiency conventions and the Net and Gross Efficiency definitions.

ANNEX 3 describes the heat exchangers which may be found in DH systems

ANNEX 4 includes a copy of a 1977 EEC Council Recommendation on setting up national advisory groups for the promotion of CHP and the use of residual heat which appears to have been pursued by Denmark.

ANNEX 5 contains a detailed discussion on why there is no conflict in assessing CHP-DH schemes viability at 3.5%/yr discount rate, whereas private sector businesses will demand a much higher rate of return.

ANNEX 6 contains an article describing in detail the technology of the Odense CHP-DH scheme.

3. OVERVIEW AND GENERAL CONCEPTS – COMBINED HEAT AND POWER WITH DISTRICT HEATING IN EUROPE – WHY IT SAVES ENERGY

3.1. Combined Heat and Power and District Heating ..... **Error! Bookmark not defined.**
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3.1. Combined Heat and Power and District Heating

In a District Heating (DH) network one or more central sources provide hot water which is conveyed to the users who can be domestic consumers, commercial buildings and appropriate industries by means of insulated water pipes, similarly for District Cooling (DC).

If the heat comes from the reject or waste heat from a power generating unit this is referred to as Combined Heat and Power, CHP for short, or Cogeneration and the whole referred to as CHP-DH. The terms are interchangeable. In reality all power generation is CHP as the second law of thermodynamics dictates that if you wish to generate power from heat you must reject some of the heat to the environment. CHP reflects conditions where the reject heat performs a useful purpose in heating buildings or processes before being finally rejected to the environment.

3.2. CHP heat carbon and fuel content

Electricity-only power stations emit waste or reject heat at too low a temperature to be used for heating, but the technique of Combined Heat and Power – CHP - allows the temperature of the reject heat to be raised to a useful level. In large power stations this is achieved by extracting some steam from the turbine at a higher temperature than which it is normally emitted in the electricity-only mode. This reduces the electrical power output of the power station, but the fuel consumption remains constant. By sacrificing a small quantity of electricity production in this way, the CHP station is able to provide a much larger quantity of useable heat.

Typically a sacrifice of 1 unit of electricity upgrades or makes available for heating 6 – 10 times that amount of heat energy. In contrast, a domestic heat pump will only upgrade 2 – 3 units of low temperature energy for the expenditure of 1 unit of electricity. Thus CHP is thermodynamically equivalent[27] to a heat pump but is 2 – 5 times as effective, depending on circumstances. See Chapter 19.

[27] Professor Robert Lowe, Combined heat and power considered as a virtual steam cycle heat pump, Energy Policy 39 (2011) 5528–5534.

3.3. All the energy savings for CHP occur in the heat sector, not the electricity sector

CHP does not make any energy savings in the electricity generation sector and all the savings occur in the heat sector, as it is in the heat sector you choose to use heat from either CHP, boiler, heat pump or electric boiler ie this is where incremental change occurs. As is described in the next section, the fuel burnt generating electricity in the power system overall will remain constant even if heat is made available for district heating from a CHP machine and the electrical efficiency of the system as a whole will remain the same. It is therefore logical that all CHP incentives should be applied to the heat and not the power. This is explained in the next section.

3.4. The method commonly used in Denmark for analysing energy content of heat from different sources

Gas heating and gas CHP compared to a gas fired power station:

In order to know how much fuel is used to produce the heat, you have in principle to simulate the whole power system to identify the additional fuel, which is necessary to produce one more unit of heat at the heated building. In the case where fossil fuel condensing plants are on the margin, or in the case where a new condensing plant is being compared with a new CHP plant the simulation can be simplified. It is in the heat supply planning you need to know how much fuel is used to produce one more unit of heat. This is calculated on the basis that:

- One more MWh of electricity demand in the system will take more electricity (and its fuel) at the marginal condensing plant
- One more MWh of heat from the CHP plant will cause a drop in electricity production by 1/Z[28] or CV, e.g. 0,15 MWh say, lost electricity, which will be produced instead by the marginal condensing plant entailing its increased fuel consumption. (not the CHP plant)

Table 3-1 below shows a simple estimate of how much fuel is used for production of heat from electricity, heat-only boilers, heat pumps and that of a CHP plant.[29] (The detail of the calculation are shown under table 3.2) We can see from the figures in red (in the table) that:

Comparing a gas fired combined cycle gas turbine (CCGT) CHP unit, with a gas boiler, then every unit of heat from the CHP utilises 0.27 units of energy, whereas the boiler utilises 1.11 units, a factor of 4 higher. The heat pump utilises 0.66 units, a factor of 2.44 higher. And electric heating utilises 1.98 a factor of 5 higher. Thus CHP heat is a very low energy / carbon content heat source.

The basic assumption behind the table is that the plants are connected to a power grid in which there is a condensing power plant on the margin. (i.e. the next most economic plant). Thus when the power plant begins to operate as a CHP plant and its electrical output falls,

[28] Thus Z, or the Z factor is a characteristic of a CHP plant, and is the ratio of *the heat made available* to the *electricity that becomes consequently unavailable*. See also Chapter 19 for more on Z.
[29] Smart Energy Cities Seminar in DG17 28.09.2011 by Anders Dyrelund, market manager energy Rambøll

another condensing[30] plant somewhere in the system will increase its output to compensate, and also therefore its fuel consumption. This extra fuel consumption is then allocated to the heat produced by the CHP, since it is the only increase in fuel consumption on the system.

Because the marginal plant will always be operating at close to its maximum output, by definition, it is clear that the fuel burn for generating electricity in the system as a whole remains constant, and is at a constant efficiency. Therefore it is logical to apply this extra fuel burn to the heat sector only.

It is also assumed that the same fuel is used at the CHP plant and at the condensing power plant. For a more precise calculation it would be necessary to simulate the whole power system hour by hour with the various alternative heat sources, but the result would be close to this simple approach.

Gas heating / gas CHP compared to a coal fired power station:

In the case where a gas fuelled CHP plant has its loss of electricity replaced by a coal fuelled condensing plant, it is necessary to divide the effects of the CHP plant into to two steps:

- Step 1 is to imagine and compare the situation in which a large efficient gas fuelled CCGT condensing replaces the coal fuelled condensing plant. This comparison will show that the fuel efficiency has improved in the power system, but we have used a more expensive fuel.
- Step 2 is to compare the gas fuelled CHP plant's loss of electricity with the gas fuelled condensing plant and calculate how much additional gas is needed in the condensing plant to replace the loss of electricity in the gas CHP.

Results of Table 3-1

In Table 3-1 figures in red shows that heat from a gas boiler needs 1.11 units of primary fuel per unit of heat delivered, whereas the large gas CHP plant only needs 0.27 units of primary fuel per unit of heat delivered, which makes the CHP heat 4.1 times as effective. Small scale gas CHP plants with lower electrical efficiency will use more units of fuel, e.g. 0,5 - 0,6 units[31].

It is also clear that there is no CHP potential in the case where there is a surplus of electricity in the grid, e.g. if hydro turbines are being by-passed or wind turbines are constrained off. In that case the CHP plant should stop and heat be produced from heat storage or heat only boilers. However, in case the hydro power has capacity to adjust its production, the CHP based electricity can be stored in the hydro system and later replace condensing power.

In case CHP based electricity is on the margin the situation is not so simple and a simulation of the power system is necessary. In a case where this situation happens frequently, it will be time to improve the flexibility further by increasing the heat storage capacity, and introducing

[30] In the case where the CHP plant itself is not at full load, it may as well itself increase its condensing electrical production in order to keep a constant electrical output by increasing its fuel consumption. Thus it is a plant with the same electrical efficiency that produces the lost electricity in this case.

[31] In a case where the CHP plant is isolated from the power grid, e.g. a diesel engine in say Greenland, this calculation method is not valid. The engine produces the required electricity and emits the waste heat anyway irrespective of whether the heat is used for heating. In this case the fuel consumption for producing the heat is zero. If there is need for more heat, it has to be generated by a boiler and not by generating more electricity.

electric boilers and heat pumps. In such a CHP Heat pump system, it will also be possible to estimate the fuel cost of heat and electricity, and low temperature heat will normally use at least 3 times less fuel than electricity.

This method of illustrating the energy efficiency of CHP gives information on the savings in a direct way. The normal method which is to compare primary energy savings as is described in 3.5 could also be used and will give the same correct answer if it is used correctly on the two scenarios (with and without CHP), which are compared. However there is a risk that the method is misunderstood by assuming that there is the same saving on heat and electricity.

Table 3-1 Danish method of comparing primary fuel or energy consumed per unit of heat delivered for CHP and other forms of heating[32].

Cases		**1**	**2**	**3**	**4**	**5**	**6**	**7**
		Old coal extraction	Old coal backp res.	New coal extraction	Gas CC extraction	Gas CC backp res.	Gas engine	small Gas engine
Reference power condensing on the margin		Old coal	New coal	New coal	New gas	New gas	New gas	New gas
CHP heat	efficiency of plant	53%	53%	50%	41%	45%	52%	55%
CHP power	efficiency of plant	32%	32%	39%	49%	45%	38%	35%
Total	**efficiency of plant**	**85%**	**85%**	**89%**	**90%**	**90%**	**90%**	**90%**
Power to heat ratio		**0.60**	**0.60**	**0.78**	**1.20**	**1.00**	**0.73**	**0.64**
Ref heat		90%	90%	90%	90%	90%	90%	90%
Ref power	**central most efficient**	**40%**	**46%**	**46%**	**55%**	**55%**	**55%**	**55%**
Estimated marginal loss from central plant		0%	0%	0%	0%	2%	4%	6%
Ref power	local plant	40%	46%	46%	55%	54%	53%	52%
Extraction CV		15%		14%	15%			
Saving of fuel to heat and power, EE directive		28%	22%	29%	26%	25%	23%	22%
Marginal fuel consumption for heat from plant								
Extraction of heat	MWh fuel/MWh heat	0.38		0.30	0.27			
Back pressure heat	MWh fuel/MWh heat	0.38	0.57	0.30	0.27	0.37	0.54	0.59
Heat only boiler	MWh fuel/MWh heat	1.11	1.11	1.11	1.11	1.11	1.11	1.11
Heat pumps								
Heat pump COP		300%	300%	300%	300%	300%	300%	300%
Marginal loss from central plant to individual		8%	8%	8%	8%	8%	8%	8%
Marginal efficiency for heat pump		110%	127%	127%	152%	152%	152%	152%
Marginal fuel consumption for heat pump		0.91	0.79	0.79	0.66	0.66	0.66	0.66
(Fuel consump. CHP)/(fuel consump. heat pump)		0.42	0.73	0.39	0.40	0.56	0.82	0.89
Electric heating								
Marginal efficiency for electric heating		37%	42%	42%	51%	51%	51%	51%
Marginal fuel consumption for electric heating		2.72	2.36	2.36	1.98	1.98	1.98	1.98
(Fuel consump. CHP)/(fuel consump. Elec. heat)		0.14	0.24	0.13	0.13	0.19	0.27	0.30

[32] Smart Energy Cities Seminar in DG17 28.09.2011 by Anders Dyrelund, market manager energy Rambøll

The Danish method is probably more suitable for use in detailed energy planning, in which it is needed to know the incremental / marginal changes in the system for each choice made in the scenarios (heating by electricity, boiler, heat from CHP or heat from large CHP etc.) so that the optimum solution at a societal level can be easily determined.

3.5. The standard method of showing CHP-DH energy savings - the primary energy savings of CHP

The standard method of indicating the carbon and energy savings potential of CHP is shown in an example[33] in figure below. This is an excellent and simple method for specifying the performance required for CHPs at a European level. An existing and distant, centralized condensing plant and a local heat only boiler is compared with a new local and more efficient CHP plant, which supply heat and electricity to the local network (excluding 7% grid losses for the local plant)

The first two blue coloured diagrams illustrate primary energy flowing in from the left and going into a power station and a boiler to provide separate heat and electricity, 35 units of electricity and 50 units of heat. Thus requires 180 units of input primary energy.

If we generate the same 35 units of electricity and 50 units in a CHP unit, as in the lower blue coloured diagram, it turns out that we only need to use 100 units of primary energy. Thus this is a saving of 80 units in 180 or 44%.

In this example[34] the electrical efficiency is indicated as 35% for both the old less efficient condensing plant and the new CHP plant when it is in CHP (also called "back pressure mode"). If the two power plants were the same type of plant, the electric efficiency in back pressure mode would be slightly lower than the efficiency in condensing mode as illustrated in the table above.

Thus in the example, the fuel consumption for producing the heat and electricity in the local CHP is only 100 units of fuel which is less than the 121 units of fuel which is used in the centralized power only plant to produce the electricity only. Therefore the total saving is 44%, whereas it is typically 30% in the case of the CHP plant and the condensing plant are comparable and we do not take into account the grid losses. So this chart is perhaps slightly confusing, but it illustrates very well the reality which is that old inefficient condensing plants in remote areas remote from cities can be replaced by new more efficient CHP plants close to both the heat and the electricity markets.

[33] Danish District Heating Association.

[34] This example (from the DDHA) is somewhat unrealistic, as it takes into account that the new CHP has a slightly greater electrical efficiency than the old, distant condensing plant it is being compared with, and that there are no losses in the power transmission grid from it because the new CHP plant is situated near the electricity (and heat) markets. Thereby the marginal fuel consumption for producing heat and electricity from the new plant compared to the old condensing plant can be zero (as in the example. This is somewhat misleading).

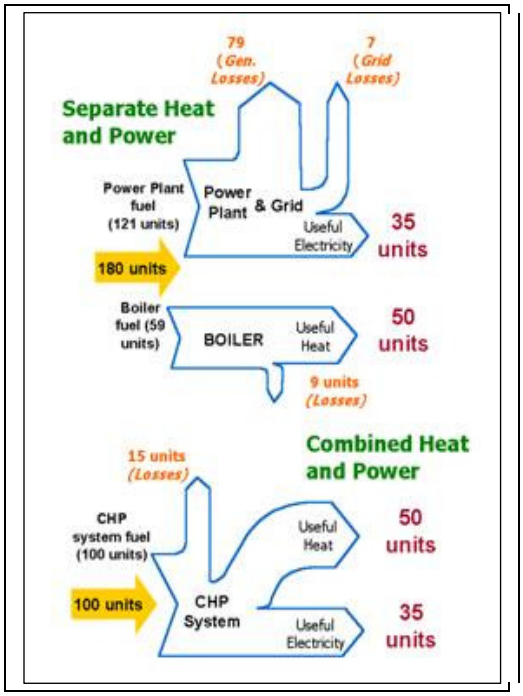


Figure 3-1 The primary energy saving and CO_2 displacement benefits of CHP-DH[35,36]according to the Danish District Heating Association.

It is important for the decision makers to know the consequences of their choice regarding heat cities with e.g. electric heating, gas boilers, heat pumps or heat from a large CHP plant.

The EE directive estimate the total saving producing electricity and heat together compared to individual supply. This total saving is roughly 30% and this is a good reason for investing in CHP plants instead of power only plants, and the Directive method has been a major stimulus for CHP.

However in the urban heat planning which is required by the Directive, additionally it is important for the decision makers to know how much fuel consumption is needed for producing heat from a CHP plant compared to e.g. heat only boilers and electric heating. A system analysis of the type required for this purpose, shows that in a power system (with condensing on the margin) CHP heat only uses roughly 0,25 MWh fuel per MWh heat at a new state of the art CHP plant near the urban area, whereas we use over 2 MWh fuel/MWh electricity for producing more electricity from a state of the art CCGT condensing plants.

In the planning additional losses in the power grid and in the DH grid has to be taken into account as well as the ability to store the heat and disconnect the heat production in power peak periods.

Below is a more realistic example for a new gas fuelled CHP plant compared to a new gas fuelled condensing CCGT plant as analysed[37] in Denmark. This is prepared in the same way as Table 3.1 but with different numbers:

[35] Danish District Heating Association.

[36]This example (from the Danish DHA) is somewhat unrealistic, as it assumes that the new CHP has a slightly greater electrical efficiency than the old, distant condensing plant it is being compared with, and that there are no losses in the power transmission grid from it because the new CHP plant is situated near the electricity (and heat) markets. Thereby the marginal fuel consumption for producing heat and electricity from the new plant compared to the old condensing plant can be zero (as in the example).

[37] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

Table 3-2 a new gas fuelled CHP plant compared to a new gas fuelled condensing CCGT plant as analysed[38] in Denmark:

State of the art	Total eff.	Fuel input	Heat	Electricity
Boiler	90%	100	90	0
Gas CC condensing	55%	100	0	55
Gas CC CHP	90%	100	40	50
Boiler	90%	44	40	
Gas CC condensing	55%	91		50
Total of individual		135	40	50

Fuel consumption in the energy system due to heat production		
Cost of heat from boiler	MWh fuel/MWh heat	1,11
Cost of heat from electricity 400 kV	MWh fuel/MWh heat	1,82
Cost of heat from CHP	MWh fuel/MWh heat	0,23

Explanation:
The heat only boiler has an efficiency of 90%
The condensing plant has a power efficiency of 55%,
The same plant designed as a CHP plant has a total efficiency of 90% in back pressure mode (maximal heat output and no thermal losses)
We see that the electric efficiency drops from 55% to 50% in case maximal heat is extracted in CHP mode.
The power to heat ratio is 50/40 = 1,2
The CV factor is (55-50)/40 = 0,125
The Z-factor is 1/CV = 8
The fuel consumption for one more unit of electricity is 1/0,55 = 1,82
The fuel consumption for one more unit of heat is 0,125/0,55 = 0,25
The total CHP saving of fuel to both electricity and heat is (135-100)/135 = 26%
The total saving of fuel for heating is (1,11-0,23)/1,11 = 79%

This figure 80% indicates the saving of the fuel for heating, which is derived in the Danish Heat planning method of analysis.

Thus CHP heat uses about 1/5th the primary energy of the gas boiler.

This issue is covered in more detail in Chapter 21

3.6. Individual heat pumps in large cities for heating purposes – potential stress on power grids

Overall it is likely that District Heat is a more economic method of delivering heat to houses compared to the use of the electricity grid even with heat pumps because most European grids have not been sized to deliver the necessary power and would need upgrading. Also it seems[39] that an electric heat pump in a building costs more than the pipe to connect a building to a CHP plant

The Coefficient of Performance[40] – COP - of Air Source Heat Pumps - ASH - falls off as air temperature drops, which of course coincides with maximum building heat demand. This

[38] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[39] Ie various internet offerings.
[40] COP = the ratio of electricity in to heat out

means that widespread use of individual ASH will significantly increase winter peak demand during extreme cold periods, not only due to the fall-off in efficiency as air temperature drops, but also because during these extremely low external temperatures, users tend to resort to direct resistance heating. Ground Source Heat Pumps are not widely applicable in dense cities due to problems of ground freezing and locating heat source wells.

The UK's Energy Savings Trust field trials revealed that none of the heat pump installations had a higher COP than 2.5 and this means none were as good as simply burning gas according to Brian Mark of Mott Macdonald, a leading UK consultancy house. The reports state that industry average COP for a Ground Source Heat Pump (GSHP) is just 2.3. Also when a cold snap (<0 degree C) arrives the COP of main stream heat pumps drops considerably to around 1:1, little more efficient than electrical resistance heating.[41]

Average losses on the grid transmission and distribution systems are around 3% to 6% respectively, but at peak times they are much higher proportionally. This is because the resistance of an electrical network is proportion to the square of the current, I, passing through the wires and transformers – these are known as I^2R losses. Thus at system peak, whilst the power may be 4 times the minimum load on the system, that resistance can increase by a greater factor. This again increases the stress on the power transmission and distribution system at system peak.

This means widespread use of domestic heat pumps in cities is likely to impose severe stress on electrical networks as happened recently in France[42]. This may require additional expenditure on upgrading electrical distribution, transmission and interconnectors. This view is supported by a report from Redpoint Energy Ltd which indicated that an all-electricity future would require significant upgrading, by a factor of 5 in terms of peak capacity to provide widespread electric heating.[43]

In Denmark, Finland and Sweden one approach is to use large scale heat pumps to feed heat based on surplus wind or off-peak electricity to large heat stores from which the heat can then be conveyed by DH networks to consumers. Because these stores can hold heat with low losses for long periods, this decouples the electrical generation from the peak heat demand ie generation can be scheduled at will, irrespective of actual heat demand. And the power for the large heat pumps is provided in the low loss high voltage grid. As these large pumps are cheaper and more efficient, and based in the high voltage network they do not incur the large losses of the distribution grid.

3.7. The benefits of CHP-DH

Significant benefits arise from CHP-DH:

- Dramatically increased overall energy efficiency for the heat sectors combined as noted above.
- Reduced CO_2 emissions and other pollutants - even more so when the synergies with renewables are factored in.

[41] Journal of the Chartered Institute of Building Services Engineers, UK, CIBSE Feb 2012

[42] Karolin Schaps (Feb 14, 2012). "Germany powers France in cold despite nuclear u-turn". Reuters. http://www.reuters.com/article/2012/02/14/europe-power-supply-idUSL5E8DD87020120214.

[43] A report on a study for the Energy Networks Association Gas Futures Group, November 2010. Redpoint Energy Ltd.

- Increased energy security through reduced dependence on imported fuel and fuels switching capability.
- The ability to deliver heat to the consumer without having to entirely replace the electrical distribution system, which is inadequate for widespread electrical heating.
- Cost savings for the energy consumer due to low marginal cost of the waste heat.
- Beneficial use of local energy resources or sources that cannot be used on an individual basis (particularly through the use of waste, biomass and geothermal resources in district heating and cooling systems), providing a transition to a low-carbon future.
- There is an argument for the reduced cost of not having to insulate or glaze the windows to such high specifications (A paper from Orchard shows these are less cost effective in a particular case than CHP-DH [44]).
- CHP-DH addresses the domestic heat sector which is the largest and most difficult area to decarbonise sector in many EU countries and CHP-DH offers the potential to decarbonise the heat sector whilst at the same time securing local heat and electricity supplies.
- CHP-DH can pave the way for a robust infrastructure supporting the integration of wind power, solar energy and low energy buildings and dealing with intermittency and the need to meet peak heat demands.
- The installation of the technology is labour intensive likely to provide indigenous employment using indigenous products.
- Improved safety through having no fuel in dwelling.

[44] Technology Strategy Board Retrofit for Future a study to minimise CO2 emissions for typical UK housing comparing Combined Heat and Power District Heating with Insulation. March 2011. Orchard Partners London. http://www.claverton-energy.com/technology-strategy-board-retrofit-for-future-a-study-to-minimise-co2-emissions-for-typical-uk-housing-comparing-combined-heat-and-power-district-heating-with-insulation-march-2011.html

4. IS CHP-DH ECONOMIC COMPARED TO SEPARATE PRODUCTION?

4.1. Is CHP-DH economic in Denmark because of the colder climate, and not therefore applicable to the rest of Europe? ..... **Error! Bookmark not defined.**

4.2. Joint Research Centre / Institute of Energy and Transport **Error! Bookmark not defined.**

4.3. Energy Paper 35 (UK Government – 1979) ..... **Error! Bookmark not defined.**

4.4. IEA Study ..... **Error! Bookmark not defined.**

4.5. Energy Policy Study - "An assessment of the present and future opportunities for combined heat and power with district heating (CHP-DH) in the United Kingdom" **Error! Bookmar**

4.6. AEA Energy & Environment, Building Research Establishment (BRE) and PB Power study ..... **Error! Bookmark not defined.**

4.7. AECOM Study..... **Error! Bookmark not defined.**

4.8. Newton Abbott, South West England Study ..... **Error! Bookmark not defined.**

4.1. Is CHP-DH economic in Denmark because of the colder climate, and not therefore applicable to the rest of Europe?

It is often suggested that CHP-DH is only economic in the Nordic countries because they have colder climates and therefore much higher heating demands, and are therefore not applicable to the rest of Europe. In fact because their buildings are better insulated they tend to have lower specific heating demands.

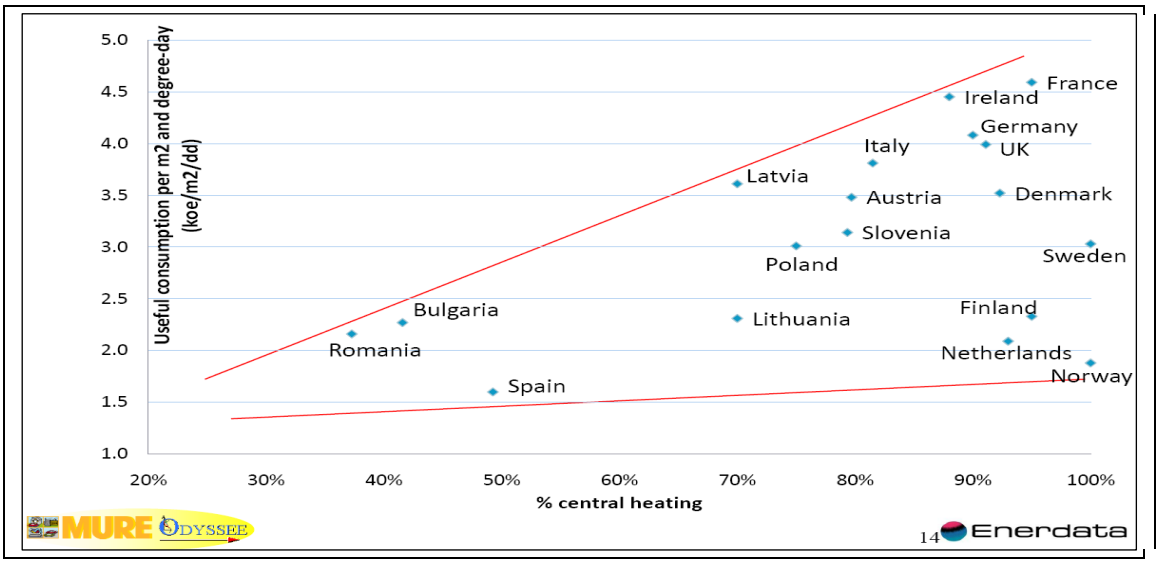


Figure 4-1 Energy consumption for space heating per m2 and diffusion of central heating

The studies cited below are all based on local climate data and building energy demands.

4.2. Joint Research Centre / Institute of Energy and Transport[45]

A detailed total cost assessment for three cities – Liverpool UK, Cologne – Germany, and Barcelona – Spain, carried out by the JRC (Chapter 17) shows that the total costs of Combined Heat and Power and District Heating - CHP-DH is less than the traditional energy supply option of individual heating and electricity-only generated at a power station.

A number of other independent studies mentioned below, have been conducted which support the JRC conclusion:

4.3. Energy Paper 35 (UK Government – 1979)

Detailed studies carried out in the UK on behalf of the Government in 1979[46] (perhaps influenced by "1977 EEC Recommendation on Advisory Groups for CHP" - Annex 4) showed that CHP-DH competed with the existing heating fuel mix. The higher capital costs were offset by lower running costs. Details have changed but in general the conclusion is likely to remain the same if the detailed exercise were to be repeated – fuel and power costs are higher compared to capital costs and CCGTs are just as able to provide reject heat as the coal fired stations on which the study was based. Piping and heat metering technologies have all improved. The study authored by senior figures from the UK Energy Industry recommended an immediate programme should be begun to install CHP-DH in major UK cities. This progress was stopped due to opposition from the then British Gas who published a minority report arguing that gas fired heat pumps would be a better solution.

Whilst the study was made some 33 years ago, the results are still likely to be valid for two reasons. Firstly the techniques of installing DH have improved thus lowering costs, and secondly fuel costs in general have risen relative to capital costs so the value of fuel savings will be greater compared to the capital costs.

The study was based on an extremely detailed heat load survey of all cities.

4.4. IEA Study

The IEA study chose a representative city in the UK to study as a proxy for Europe. This study showed that whole city CHP-DH even in a country such as UK with a well developed gas grid was economic compared to the alternative which was CCGT plus individual heating.

[45] Institute of Energy and Transport, in Petten, Holland, is part of The Joint Research Centre, the EU's in-house scientific service.

[46] Combined heat and electrical power generation in the United Kingdom – Energy Paper 35. HMSO 1979

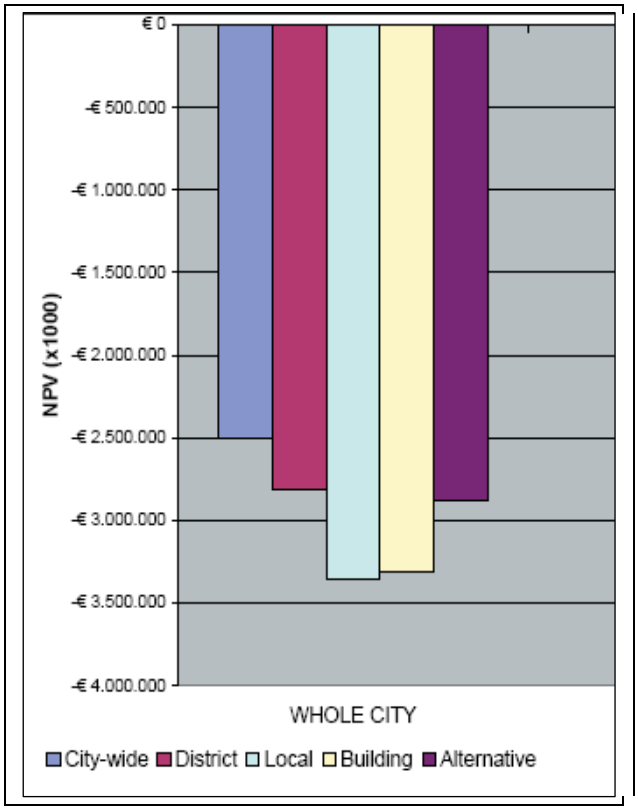


Figure 4-2 CHP-DH is the lowest cost method of heating compared to new CCGT plus separate boilers when applied to a whole city[47].

4.5. Energy Policy Study - "An assessment of the present and future opportunities for combined heat and power with district heating (CHP-DH) in the United Kingdom"

This study published in the peer reviewed journal "Energy Policy" again looking at the UK came to similar conclusions[48]

> "Furthermore, it has been shown by DECC (2009) that CHP-DH networks have some of the highest technically possible CO_2 savings and some of the lowest costs per tonne of CO_2 saved when compared against other competing technologies (Fig. 4). For example, it is shown in the Heat and Energy Saving Strategy (DECC, 2009) that CHP-DH using biomass could save approximately 19.3 $MtCO_2$ annually compared with individual ground source heat pumps saving just 2–3 $MtCO_2$ per year when connected to the same homes.[2] In conclusion, heat distribution networks that utilise CHP therefore offer the following benefits: increased energy efficiency, minimisation of pollution, lower fossil fuel consumption, increased employment and other economic benefits for the community, a capacity to use local renewable energy resources,

[47] "IEA District Heating and Cooling Project Annex VII - A Comparison of Distributed CHP/DH with Large-Scale CHP/DH - report 8DHC-05.01 by Paul Woods, Oliver Riley, Jens Overgaard, Evert Vrins, Kari Sipilä, Richard Stobart, Adam Cooke ". The study was undertaken by Parsons Brinckerhoff Ltd (UK) together with Ramboll (Denmark), W-E, (The Netherlands), VTT (Finland) and University of Sussex (UK), assisted by Canmet (Canada)

[48] Energy Policy. Volume 38, Issue 11, November 2010, Pages 6936–6945. Energy Efficiency Policies and Strategies with regular papers. An assessment of the present and future opportunities for combined heat and power with district heating (CHP-DH) in the United Kingdom. Scott Kellya .Michael Pollitt

opportunities for intelligent system balancing and some of the cheapest and largest CO_2 savings when compared with other competing technologies..”

4.6. AEA Energy & Environment, Building Research Establishment (BRE) and PB Power study

The AEA Study[49] uses a computerised methodology to estimate the total CHP-DH potential at various discount rates. Using the rate commonly used by government to assess infrastructure projects there is a total of 33 GW of CHP-DH potential in the UK, which has a maximum electrical demand of around 60 GWe. This is likely to be illustrative for the situation across much of Central and Northern Europe. The crucial importance of using the correct discount rate can be seen in this example.

Table 4-1 Summary of the UK potential for CH/CHP at discount rates (Table 7 from[50])

Table 7 - Summary of the UK potential for CH/CHP at discount rates

CH/CHP potential	Units	3.5%	6%	9%
Total net CH/CHP Potential for UK	MW_e	33,125	21,517	75
Number of postcode sectors	-	6,897	4,204	46
Total electricity produced	GWh p.a.	189,472	123,119	518
Total heat sold	GWh p.a.	230,358	149,686	630
Primary Energy Saving	GWh p.a.	159,881	103,890	437

4.7. AECOM Study

The AECOM[51] study noted that CHP-DH is the most cost effective solution in terms of carbon saved for a given additional lifecycle cost as per the Figure below.

[49] “Analysis of the UK potential for Combined Heat and Power “, published in October 2007 which is downloadable from DECC’s website.

[50] “Analysis of the UK potential for Combined Heat and Power “, published in October 2007 which is downloadable from DECC’s website.

[51] Smart Heat Grids - The potential for District Heating to contribute to electricity demand management to facilitate renewable and nuclear electricity generation. Paper C92-EIC_029 to Energy in the City Conference, LSBU, June 24th 2010. Paul Woods, MA MSc CEng FEI FIMechE MCIBSE. Andrew Turton, PhD Sustainable Development Group, AECOM

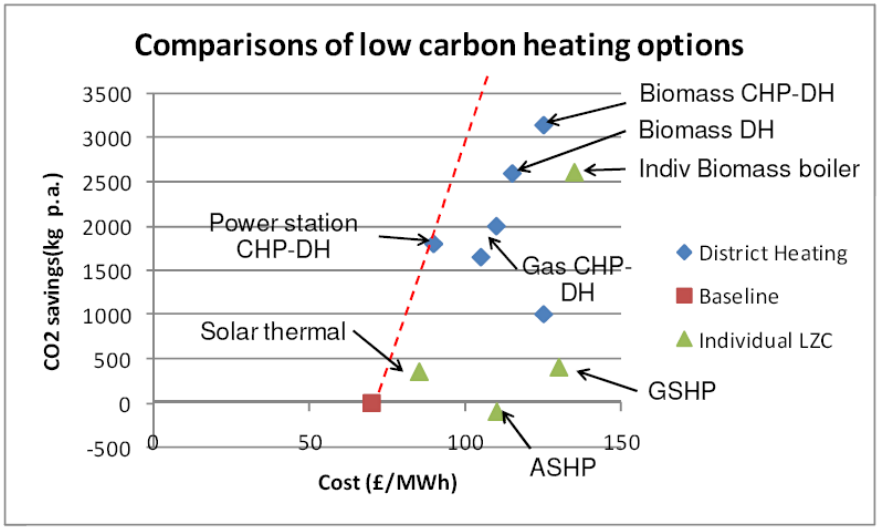


Figure 4-3 Comparison of low carbon heating options (derived from Poyry/AECOM).

(Note – GSHP / ASHP = Ground / Air Source Heat Pump)

4.8. Newton Abbott, South West England Study

This preliminary study[52] looked at installing a new 150 MW CCGT in the small market town of Newton Abbott in the South West of England. (CCGTs were still in an early phase of development and were not then accepted by the monopoly power generator the CEGB)

This study showed that even such small power stations could produce power at a comparable cost to that produced in large electricity only coal fired stations.

[52] Combined Heat and Power for Small Towns and Cities. C.D.Chandler. M.A. C.Eng. D.C.Andrews. B.Sc. (Hons) Open University Energy Research Group. J.H. Birch, Joint Chairman, Utilicom Ltd. District Heating Association Annual Conference, Torquay, 1981.

5. THE CONVERSION OF FUELS TO ELECTRICITY IN ELECTRICITY-ONLY POWER STATIONS

Each year European power stations waste more heat than is used to heat buildings.

This is illustrated in the Figure below, which shows that annually large power station waste heat is approximately equal to the annual total heat demand much of which is for dwelling heating, and which is in turn roughly equal to the demand for natural gas. If this waste heat were used (but suitably upgraded) in District Heating Schemes to heat buildings much of the demand for natural gas (or the equivalent amount of coal or other energy) could be avoided.

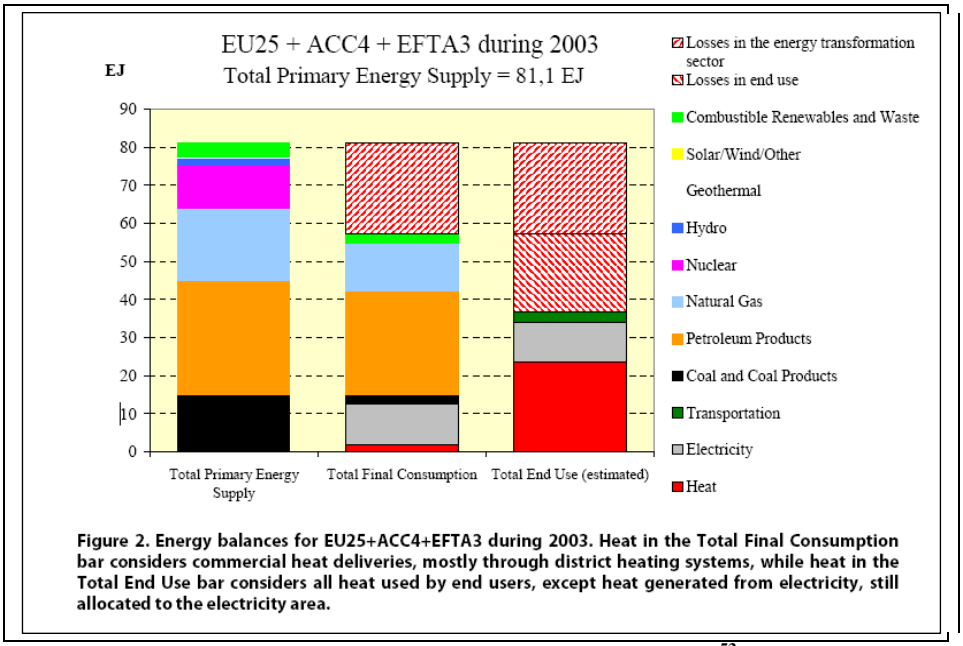


Figure 5-1 Energy losses in transformation[53]

The low temperature heating and is one of the largest demands for energy in Europe11.1 EJ in the above estimate of the and this demand will not go away in the long term. (See section 6.2)

We cannot say from the figures above to what extent the heat can be used. Many power stations are necessarily distant from heat loads in cities. For example lignite power stations tend to be cited near the lignite, which may not be close to a city heat load. Or they may be sited close to a port to assist coal import. This issue is examined in greater detail in Chapter 25. It is worth noting, that as time progresses, it may be that a cost benefit study will show it more effective to co-locate new power stations adjacent to cities, and de-commission old power stations when refurbishment is due, and incur the extra cost of coal transport in order to gain from the sale of the waste heat. In using this waste heat there are also issues with seasonality. There may too little produced in the winter, and too much in the summer. Only detailed modelling can resolve this issue and this is done for representative cities in Chapter 17.

Another way of looking at the energy flows is depicted in the figure below, which again indicates that power station waste heat is significant each year compared to the demand for low temperature building heating.

[53] The graphic comes from WP1 of the ECOHEATCOOL Work package 1. 2005-December 2006, page 11, The project was co-financed by EU Intelligent Energy Europe Programme and took place from January 2005-December 2006. http://www.euroheat.org/ecoheatcool

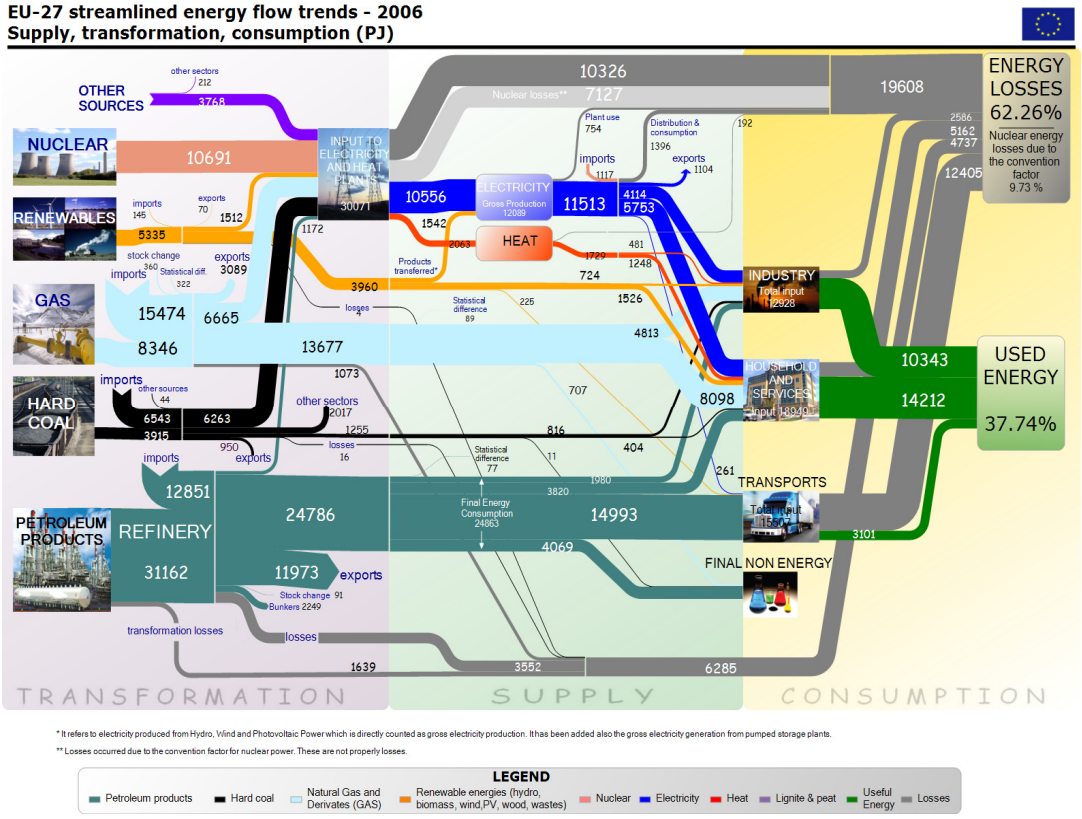


Figure 5-2 European Energy Flow in EU Sankey Diagram.

We can get an approximate idea of the potential for CHP-DH, if we assume that half the end use of energy in Europe that is going to industry is used for low temperature heating. (The majority of the electricity in blue above for industry will be for motors and or high temperature heating – melting etc.) We can also estimate that 70% of the energy going to the Household and services (almost all the fuels, and a good part of the electricity) will be for heating and hot water. This gives a figure of 15,000 PJ/y = 4,100 TWh for low temperature building heat demand which could potentially be met with power station or industrial waste heat. Note that this figure 15,000 PJ/y is less than the total waste heat emitted from power stations – 19,600 PJ.

Not all of this could be provided by power station or industrial waste heat in practice because there are inter-seasonal mismatch issues but this chart serves to very quickly indicate the scope of the potential. (And the waste heat is at too low a temperature to be used, but the technology of CHP can economically upgrade this heat to a useful temperature).

The very rough estimate here is in line with a very detailed analysis carried out by JRC which will be published later in 2012 which gave around 10,693 PJ for 2009 for end use of energy per annum for the low temperature building heat demand[54], 43% of end use of energy excl. transport. A more rigorous analysis of the potential which could be met by CHP is carried out in Chapters 17 and 18. From Eurostat in 2010 the average cost of gas in the domestic and commercial sector was 11.59 Eur/ GJ. Hence the annual value of this heat, if met by gas at an average efficiency of 80% is €151 Billion/y (This later Chapter 17 analysis uses a total European demand of 12,253 PJ using data because the later JRC study was not then available. The difference however is not significant for our purposes.

[54] "Study on the European heat and cooling market and its technology mix" Under Energy Systems Evaluation Unit, Institute for Energy and Transport, JRC, European Commission. 2011.

6. LONG TERM PROSPECT FOR CHP-DH HEAT LOADS

6.1. CHP-DH role in integrating fluctuating renewable energy**Error! Bookmark not defined.**
6.2. Temporal persistence of heat loads.....**Error! Bookmark not defined.**
6.3. The low energy Passivehaus – CHP-DH is still recommended**Error! Bookmark not defined.**
6.4. Application of CHP-DH and DC – type of suitable buildings**Error! Bookmark not defined.**
6.5. CHP-DH is not considered incompatible with low energy buildings**Error! Bookmark not defined.**

6.1. CHP-DH role in integrating fluctuating renewable energy

A document by Danish experts gives an overview of how DH is seen as fundamental to energy saving in not only Denmark but also in Europe.[55] The vision perceives DH as being the ultimately flexible tool for integrating power station waste heat, industrial waste heat, large-scale solar heat in summer, and surplus wind energy via electrode boilers and heat pumps. Heat Plan Denmark goes into some detail on this topic.[56]

The basic concepts are that:

- Building heat loads (one of the largest demand for energy) will not significantly diminish even with enhanced cost-effective insulation
- Enhanced insulation will automatically also reduce the return temperature and reducing the return temperature even more is also an important energy saving measure, as low temperature demand will improve the efficiency of the DH
- Electricity savings and shift from electric heating of hot water and drying etc. will increase the demand for low temperature heating
- The large heat stores inherent with DH permit the utilisation of surplus wind energy via heat pumps or resistance heating
- This heat can be transported to customers economically using the DH pipes
- The CHP stations can provide instant back up and load following to fluctuating wind sources.

One expert Danish practitioner[57] states "a strong development of CHP plants and district heating networks is very important to reduce total energy consumption (CO_2 emissions) in Europe; doing this, together with an increase in the requirements to building energy conservation are the single most important reasons for Denmark being able to avoid an increase in its energy consumption despite a 2-3% annual economic growth over the past 30 years"

See also Danish District Heating and Heat Plan Århus, Denmark[58], and Annex 6 which fully describes the technical features and background of the Odense scheme.

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[55] Low resource district heating http://www.braedstrup-fjernvarme.dk/)

[56] Heat Plan Denmark. Low Carbon Urban Heating, Anders Dyrelund, Ramboll, Denmark. http://www.copenhagenenergysummit.org/Low%20Carbon%20Urban%20Heating,%20Heat%20Plan%20Denmark%20paper.pdf

[57] Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

[58] Heat Plan Denmark. Low Carbon Urban Heating. Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark http://www.copenhagenenergysummit.org/Low%20Carbon%20Urban%20Heating,%20Heat%20Plan%20Denmark%20paper.pdf

6.2. Temporal persistence of heat loads

The demand for building heating is unlikely to diminish to such an extent as to make CHP-DH unfeasible, even with conservation measures, or disappear entirely as can be the case with industrial cogeneration when the plants are relocated abroad. This point is especially true in countries with badly-insulated buildings. Reductions in building heat loss can lead to warmer buildings, and the reductions in heat consumption are often not as high as would theoretically expected – the users may take some of the gains in what is now more affordable comfort levels - this is known as the rebound effect. A study by the UKERC[59] indicated that the rebound effect is real though hard to quantify, but could plausibly be such that heat load reductions were 10 - 30% less than anticipated.

It says this: "For household heating, household cooling and personal automotive transport in developed countries, the direct rebound effect is likely to be less than 30% and may be closer to 10% for transport. Direct rebound effects for these energy services are likely to decline in the future as demand saturates. Improvements in energy efficiency should therefore achieve 70% or more of the reduction in energy consumption projected using engineering principles. However, indirect effects mean that the economy-wide reduction in energy consumption will be less."

Even after quite high insulation levels are added a UK house may still have a heat load of 7,000-12,000 kWh/y rather than the previous 15,000-20,000 kWh/y, because it is kept at say 21^{o}C internally instead of 16^{o}C.[60] Denmark which has encouraged energy conservation for 30 years, still has typical detached house heat loads of 15 – 20,000 kWh/yr[61]. The Open University report cited earlier[62] shows that even low energy houses can be heated by CHP-DH economically.

Other factors will also compensate for reduced heat losses in buildings:

In most cities, the building density (m^2 of heated floor area per km^2) increases in time and compensates for the heat savings in the old building stock.

The demand for heating is the heat losses minus the waste heat from persons and electrical appliances. In office buildings the waste heat from electrical appliances significantly reduces the demand; however this demand will probably be reduced as a result of more energy efficient appliances, due to low energy electronics and heating of hot water by the heat source instead of electricity (laundry and dish washing).

Moreover, the optimal level of insulation depends on the efficiency of the heat source. Thus, if the insulation is driven by market forces or regulations based on cost effectiveness criteria, the insulation will be less and the optimal heat load larger in buildings supplied from CHP-DH compared to buildings supplied from boilers or direct electric heating.

Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

[59] The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. October 2007. UK ENERGY RESEARCH CENTRE. ISBN 1-903144-0-35

[60] D Olivier. Domestic Energy Consultant. Personal Communication.

[61] David Olivier, energy consultant, private communication.

[62] ERG 056 An Introduction to domestic micro-chp R.Everett and D.C. Andrews. Open university Energy Research Group, Milton Keynes U.K. September 1986

Figure 6.1 below shows that forecasted[63] heat demand is unlikely to decrease substantially.

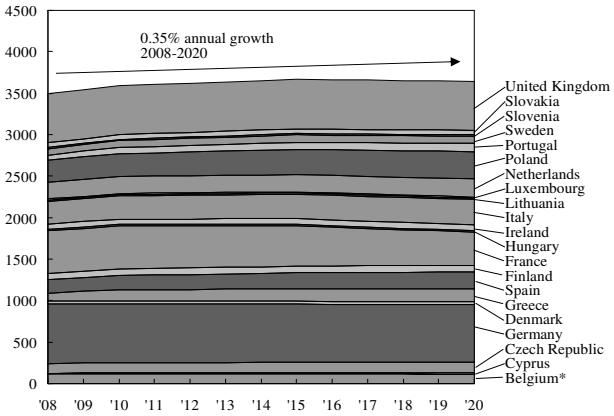


Figure 6-1 Forecasted heat demand 2008-2020, based on templates and/or national reports from 21 Member States [TWh thermal] [64]

6.3. The low energy Passivehaus – CHP-DH is still recommended

A very small 23 unit scheme Passivhaus scheme[65] in England is heated through a district heating system. This could have a gas engine chp unit fitted.

Passive houses and low energy houses have a common future with district heating according to Günther Lang[66], manager of IG Passivhaus in Austria. "I think district heating makes good sense in combination with passive houses. But district heating systems and the needed technologies must be modernized, so that they fit to the much lower supplies of heat that low energy houses need. The whole point of passive houses is that they use a very low amount of extra energy - up to 90% less than conventional buildings. But especially in blocks of flats, where a lot of m2 are put on top of each other, it is a good idea to supply with district heating, what the building cannot generate by itself. …….Here in Vienna we have a lot of old and often listed houses from the Kaiserreich period, which old listed houses in Vienna are ifficult to turn into low energy houses"

And the passive house concept has functioned very well in combination with district heating since it was finished in 2005, According to Günther Jedliczka [67], manager of the ÖAD Housing Office, Vienna.

6.4. Application of CHP-DH and DC – type of suitable buildings

District heating is optimally applied to dwellings, because these buildings are lived in and have much higher occupancy rates than commercial buildings. As a group, dwelling are inhabited 24 hours per day, 7 days per week, whereas offices and shops much less. Dwellings consume large amounts of hot water for domestic purposes, year round. These different

[63] Background Report On Implementing The Cogeneration Directive. Deliverable 1.2 within the framework of the Administrative Arrangement on Cogeneration between DG ENER and JRC. 2012
[64] Background Report On Implementing The Cogeneration Directive. Deliverable 1.2 within the framework of the Administrative Arrangement on Cogeneration between DG ENER and JRC. 2012
[65] http://www.passivhaustrust.org.uk/news/detail/?nId=43#.T6osYsVyDQI
[66] http://heating.danfoss.com/PCMPDF/VZKQR102_Passive-houses_Austria_CaseStory_lores.pdf
[67] http://heating.danfoss.com/PCMPDF/VZKQR102_Passive-houses_Austria_CaseStory_lores.pdf

characteristics make dwelling a much more attractive proposition to heat with district heat than most commercial buildings. Some commercial buildings like hotels are also a good load.

For a given city, the commercial heart of the city is generally much smaller than the areas devoted to dwellings. The commercial areas are less economic for district heat than the surrounding residential areas however often some or all parts of some city's commercial districts are heated using district heat. This is probably due to convenience – but without the surrounding high volume high load residential areas the commercial areas would generally not justify district heat due to the poor load factors – only 12 hours per day heating, waste heat from electric appliances, little heating at weekends, and low demand for domestic hot water. On the other hand, the heat building density is very high and there are after all, relatively high heat demands. Therefore it is cost effective to establish district heating networks. Moreover the space is valuable and it is a big advantage that the buildings do not need space for boilers and stacks. In particular in these areas, avoiding local combustion and the associated pollution is important.

City centre commercial districts are frequently cooled using District Cooling (DC) due to their high cooling loads which must be satisfied. It turns out, despite the relatively lower occupancy hours; it is still worth investing in DC for these centres, partly because the chilling load persists throughout the year. Also district cooling will release valuable space in buildings and on the roofs to be used for other purposes, e.g. car parking in the cellar and useful space on the roof.

Thus we see that District Heating and District Cooling are not symmetric in applicability – District heat will generally apply to a much larger, domestic area of a city, whereas District Cooling will tend to only apply to the city centres, in typical cities in the EU. So far as we know there are few if any widespread areas where District Cooling is applied to residential areas but it might be in the future and only in warm climates. One of the largest is the new district in Barcelona - 23@barcelona[68] - in which both DH&C is distributed in parallel to all buildings. District cooling is based on much lower temperature differences than DH and therefore may not be transmitted economically for as long a distance as heat. However as we model later, buildings could use individual absorption chillers operated by the DH hot water in summer. A new technique taken up recently in Denmark is Ground Water Cooling; thus from a well ground water is pumped up, heated (to do the cooling) and then returned to the ground. [69]

Cities that have reached or are on the way towards reaching 50% district cooling shares include Paris, Helsinki, Stockholm, Amsterdam, Vienna, Barcelona, Copenhagen.[70]

As an example: the cooling could be a combination of e.g. a 5 km tunnel for cold seawater to a district cooling plant near a city centre from which a district cooling grid can transmit cooling 5 km further in a network to the whole centre whereas the heating could be transmitted 10 km in one grid and even 10 km further to the suburbs with residential apartment buildings[71].

[68] http://www.22barcelona.com/documentacio/22bcn_1T2010_eng.pdf (chapter on advanced infrastructure)
[69] Link: http://www.enopsol.dk/artikler/online-artikler/horizontal-wells-a-novel-technology-to-be-used-in-groundwater-cooling-and-cold-storage/
[70] Ecoheatcool & Capital Cooling
[71] Pers Com. Anders Dyrelund, market manager energy Rambøll Smart Energy Cities Seminar in DG17 28.09.2011 Anders Dyrelund, market manager energy Rambøll

6.5. CHP-DH is not considered incompatible with low energy buildings

This paper[72] which has analysed this issue states: "From environmental perspective energy efficient buildings and district heating don't oppose each other – good parts connected in a good system will give an optimal solution"

[72] *The 12th International Symposium on District Heating and Cooling, September 5th to September 7th , 2010, Tallinn, Estonia.* DISTRICT HEATING AS PART OF THE ENERGY SYSTEM: AN ENVIRONMENTAL PERSPECTIVE ON 'PASSIVE HOUSES' AND HEAT REPLACING ELECTRICITY USE. Morgan Fröling1,2 and Ingrid Nyström3 1 Engineering and Sustainable Development, Mid Sweden University, Östersund, Sweden. 2 Chemical Environmental Science, Chalmers University of Technology, Göteborg, Sweden. 3 CIT Industriell Energianalys, Göteborg, Sweden

7. POTENTIAL GROWTH RATES OF CHP-DH, PRICE LEVELS IN EUROPE AND PENETRATION

7.1. Rate of growth of District Cooling sales ..... **Error! Bookmark not defined.**
7.2. European District heat price levels: ..... **Error! Bookmark not defined.**
7.3. Present contribution to heating of CHP-DH ..... **Error! Bookmark not defined.**
7.4. Total share of CHP in national electricity production **Error! Bookmark not defined.**

The growth rates can be considerable. The figures below show how quickly CHP-DH can be built even in existing European cities[73]. It may take decades to achieve a full penetration of DH in a large city but the rate is really dependent on the commitment of the various authorities.

The steep increase after 1980 in Copenhagen, see figure 7.1 below due to the oil price increase and the heat supply planning and subsidy schemes to new networks). The steep increase after 1990 is e.g. due to an agreement in the parliament that all municipalities should use the power in the Heat Supply Act to enforce all boiler plants larger than 250 kW (defined as a "public heat supply plant" of interest for the society) to connect within one year to the approved heat supply, which could be either DH or natural gas. Parallel to this the price commission decided that the heat price should not exceed the cost of heat from an individual boiler.

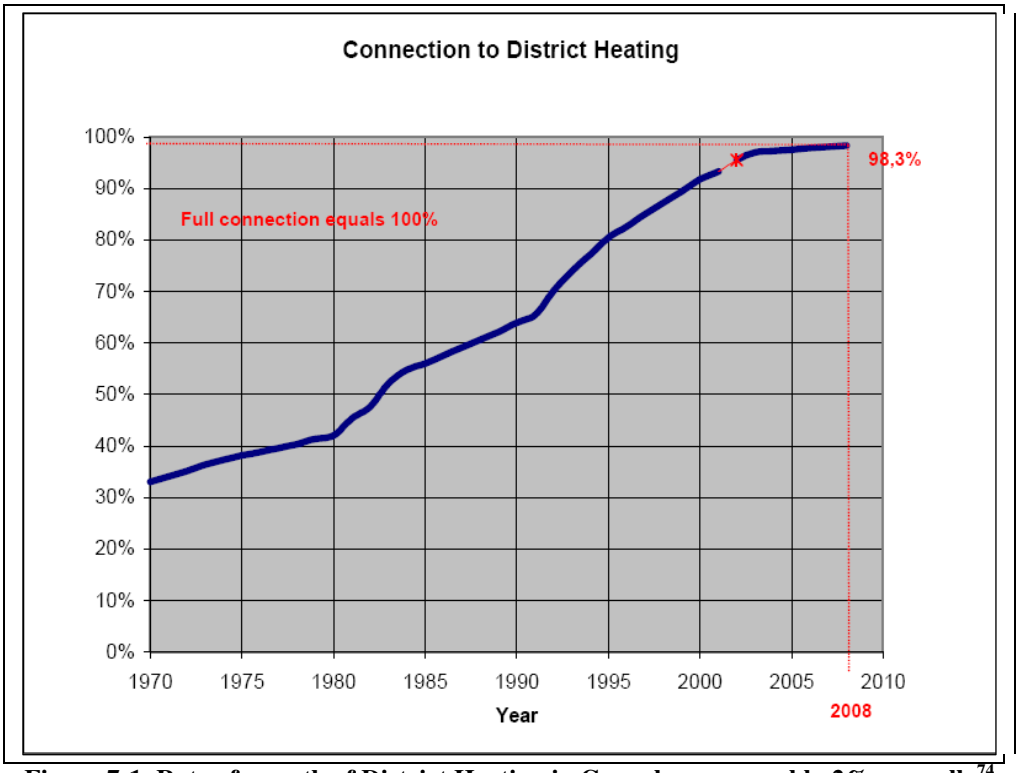


Figure 7-1 Rate of growth of District Heating in Copenhagen, roughly 2% annually[74]

[73] Stadt Frankfurt am Main, 2007
[74] Stadt Frankfurt am Main, 2007

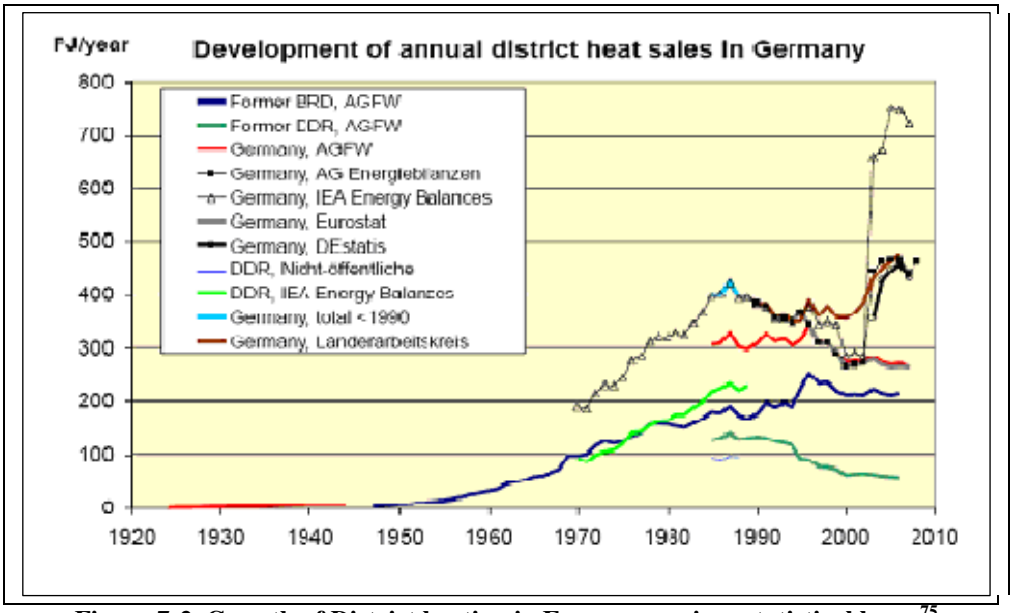


Figure 7-2 Growth of District heating in Europe – various statistical bases[75]

In China the growth rate has been 17% p.a. in the period from 1990 to 2000[76] and this increase has continued to 2010[77].

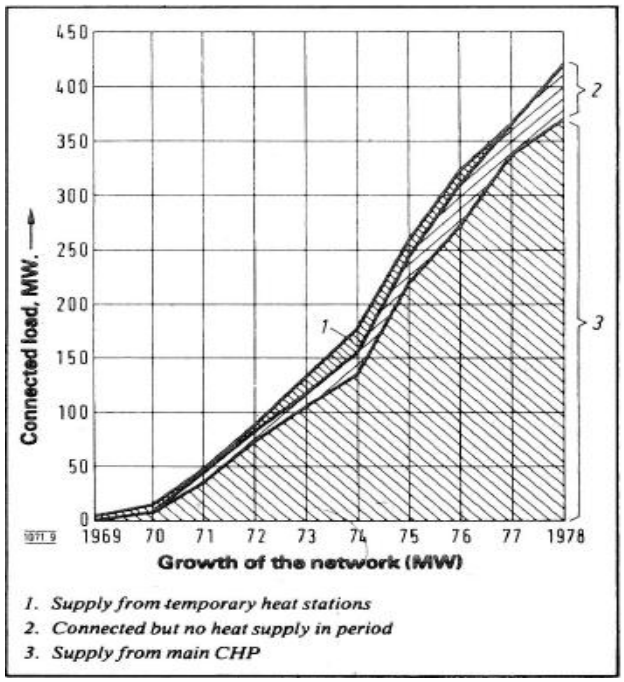


Figure 7-3 Rate of growth of Flensburg District Heating CHP-DH[78].

[75] EuroHeat, Brussels

[76] Pers Com.Anders Dyrelund, market manager energy Rambøll Smart Energy Cities Seminar in DG17 28.09.2011 Anders Dyrelund, market manager energy Rambøll

[77] The Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), agreed and released by the Intergovernmental Panel on Climate Change (IPCC) on May 9th in Abu Dhabi, 2011. page 647

[78] Wolfgang Prinz, The then Technical Director, (1985) Flensburg Heat and Power Utility. Personal Communication

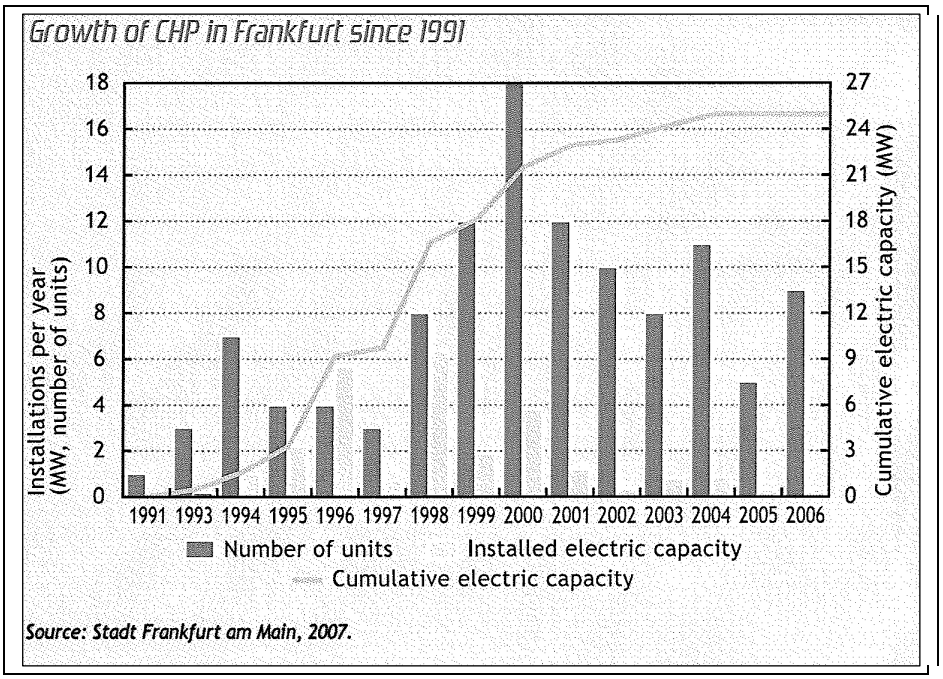


Figure 7-4 Growth rate of CHP-DH in Frankfurt.

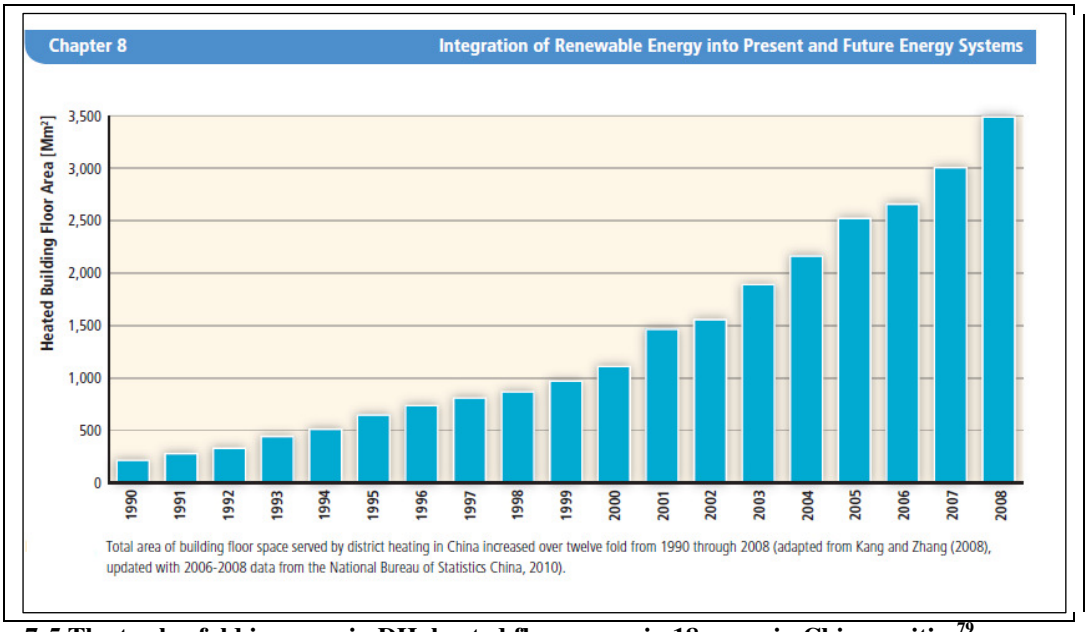


Figure 7-5 The twelve fold increase in DH heated floor space in 18 years in Chinese cities[79]

Chinese DH is driven by:

- **first priority** the environment, to replace small coal stoves and boiler with black smoke with large stacks and white smoke
- **secondly** by the use of CHP, in order to save coal for heating to 1/3 of coal from boilers
- **thirdly** for climate reasons and for integrating RES.

[79] The Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), agreed and released by the Intergovernmental Panel on Climate Change (IPCC) on May 9th in Abu Dhabi, 2011. page 647

Only in some new ECO cities RES is a driver.

The Chief Engineer from Beijing visited Copenhagen around 1985 and studied the DH scheme. With support from Danish AID and consultants Danish technology was implemented and the development of DH in Beijing started around 1990. Danish Technology has to some extent replaced the Russian. The Chinese can plan their cities and construct tight concrete duct systems with long life time, however also new pipe systems are introduced. Currently LOGSTOR a Danish District heating company invests in pre-insulated pipe factories in China.

The above information provided by[80]

7.1. Rate of growth of District Cooling sales

The figure below shows the rate of growth of District Cool sales. According to statistics from Euroheat and Power and the Ecoheatcool project, about 1% of European cooling demand is met from centralised District Cooling.

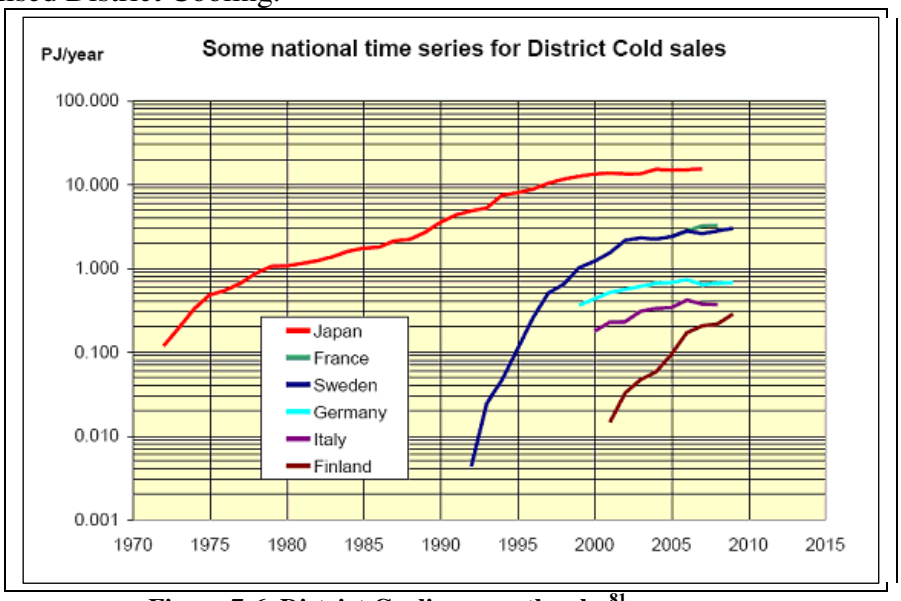


Figure 7-6 District Cooling growth sales[81] .

7.2. European District heat price levels:

European District heat price levels are shown below:

[80] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[81] EuroHeat, Brussels

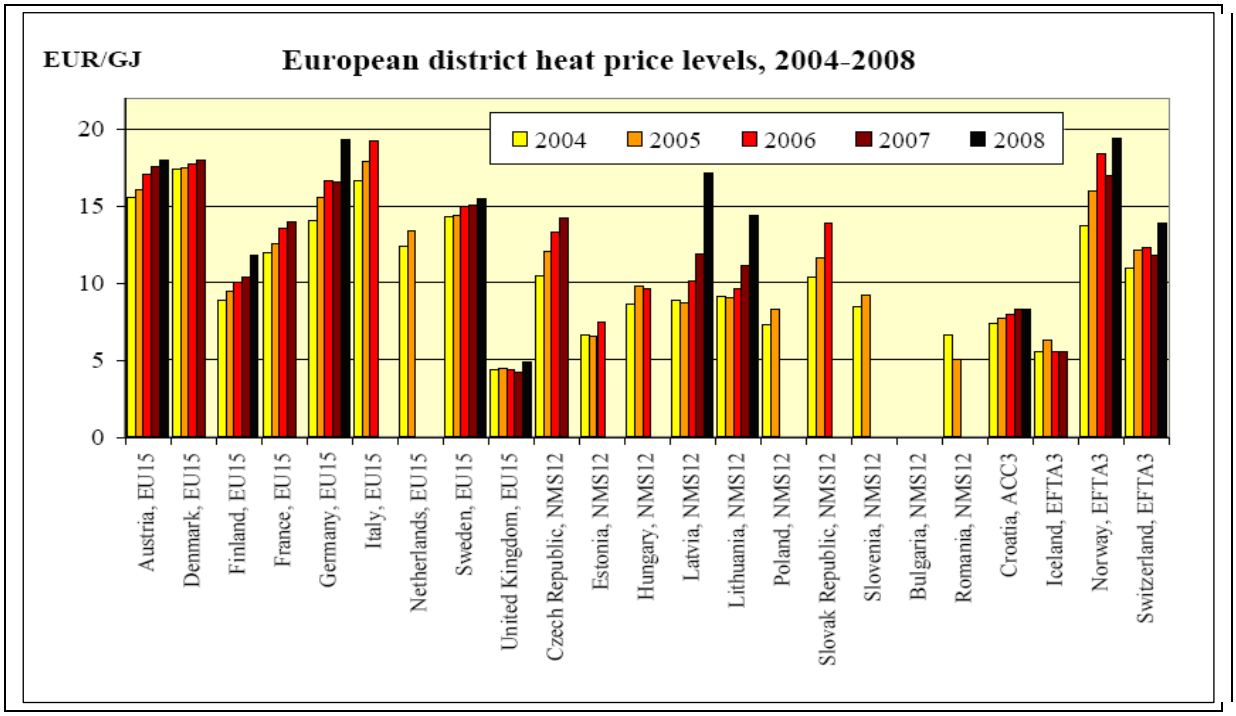


Figure 7-7 European District heat price levels

7.3. Present contribution to heating of CHP-DH

The chart below shows the percentages of the heat market satisfied by leading Member States users and EEA members of CHP-DH. If all national district heating fractions were brought up closer to the leading practitioners' levels, namely Iceland, Denmark, Sweden and Finland, then this would represent a very significant increase in CHP-DH. (See Chapter 18 where an estimate is performed.) According to Euroheat 6% of the low temperature heat demand in EU27 is currently met by District Heating. Euroheat switched to share of citizens served by DH as a more reliable method of expressing the data.

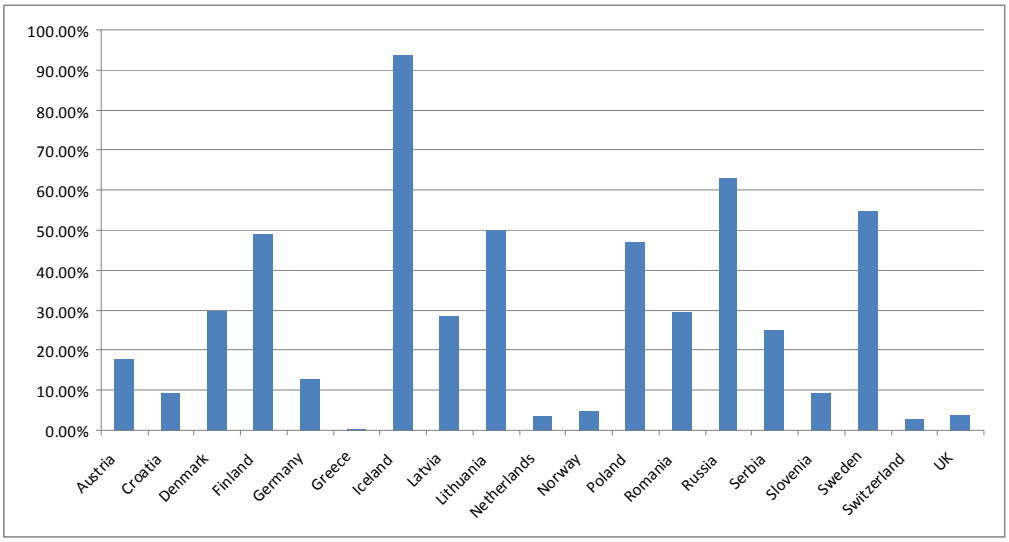


Figure 7-8 The share of the low temperature heat demand in Europe currently met by District Heating[82].

The data in figure 7-8 are based on different opinions on what is low temperature heat. The Danish market share of hot water district heating in MWh/a, which can be compared with the numbers in the other countries is 50%. (The market share of heated homes is however

[82] Euroheat – the European District Heating trade association

62%)[83]. The aim is that the municipalities shall find the least cost zoning between DH and individual solutions. In Heat Plan Denmark, a report prepared by AUC and Ramboll and financed by the Heat consumers (a Small PSO) it was estimated that it could increase from 50% to 70%.

7.4. Total share of CHP in national electricity production

The figure below shows the total share of CHP in national electricity production

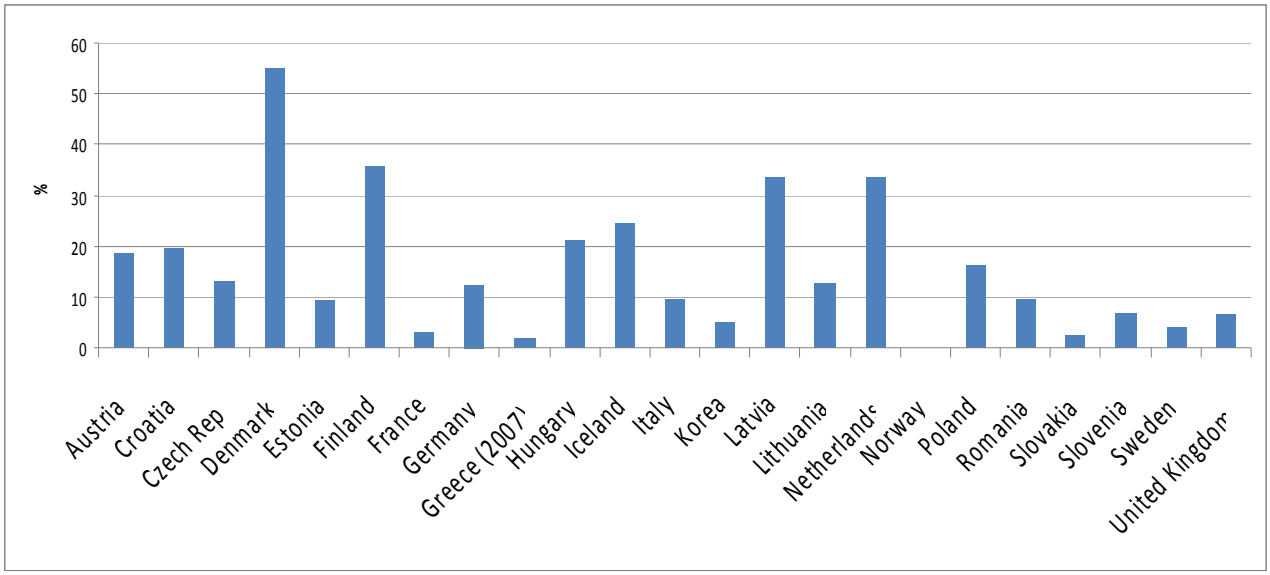


Figure 7-9 Total share of CHP in national electricity production[84]

[83] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[84] Euroheat – the European District Heating trade association

8. SMART CITIES HEAT AND POWER GRIDS

8.1. Introduction..... **Error! Bookmark not defined.**
8.2. The Copenhagen Region example of implementation of smart city features **Error! Bookmark not d**
8.3. AECOM paper on impact of smart heat grids to UK . **Error! Bookmark not defined.**

8.1. Introduction

The European Industrial Initiative "Smart Cities and Regions", already included in the SET-Plan[85], aims at positioning committed cities at the forefront of the development of the low carbon economy. For the renewable heating and cooling (RHC) industries, this initiative represents a unique opportunity for deploying large-scale innovative renewable heat solutions[86]

As the power grids become smarter so will the heat and cooling grids. The near future is important for smarter systems, smarter tariffs and smarter customers. Since half of the energy consumption in the EU is due to cooling and heating, smart heat and cooling are also a near future objective. Consequentially, in smart grids electricity, heat, cooling and gas will operate as an integrated system where surplus energy can be used. In particular it is important that the district heating and district cooling can include large thermal storages and that the gas grid also includes storages. Moreover that large capacities of CHP plants, electric boilers and heat pumps in district heating and cooling can react quickly to the price signals in the power grid and can be used to stabilize the power grid when dealing with fluctuating renewables.

The pipes and the ability of using very large tanks to store hot water as in the Danish DH systems are by far the largest energy storage available for wind power balancing in Denmark. This could be replicated over Europe in smart cities. Danish experts[87,88] have worked for some time on simulating the interaction between wind power, electricity demand and CHP systems. The idea is to make the DH systems work as a backbone of an energy system for the heat sector with a high share of renewable energy.

Smart heat and cooling systems involve to a great extent smart DH and DC, especially when it comes to Renewable heating and cooling technologies. Growth of modern DHC systems in Europe will entail major contributions to better energy efficiency (reducing 2.6% of European primary energy supply) and security of supply (reducing 5.5% of European primary energy supply), together with increased renewable energies integration and significant carbon reductions[89]. Since energy efficiency, security of supply, renewable integration, carbon

[85] **"**The European Strategic Energy Technology Plan - Towards a low-carbon future" The Commission presents a strategic plan to accelerate the development and deployment of cost-effective low carbon technologies. This plan comprises measures relating to planning, implementation, resources and international cooperation in the field of energy technology.

[86] The European Technology Platform on Renewable Heating & Cooling (RHC-Platform), Smart Cities need Renewable Heating and Cooling, April, 2011 http://www.rhc-platform.org/cms/fileadmin/user_upload/Structure/NEWS/Press_Release_Smart_Cities_Workshop.pdf

[87] Paul-Frederik Bach who retired in 2005 from a position as deputy director at Eltra, the west Danish system operator. "Wind Power and District Heating – New Business Opportunities for CHP: Sale of Balancing Services" EuroHeat & Power, English Edition IV/2011

[88] Intended for Seminar on Smart Cities, September 28th 2011, "SMART ENERGY CITIES DISTRICT ENERGY IN THE COPENHAGEN REGION"

[89] Best Practice Legislative examples for District Heating & Cooling, Sustainable Energy Week, Bruxelles, April 2011

reductions and moreover flexibility, customer added value, services and demand side management are the main concepts of smart grids, smart DH and DC systems will play an active role.

Renewable energies will on the one hand produce electricity when prices in power markets are high and heat demand is low and on the other hand produce heat over night. During the night the demand is low, but stored heat can cover the morning peak by reloading the storage tank.[90] In general a smart supply system will combine local resources and it will operate flexibly interacting with different sources according to availability and costs. Especially when it comes to renewable energies, weather forecast tools may be applied. Furthermore, the smart DHC supply system will interact with the electricity grid and other networks/ infrastructures.

As regards the heat / cooling load, smart DH and DC systems will smooth the heat cooling demand, thus reducing the peak load production. Thereby pumping costs will be reduced and there is also the possibility to reduce the flow temperature. Absorption chillers will be improved in order to use more efficiently waste heat. The heating and cooling demand will be smartly managed with systems where interaction between buildings, substations and networks are possible.[91]

With the electricity consumption, heating / cooling demand there will be cost effective remote smart controls and metering. Heat pumps can use aero thermal, hydrothermal and geothermal energy sources to provide heating and cooling and can be combined with heat coming directly from other renewable energy sources in hybrid systems. Heat pumps can be driven by electricity or by thermal energy. In electrically-driven heat pumps, the electric motor activates a compressor. The necessary components are mass-produced and proven. Electric heat pumps switched on and off by controllers reacting to the price of electricity on the grid (smart grids), can help energy generation capacity to operate at optimum load.

Rights protection issues, such as data protection, will occur also in smart DH and DC systems[92].

8.2. The Copenhagen Region example of implementation of smart city features

The Copenhagen Region is a good example of a city which during the past 30-40 years has implemented most of the smart city features as recommended by the EU related to energy and continues this development. It is probably the region in the world which most successfully has integrated power, district heating, natural gas, district cooling and waste management. To give some examples:

- The development of the integrated DH system was heavily stimulated by co-ordinated heat supply planning in accordance with the Heat Supply act and approval of new power capacity in accordance with the Electricity Supply Act. The heat supply planning took place in the Regional authority and the more than 20 local authorities guided by the Energy Authority.

[90] VEKS, District heating and smart grids, October 2010 presentation to Danish board of District Heating
[91] Birgitta Resvik, Smart grids for smart cities. Research priorities for DHC, Second Annual Conference of the European Technology Platform on Renewable Heating and Cooling, 5-6 May 2011, Budapest May 2011
[92] Rhc-platform, Common Vision for the Renewable Heating and Cooling sector in Europe: 2020 - 2030 - 2050. http://www.rhc-platform.org/cms/fileadmin/Documents/RHC_BROCHURE_140311_web.pdf

- The Avedøre Power plant was the first large power plant to be located at **a new** site close to the centre of the potential heat market approved by the Minister of Energy in accordance with the Electricity Supply Act. (The Minister would only approve new power plant capacity if it was CHP located near the power market and therefore two new units, Amager 3 in 89 and Avedøre 1 in 91, were approved parallel with approval of a plan for a regional integrated heat transmission network). The two new power plant units were located in districts for special technical facilities (also waste water etc.) and at the new Avedøre 1 special attention was paid to architectural design (to mitigate NIMBY). Later Avedøre 2 followed in the same design.
- The local authorities have been responsible for elaborating heat plans in all urban area and have defined the optimal least cost zoning between a further development of the existing DH systems, new DH systems and a new natural gas infrastructure, in accordance with criteria for economic analysis at the national level set down by the Energy Authority.
- The municipalities have formed municipal partnership companies CTR and VEKS to develop the main transmission system whereas local municipal or consumer owned companies distribute the DH and the waste management company Vestforbrænding has developed its own transmission system interconnected with the main system. The heat market unit formed by CTR, VEKS and Copenhagen Energy, ensures that the heat is produced in an optimal way.
- In 2010 there was typically 98% connection to DH in all the DH zones and roughly 85% connection to the gas grid in the natural gas zones.
- Municipal owned waste management companies have merged to be able to treat the waste more optimal including recycling to the optimal level and investment in large waste incineration CHP plants. Thus all the energy from waste which not can be recycled is utilized. This includes waste from the 20 local municipalities plus neighboring municipalities in which the heat market is not sufficient.
- At the CHP plants, heat accumulators allow a more optimal production of the heat and power

The main data of the current integrated DH system in 2012 is:

- 160 km 25 bar transmission system up to 110 °C
- 40 km distance from east to west
- heated floor area: around 60 mio.m^2
- 97% heat produced by CHP and 3% by boilers
- 25% of CHP is based on waste
- 35% of CHP is based on renewable
- 3 thermal storages tanks up to 110 °C, in total 72.000 m^3

The heat market is expanding dramatically these years by expanding the transmission system to interconnect more local DH systems by shifting from individual mainly large gas boilers and small gas engines to the integrated DH system and by shifting from steam to hot water in the city centre. Moreover several projects for more RES and storage capacity is in the pipeline

There is no single authority or utility, which is responsible for the system. The operation and development is based on co-operation and regulation in accordance with the Heat Supply Act stating that all new investments shall be cost effective for the society. Thus more than 20 local authorities and more than 20 municipal and consumer owned utilities are responsible for this development. District cooling systems are now being developed in the central districts of some of the municipalities of the region

based on sea water, ground water, chilled water storage, absorption chillers and compressor chillers. Energy utilities in the region plan to shift from fossil fuels to wood pellets at the large CHP plants and to invest in new biomass fuelled CHP as well as large wind farms near the coast or off shore, which currently are the most cost effective way to generate heat and electricity based on renewable energy. In the metropolitan area, the integrated DH system and the local District Cooling systems can deliver renewable energy for heating and cooling to existing buildings and new city districts in a more cost effective way than building level installations.

The city of Copenhagen, which is by far the largest local authority and owner of the largest distribution company, Copenhagen Energy, has taken initiatives to present the major sustainable solutions of Copenhagen as a smart city, not only for heating, cooling and waste, but also for traffic and environment.

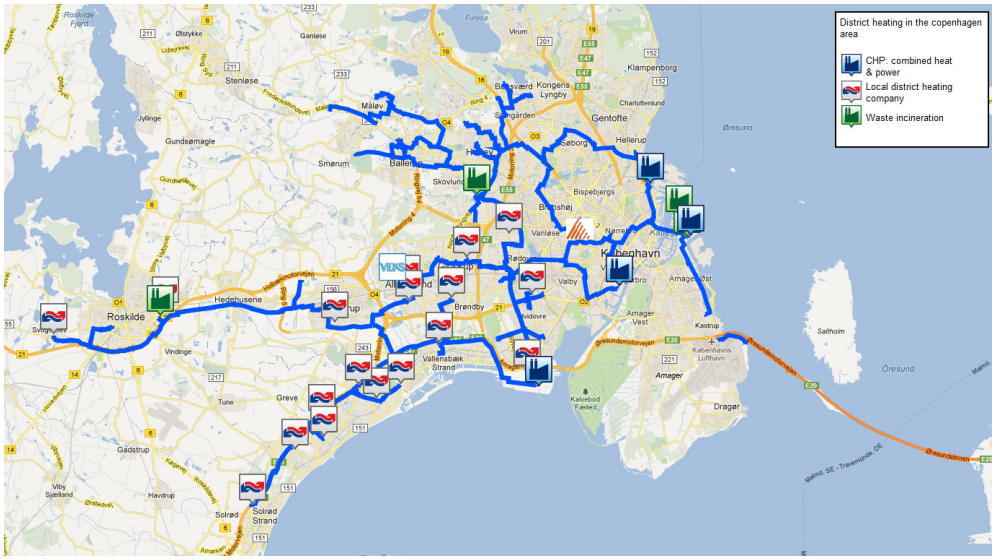


Figure 8-1 This map from VEKS shows the transmission system, but only the local DH systems in the VEKS area

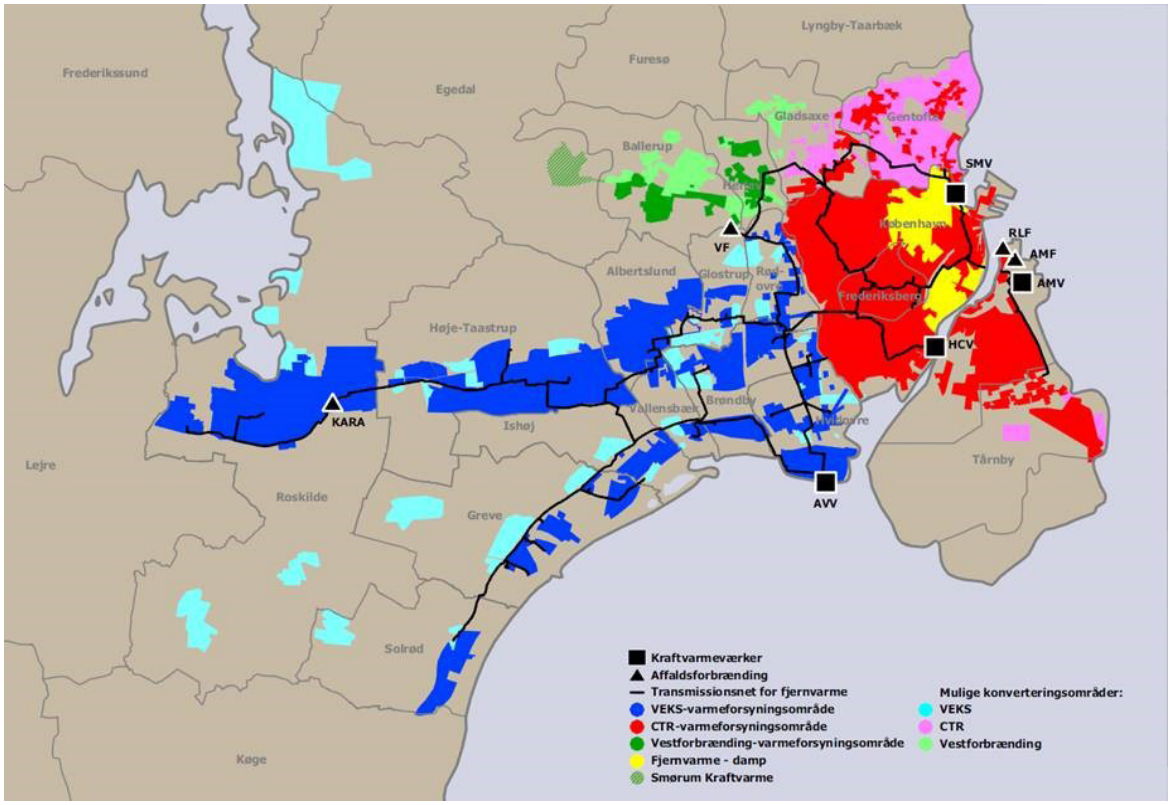


Figure 8-2 This map from CTR and VEKS shows the main transmission system, CHP plants waste plants existing supply areas for hot water (blue, red and green), for steam (yellow) and for new districts (light blue, light red and light green)

8.3. AECOM paper on impact of smart heat grids to UK

A paper[93] by Paul Woods, technical director of AECOM, looks at the potential for smart heat grids in terms of load management of a large penetration of wind in the electricity grid. The paper also notes that for a fairly small penetration of 5 million households out of 60 million, a significant and instantaneous contribution to grid management would be provided....” this would amount to 8.6GW of export to the grid and 10GW of import, a total swing of 18.6GW and could be higher if non-domestic buildings are included. This is about 30% of the current electricity demand of around 60GW in winter.

[93] Smart Heat Grids - The potential for District Heating to contribute to electricity demand management to facilitate renewable and nuclear electricity generation. Paper C92-EIC_029 to Energy in the City Conference, LSBU, June 24th 2010. Paul Woods, MA MSc CEng FEI FIMechE MCIBSE. Andrew Turton, PhD Sustainable Development Group, AECOM

9. DISTRICT HEATING TECHNOLOGY - SOURCES OF HEAT

9.1. Sources of heating and cooling ..... **Error! Bookmark not defined.**
9.2. Current sources of heat for District Heating in the EU27 **Error! Bookmark not defined.**
9.3. Industrial Waste heat ..... **Error! Bookmark not defined.**
9.4. Current sources of heat for District Heating in Sweden **Error! Bookmark not defined.**
9.5. Solar heat ..... **Error! Bookmark not defined.**
9.6. Multiple heat sources ..... **Error! Bookmark not defined.**
9.7. Geothermal Heat ..... **Error! Bookmark not defined.**
9.8. Heat only boilers ..... **Error! Bookmark not defined.**
9.9. District Heating based on Fossil fired Heat only boilers **Error! Bookmark not defined.**
9.10. Biomass fired heat only boilers ..... **Error! Bookmark not defined.**
9.11. Temporary Boilers ..... **Error! Bookmark not defined.**
9.12. Small gas engine CHP units ..... **Error! Bookmark not defined.**
9.13. Large heat pumps as sources of heat for District Heating **Error! Bookmark not defined.**
9.14. Nuclear power station waste heat ..... **Error! Bookmark not defined.**

9.1. Sources of heating and cooling

For DH systems sources of heating can be from a variety of sources such as:

- Power plant reject heat (also termed waste heat) from small engines – 1kWe – 5MWe or gas turbine generators – 100 kWe – 40MWe
- Reject heat from refuse/waste combustion power generation plant – 2MWe – 50MWe
- Reject heat from large combustion (or nuclear based) electricity power stations 40MWe – 4GWe
- Heat only boilers – 500MWth
- Industrial waste heat from for example a cement or steel works 100kWth – 500MWth
- Geothermal heat
- Surplus electricity from wind generators transmitted via electricity to large electric heating elements installed within the DH water network
- Electrically driven heat pumps
- Gas or diesel engine driven heat pumps (where additionally the engine reject heat can be used)
- Large scale solar water heating.
- Biomass boilers (wood chip or straw)

For large district heating schemes, there are generally multiple sources, often with several power stations and several boilers. These are not always located in the same place.

Thus the modern district heating systems with variable flow operation and accumulators opens up the possibility of efficient use of the market forces as the heat supply to the network can be based on the cheapest available sources at any location in the grid area and almost at any time and it can shift from source to source depending on the price.

9.2. Current sources of heat for District Heating in the EU27

The figures below indicate the make up of heat for present distinct heating – the majority of the heat is from power station waste heat.

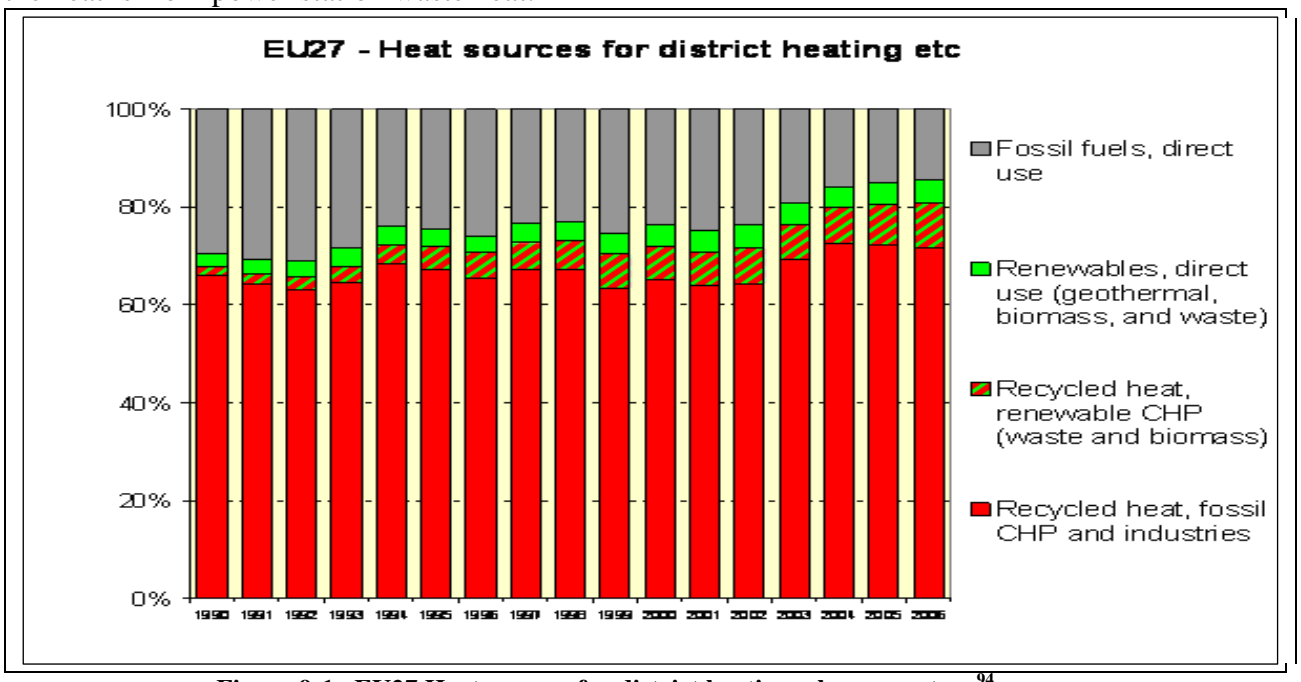


Figure 9-1 EU27 Heat sources for district heating – by percentage[94]

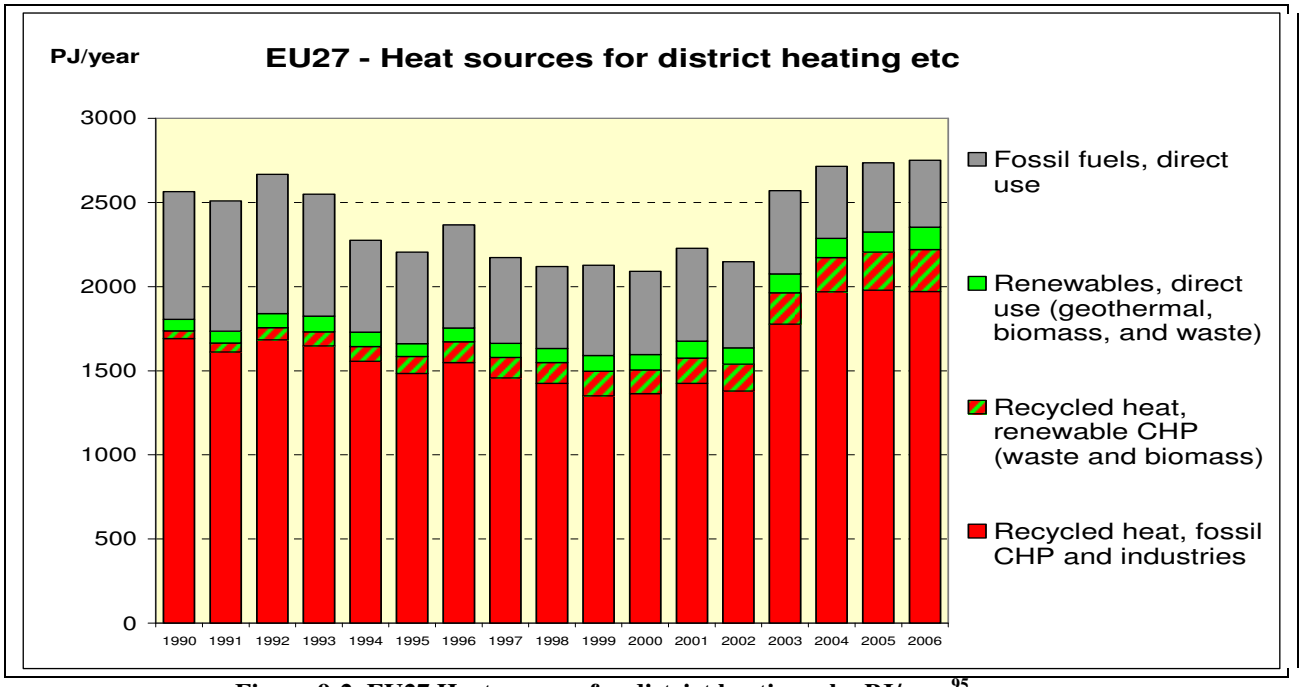


Figure 9-2 EU27 Heat sources for district heating – by PJ/year[95].

[94] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

[95] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

9.3. Industrial Waste heat

Many industries need high temperature heat for a variety of purposes, from melting metals, to making cement at the very high temperature end, ranging down to food processing, brewing and pharmaceuticals and calcium silicate brick/block manufacture which may require low pressure steam (i.e. temperatures just above the boiling point of water). Often the products – iron, cement, food, medicine etc., - will require cooling at some point, and this inevitably involves the rejection of this heat to the environment – this ultimately can be for example via a fan coil unit (a device similar to a very large car radiator), or heat exchangers placed in rivers or sea water, or cooling towers where water is evaporated to provide this cooling.

For example, in a float glass plant, only 7% of the energy supply is embedded in the glass leaving the site, so 93% of the energy supply is released on site as heat at various temperatures – in principle this can be captured and used for district heating networks.

In many cases, effort is expended on increasing the thermal efficiency of plants and to decrease the heat rejected to atmosphere or river water, but this is inevitably an exercise with diminishing returns, ie it becomes ever harder and more expensive to get successive increments of efficiency. In many cases it has been found that beyond a certain point, it is more cost efficient to invest further money towards the re-use of the waste heat for heating buildings via district heating rather than attempts to increase plant efficiency.

9.4. Current sources of heat for District Heating in Sweden

The figure below indicates the sources of District Heat in Sweden. Considerable quantities of industrial waste heat and heat from central heat pumps are used.

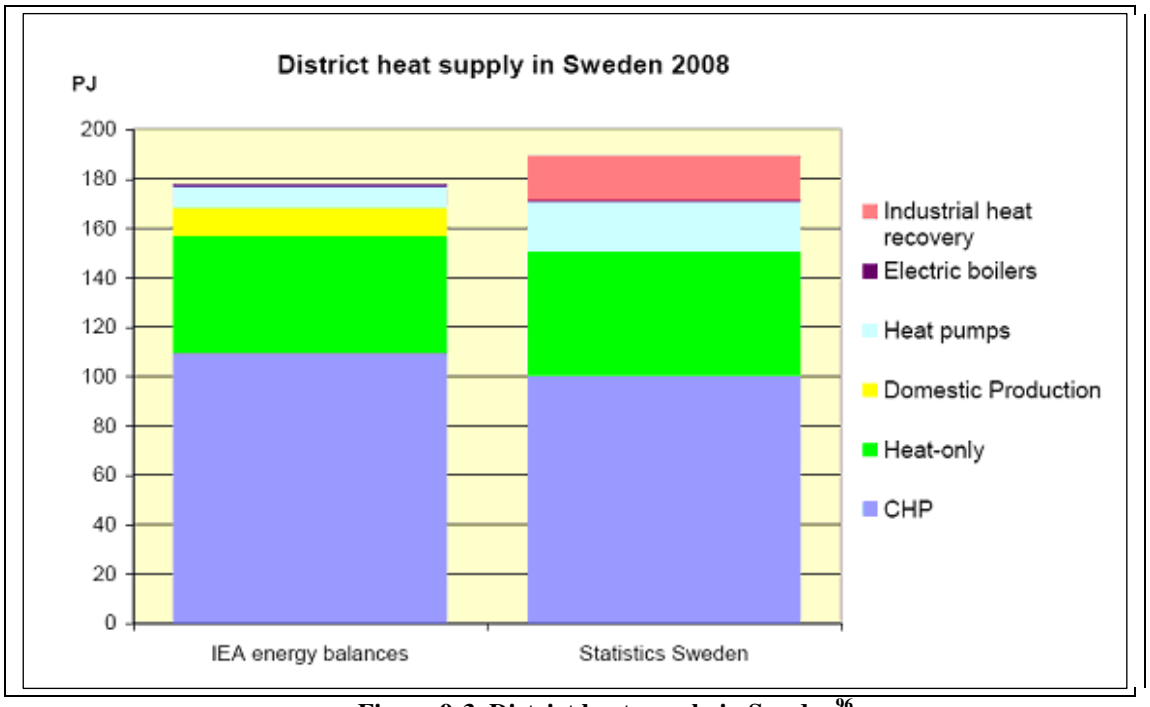


Figure 9-3 District heat supply in Sweden[96]

[96] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

9.5. Solar heat

Perhaps surprisingly, even in countries such as Denmark solar district heating can be economic:

..."Danish authorities estimate the cost of the heat output from medium and large solar arrays to be as in the table below. Given a market for the heat, large solar arrays are profitable today without subsidy against the ex-tax price of fossil fuel imports, which is not a claim that many renewables can make."[97]....

Table 9-1 Solar heat cost versus system size.

Size of Solar Collector Array		Annual Heat Production	Cost of Heat
m^2	MW	kWh	p/kWh, FOB
500	0.25	250,000	7.3
1.000	0.5	500,000	6.2
5,000	2.5	2,500,000	3.8
10,000	5	5,000,000	2.8
20,000	10	10,000,000	1.6

(NOTE: Assumes that 1 m^2 is rated at 700 W and produces 700 kWh/yr. Annuity factor is higher than the UK social/public sector rates used in this report.")



Figure 9-4 Marstal District Heating, Denmark[98]

The existing Marstal District Heating installation, above, of 18.000 m^2 solar collectors will soon be increased by 15,000 m^2. This is the world largest thermal solar installation. Other examples of solar district heating are discussed at[99]. Solar DH systems are in most cases

[97] Quoted from LESS IS MORE Energy Security After Oil David Olivier – AECB, 2011. http://aecb.net/news/wp-content/uploads/2012/02/LessIsMore-03.02.12-V1.0.pdf

[98] http://www.solarge.org/index.php?id=1235&no_cache=1

[99] http://www.solar-district-heating.eu /

coupled to heat storage systems to level the daily or weekly load fluctuations – these are discussed in relation to District Heating systems in more detail in Chapter 10. Marstal is presently testing two new types of heat storages, one with gravel water and one pit heat storage. The pit heat storage showing promising results in the terms of operating, low heat losses etc.
The latest development is that solar heating is stored from summer to winter in underground pit storages. Basically the pit is based on the technology from land fills combined with a floating insulated cover, whereas the unloading and loading system is the same as in the steel tanks.

The Marstal scheme is now being supplemented by a 70.000 m^3 storage which in combination with more solar panels will increase the share of solar heating from 20 to around 50 %.

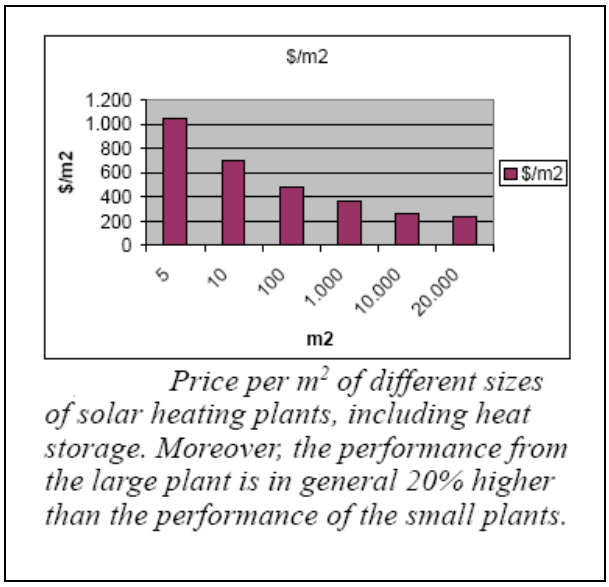
The example of Marstal is currently being followed by an increasing number of minor district heating companies in Denmark. The market for large scale solar water heating is booming. Heat Plan Denmark 2010 elaborated by Ramboll and Aalborg University and financed by the district heating consumers predicts 4 million m^2 of panels in 2020 and 8 million m^2 in 2030. Some companies have decided to increase the share of solar water heating up to around 50% by means of seasonal pit storages, on commercial basis without subsidies (only free of natural gas tax).

Building	
Type of building	District heating plant
Number of dwellings, floors	1,420 users
Year of construction	different
Total *living* area (heated)	209,769 m^2
Hot tap water consumption (measured/estimated)	not available
Whole energy consumption for heating purpose after CSTS implementation	19,034,000 kWh/a
System engineering	
Year of construction of CSTS	1996–2003
Type of collectors	Flat plate collectors, vacuum tube collectors
Thermal power	12,850 $KW_{therm.}$
Aperture area of collectors*)	18,365 m2
Buffer storage	14,000 m^3
Hot tap water storage	not available (in the buildings)
Total capacity of boilers with energy source	18,000 kW
Type of hot tap water heating	Decentralised
Type of heating system	Centralised
Costs	
Total cost solar system	7,333,000 Euro
Cost of the CSTS/gross area of collectors	386 Euro/m^2
Subsidies	37 %
Output	
Output of solar heat**)	8,824,000 kWh/a
Reduction of final energy***)	7,792,000 kWh/a
CO_2-emissions avoided	2,500 t CO_2/a
Solar performance guarantee	Yes

Table 9-2 Details of the Marstal scheme[100]

The figure below shows how the costs of solar energy rapidly decrease with size, indicating that Solar based District Heat is much more economic than individual systems.

[100] http://www.solarge.org/index.php?id=1235&no_cache=1



Price per m² of different sizes of solar heating plants, including heat storage. Moreover, the performance from the large plant is in general 20% higher than the performance of the small plants.

Figure 9-5 The cost of solar district heating falls off with increasing size[101]

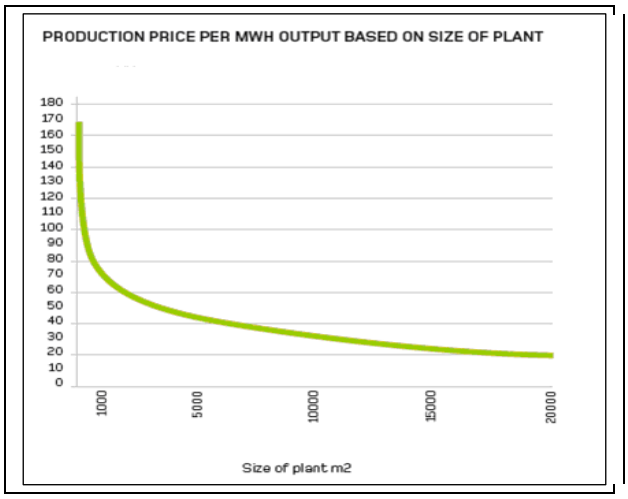


Figure 9-6 The cost of solar district heating falls off with increasing size[102]

9.6. Multiple heat sources

Multiple heat sources are provided to DH schemes for a variety of reason. Most importantly as a back up – if one source fails, it is necessary to provide an alternative. It often turns out, due to historical progression, and deliberate design, that the peak / standby boilers are located at various places within the heating pipe network as this provides flexibility in operations – such as allowing sections of pipe to be taken out of service for modification and connections, whilst providing continuity of heat supply.

Generally speaking large DH networks are built up over decades, often starting with small networks on either small CHP units or boilers, and as these are gradually connected up, some

[101] DBDH 2005 District Heating - a precondition for efficient use of solar heating
[102] DBDH 2007 EU aim at great expansion of large-scale solar thermal plants

of the original boilers are retained as peaking and back up, and as a result are spread around a city.

If the DH is fed from a CHP plant, then generally this is sized to only provide about half the peak heating load, with the peaks being provided by the other boilers. However this small amount of peaking heat accounts for a large fraction of the CO_2 emissions from a DH system using low temperature heat from a CHP plant. It is possible that in the future CHP in combination with the thermal storages may be used further up the load duration curve as the need to reduce CO_2 emissions increases.

9.7. Geothermal Heat

This is available in many parts of Europe and DH is a method by which it can be distributed on a large scale to buildings economically.

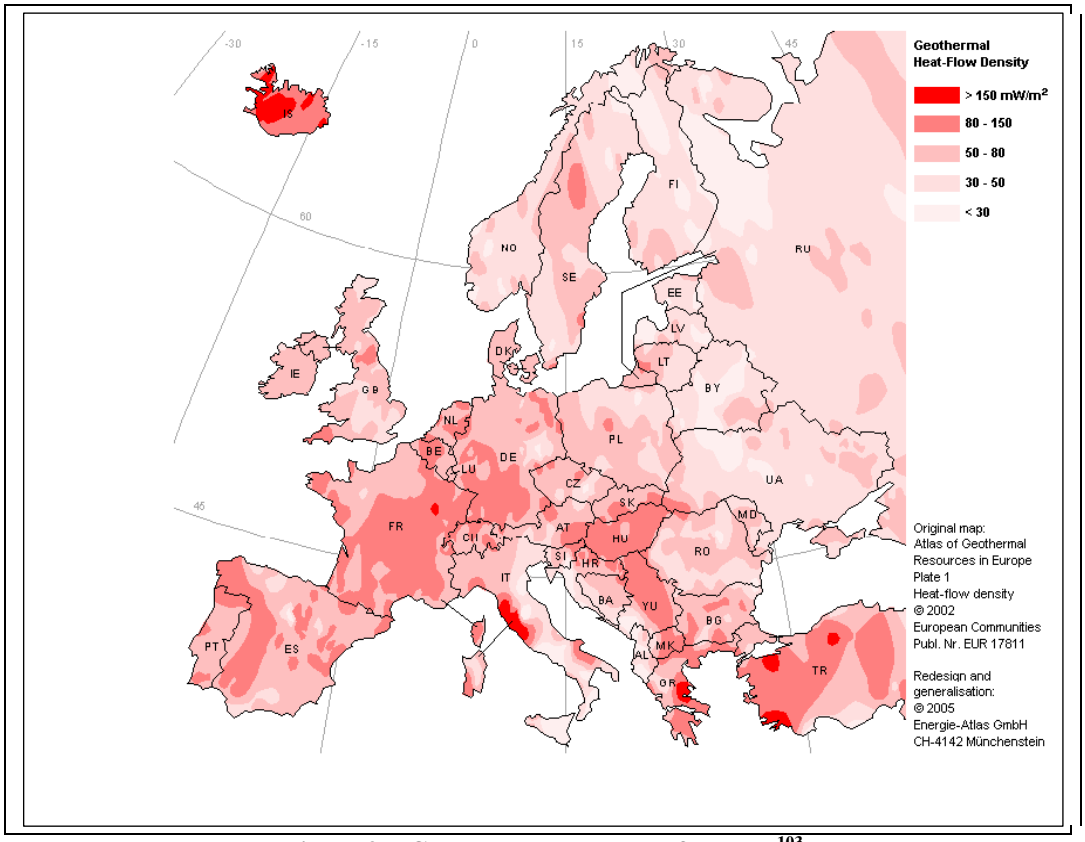


Figure 9-7 Geothermal heat map of Europe[103]

9.8. Heat only boilers

As noted, Heat only boilers may be used in an initial phase of a scheme, as in fact many were in early schemes throughout Europe. Often the intention was to leave these schemes permanently based on boilers and they were never intended to become CHP based. They were often based on cheap or subsided fuels, or fuels such as coal and heavy oil which could not be

[103] Atlas of Geothermal heat resources in Europe. Heat flow density. EC Publication EUR17811. 2002

burnt in individual appliances, or at least could not be burnt cleanly. As economic factors changed it became clear that some of these schemes could be connected to power station waste heat with the original boilers retained as back up or peaking as for example happened in Prague and many other cities.

This move was partially driven by the recognition that even in central boilers with large chimneys it was inappropriate to burn these dirty fuels such as coal and heavy oil, due to the large amount of sulphur and other toxic pollutant which they emitted. In Prague for example, at the same time as it was realised that the power stations burning this dirty fuel, would need to be de-sulphurised and hence it made a lot of practical sense to connect the power station, duly de-sulphurised to the existing district heating scheme, even though the pipe lines were 67 km in length.

At the same time it became in most systems more economic to shift the peak and spare capacity boilers to light oil. Although it is expensive in operation, it is cheap and easy to store and the boilers are easy to operate. Moreover the boilers could use gas in case there is gas available. In the Copenhagen system e.g. around 50% of the installed capacity is split on many small decentralized light oil/gas boilers, but they only produce around 2% of the annual production.



Figure 9-8 Coal heat only plant in Wieluń (Poland)[104]

[104] Wikipedia.- District Heating

9.9. District Heating based on Fossil fired Heat only boilers

Many of these large central boilers which were not connected to CHP were retained and switched to gas when it became available because it was cheap and could be burnt even more cleanly. However, the environmental benefits of burning gas in a central boiler in this way are not clear. Whilst large central boilers are more efficient than the older (still common) individual gas boilers, this advantage tends to be outweighed by the greater heat loss of the heat network itself – which can be 10 – 20%.

With the advent of more efficient individual condensing gas boilers, the advantage of the central plant becomes even less. In essence, it is generally the case that a fossil fired central boiler will have a worse carbon performance than individual gas, so there is really no case for them in the long term. The clear best practice is to replace them with a CHP source or some other form of low carbon heat such as industrial waste heat, only retaining them for back up or peak.

There always remains of course the advantage of no risk of gas explosion (with no gas cooking) and the avoidance of routine annual service visit of the technician, nor the cost of individual boiler replacement.

9.10. Biomass fired heat only boilers

Clearly biomass boilers have a potentially far lower carbon footprint if their fuel comes from sustainable forest. Notwithstanding the fact that they may have already extracted the carbon quite recently from the atmosphere, they are nevertheless emitting carbon via the chimney[105]. It can be argued that such emissions should therefore displace as much fossil fuel as possible to maximise the benefit of this limited resource. Thus arguably fuels should be burnt more efficiently in large central CHP station, where they are displacing coal which would otherwise be burnt and the biomass can be burnt at a much higher efficiency in this large plant.

However in e.g. Sweden, Denmark and Austria small local heat only systems are often run from biomass boilers, as biomass CHP is not economic in smaller scale below around 10-20 MW. In particular in small communities, it is very clear that a district heating biomass boiler of e.g. 1 MW, which as a base load plant can supply 250 one family houses with heat via a district heating system is significantly more environmental friendly and efficient than 250 individual wood boilers (15 kW each) [106].

The small DH system with the biomass boiler and a storage is open for additional cheaper heat sources, e.g. large scale solar water heating, electric boilers (for surplus wind) and heat pumps.

9.11. Temporary Boilers

When a scheme is being planned with the intention of connecting it to a power station when sufficient load has been built up, temporary portable boilers are used. When the heat load

[105] The biomass will emit precisely the same amount of CO2 when burnt as it would emit if it rotted (biological degradation) in the field or in the forest. This amount of CO2 being the same amount acquired from the atmosphere when it grew. Emissions from fossil fired transport and preparation must be accounted for.
(however forested land slowly sequesters more organic matter in perpetuity)

[106] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

using these boilers has reached sufficient size they can be removed once the load is connected.

9.12. Small gas engine CHP units

An alternative to temporary boilers is the use of packaged portable CHP units which can again be moved around and reconnected as the load builds up to permit connection to the main CHP power station. These are available in sizes of about 2 MWe in ISO standard containers and around 5 MW in oversized transportable containers. Their use improves the cash flow as a scheme is being built up because it can make electrical income from the earliest days in a project. Thus these have great application during the build up stage of a large district heating scheme. They can be retained to act as local power supply back up if needed, to give greater energy security[107].
Some older Eastern European schemes have had obsolete coal fired central power plants decommissioned and the heat and power instead coming from locally sited gas engine CHP plant of a few MW.[108]

In small power systems in electrical island operation, e.g. isolated islands and settlements in the arctic areas, diesel driven engine generators are vital for the communities. The waste heat from these engines can be used for low temperature heating without additional costs. In the most northern community Quaanaaq, in Greenland, the total efficiency of the electricity and heating of all buildings is more than 85% and the waste heat comprises more than 70% of the heat production[109].

9.13. Large heat pumps as sources of heat for District Heating

Central heat pumps are more efficient, more compact, cheaper and deliver higher temperatures than individual heat pumps. The Swedish units deliver about 3.75 units of heat per unit of electricity, whereas a domestic unit will deliver only about 3 dropping off as air temperatures fall. In Denmark the plan is to use the large heat pumps to use wind during surplus periods to feed heat to the DH networks. Being located in the high voltage network, these do not incur the high losses which a domestic heat pump will. The unit cost is also lower.

[107] William Orchard, Orchard Partners, London has looked at this issue.
[108] Metamorphoses of cogeneration-based district heating in Romania: A case study. Flavius Iacobescu a, Viorel Badescu b,n Energy Policy 39 (2011) 269–280
[109] Source: http://www.stateofgreen.com/en/Profiles/Ramboll/Solutions/Low-Carbon-Arctic-community-Qaanaaq-in-Greenland



Figure 9-9 90 MW thermal, heat pump feeding Helsinki District Heating[110]



Figure 9-10 180 MW thermal, heat pump feeding Värtan Ropsten District heating plant part of Stockholm District Heating.[111]

9.14. Nuclear power station waste heat

Given that nuclear energy presently provides about 1/3 of EU27 electricity, and in fact the proportion of waste heat from these stations is higher than in a fossil fuel station (nuclear steam cycles are less efficient than fossil fuel because for operational reasons the steam is not at such a high temperature) there will be clearly a great amount of district heating which can be accomplished from this source. In Chapter 12 it is shown that waste heat from large nuclear power stations can be transmitted up to 150 km with good economy. According to Stephen Tindale[112] – "Switzerland got 7.5 per cent of its heat from nuclear power stations in 2009. Within the EU, Slovakia got over 5 per cent of its heat from nuclear stations in 2009. Hungary and the Czech Republic also use nuclear heat. But in the EU's main nuclear players, such as France and the UK, the heat is simply expelled into rivers and seas."

[110] Helsingin Energie

[111] Friotherm AG. Zürcherstrasse 12 · P.O.Box 414.CH-8400 Winterthur · Switzerland

[112] "Energy Efficiency: made in Denmark, exportable to the rest of the EU?"- Stephen Tindale. April, 2012

Fortum[113] applied in February 2009 for a political permission (Decision in Principle) from the Finnish Government to construct a new nuclear power plant unit (Loviisa 3) at its existing Loviisa nuclear power plant (NPP) site. The application concerns a nuclear power plant unit ranging from 2800MWth–4600 MWth. The location of the Loviisa NPP site at the southern coast of Finland approximately 75 km east of the Helsinki metropolitan area (i.e. Helsinki, Espoo and Vantaa) with one million inhabitants offers a good opportunity for large-scale district heat generation for the region from the Loviisa 3 unit.

In Helsinki, the total installed capacity is around 1150 MWe and 3600 MWth, with the largest base load CHP power plants located in Salmisaari, Hanasaari and Vuosaari. The Vuosaari power plant is connected to the central city area, by an approximately 30 km long tunnel, which is the longest continuous district heating tunnel in Europe.

[113] Cogeneration and On-site Power Production. 01/05/2010. "Carbon-free nuclear district heating for the Helsinki area?"

10. HEAT /THERMAL STORAGE IN ACCUMULATORS IN DH SCHEMES

10.1. Electricity storage vs. thermal storage ..... **Error! Bookmark not defined.**
10.2. Heat storage – benefits to CHP plant operations ..... **Error! Bookmark not defined.**
10.3. Examples of heat storage durations from Denmark ... **Error! Bookmark not defined.**
10.4. Heat storage (hot water) scale economies. ..... **Error! Bookmark not defined.**
10.5. The Avedore heat storage ..... **Error! Bookmark not defined.**
10.6. Connection diagrams of heat storages ..... **Error! Bookmark not defined.**
10.7. Examples of Danish heat stores ..... **Error! Bookmark not defined.**
10.8. Interseasonal heat stores ..... **Error! Bookmark not defined.**
11. District cooling ..... **Error! Bookmark not defined.**

Heat storage in large central water tanks, where they are known as heat accumulators is commonplace in Denmark and Sweden. They are also in use in other European countries such as Austria and Germany. For DC systems cold storages in the form of ice are in use e.g. Helsinki and Paris[114]. Odense has the largest DH heat store in Denmark - 73,000 m^3, installed in 2003 to match a power generating capacity of 656 MWe / 1,000 MWth. They are also widely used in solar thermal based systems. One study simulated the possible interaction between a power system and a DH system. In a Danish case with 50% wind energy (in 2020 or 2025) it demonstrated that the Danish DH systems will be able to absorb a considerable part of the wind power variations[115].

10.1. Electricity storage vs. thermal storage

There is much interest in large scale electricity storage to deal with the intermittency of wind and solar energy. At present only a few per cent of the electricity which is generated in Europe goes into and out of a store almost always Pumped Hydro Electricity Storage Plant indicating that it is a very small fraction and any significant increase such as would be needed to use intermittent wind to heat buildings would be extremely large and extremely costly. Furthermore this increase would imply a very large increase in the transmission and distribution systems in order to deliver this stored energy to buildings, possibly by a factor of 5. (Most European dwelling have a peak power use, after diversity for lights and appliances of about 1 kW, whereas at least 5 kW even with heat pump heating would be required).

PHES which is the presently only viable form of long term electricity storage for grid use is about 50[116] €/kWh, whereas thermal storage appears to be much cheaper at around 0.1 - 10 €/kWh[117] and does not need any costly electrical infrastructure upgrade in order to deliver this energy to domestic users, if it were to be used to replace present forms of non electrical heating.

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[114] http://www.fluorocarbons.org/mediaroom/228/74/Ice-storage-to-improve-the-performances-of-HFC-134a-based-paris-district-cooling-one-of-the-biggest/

[115] Published in "EuroHeat & Power", English Edition IV/2011. The article is also available: http://pfbach.dk/firma_pfb/forgotten_flexibility_of_chp_2011_03_23.pdf

[116] Electricity storage association. http://www.electricitystorage.org/technology/storage_technologies/technology_comparison

[117] IEA-ETSAP and IRENA Technology Policy Brief E17 - January 2012

10.2. Heat storage – benefits to CHP plant operations

To a large extent, the heat accumulator has the effect of decoupling the heat and the power production, so it can offer these functions and benefits:[118]

- To allow the CHP plant to produce maximum electricity until the accumulator is fully discharged, in case of capacity problems in the electricity grid. Dropping the heat production is almost instant, thus leaving the plant with a substantial spinning reserve.
- Allow CHP to offer electrical capacity at any time, when no heat is needed, and still use the waste heat during the periods when it is needed.
- The heat accumulator may reduce or avoid income losses, if produced electricity is to be sold below production cost in case the CHP plant being in operation only for heat production.
- Large accumulators can allow a total stop of the plant during weekends, when the electricity price is often lower than on weekdays.
- The accumulator can compensate for the daily load variations in the heat demand (mainly caused by night setback), and thus reduce start – stop and the use of more expensive heat sources in the daily peak load periods.
- In particular the maximum capacity of the CHP plant can be reduced if the accumulator can be used for this purpose on the "coldest day".
- The heat accumulator tank can maintain the static pressure in the district heating network and also function as expansion reservoir.
- A CHP plant of extraction type can in periods with low electricity prices, e.g. at night, produce heat at a low cost and store it in the accumulator. Then, when the price is high, e.g. in the morning hours, the heat can be supplied from the accumulator, while the CHP plant produces maximum electricity in condensing mode.
- Increased flexibility for a CHP of extraction type by the possibility of shut-off heat production (spinning reserve). (A CHP of backpressure type can only generally only produce the heat while the electricity price is high.)

Accumulators thus generally enable the CHP to operate more economically by enabling the power station to operate in a more decoupled way from the heat load. This allows for the CHP plant to produce the DH energy when it is most favourable with respect to electricity prices; also making the proportion of (lower cost) heat in the DH network coming from the power station higher than would otherwise be the case.

10.3. Examples of heat storage durations from Denmark[119]

In order to understand how many hours the storage can replace the CHP unit, it is necessary to look at the heat market and the most efficient CHP unit, which is supposed to be in operation on a normal day and supply heat.

In the table below is summarized the data in very general numbers for 3 Danish cities. They all have a city-wide district heating network, which is supplied by waste-to-energy-CHP and some industrial surplus heat which has first priority. Next in priority comes the heat which is

[118] News from DBDH 1/2004 http://www.energymap.dk/Cache/03/0347cf9a-32da-429a-a1ca-2dbc68431158.pdf
[119] Anders Dyrelund, M.Sc.(Civ.eng.),B.Com, Market Manager for Energy Supply and Planning) Ramboll. Personal Communication

extracted from the coal fuelled CHP unit, which is in operation and which is competitive in the market. The typical peak load to the heat network is equivalent to 3.000 hours of max load. The typical base load capacity, which corresponds to 95% of the annual heat demand and which should be supplied by the CHP capacity, is equivalent to 5.000 hours max load hours. What is of interest, with heat storages, is for how many hours the operators can stop the heat extraction from the CHP plant to provide maximum power and to use the storage capacity to supply the heat:

1) On a typical winter day (base load)
or e.g.
2) On an average day equal to 50% base load.

It is also interesting to see how many hours it will take to load the accumulator using the maximal available capacity (maximal heat production capacity minus the remaining demand from the network). Simple estimates are below in the table overleaf.:

Table 10-1 Estimates of storage durations[120]

City Plant		Aalborg Nordjyllandsværket	Odense Fynsværket	Esbjerg Vestkraft
Demand for heat to network	GWh/a	2.000	2.200	1.100
Demand for Peak load, 3.000 h	MW heat	667	733	367
Demand for base load, 5.000 h	MW heat	400	440	220
First priority base load waste	MW heat	80	70	55
Demand for CHP base load	MW heat	320	370	165
CHP unit back pressure cap.	MW heat	460	480	460
Heat accumulator storage	m3	25.000	75.000	55.000
Storage capacity, 45 gr.	MWh	1.305	3.915	2.871
Storage capacity base load	h	4	11	17
Storage capacity 50% base load	h	11	26	52
Load time storage at base load	h	9	36	10
Load time storage at 50 % base load	h	4	12	7

As more wind power is required to be integrated into the system in the coming years the Danes[121] can foresee that it will be optimal to install even larger heat accumulator volumes, possibly even pit storages up to 400.000 m^3. The financial issue about large storages (compared to small micro storages) is that the costs and the heat losses per m^3 are much lower for large storages; the larger storage – the lower the cost and loss.

10.4. Heat storage (hot water) scale economies.

The cost of storing heat becomes considerably cheaper with size of store,[122] which indicates that using solar heat distributed by DH will be more economic than individual roof mounted units.

[120] Anders Dyrelund, M.Sc.(Civ.eng.),B.Com, Market Manager for Energy Supply and Planning) Ramboll. Personal Communication
[121] Anders Dyrelund, M.Sc.(Civ.eng.),B.Com, Market Manager for Energy Supply and Planning) Ramboll. Personal Communicatoin
[122] Dr Mark Barrett, Senior lecturer Barrett M, 2012, Private Communication. UCL Energy Institute, Central House. 14 Upper Woburn Place London WC1H 0NN

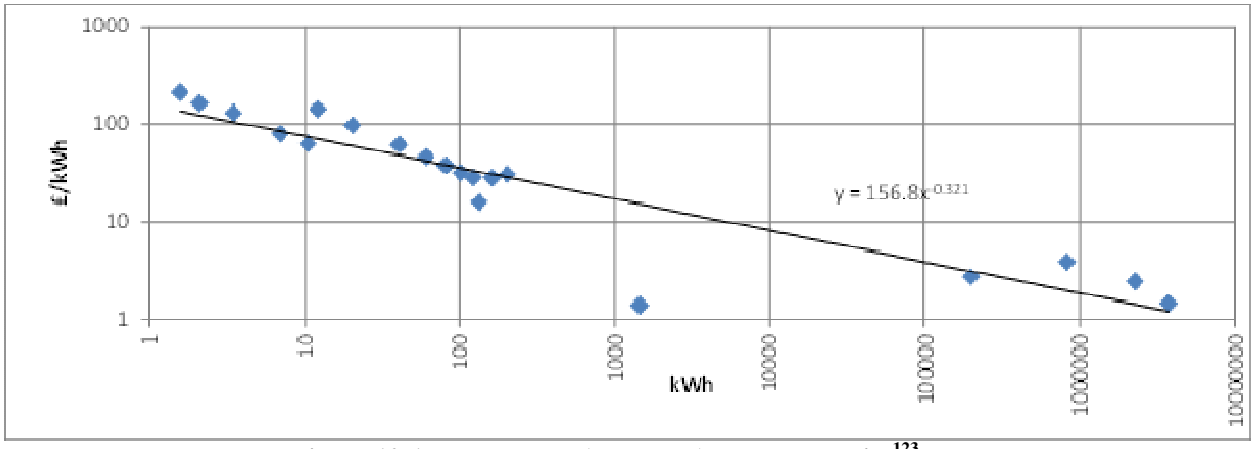


Figure 10-1 Heat storage (hot water) scale economies[123]

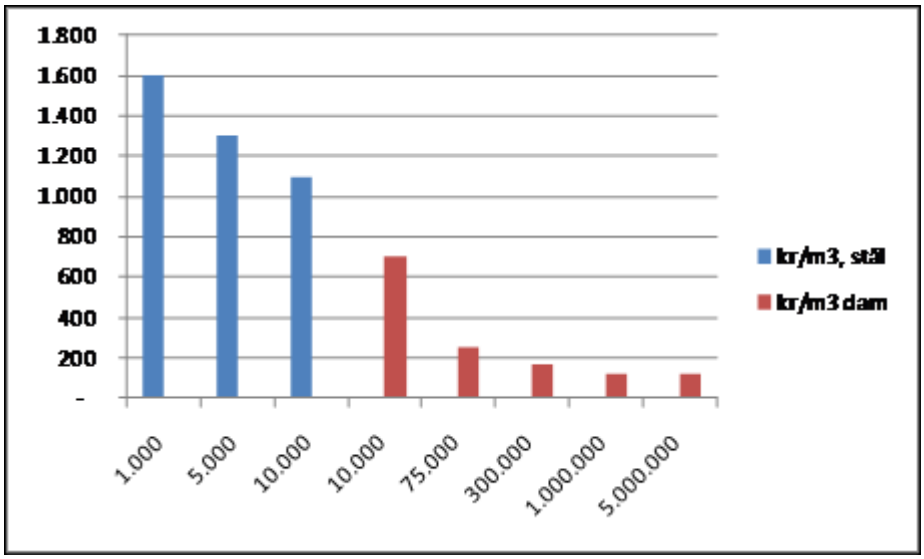


Figure 10-2 Heat storage cost decline rapidly with size. The blue is steel tanks, and the red is for pit storages.[124]

10.5. The Avedore heat storage

According to VEKS[125] one of the Copenhagen DH contractors, the tank pictured over the page has the following characteristics:

- Total volume 44.000 m^3
- Capacity: charging/discharging 330 MJ/s
- Max. Temperature 118°C (pressurized, more costly than non-pressurized))
- Total investment in mid '90-ties. DKK 105 million. (excl. VAT) Using the index for "steel construction" that's DKK 189 mio today or €25 mio.

[123] Dr Mark Barrett, Senior lecturer Barrett M, 2012, Private Communication. UCL Energy Institute, Central House. 14 Upper Woburn Place London WC1H 0NN

[124] Heat Plan Denmark 2010, Ramboll and Aalborg University.

[125] Personal communication. Jens Brandt Sørensen, Projektudvikling, VEKS, Roskildevej 175, 2620 Albertslund, T 43 66 03 66 D 43 66 03 50,www.veks.dk



Figure 10-3 Heat accumulators at Avedøre Power Station situated at Avedøre Holme south of Copenhagen. The overall production capacity of the two Avedøre Power Station units is 810 MW of electricity and 915 MW of heat. [126]



Figure 10-4 10.000 m2 pit storage in Marstal District heating Denmark[127]

[126] News from DBDH 1/2004 http://www.energymap.dk/Cache/03/0347cf9a-32da-429a-a1ca-2dbc68431158.pdf
[127] Provided by Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

10.6. Connection diagrams of heat storages

The figures below show heat storages directly and indirectly connected to the DH network.

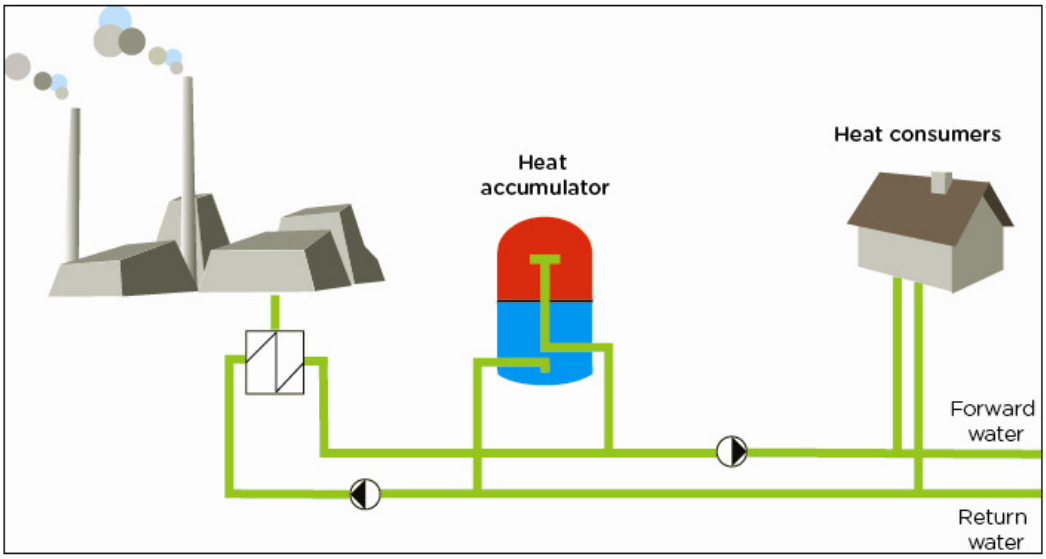


Figure 10-5 Heat accumulator directly connected into a DH system. [128]

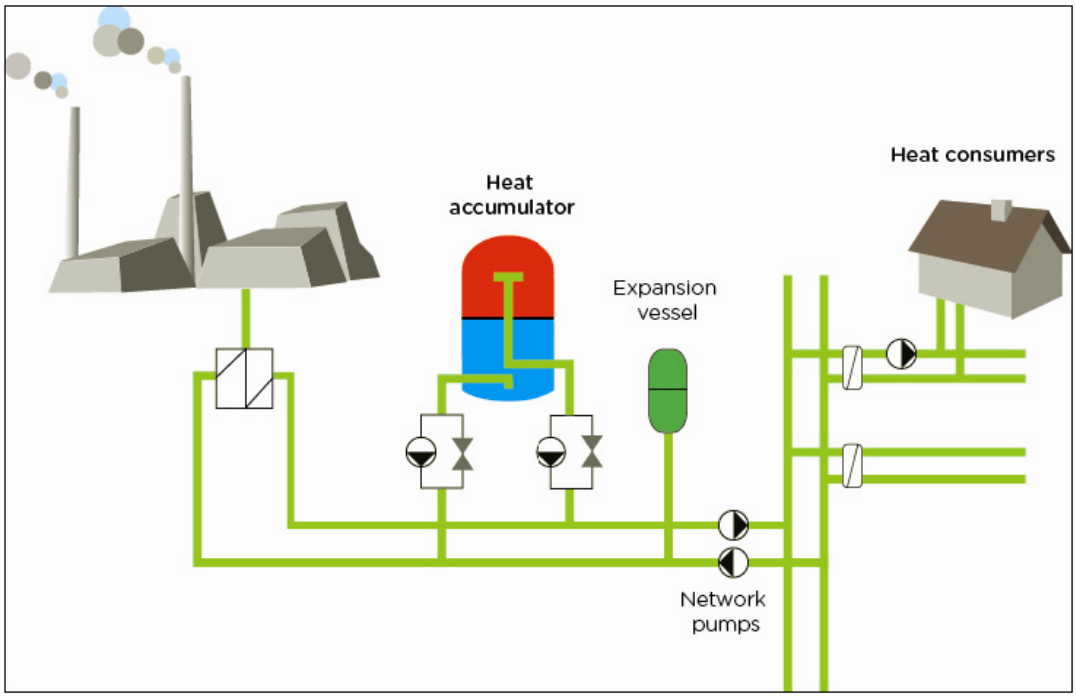


Figure 10-6 Accumulator with hydraulic separation from a DH system. [129]

[128] Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

[129] Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

10.7. Examples of Danish heat stores

Table 10-2 details of some Danish heat stores[130].

Project	Year	Type	Temp. ◦C	Dimension m	Volume m3
Slagelse CHP	1990	Pressure less	95	H:22 D:15	3600
Hillerød CHP	1991	Pressure less	85	H:25 D:22	16000
Esbjerg CHP	1992	Pressure less	100	H:47 D:40	55.000
Helsingør CHP	1993	Pressure less	98	H:43 D:24	14500
Avedøre CHP	1993	pressurized	120	H:50 D:26	2x 24000
Madsnedø CHP	1995	Pressure less	95	H:33 D:14	5000
Silkeborg CHP	1995	Pressure less	85	H:31 D:28	2x 14000
Østkraft	1995	Pressure less	90	H:40 D:15	6700
Studstrup CHP	1998	pressurized	125	H:55 D:29	33000
Skærbæk CHP	1998	pressurized	120	H:48 D:28.5	28000
Nordjylland CHP	1998	Pressure less	85	H:30 D:40	25000
DTU CHP	1998	Pressure less	98	H:28 D:18	8000
Maribo CHP	2000	Pressure less	85	H: 25 D:18,5	6000
Asnæs CHP	2002	Pressure less	100	H:65 D:20	20000
Amager CHP	2003	pressurized	120	H:49 D:26	24000
Fyn CHP	2003	Pressure less	92	H:40 D:50	75000

10.8. Interseasonal heat stores

Clearly an interseasonal heat store can improve the economics of a CHP-DH scheme by enabling CHP generated heat in the summer to be used for winter heat loads, providing of course the cost of the store is less than the extra benefits. This has been shown to be the case for certain granite caverns in Scandinavia[131].

[130] Provided by Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

[131] Seasonal Heat Storage in District Heating Systems. Alemayehu Gebremedhin, Heimo Zinko, Dept. of Management and Engineering / Energy Systems. Linkoping University, Sweden.

11. DISTRICT COOLING

11.1. Introduction.....**Error! Bookmark not defined.**
11.2. Growth in District Cooling .....**Error! Bookmark not defined.**
11.3. Free cooling .....**Error! Bookmark not defined.**
11.4. Compressor cooling .....**Error! Bookmark not defined.**
11.5. Absorption Chilling or Cooling .....**Error! Bookmark not defined.**
11.6. Comparison of Absorption cooling costs with compressor cooling**Error! Bookmark not defined.**
11.7. Cost of absorption chillers compared to compressor plant**Error! Bookmark not defined.**
11.8. Trigeneration.....**Error! Bookmark not defined.**
11.9. Demand for cooling is not necessarily dependant on climatic conditions.**Error! Bookmark not defi**
11.10. Statistics for District Cooling in Helsinki, Finland ....**Error! Bookmark not defined.**

11.1. Introduction

It should be noted that domestic air conditioning is still considered a luxury item in many areas of Europe, whereas heating is considered essential. This of course may change with climate change leading to hotter conditions. Air conditioning is essential in buildings with heavy computer and other modern office equipment use.

District Cooling (DC) is in general similar to District Heat where chilled water, is distributed in buried pipes. But there are important differences. The residential sector is less often supplied by District Cooling, than District Heating although this may change as the climate warms and incomes rise. There are several reasons for this some of which are:

- Air conditioning or cooling is more common in the service sector than the residential; usually DC providers tend to prefer business to business customers and contracts.
- Size matters to make a connection economical. Residential buildings might not require cooling all year around and therefore would only add to the summer peak, while in the service sector cooling is often a must due to the operation of electronic equipment, employees comfort to maintain productivity, etc).
- The cooling load has to be usually quite dense to make a District Cooling system run profitably. These customers tend to be located close to each other like office buildings, shopping malls or IT centres.
- Also the relatively lower amount of energy that can be supplied with the same amount of liquid in District Cooling systems (compared to District Heating). This is due to the smaller ΔT in DC (the flow line is typically around +5°C and the return temperature would be typically +15°C so there might only be a temperature difference of 10 degrees, while in a DH system it might feed in at 90°C and achieve a return temperature of 40°C where the temperature difference is 50 degrees. This is also why DC pipes tend to be bigger than the ones used for heating and cost more

11.2. Growth in District Cooling

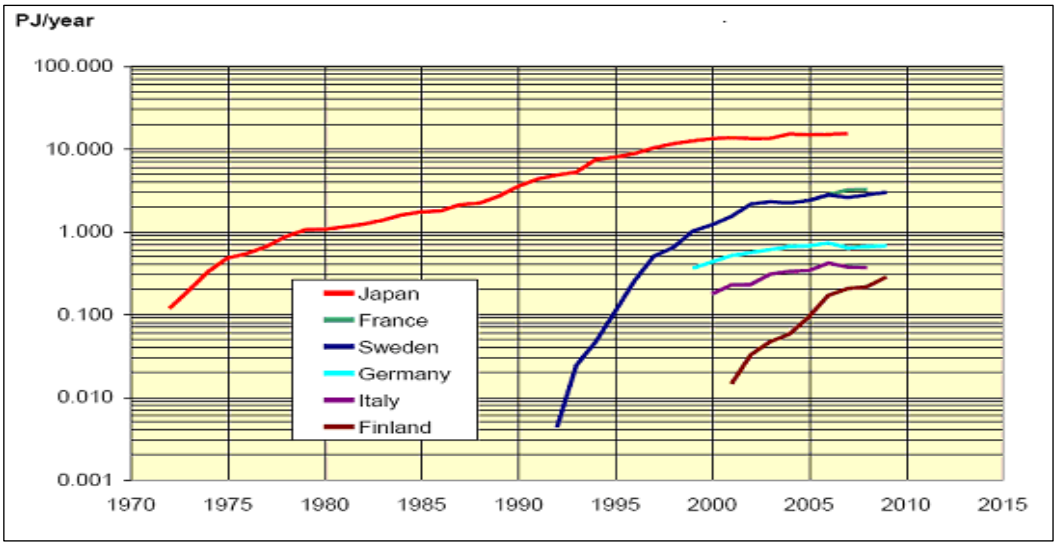


Figure 11-1 Growth in District Cooling sales based on various statistics. Ecoheat4EU, DHC Barometer. Seminar Brussels, March 30, 2011

The figure above gives some statistics for the growth in District Cold Sales:

11.3. Free cooling

Free cooling refers to sources of cooling such a low temperature air in the winter, river or sea water. Cooling towers can offer considerable free cooling especially in dry conditions and can at least pre-cool water to take some of the load of absorption chillers.

In another example[132], Toronto, Canada, has pumped cold water drawn from nearby Lake Ontario to a 207 MW cooling plant since 2004. The DC system cools 3.2 million m2 of office floor area in the financial district. The lake water intake pipe at 86 m depth runs 5 km out into the lake to ensure clean water is extracted, since this is also the supply for the city's domestic water system. No warm water return discharge impacts to the lake therefore result. Stockholm has a similar but smaller district cooling system based on extracting sea water from the harbour[133].

Natural gas expander stations in large gas transmission pipelines at pressure reduction stations are a source of free cooling. The expanding gas cools and has to be heated. Currently gas fired heaters warm the expanding gas which uses energy to dissipate this free cooling.[134] This heating can come from the return water of DC, and the cooling used in cooling networks.

[132]The Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), agreed and released by the Intergovernmental Panel on Climate Change (IPCC) on May 9th in Abu Dhabi, 2011. page 647

[133] The Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), agreed and released by the Intergovernmental Panel on Climate Change (IPCC) on May 9th in Abu Dhabi, 2011. page 647

[134] Natural gas is conveyed in pipes at high pressure up to 60 bar. (60 times atmospheric pressure) This is expanded down to low pressure – 25 millibar for delivery to consumers. This expansion creates significant cooling of the gas – up to 25 MW in some cases and to prevent the gas freezing the pipe work it has to be reheated using some of the natural gas. This heat could be provided by district cooling systems.

In Sweden, at Sundsvall Hospital, some summer chilling is centrally provided by snow recovered and stored from clearing roads in the winter.[135,136] The cooling power is close to 2 MW and provides annually about 80% of the cooling. This use of stored free cooling using ice has a long history. There are still the remains of pits in Spain used by the Roman to store mountain snow for summer cooling.

As regards the energy performance of buildings it is important that the building can be cooled by "high temperatures", e.g. 15°C instead of 5°C. This will increase the free cooling significantly and increase the performance of chillers.

11.4. Compressor cooling

The vast majority of cooling applications worldwide are driven by motor driven cooling compressors. These work by compressing a gas – the refrigerant, which causes it to become hot. The heat is rejected with a fan coil unit, a device similar to a car radiator. This compressed gas condenses to liquid as it cools. The liquid is then pumped to a cooling fan coil unit, where it evaporates. As it evaporates it absorbs the latent heat of vaporisation from the air being blown through the fan coil unit, thereby cooling it. This is the same type of device as found in a domestic fridge for example. This device is also known as a heat pump.

The Coefficient of Performance (COP) of such units is 3 to 4 meaning that for every kWh of electricity used 3 – 4 units of cooling are delivered. The COP is very dependant on the temperature differential – the cooler the heat dump the better the COP. If cooling water such as a river is available then the COP can be closer to 4. If the ambient air is used for cooling, then the COP is closer to 3.

11.5. Absorption Chilling or Cooling

Absorption coolers or absorption heat pumps operate on a different principle. They use heat to drive the cycle rather than mechanical energy from a motor:

- Evaporation: The liquid refrigerant evaporates extracting heat from its surroundings.
- Absorption: The gaseous refrigerant is absorbed into another liquid allowing more liquid to evaporate.
- Regeneration: The refrigerant-laden liquid is heated, (perhaps by the DH system) causing the refrigerant to evaporate.
- Condensation: It is then condensed through a heat exchanger which rejects heat at low temperature to replenish the supply of liquid refrigerant

The potential advantage of such systems is that they can utilize waste heat. However the COP is not as good as for electrically driven compressor types. For the low temperatures of modern DH systems then the COP could be 0.8 – 0.9 i.e. one unit of low temperature heat, gives 0.8 – 0.9 units of low temperature cooling. Hitherto these devices have been large and use quite high temperatures such as low pressure steam. As the supply temperature comes down both the COP and the cooling capacity falls off dramatically. This has the important

[135] http://www.cowiprojects.com/SoilCool/pdf/Pre-guide-final.PDF. Nordic Energy Research. Soil cool Rekyl Project. October 2004.
[136] http://www.snowpower.se/sundsvalls-kylanlaggning_en.asp

effect of making the device expensive for a given capacity, the cooler the supply temperature of the driving heat:[137] Nevertheless such devices are frequently found in DC systems. This is illustrated in the figure below.

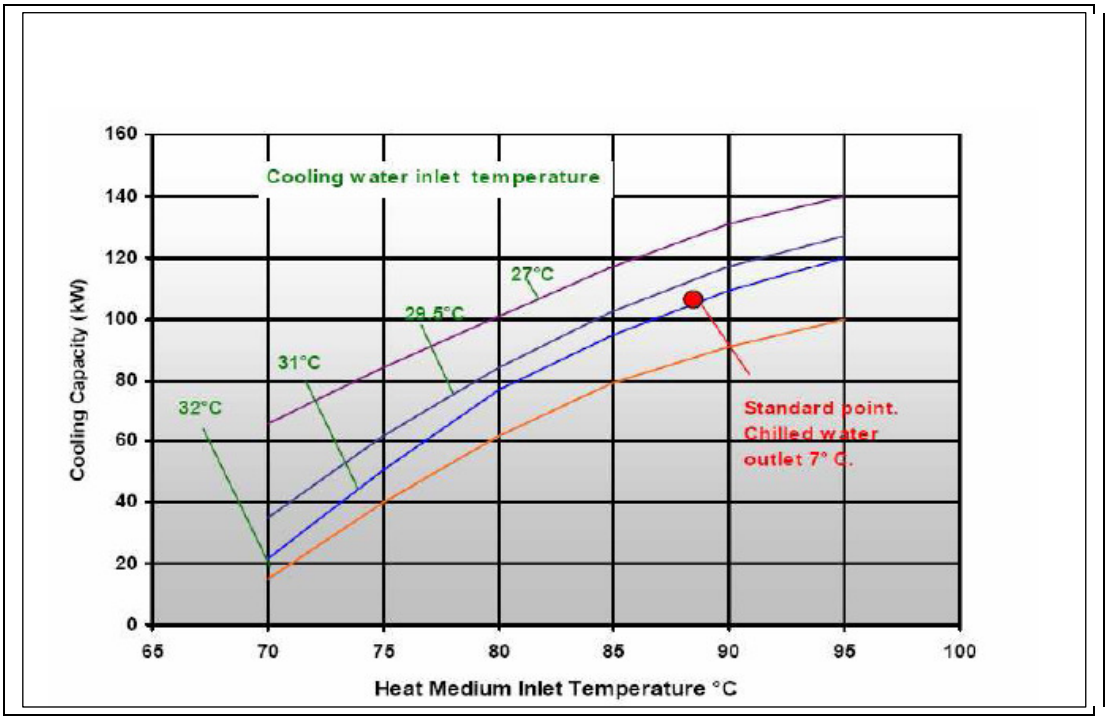


Figure 11-2 Cooling performance of absorption chillers against hot water temperature[138]

11.6. Comparison of Absorption cooling costs with compressor cooling

A study by Holler showed that there is little difference when comparing total costs between absorption cooling and compressor cooling systems as shown in the table below:[139]

Table 11-1 Relative costs of Absorption and compressor chillers.

Annual operating hours	hrs	4730	2560	1350	970	700
Absorption	EUR/kWh	0.09	0.12	0.18	0.23	0.3
Compressor	EUR/kWh	0,08	0.11	0.16	0.2	0.26
Compressor	EUR/kWh	0.09	0.12	0.18	0.22	0.29

[137] Meeting cooling demands in SUMMER by applying HEAT from cogeneration.Technology Report eliverable 2.3. Austria. Österreichische Energieagentur. Austrian Energy Agency. Robert Krawinkler, Günter Simader,23.07.2007

[138] Meeting cooling demands in SUMMER by applying HEAT from cogeneration.Technology Report eliverable 2.3. Austria. Österreichische Energieagentur. Austrian Energy Agency. Robert Krawinkler, Günter Simader,23.07.2007

[139] Yazaki Energy, 2007.

11.7. Cost of absorption chillers compared to compressor plant

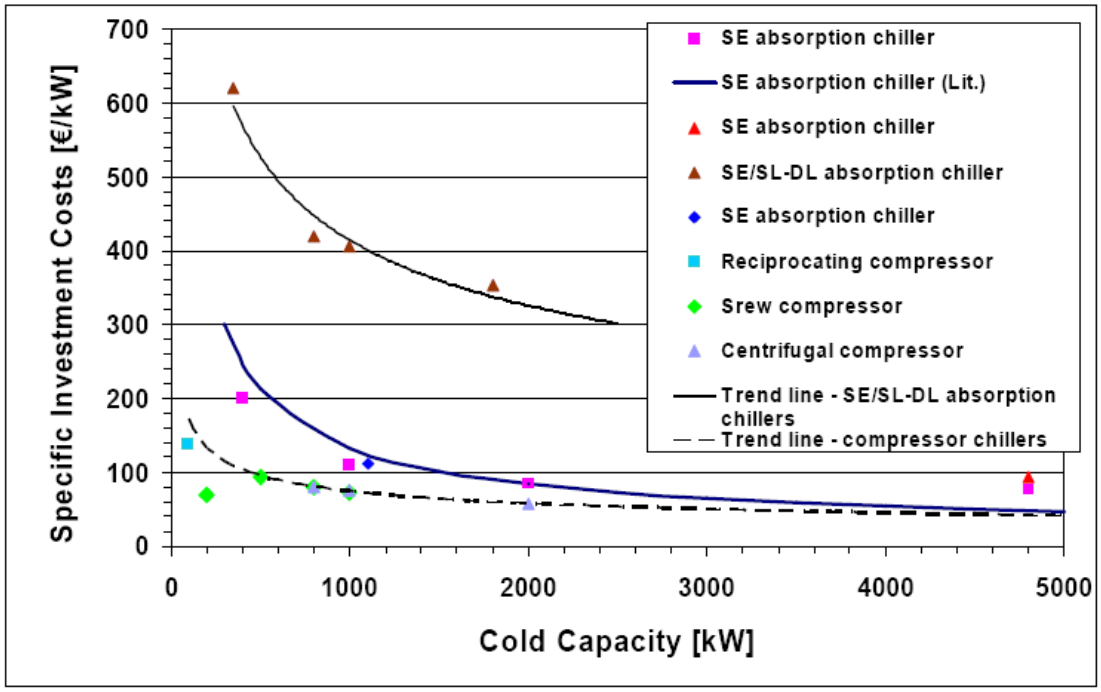


Figure 11-3 Cost comparison of absorption chillers versus compressor machine[140].

As it can be seen from the figure above, absorption machines are generally significantly more expensive in overnight cost than compression machines, and appear to be much less available in smaller sizes, but become more competitive as size increases. But running costs will generally be lower.

11.8. Trigeneration

Trigeneration is a term used to describe CHP units that can produce both heating and cooling. Tri-generation often uses the heat from engines, since this can be available at high temperature – 20 ^{0}C is quite easily achieved in an engine, with no effect at all on its efficiency, and the absorption chiller can operate without any loss of cooling capacity.

[140]Meeting cooling demands in SUMMER by applying HEAT from cogeneration.Technology Report eliverable 2.3. Austria. Österreichische Energieagentur. Austrian Energy Agency. Robert Krawinkler, Günter Simader,23.07.2007

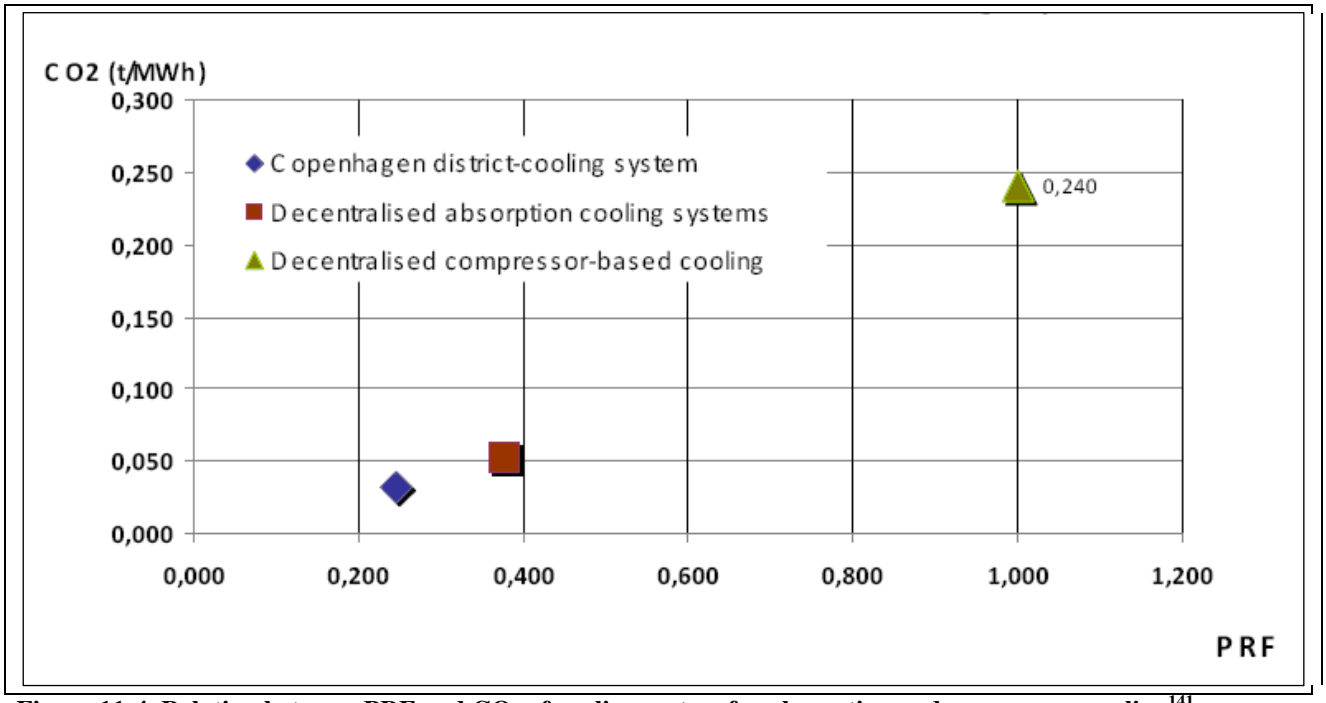


Figure 11-4 Relation between PRF and CO_2 of cooling system for absorption and compressor cooling[141]

The table above is for a proposed centralised district cooling system for Denmark. The approximate size of the units is about 15 MWc – well above that of a house which might be 5kWc. Clearly the absorption chiller has a much better performance in terms of CO_2.[142]

(On this figure the value of the Primary Resource Factor (PRF) is the ratio between net fossil energy supply and heat energy used in building during one year. CO_2 emissions are related to the use of fossil fuels and therefore CO_2 emissions are related to the primary resource factor value. Total CO_2 emissions of heating or cooling systems also dependant on the specific emission factor of fossil fuel used.)

11.9. Demand for cooling is not necessarily dependant on climatic conditions.

One interesting finding of the ecoheatcool study is that the thermal energy demand for heating and also cooling per m^2 is not necessarily directly dependent on the climatic condition since buildings in colder climates are usually better insulated, see table below. For example UK which has a warmer climate than Sweden or Denmark has a higher heating demand than Sweden or Denmark which are both colder.

[141] h ttp://www.eu-summerheat.net/download_files/D2.3_Summerheat_Technology_Report_Denmark.pdf
[142] http://www.eu-summerheat.net/download_files/D2.3_Summerheat_Technology_Report_Denmark.pdf

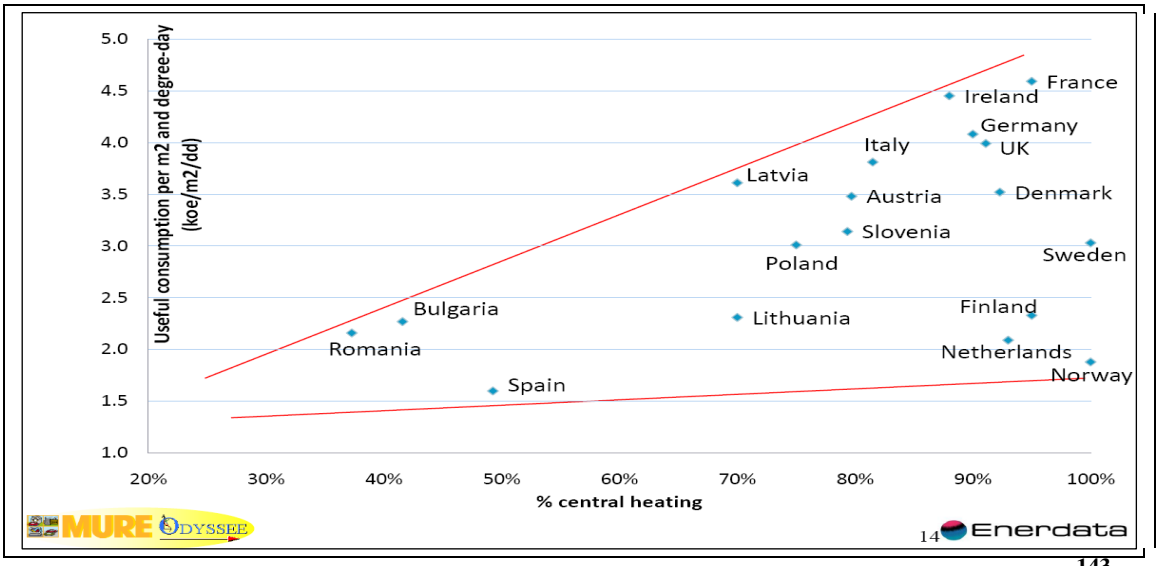


Figure 11-5 Energy consumption for space heating per m^2 and diffusion of central heating[143]

11.10. Statistics for District Cooling in Helsinki, Finland

Some statistics from Finland[144] showing sources of heat and growth of District Cooling are shown in the figures below.

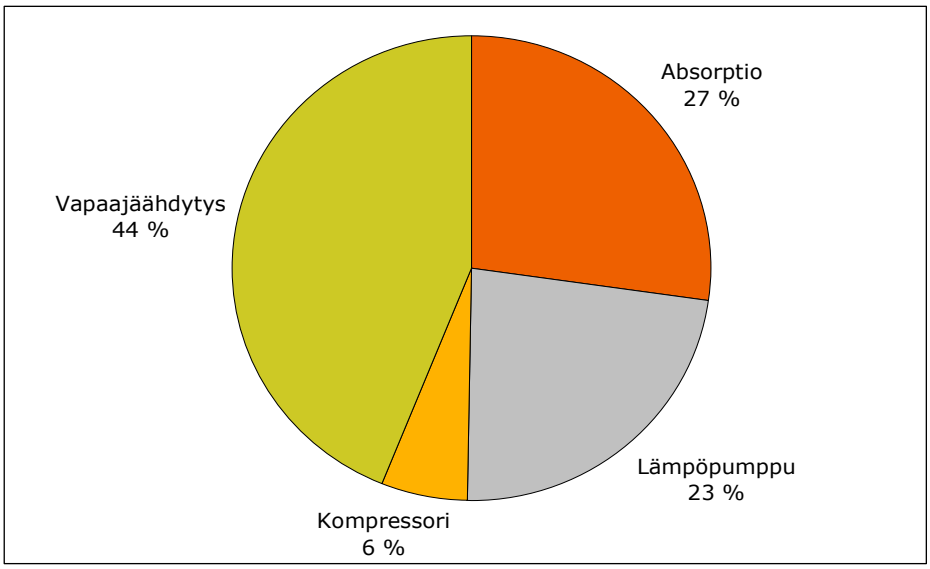


Figure 11-6 Production percentages for production technologies in district cooling in 2010 (cooling by absorption is essentially produced by cogeneration). (Trans: Absorption 27%, Heat pump 23%, Compressor 6%, Free cooling 44%)[145]

[143] ECOHEATCOOL Work package 1. EU Intelligent Energy Europe Programme. 2005-December 2006.
[144] Finish National Reports, (as required under the Cogeneration Directive). 2011.
[145] Finish National Reports, (as required under the Cogeneration Directive). 2011.

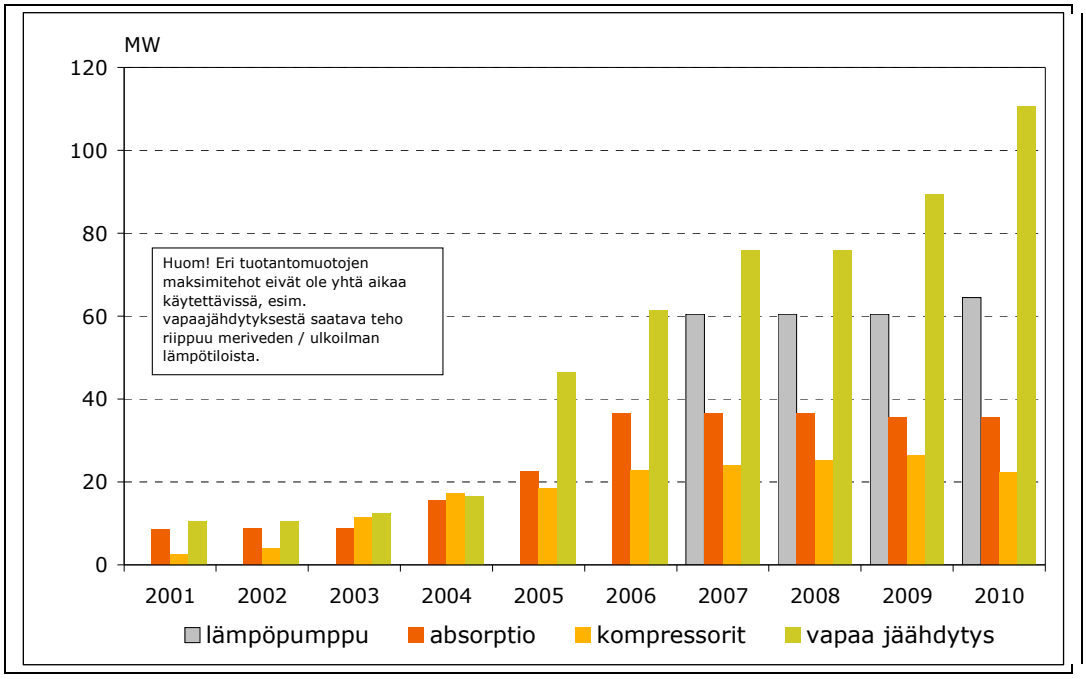


Figure 11-7 Production capacity of district cooling (trans: heat pump, absorption, compressors, free cooling) [146]

Note: The maximum capacities of the different production methods in the table above are not available simultaneously, e.g. the capacity of free cooling depends on the temperature of the sea water / ambient air.

[146] Finish National Reports (as required under the Cogeneration Directive). 2011.

12. BULK HEAT TRANSMISSION TECHNOLOGY

12.1. Some Large District Heating Transmission Pipes – Actual and Notional**Error! Bookmark not defi**
12.2. Aarhus, 130 km interconnected bulk heat transmission pipeline**Error! Bookmark not defined.**
12.3. Bulk Heat Transmission Prague – the longest point to point in Europe**Error! Bookmark not define**
12.4. Costs of bulk heat transmission ..... **Error! Bookmark not defined.**
12.5. Limit of bulk heat transmission distances ..... **Error! Bookmark not defined.**

As noted earlier, heat is normally conveyed by hot water carried in insulated pipes as per below:



Figure 12-1 Bulk transmission pipes being installed – notice thinness of insulation on large pipes. [147]

Intense research and development activities in Denmark and other European countries, have, over time, provided better quality and more cost effective systems. Today, pre-insulated pipes are buried directly in the ground, carried under seawater and fitted without the use of compensators or other stress releasing methods. The service life is calculated to be a minimum 30 years, but it is expected that many pipes will be in service many years after this theoretical limit. Many of the pre-insulated pipes installed in the 60s and 70s still operate satisfactorily.[148]

[147] Danish Board of District Heating http://www.dbDH.dk/artikel.asp?id=463&mid=24
[148] Danish Board of District Heating http://www.dbDH.dk/artikel.asp?id=463&mid=24



Figure 12-2 Installation of transmission pipelines in Central Copenhagen. [149]

12.1. Some Large District Heating Transmission Pipes – Actual and Notional

The table below gives some indications of some large district heating transmission pipes, Actual and Notional, built or considered in Europe.

Table 12-1 Some Large District Heating Transmission Pipes – Actual and Notional

Some Large District Heating Transmission Pipes – Actual And Notional					
Location Linkoping Mjolby	***Length*** 28 km	***Heat capacity*** 25 MW	***Built ?*** Yes	***Diameter***	***Type*** CHP heat*
Lindesberg (A s s i D o m ä n C a r t o n A B, Frövi) Sweden	18 km	25 MW			Wrangensten (2000), p.31). Industrial Waste heat & Biomass

[149] Danish Board of District Heating http://www.dbDH.dk/artikel.asp?id=463&mid=24

Sizewell - London	140 km	2200 MW	Costed Only		CHP heat*
Melnike - Prague	65 km	200 MW	Yes		CHP Heat*
Lulea					CHP from blast furnace gas*
Severo-Mutnovskoe field to the town of Elizovo, Russia	80 km	70 MW	Yes		Mutnovskaya power plant*
Triangle Area Denmark	80 km	300 MW	yes		CHP heat*
Triangle Area Denmark		50 MW			Industrial waste heat*
Triangle Area Denmark		20 MW			Domestic waste heat*
CTR - Copenhagen	54 km	800 MW	Yes		CHP heat*
CTR - Copenhagen[150]	160 km	110 MW			Domestic waste heat*
Aarhus Transmission	130 km	900 MW	Yes	DN200 -> DN 1000	CHP heat*
Aarhus Transmission		70 MW			Waste Incineration CHP*
Torness nuclear to Edinburgh	55 km	2000 MW	Costed - CEGB		Nuclear chp**
Ferrybridge to Sheffield	38 km	250 MW	Costed - CEGB	800 mm	chp**
Oslo	13 km	250-300 MW	under constructio n	700-500 mm	***
Helsinki	20 km	400-580 MW	early 1990'es	1000 mm	CHP***
Turku	25 km	300-380 MW	early 1980'es	800 mm	CHP***
Geertruidenberg / Breda/Tilburg	25 km	170 MW	built 1982	500 mm	CHP***
Diemen / Almere	10 km	170 MW	Ready ultimo 2011	500 mm	CHP***
Sources: * [151] . The length indicates the length of the total transmission grid.					

Fortum[152] applied in February 2009 for a political permission (Decision in Principle) from the Finnish Government to construct a new nuclear power plant unit (Loviisa 3) at its existing

[150] http://www.aarhus.dk/~/media/Subsites/AVA/Om-AVA/Bibliotek/Publikationer/Varme/Varmeplan-Aarhus-2010---engelsk.ashx

[151] Danish District Heating Association. ** = Euroeheat and Power. *** = Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

[152] Cogeneration and On-site Power Production. 01/05/2010. "Carbon-free nuclear district heating for the Helsinki area?"

Loviisa nuclear power plant (NPP) site. The application concerns a nuclear power plant unit ranging from 2800MWth–4600 MWth. The location of the Loviisa NPP site at the southern coast of Finland approximately 75 km east of the Helsinki metropolitan area (i.e. Helsinki, Espoo and Vantaa) with one million inhabitants offers a good opportunity for large-scale district heat generation for the region from the Loviisa 3 unit. This implies that Fortum plans an up to75 km transmission pipeline

In Helsinki, the total installed capacity is around 1150 MWe and 3600 MWth, with the largest base load CHP power plants located in Salmisaari, Hanasaari and Vuosaari. The Vuosaari power plant is connected to the central city area, by an approximately 30 km long tunnel, which is the longest continuous district heating tunnel in Europe.

12.2. Aarhus, 130 km interconnected bulk heat transmission pipeline

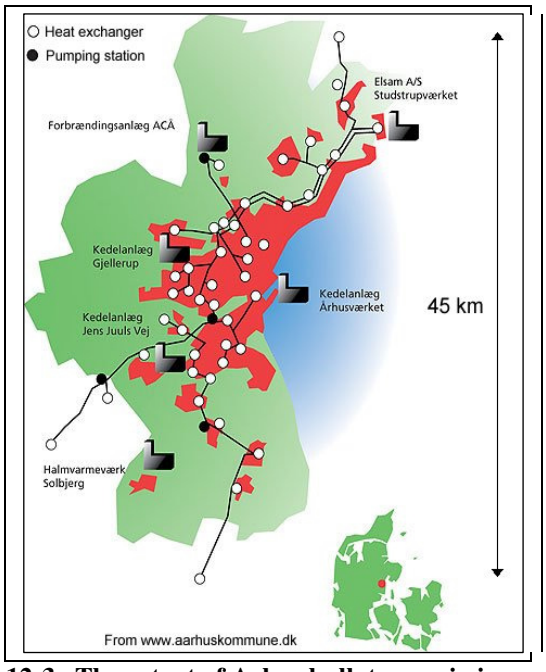


Figure 12-3 The extent of Arhus bulk transmission system[153]

In Aarhus the total grid length is 130 km, however the length from the CHP to the city centre is "only 20 km" and the length from the CHP to the other end is around 45 km, see figure below. 130 km is the total length of all transmission pipes in Århus which are continuously connected (but not distribution).[154] But this is part of a network with a power stations (Studstrupværket) in one end, a waste incinerator (ACÅ) along the line, and decentralised peak boilers. The hypothetical Sizewell example would have with the power station at one end, and the load at the other.
This network was the first in Denmark which in 1981 was approved by the authorities in accordance with the Heat Supply Act and at the same time 2 new CHP units at the power station were approved in accordance with the Electricity Supply Act.

[153] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[154] Claverton Energy Group conference in November 2007, Bath. - Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator

In fact (The longest bulk heat may be the Copenhagen Region, which is more than 160 km) [155]

12.3. Bulk Heat Transmission Prague – the longest point to point in Europe

For a large central heat sources such as a power station, heat will be transmitted in large hot water pipes. These pipes can be up to 1.2 metres in diameter and can extend considerable distances, and be laid in multiples if necessary. One of the longest in Europe is the line from the Melnik power station to the centre of Prague, which is a length of pipe of some 67 km for a direct distance of some 32 km. This transmission pipe is for a large part on the surface. In other cases the transmission has been under large bodies of water.



Figure 12-4 Melnik-Prague heat main (2 x DN 1200). The distance is almost 40 km to the Prague city gate and 64 km to the opposite city gate. It was started in 1996. [156] .

12.4. Costs of bulk heat transmission

Based on work by William Orchard Partners London Ltd., the cost of transmitting a large amount of heat – 2 GW (32,800 TJ for comparison with next tables) using 2 x 2m diameter

[155] http://www.aarhus.dk/~/media/Subsites/AVA/Om-AVA/Bibliotek/Publikationer/Varme/Varmeplan-Aarhus-2010---engelsk.ashx

[156] Prague District Heating System. Application for 1st Global District Energy. Climate Awards. September 2009.
http://www.copenhagenenergysummit.org/applications/Prague,%20Czech%20Rep-District%20Energy%20Climate%20Award.pdf

pipes 140 km is low. Orchard's estimate is about 0.0035 EUR/kWh (0.35 euro cent) for the delivered heat). This is because the carrying capacity of the pipe increases in proportion to the square of the diameter whereas the pipe cost increases only in proportion to the diameter. Heat loss was 35 MW and the pumping losses 50 MW meaning the heat would actually arrive warmer than when it left the power station[157].

[157]"Heat call for evidence" City wide piped heat supply option. Installed costs for pre-insulated piped heat supply systems. Benefits and CO2 footprints for different sources for piped heat compared to insulation measures. Outline evaluation of Nuclear CHP to heat London from Sizewell in line with Energy Paper 35 proposals. April 2008. Orchard Partners.

4 Pipeline from Sizewell to London

An indicative calculation was carried out to look at the economic viability of carrying heat from the Sizewell power plant to London. For this example it was assumed that the plant is rejecting 2100MW of heat and that this heat would be piped to the centre of London, which is 140km (about 80 miles) away.

No preinsulated pipe of this diameter has been made so we obtained figures for piping installed by the water industry and suitable for cold water.

The figures thus may be underestimated however the pipes are lined pipes for raw water that is corrosive and the heating water would not require lined pipes.

We recommend that the cost of such lines is evaluated in greater detail.

Cost per metre of DN2000 pipe [£/km]	£ 7,000,000
distance [km]	140
total cost of pipeline	£ 980,000,000
connected load [kW]	2,200,000
cost per [kW]	£ 445
number of flats that could be connected (assuming 9kW per flat)	244,444
cost per typical flat connected	£ 4,009
number of Edwardian semi-detached houses that could be connected (assuming 24kW per house)	91,667
cost per typicall house connected	£ 10,691
Assumed annual heat supplied (8760h operation as base load supply) [GWh]	19,272
annual capital payment, assuming public sector real rate of returns and a lifetime of 30 years (resulting in a discount factor of 18.39)	53,289,831
Cost of pipeline per GWh delivered	£ 2,765
cost of pipeline per kWh delivered [pence per kWh]	0.28 p

Figure 13: cost of 2m diameter pipeline from Sizewell to central London

The table shows, that the pipeline would cost around £900 million, which would represent a cost of about £400 per kW or between 3 and 9 thousand pounds per dwelling.

Figure 12-5 Extract from submission by Orchard Partners Ltd.to UK Government call for evidence on cost of notional bulk heat transmission pipeline[158].

158 "Heat call for evidence" City wide piped heat supply option. Installed costs for pre-insulated piped heat supply systems. Benefits and CO2 footprints for different sources for piped heat compared to insulation easures. Outline evaluation of Nuclear CHP to heat London from Sizewell in line with Energy Paper 35 proposals. April 2008. Orchard Partners.

In 1984[159] a 38 km pipeline connecting Ferrybridge power station, 2 GWe to Sheffield was costed at around £50 million.

12.5. Limit of bulk heat transmission distances

As noted in the previous paragraph, as pipes get bigger, the fraction of heat lost becomes smaller and smaller. This means that for very large heat quantities can be transmitted very large distances without significant losses. Most of the losses occur in the distribution piping. Conversely, the smaller consumer's demand and the pipes, the larger heat percentage heat losses in pct, and the larger costs per unit. The tables below give an indication of transmission costs.

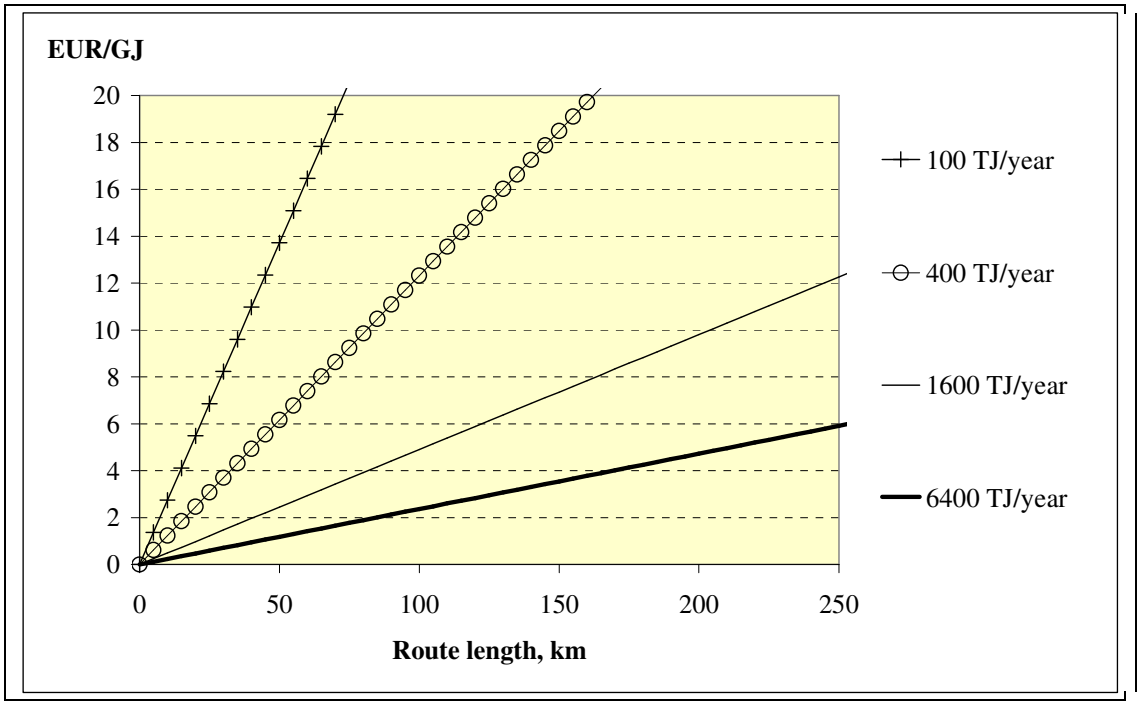


Figure 12-6 Transmission capital costs for four different amounts of heat annually transmitted. Each heat amount is four times higher than the preceding amount. Estimation conditions: 10% annuity, capacity factor of 0.57, temperature difference of 40 ºC, and the Swedish cost level of 2007. [160]

[159] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

[160] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

Table 12-2 Heat loads and transmission costs with comparative UK domestic gas prices estimated based on Figure 12.5 above.

Heat loads and transmission costs with comparative UK domestic gas prices estimated from above:					
Heat Load TJ/y	Average power 100% load factor, MWth	Cost, EUR/GJ for 250km	Cost, EUR/GJ for 70km	UK cost of domestic gas, approx, EUR/kWh	**UK cost of domestic gas, approx, EUR/GJ**
100	3	64	20	6*	**1662***
400	12	30	9		
1600	48	12	3.5		
6400	202	6	1.7		
*** boiler losses increase cost of heat by a factor of about 1.2**					

According to Russian experts at a recent JRC seminar (April 2012) 150 km is a reasonable distance to pipe waste heat.

13. HEAT DISTRIBUTION IN MODERN DH SCHEMES

13.1. Heat Distribution pipes ..... **Error! Bookmark not defined.**
13.2. Heat exchangers ..... **Error! Bookmark not defined.**
13.3. The current situation in Sweden with regard to heat distribution costs **Error! Bookmark not defined**
13.4. Cost of a District Heating network for a major city – Vienna **Error! Bookmark not defined.**
13.5. Heat Metering ..... **Error! Bookmark not defined.**
13.6. Benefits of lower return water temperatures ..... **Error! Bookmark not defined.**
13.7. Legionnaires disease ..... **Error! Bookmark not defined.**
13.8. Heat storage in individual hot water domestic tanks .. **Error! Bookmark not defined.**
13.9. Connection to dwellings – direct or indirect connection **Error! Bookmark not defined.**

Heat distribution is almost always done in modern systems using a network of pre-insulated pipes conveying hot water. In some older systems steam is used but this is not modern practice for a variety of reasons. Whilst steam pipes are more compact than water pipes, they are inherently more dangerous, and more expensive to install as they require special concrete ducts to enable inspection and maintenance, whereas hot water pipes can be buried as other services are which is much cheaper and requires no maintenance.

Furthermore, as we shall see later, the lower the temperature at which heat can be extracted from a power station, the more efficient it is in terms of electricity production and thus the heat is cheaper in fuel cost and has lower carbon content. This means that there is a general trend towards lower water temperatures – in some cases as low as 50°C have been successfully used, although 75°C is probably a more realistic supply temperature for large brand new systems supplying a range of buildings.

13.1. Heat Distribution pipes

Modern designs of DH pipe work and lower distribution temperatures permits installation without the considerable amount of welding in earlier systems, and without the need for anchor blocks and expansion joints.



Figure 13-1 Modern plastic low temperature DH pipe. Laying the pipes in a curve means thermal expansion joints are unnecessary[161]

.

13.2. Heat exchangers

Heat exchangers (large ones are called sub-stations) can occur at various points in a District Heating network[162] – the power station, the sub-stations and at the end users' premises. A heat exchanger is usually a passive device (i.e. no moving parts) for moving heat from one fluid – typically in our case water or steam, to a physically separate fluid, in our case again likely to be water. This is achieved by physically separating the fluids by a thin sheet of thermally conductive material, such as copper alloy

For further info see Annex 3.

[161] Danish District Heating Association

[162] Euroheat provides a guideline on DH substations also including info on heat exchangers:http://www.euroheat.org/Admin/Public/DWSDownload.aspx?File=/Files/Filer/EHP_Guidelines_District_Heating_Substations.pdf

13.3. The current situation in Sweden with regard to heat distribution costs

The table[163] below summarizes the current situation in Sweden. The range is wide, since conditions for district heating can vary:

Table 13-1 Heat distribution costs in Sweden.

	Heat-dense areas		City average heat density		Detached houses	
	EUR/ Annual GJ		**EUR/ Annual GJ**		**EUR/Annual GJ**	
Severe conditions	19		45			
Normal conditions	14		31		75	
New buildings	9		19		36	
Severe conditions means connection of existing buildings in typical narrow streets in downtown areas						
Normal conditions means connection of existing buildings in typical residential areas						
New buildings means situations when the network is built at the same time as the new buildings						
Investment costs for distribution networks in Sweden per GJ / year sold to customers, excl substations. At the cost level of 2007.						

For comparison the power distribution (not transmission) charges in the UK are about 1.3p/kWh.[164]

13.4. Cost of a District Heating network for a major city – Vienna

According to[165] the cost of bringing District Heat to 270,000 dwelling comparable to Vienna is around 1.8 billion Euros, or 6,600 Eur per dwelling. By contrast domestic heat pumps are advertised at around 8,000 Eur per installation.

[163] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

[164] http://www.claverton-energy.com/?dl_name=Bath_Oct_09_Rev1.ppt,. "Typical Power Distribution and Transmission Costs - Summary of these costs by Bernard Quigg Senior Electrical Engineer, UK" Claverton Conference, Wessex Water, Bath, October 2009. Claverton Energy Group.

[165] The potential and costs of district heating networks. A report to the Department of Energy And climate changes April 2009

13.5. Heat Metering

In general it is advisable to charge for heat delivered in some way to optimise the overall operation to the benefit of the supplier and the consumers. This can be achieved by measuring the actual heat quantity which consumers extract from the primary district heating water and heat meters are readily available for this purpose. They comprise a water flow meter to measure the flow rate, and a means of measuring the temperature differential between the inlet and the outlets, which permits the meter to calculate the amount of heat extracted by integrating the two quantities. A variety of information is available on the display. Recorded hourly data is transmitted automatically to the heat supplying company. However these meters are relatively expensive and require connections to both flow and return pipe work.



Figure 13-2 A typical heat meter[166]

In other systems, such as Odense, see Annex 6, the district heating primary water is sold on the same principle as other fuels where the fuel is sold by volume. For example petrol is sold by volume, but it is up to the consumer to maximise the energy extracted from the energy source – heat in the case of DH or km to the litre in the case of petrol. In this case simple water metering is used. This method encourages consumers to extract the maximum heat from the water thereby reducing the volume used.

The method also results in lower pumping costs for the utility and lower return water temperatures with lower heat losses and the potential to extract heat from the CHP with less loss of electrical output (see Section 19.4). Water meters are cheaper, much more reliable and only need one connection instead of two.

In some cases only the flow temperature of the heat is used together with the volume taken. In other cases heat is charged on a basis of a set return temperature to discourage people taking large volumes of water and returning it at a high temperature. There also exist tariff forms encouraging low return temperature.

166 Landis+Gyr GmbH, Humboldtstr. 64, D-90459 Nuremberg,Germany

If one meter is used to measure heat to say a block of flats, then often it is more economical to fit heat usage allocation devices to individual premises – these comprise a device fitted to each radiator which in some way indicates the amount of time the radiator was on and at what sort of temperatures.

13.6. Benefits of lower return water temperatures

Again as noted earlier ensures maximum power station operating efficiency (see Carnot's Law and the Z factor 19.4), minimises pumping losses, and heat losses from the network. Furthermore, installation costs are much lower since less allowance has to be made for expansion, and lifetimes of up to 60 years can be expected. Moreover a number of heat sources will be more efficient, such as geothermal heat, heat pumps, condensing boilers, solar heating plants.

13.7. Legionnaires disease

This is a severe form of pneumonia caused by the inhalation of water droplets communicated with the bacteria which can thrive in hot water tanks and shower heads etc. Regulations require all stored hot water to be heated to about 60°C at least once per day. There are various patented methods of raising the temperature to this temperature, by a clever arrangement of counter flow heat exchangers and a small amount of electrical "sweetening" which adequately deals with this problem even with very low supply temperatures.

13.8. Heat storage in individual hot water domestic tanks

In a similar way to large heat storage in the previous paragraph, heat storage can also usefully be applied to the internals of domestic premises. This comprises a hot water tank and with some sort of remote control so that the charging of the tank can be manipulated to suit the power station operator as far as possible. The advantages are similar to the above for the heat accumulators, but also to give the consumer security of domestic hot water supplies if there is an interruption in the main service for maintenance.

Electrical back up heating can be readily applied to domestic hot water stores with typically a single phase heater of around 3kW capacity. Where instantaneous plate heat exchangers are used for domestic hot water supplies instead of such storage tank, they have the advantage they do not take up as much space as a hot water store. However they may well require a peak capacity of supply of 30kW which dictates the pipe size to the house as the hot water load is often greater than the heat load.

13.9. Connection to dwellings – direct or indirect connection

Local connections are made to houses and these may be a pipe of 25 mm in diameter with 50 mm of insulation, depending on the connected heat load and DH temperature. Customers can be connected to the primary network using two main connection methods - direct connection or indirect connection.

With indirect connection a heat exchanger provides a hydraulic separation between customer's heating circuit and district heating network. This has the disadvantage of some loss of temperature, extra cost, and extra pumping costs. In certain cases, typically in areas without significant hills and where the DH system has low design temperature (less than

90°C) direct connection of the house to the main can be implemented. This has the advantage of enabling the lowest temperatures to be used for heat extraction from the power station turbine and this gives the most efficient power station performance (i.e. there is less loss of electrical output for each unit of heat taken, (see Carnot's Law and the Z factor).

Furthermore, the cost of any heat exchangers is minimised. Typically a temperature limiting valve is fitted, which only lets the water leave the house for return to the power station if it has been cooled to a certain minimum level. This again minimises pumping losses and maximises the efficiency of the power station. A pressure reducing valve is used on each consumer to prevent over pressurising final user's systems. Due to the higher risk of damages and leakages in pipes and radiators inside the house directly connected systems are recommended to have some kind of leakage alarm system.
(There are patented systems which claim to enable direct connection even in topographically challenging areas)
Clearly direct connections have many advantages since it does not require the cost of the heat exchangers and permits more efficient CHP operation in terms of power generation.

A leading Danish expert has this to say about Odense:

> "Fjernvarme Fyn, previously Odense district heating, is supplied from Fynsværket CHP plus waste to energy CHP and a straw CHP unit. Fjernvarme Fyn has 60.000 consumers, almost 2.000 km network and branch lines from 6 to 25 bar but no heat exchangers. Instead they have pressure control and pressure vessels to secure the pressure maintenance in the system and prevent water hammering.
>
> The return temperature from the district heating consumers are now around 40 dgr.C which is normal in a modern district heating in which the consumers have got price incentives to reduce it for some time, but still they of course encourage consumers to operate their installations more efficient.
>
> Yours sincerely
> Anders Dyrelund
>
> M.Sc.(Civ.eng.),B.Com.
> Market Manager for Energy
> Energy Supply and Planning

(See also Guidelines for District Heating Substations[167])

More complete details of these schemes from the company's point of view are contained in Annex 6.

[167] Euroheat provides a guideline on DH substations also including info on heat exchangers:http://www.euroheat.org/Admin/Public/DWSDownload.aspx?File=/Files/Filer/EHP_Guidelines_District_Heating_Substations.pdf

14. LOAD PROFILES AND SIZING OF CHP PLANTS, SIZE OF SCHEMES

14.1. Typical load profile for a DH scheme – Vienna ..... **Error! Bookmark not defined.**
14.2. Typical load profile for a DH scheme – Denmark..... **Error! Bookmark not defined.**
14.3. Sizing of CHP heat sources and boiler power ..... **Error! Bookmark not defined.**
14.4. Conversion cost planning guidelines from one Danish heat transmission operator **Error! Bookmark**
14.5. Minimum heat load densities – Denmark ..... **Error! Bookmark not defined.**
14.6. Professor Sven Werner on the inappropriateness of measuring heat load in terms of Energy density per km^2 compared to per linear km. .. **Error! Bookmark not defined.**
14.7. Very small schemes ..... **Error! Bookmark not defined.**

14.1. Typical load profile for a DH scheme – Vienna

The heat load on a District Heating scheme in Europe typically peaks in winter with a summer minimum. In northern countries the peak winter load tends to be proportionally higher, though not as high as might be expected since the houses tend to be better insulated than the more southerly housing stock. Vienna is typical of the shape, shown below. This is energy delivered, i.e. GWh, not peak heat demand. Note the inverted temperature scale:

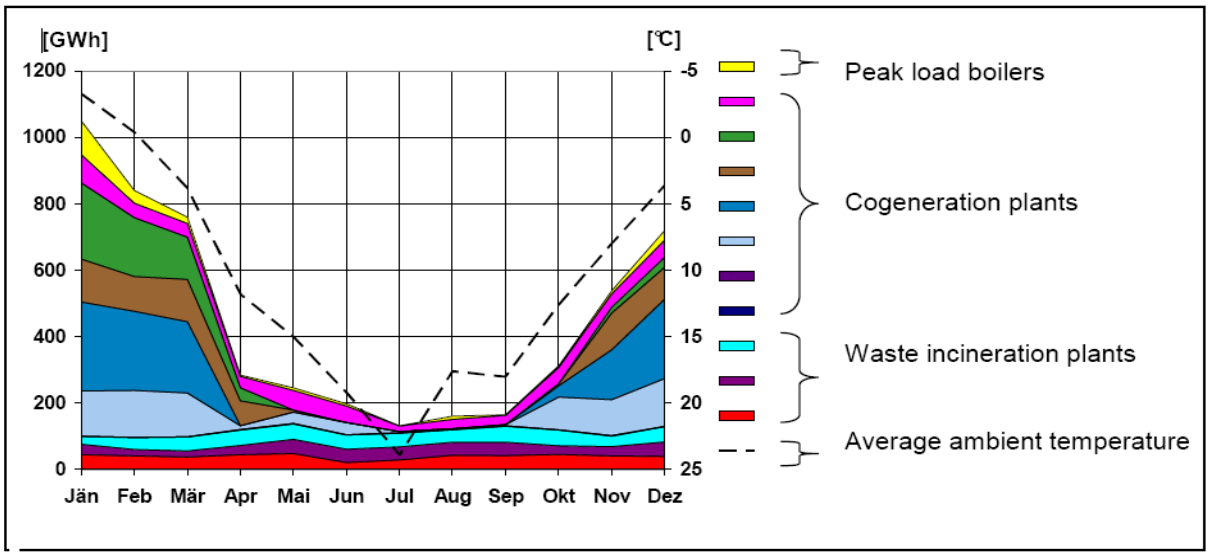


Figure 14-1 Thermal energy production of Vienna's district heating supplier - year 2006[168].

14.2. Typical load profile for a DH scheme – Denmark

The curve below is for a notional scheme with annual heat production of 10,000 MWh used by DH designers. The curve shows the heat production in kW to the network hour by hour including a typical daily load variation for a typical year. In order to take into account the annual fluctuations and that we may expect a very cold period and the coldest design situation e.g. every 10 years, there is included a short cold peak period. Such curves are used by designers of District Heating schemes.

[168] Meeting cooling demands in SUMMER by applying HEAT from cogeneration.Technology Report eliverable 2.3. Austria. Österreichische Energieagentur. Austrian Energy Agency. Robert Krawinkler, Günter Simader,23.07.2007

These charts and description have kindly been provided by Anders Dyrelund [169]

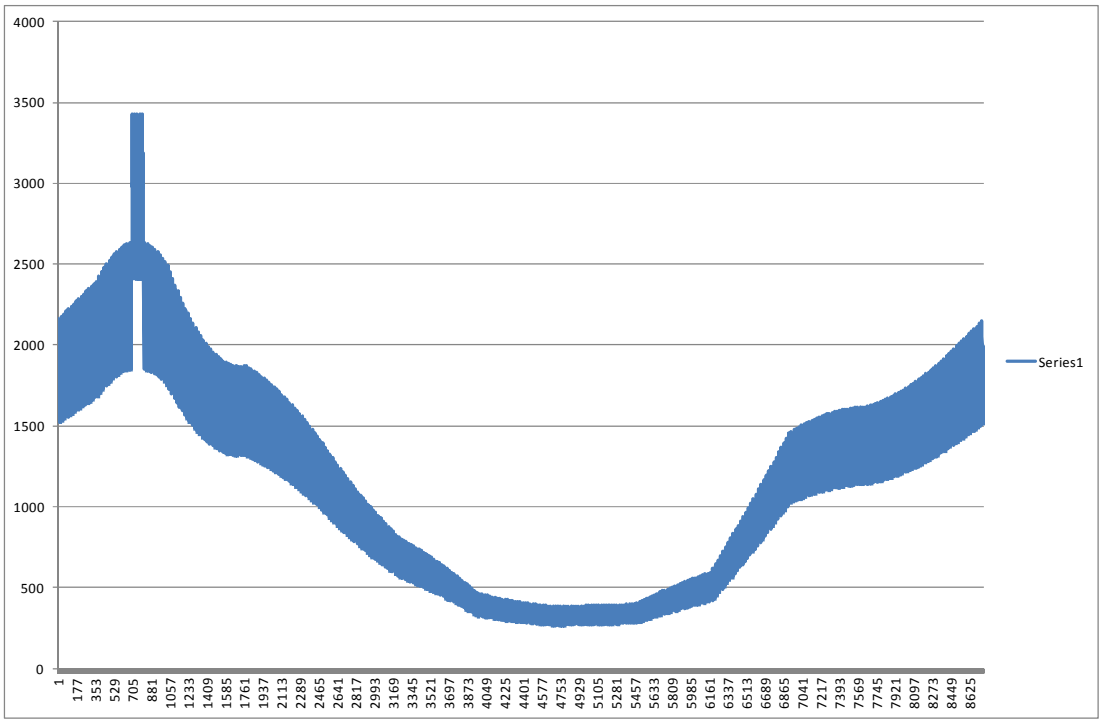


Figure 14-2 Standard heat duration curve for a large district heating system in Denmark, kW on x-axis[170].

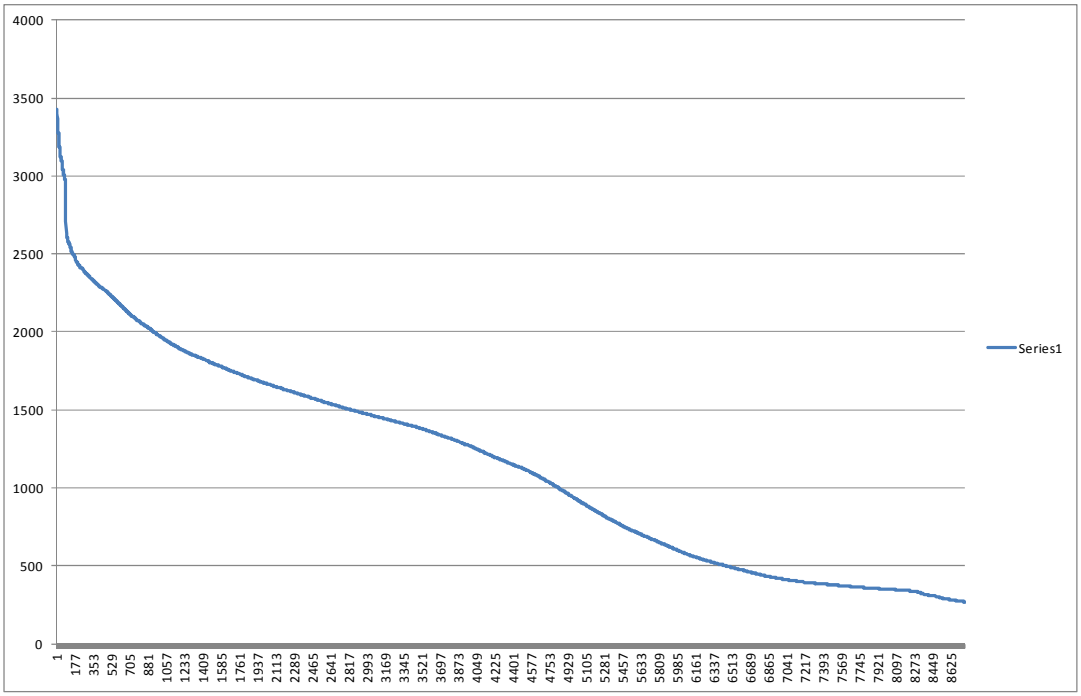


Figure 14-3 standard heat duration curve for a large district heating system in Denmark, kW on X - axis[171]

[169] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[170] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark
[171] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

The above is the duration curve for typical large DH system in total at the exit of the production plants (therefore including hot tap water and network losses) and with the hourly load sorted according to capacity. The total daily variations are typically from 0,78 to 1,28 of daily average, as some consumers have night set back. This curve is useful for heat planning of base load, medium load and peak load plants and for main transmission networks.

The figure above shows the data for figure 14.2 sorted by hours. This curve is suitable for the heat planning to get an overview of a system with an annual production of 10,000 MWh.

- the peak load of 5.5 MW
- the necessary base load (e.g. a base load of 2 MW can produce around 97% of the annual production corresponding to around 5.000 max load hours.
- the summer load of 300-500 kW
- any combination of production units including break down

The curve can be transformed to the actual heat market for a network and its base load plants. It is to be noticed that the shape of the curve is determined mainly by the climate and is thus almost invariant from year to year. The variation is primarily in the Y direction. With the shape given, there is a unique relation between the annual heat consumption (the area below the curve) and the maximum peak load power required.

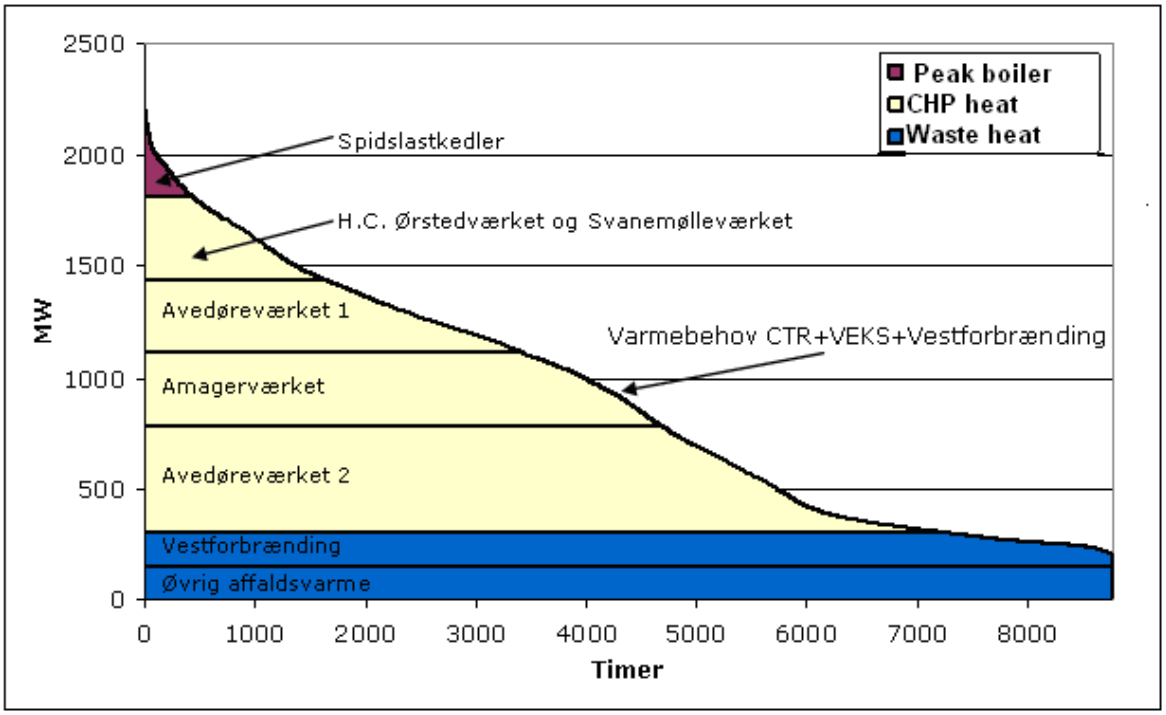


Figure 14-4 Total heat production to the integrated district heating system in Copenhagen region[172].

The curve in above illustrates the total heat production to the integrated district heating system in the Copenhagen Region. (Notice, the scale on the Y-axis is very different from the previous figure.)

- waste to energy (blue)

[172] Anders Dyrelund, Market Manager. Rambøll (consultants).Denmark

- CHP units (yellow)
- Peak boilers (red)

14.3. Sizing of CHP heat sources and boiler power

Where power station waste heat is used in a CHP-DH scheme, then detailed design of course is carried out. However in general it turns out that the CHP maximum heat output – (in MWth / GWth) is made equal to half the peak demand for heat on the network (ie that which will occur once a year on the coldest winter days). Experience has shown that then the CHP unit will provide 90% - 97% of the heat delivered – GWh / MWh over a typical year. (See previous section and load duration curves in the previous section). It is uneconomical to provide expensive CHP heat capacity to meet 100% of the peak heat load, since such a large and comparatively expensive capacity would only operate at maximum output for possibly a few hours per year. So cheaper capital cost heat-only boilers provide the peak heat demand, albeit at a higher cost per unit of heat sent out.

The peak heating boilers also provide the back up heat supply should the power station become unavailable due to maintenance or breakdown of the pipes.

The use of heat accumulator storage can also increase the proportion of heat supplied from the CHP.

According to the Poyry report[173] the cost of providing a District heating network to a city like Vienna would be around 1.8 Billion Euros for 270,000 dwellings, or 6,600 Eur per dwelling.. Wien Energie (the district heating operator for Vienna) sold 5605 GWh of heat to their clients between 1st of October 2009 and 30th of September 2010. They are supplying 305.557 private dwellings and 6012 big companies, i.e. €5,900 per dwelling. Amortised over a 60 year life, the cost is quite low compared to the cost of heat from boilers. The market share in Vienna is 35%. The network has a length of 1120 kilometres (542.4 primary – i.e. large pipes and 575.8 secondary i.e. smaller pipes) and overall losses are around 9.2%.

According to a European study[174] published in March 2011 in Applied Energy it was estimated that the average investment cost of €30 per GJ of annual heat demand would be capable of reaching a DH market share of 60% in 83 cities in France, Germany, Belgium and the Netherlands. It will be 24 EUR/GJ in more heat-dense areas and €32-35 /GJ. - in medium heat dense-areas. Where district heat is less feasible in areas with one-family houses, the average investment cost is about €90 /GJ, although it should be noted that Denmark has connected most of its one-family houses

14.4. Conversion cost planning guidelines from one Danish heat transmission operator

These are the prices on which VEKS, one of the companies involved in DH around Copenhagen, bases projects concerning conversion from natural gas to DH.

- Large customers or easy access (unpaved or similar): €73.000/TJ sold per year.

[173] The potential and costs of district heating networks. A report to the Department of Energy And climate changes April 2009

[174] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden (not published at the time of writing, but information supplied by the author)

- Medium size customers or somewhat more difficult terrain/access: €86.000/TJ sold per year.
- Small customers and pipes mainly positioned under paved areas: €99.000/TJ sold per year.
- Individual houses (common to connect to DH in Denmark) €185.500/TJ sold per year.
- In an area planned to convert from natural gas to DH (starting with larger customers) the relation for the whole project is €109.000/TJ sold per year.
- These prices include all DH-pipes, including building supply pipes, removal of boilers and installation of heat exchangers. [175]

VEKS noted that costs in smaller cities could be lower than this.

14.5. Minimum heat load densities – Denmark

Heat load densities are often discussed in terms of MW/km^2. However this is little used by the Danes, because both energy density and number of consumers (and connections) influences construction costs. In Broendby the District Heating Company has achieved good economics with 10 MW/ km^2[176].

Danish studies indicate that even for very low heat density district heat may be economically preferable to individual boiler schemes as this extract indicates[177]:

"……It is very expensive to insulate a house, so it will comply with the specifications of Low Energy House Class & 2 (LE1 & LE2). In general it costs about 10-15% extra to build a LE2 house compared to an ordinary BR08 house, and extra 10-15% to build a LE1 house compared to a LE1 house, and it is much more expensive to insulate existing buildings. If the criteria for including low resource district heating, which is developed in phase 1 is accepted in a new Danish Building Regulation, then it is probably better (socioeconomically) even for new buildings to spend some of the "insulation money" on low resource district heating.." [178]

The screen shot below shows the eastern side of Braestrup, (which the above report covers) Denmark, from Google Streetview. Most of urban Europe is more densely built-up than these detached houses.

[175] Jens Brandt Sørensen Projektudvikling VEKS Roskildevej 175, 2620 Albertslund
T 43 66 03 66 D 43 66 03 50 www.veks.dk

[176] Pers. Com. Jens Brandt Sørensen, Projektudvikling, VEKS, Roskildevej 175, 2620 Albertslund

[177] http://www.braedstrup-fjernvarme.dk/files/files/Low%20Resource%20District%20Heating.pdf Low Resource District Heating.

[178] http://www.braedstrup-fjernvarme.dk/files/files/Low%20Resource%20District%20Heating.pdf Low Resource District Heating.



Figure 14-5 The eastern side of Braestrup, (which the above report concerns) Denmark, from Google Streetview. Most of the UK and urban Europe is more densely built-up than these detached houses[179].

14.6. Professor Sven Werner on the inappropriateness of measuring heat load in terms of Energy density per km^2 compared to per linear km.

Professor Sven Werner[180] agrees with the inappropriateness of measuring heat load in terms of Energy density per km^2, and points out that this has been known in the district heating community for a long time. He says it is mentioned in every text book about district heating (but written in Russian, Danish, Finnish, Swedish, German, and Polish). "The Danish threshold of 0.3 MWh/m is very low from a European perspective, according to the Professor Robert Lowe remarks (quoted in 4.23). A plot ratio of 0.3 corresponds to a linear heat density of 2.5 MWh/m, giving a preference to areas where district heating is directly feasible. With respect to national and local conditions, you can find areas below 2.5 MWh/m that are suitable for district heating. The current Swedish average linear heat density is actually 2.5 MWh/m, since very many low heat demand areas are connected. But a European expansion of district heating should start in the heat dense areas, not in the low heat density areas. I am convinced that this indicative threshold will be lower in the future, when fossil alternatives are not available for heating buildings." The Danes [181] have reportedly lowered their threshold to 150 kWh/m/yr.

14.7. Very small schemes

As heat densities drop, e.g. in suburbs, or begins to consider quite dispersed groups of houses, the situation changes. First there is possibly no need for the cost of a long heat main for bulk transmission, or this might already have been paid for as part of the cost of connecting the city centre. Secondly, there may be no need for secondary distribution mains. Thirdly, the cost of digging and burying pipes is much lower due to the general greater ease of excavating in less crowded streets. Finally, pipes do not always have to go in roads and can be installed in front gardens or under pavements or grass verges which again keeps piping costs down by not having to engage in the expense of road breaking and reinstatement. These

[179] Google Streetview
[180] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden
[181] David Olivier, UK Energy Expert, Energy Advisory Associates

smaller schemes can readily be heated by a biomass boiler and a large scale solar heating plant or it could be a combination of a gas boiler for peaking and standby, and a gas engine CHP which are readily available.[182,183] So it is possible that these small low density housing can be heated by CHP-DH. What this may mean is that as time progresses, such schemes can be gradually connected together via the secondary mains, and ultimately connected to a large central power station.

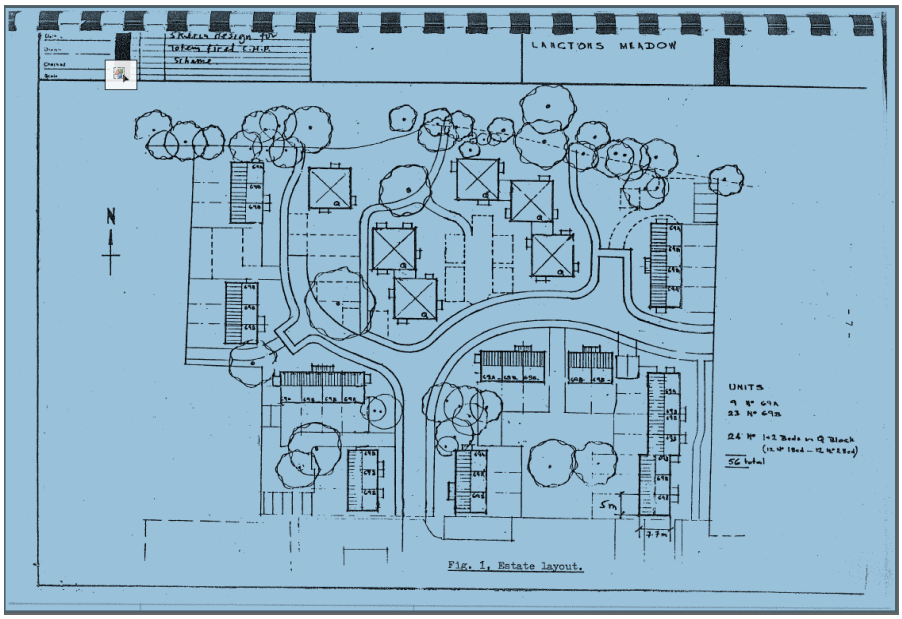


Figure 14-6 Various studies have shown that CHP-DH can be economic in small groups of houses even as low as 50 modern detached dwellings, based on modern gas engine CHP[184]

Many of the 600 DH systems in Denmark in the image below have as few as only 100 dwellings attached. Denmark has a population of five million.

[182] ERG 036. A D.C.F. . analysis of a totem based district heating scheme. DC Andrews, RJ Lowe. Open university Energy Research Group, Milton Keynes U.K. August 1981.
[183] ERG 056 An Introduction to domestic micro-chp R.Everett and D.C. Andrews. Open university Energy Research Group, Milton Keynes U.K. September 1986
[184] ERG 036. A D.C.F. analysis of a totem based district heating scheme. DC Andrews, RJ Lowe. Open university Energy Research Group, Milton Keynes U.K. August 1981.

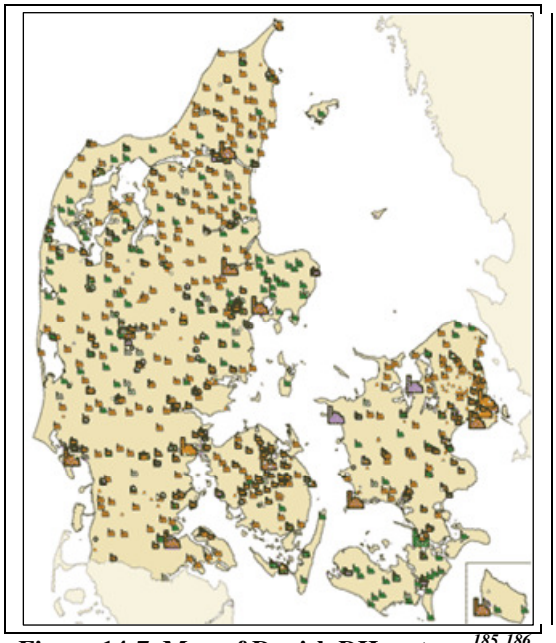


Figure 14-7 Map of Danish DH systems[185], [186].

[185] Source: Danish Board of District Heating, www.dbDH.dk.

[186] Less Is More, Unpublished as yet from the Sustainable Buildings Association, 2011, David Olivier.

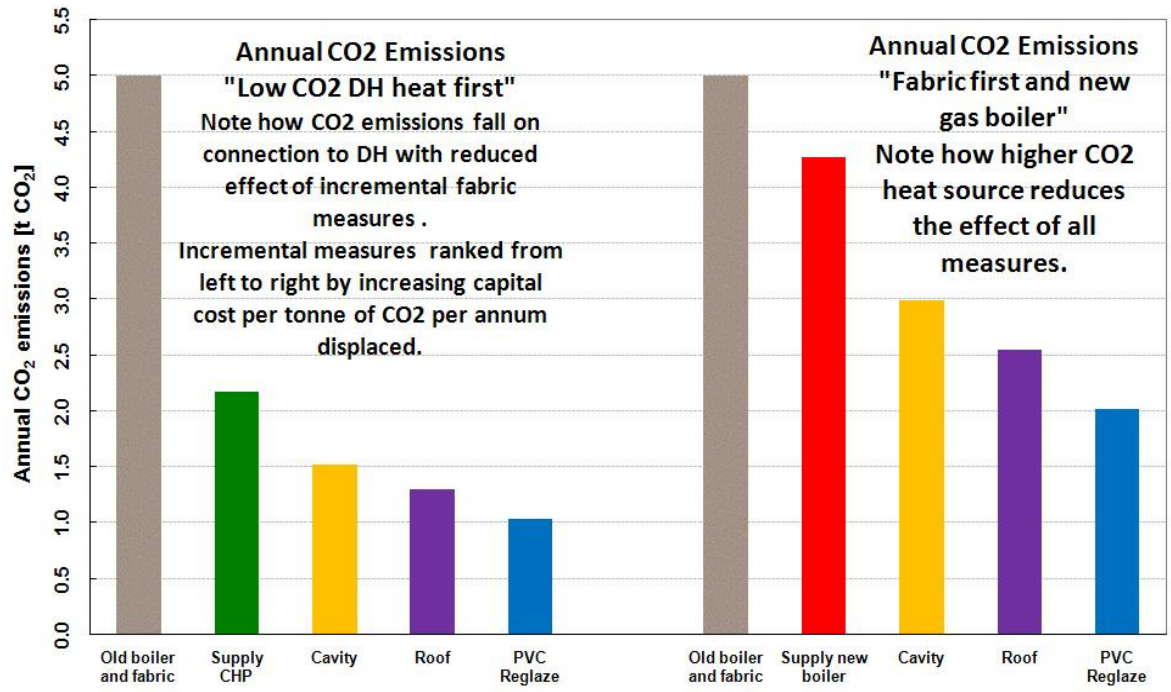
15. INSULATION AND ENERGY CONSERVATION COMPARED TO CHP-DH

There is a potential dilemma with regard to heat from CHP with a low marginal cost but high capital costs and demand side measures such as insulation. It is commonly supposed that capital investment in insulation should proceed first, and that insulation will diminish the attractiveness of CHP-DH. However this is not necessarily correct. This is because one needs to be aware that the case for insulation will be different for a house heated with high CO_2 heat from a boiler or electricity and a house heated with low CO_2 heat from CHP-DH. Also retrofitting of insulation to high enough levels to materially reduce heat consumption can be very expensive.

Some detailed studies show that capital investment in low CO_2 DH is more cost effective in cutting carbon than retro-fitting insulation to existing houses, which of course form the vast stock of the European housing estate and this estate only turns over in about 100 years.

For example, the figures below shows that extending an existing CHP-DH is a superior investment compared to putting in new and better gas boilers and upgrading insulation beyond a certain point. It states: "Evaluation of the lower CO_2 content of heat from district heating shows that investment in the district heating connection is a better investment than the insulation.[187]

The figure below show that supplying CHP, bars on the left chart, gives a lower CO_2 footprint than all the measures listed in the chart on the right, and at a lower capex per tonne of CO_2 abated.



[187]Technology Strategy Board Retrofit for Future a study to minimise CO2 emissions for typical UK housing. William R H Orchard MA(Oxon) MBA CEng FIMechE MCIBSE MIET FEI Managing Director Orchard Partners London Ltd 9 Lansdowne Close London SW20 8AS. email william@orchardpartners.co.uk
Tel +44(0)20-8296-8745 Fax +44(0)20-7060-3345 http://www.orchardpartners.co.uk/

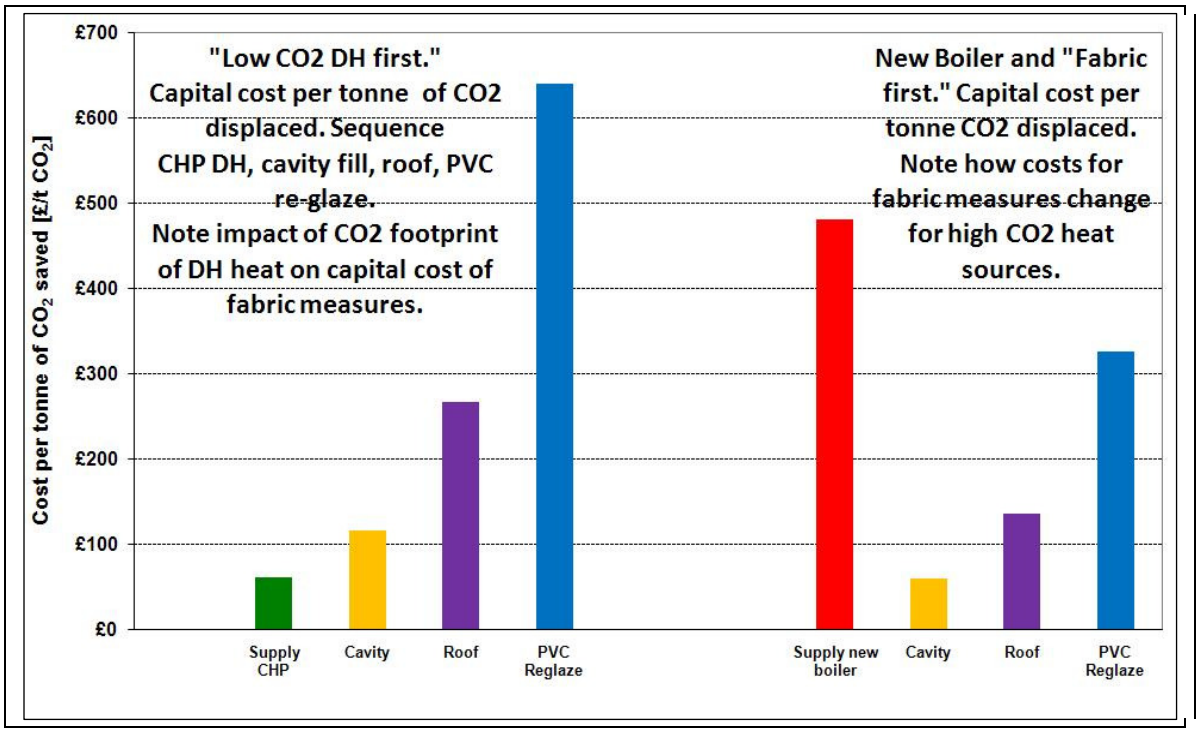


Figure 15-1 Comparison of cost and effectiveness of CHP-DH with "normal" energy conservation measures[188]

[188]Technology Strategy Board Retrofit for Future a study to minimise CO2 emissions for typical UK housing. William R H Orchard MA(Oxon) MBA CEng FIMechE MCIBSE MIET FEI Managing Director Orchard Partners London Ltd 9 Lansdowne Close London SW20 8AS. email william@orchardpartners.co.uk Tel +44(0)20-8296-8745 Fax +44(0)20-7060-3345 http://www.orchardpartners.co.uk/

16. BEST PRACTICE FOR DISTRICT HEATING

It is very difficult to identify the key factors which should represent the best practice for DH all over Europe in this kind of document, because many considerations are locally driven. Recourse should be made to leading experienced designers, which will generally be from countries such as Denmark (with a history of efficient DH systems even in one-family house districts), Germany, Sweden and Finland. Nevertheless, certain key points to be considered for district heating best practice would be:

- Lowest possible supply and return temperatures to minimise efficiency penalty at power station, ie maximise the Z-factor, minimise heat and pumping power losses, and maximise life of pipe system. This is dealt with in more detail in 19.4
- Pressure limiters if direct connection to building heating internals is provided
- Return temperature limiters to ensure maximum removal of heat from water and to provide lowest return temperatures
- Water metering rather than heat metering may be considered – this encourage users to extract the maximum amount of heat, which means the return water temperature is as low as possible which minimises pumping costs and maximises power station efficiency. This is achieved by fitting return water temperature limiters for example.
- Always some form of equitable allocation of heat usage
- Fully controllable system, so that owner occupiers or tenants may set temperatures as needed– these last points are essential to avoid a common situation with some unmetered, uncontrolled legacy systems where tenants are forced to simply open or close windows to provide temperature control which is extremely wasteful of energy
- A domestic hot water storage tank may be considered for individual users, as this limits the size of any heat exchanger, provides a means to manipulate and smooth heat load, and gives users a back up in case of interruption of heat supply (via electric immersion heater)). But note the Lystrup scheme stores the DH water and has a heat exchanger for DHW on the consumer's side, to safely operate at only 52 °C.
- Heat accumulators should be provided as appropriate
- For directly connected systems a water leakage detector

A view from an experienced Danish engineering company is "Best Practice in Danish district Heating"[189] The following documents also gives a good insight into Danish best practice at both a technical and an administrative level.[190,191,192]
Annex 6 describes the Odense system which is widely regarded as a benchmark of good practice and incorporates most of the points mentioned above.

[189] "Best practice in Danish district heating" News from DBDH 3/1999
[190] Seminar on Smart Cities, September 28th 2011, SMART ENERGY CITIES - DISTRICT ENERGY IN THE COPENHAGEN REGION
[191] Smart Energy Cities Seminar in DG17 28.09.2011 Anders Dyrelund, market manager energy Rambøll Denmark
[192] Global District Energy Climate Awards – Copenhagen DH – Application 2009, Application for the 'Global District Energy Climate Award' Copenhagen District Heating System Operated by Copenhagen Energy Ltd.

17. TOTAL SYSTEM COST ASSESSMENT OF HEATING AND COOLING SUPPLIED FROM CONVERTING EXISTING THERMAL STATIONS TO CHP

17.1. Method – Economic Analysis ..... **Error! Bookmark not defined.**
17.1.1. Economic Analysis ..... **Error! Bookmark not defined.**
17.1.2. Primary Energy ..... **Error! Bookmark not defined.**
17.2. Case Studies on Barcelona, Cologne and Liverpool .. **Error! Bookmark not defined.**
17.2.1. Power Plants ..... **Error! Bookmark not defined.**
17.2.2. District heating and cooling grid ..... **Error! Bookmark not defined.**
17.2.3. Demand ..... **Error! Bookmark not defined.**
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17.3.1. Liverpool ..... **Error! Bookmark not defined.**
17.3.2. Cologne ..... **Error! Bookmark not defined.**
17.3.3. Barcelona ..... **Error! Bookmark not defined.**
17.4. Conclusions ..... **Error! Bookmark not defined.**

In the financial assessment the total annualised cost for providing heat and cooling to three cities representing northern, central and southern European climate conditions have been studied. The conditions of today are reflected in a Base Case, which is compared to three alternative scenarios where the existing thermal power plant is converted into a combined heat and power (CHP) station. The heat from the CHP is used to supply heat (and for some cases space cooling) and thereby replace existing individual heating and cooling appliances.

The three cities representing northern, central, and southern European climate conditions were Barcelona, Cologne, and Liverpool. Single-family houses were assumed, as a means of generating the heat load profile. Proxies for cost data of individual heating and cooling systems for the actual house types in each city were used.

The aim of the study is to analyse the possible benefits from converting existing thermal power plants into CHP with associated District Heating and Cooling (CHP-DHC) infrastructure. This is done by performing a financial analysis to estimate the annual change in total system cost when supplying heat and cooling from a cogeneration plant instead of supplying these by individual heaters, air-conditioning units, and a pure power production plant. The income from sold electricity is taken into account in the analyses. For comparison purposes studies on constructing new CHP stations were also performed.

In Section 17.1 the method is described, 17.2 the different cases are presented and the main assumptions described. Section 17.3 presents the results from the study. Finally, Section 17.4 gives the conclusions.

17.1. Method – Economic Analysis

The boundary of the study is the power station and the energy needed to supply a specified number of houses with warm water, space heating and space cooling. The number of houses is unique for each city based on how many houses that could be heated by the existing power plant if it was a converted into a CHP. The base case includes the cost and revenues of the power station and the cost of heating and cooling the buildings using the present individual

gas and electric appliances. This includes capital cost, refurbishment costs and operational maintenance costs etc. as well as the gains from electricity generation. In the CHP cases the power plant is converted into a CHP and the houses switch to district heating and for some cases district cooling. This includes conversion costs and some changes in technical parameter for the power plant, investment in infrastructure (district heating/cooling) as well as conversion costs for the households. By also including a two-day heat accumulator, we can assume that the electricity generated can be sold on the spot market at optimal times in line to how the existing plant are assumed to be operating. Typical hourly spot prices are built into the model, more operative hours per month results in lower income per sold MWh electricity.

In the present study we compare the annual system costs between the specified cases as well as the net electricity, CO_2 emissions and Primary Energy. The net electricity is the difference between electricity purchased for heating and cooling by the households minus the electricity generated from the power plant. Net CO_2 missions are calculated directly from the net Primary energy for each of the case. The estimation of primary energy demand is described in Section 1.1.2.

17.1.1. Economic Analysis

For each case, the annual cost of the analysed energy system is calculated using Equation (1). Each component in the equation is described below.

$$\text{Annual Costs} = C_{Capital} + C_{OMFixed} + C_{OMVariable} + C_{Fuel} - R_{Elc} \qquad \text{(Equation 1)}$$

Where:

$C_{Capital}$: Total annualized capital costs.
$C_{OMFixed}$: Total annual fixed operation and maintenance costs.
$C_{OMVariable}$: Total annual variable operation and maintenance costs.
C_{Fuel}: Total annual fuel costs.
R_{Elc}: Total annual revenues from electricity sold

CCapital : Total annual Capital Costs
The total annualised capital costs (ie the net present value of the sum of the annual cost that occurs for each year of the investment) for each technology (plant, equipment, grid etc) are calculated using Equations (2) and (3).

$$C_{Capital} = \sum_{t=1toT} I_t * a_t \qquad \text{(Equation 2)}$$

$$a_t = \frac{d * (1+d)^{z_t}}{(1+d)^{z_t} - 1} \qquad \text{(Equation 3)}$$

Where:
I_t One time Investment cost for technology t (plant, equipment or grid)
a_t: Annuity factor for technology t
d: Discount rate
z_t: Life time

Because district heating is an infra-structural investment, a so-called social discount rate has been chosen. Social discount rates are used in projects with a broad impact and which are beneficial for society. Thus we have chosen a discount rate of 3.5 %/yr in line with recommendations for non-Cohesion countries by the EC DG Regio[193]. (DG Regio suggests a social discount rate of 5.5% for the Cohesion countries). The result from using higher discount rates is tested in a sensitivity analysis, using discount rates of 5.5 and 7.5 respectively. Using different discount rates for different actors will not be explored in the present study.

The lifetime is the technical life time of the technology. In the present study we assume that the large scale technologies will be continuously maintained and refurbished. This is reflected by the relatively higher annual maintenance costs; see below under component "Total annual fixed operation and maintenance costs".

COMFixed : Total annual Fixed Operation and Maintenance Costs
Most power plants are continually being refurbished. We have assumed that this is the case by adding a refurbishing cost to the yearly Fixed Operation and Maintenance (FOM) costs. FOM without refurbishing would be only 2% of the investment cost; to consider the refurbishment an additional 2% is added. The refurbishing is assumed to extend the life time of equipments, and maintain but not increase their efficiency (for this an additional 2% of FOM would be needed).

COMVariable: Total annual Variable Operation and Maintenance Costs
In addition to the FOM we have assumed a Variable Operation and Maintenance (VOM) cost proportional to the generated electricity.

CFuel: Total annual Fuel costs
We use different fuel prices for households and industrial sectors. The main source is the Europe's Energy Portal[194], using prices offered to households by country for households, while the energy utility is assumed to buy fuel at industrial prices applicable for large consumers.

RElc: Total annual Revenues from electricity sold

Electricity is assumed to be sold on an electricity spot market based on statistics from the respective national spot market (OMEL, EPEX). The assumptions are presented in Table 17-1.

[193] European Commission (EC), 2008, Guide to Cost Benefit Analysis of Investment Projects,

[194] Europe's Energy Portal, available at: http://www.energy.eu

Table 17-1. Electricity spot prices in the studied cities. In Barcelona the prices are arithmetic averages of 2001-2010, source: OMEL. In Cologne quarterly average from 2005-2010 are used, source: EPEX Liverpool is monthly averages from 2004-2010. All units are in Euro/MWh, source: personal communications.

Month	Barcelona	Cologne	Liverpool
APR	43.8	46.0	53.0
AUG	40.0	46.0	49.3
DEC	35.7	46.0	50.6
FEB	35.5	42.0	46.4
JAN	37.1	42.0	46.5
JUL	42.1	42.0	51.0
JUN	44.4	47.0	56.4
MAR	40.4	47.0	49.7
MAY	44.5	47.0	55.9
NOV	41.9	53.0	57.0
OCT	40.1	53.0	64.1
SEP	42.1	53.0	60.3

17.1.2. Primary Energy

In addition to yearly use of coal and gas by the power plant and the households, the primary energy demand includes the primary energy from the net electricity of the studied system.

Yearly primary energy from the electricity is estimated based on average European efficiencies assumptions of different power sources and an assumed grid loss of 9% applied on each countries electricity mix Table 17-2. The electricity mix, presented in Table 17-2 is based on Eurostat statistic. Calculated primary energy conversion factors and the assumed efficiencies are presented in Table 16. The total CO_2 emissions are for each case calculated per energy carrier multiplying the net primary with the emission factor. Emission factors used is presented in Table 17-3.

Table 17-2. Present electricity mix of studied cities, Source: Eurostat.

	Barcelona, %	Bonn, %	Liverpool, %
Biomass	1.0	1.9	2.0
Hard coal	28.3	0.0	33.3
Lignite	0.0	48.3	0.0
Natural gas	20.3	11.5	40.3
Hydropower	11.3	3.5	1.2
Oil	8.5	1.7	1.2
Nuclear	22.7	27.5	20.2
Wind	5.6	4.2	0.5
Photovoltaic	0.0	0.1	0.0
Other	2.3	1.4	1.2

Table 17-3. Estimated primary energy conversion factors, assumed electric and CO_2- emissions factors for each energy carrier.

Energy carrier	Conversion factor	Efficiency, %	Emission Factor, kg/MWh
Biomass	0.27	30	6
Hard coal	0.32	35	755
Lignite	0.32	35	755
Natural gas	0.36	40	360
Hydropower	0.91	100	0
Oil	0.27	30	505
Nuclear	0.27	30	0
Wind	0.91	100	0
Photovoltaic	0.91	100	0
Other	0.91	100	0

17.2. Case Studies on Barcelona, Cologne and Liverpool

Cases – Description
For each city their respective heat and cooling demand were taken into account, which depend on their respective climate conditions. Details about what each case contains are given below:

Base Case

The Base Case is the present situation. The existing power plants sell electricity on the spot market, but do not provide heat to a district heating network. Cooling is performed by electrical air conditioning systems.

The following technologies are included in the calculation in the Base Case:

- Existing plant based on gas for Liverpool and Barcelona. The power plant in Cologne uses coal.
- Individual heating appliances using electricity
- Individual heating appliances using gas
- Individual cooling appliances, i.e. air conditioning

Case CHP-I

In all the CHP cases, the power plant is converted to a CHP plant either by retro fitting or providing an entirely new plant. The necessary infrastructure investments to enable district heating are also taken into account. Electricity from the CHP is sold to the open market. Unlike CHP-II and CHP-III, cooling is performed by individual electric air conditioning.

By adding a heat accumulator to the system, the CHP can be assumed to generate electricity for the same hours as the thermal power unit in the Base case. This is a conservative simplification, because in reality the CHP will most likely generate electricity for more hours

compared with the non-CHP unit adding an additional benefit to the system. In reality, the additional heat output changes the economic conditions for running the plant, since each hour will now have an additional income compared with a plant only generating electricity. Consequently the plant will be running more hours.

As a sensitivity analysis, the presented CHP-I case has been compared with an alternative Base Case. In the alternative Base Case the existing house heating devices are retained, i.e. no upgrade and therefore without an investment cost, but implying a higher yearly maintenance cost and a lower efficiency.

The following technologies are included in the calculation in case CHP-I:

- Conversion cost from existing power station into CHP
- Transmission pipe (bulk pipe) from the power station to the city heating grid
- Centralized heating boiler based on gas for peak demand
- City district heating grid
- Accumulator in the district heating grid
- Connecting cost of individual house and of heat exchanger
- Investment cost of new house wet system
- Individual cooling appliances: Air conditioning

Case CHP-Ib

Case CHP-Ib is similar to CHP-I, but instead of converting a power plant to CHP, a new CHP plant is constructed.

Case CHP-II

Differently to the CHP-I case, CHP-II assumes individual absorption units that uses the district heating from the local grid to generate space cooling.

- Conversion cost from existing power station into CHP
- Transmission pipe (bulk pipe) from the power station to the city heating grid
- City district heating grid
- Centralized heating (boiler) based on gas for peak demand
- Accumulator in the district heating grid
- Connecting cost of individual house and of heat exchanger
- Connecting cost new wet system
- Individual cooling appliances: absorption air conditioning unit

Case CHP-III (Tri generation)

Differently to the CHP-I case, CHP-III assumes the space cooling is supplied by a district cooling grid with Central Absorption units that provide cooling to this district cooling network by using the heat from the CHP (tri-generation). The absorption unit is assumed to be located between the /transmission pipe and the city-grid.

- Conversion cost from existing power station into cogeneration of heat and power

- Transmission pipe (bulk pipe) from the power station to the city heating grid
- City district heating grid City district cooling grid
- Centralized heating (boiler) based on gas for peak demand
- Accumulator in the district heating grid
- Centralized absorption chilling unit for DC
- Connecting cost of individual house and of heat exchanger
- Investment cost new wet system
- Individual cooling appliances: Fan coil unit

17.2.1. Power Plants

Even though actual existing power plants for each city were selected, in reality for a Europe wide roll out, only plants fulfilling certain conditions, e.g. being reasonably easy to convert into CHP, in reasonable distance, etc. would be chosen. Thus the plant data for Barcelona, Cologne, and Liverpool are real, but it is not known whether these plants suitable for conversion to CHP in reality. Nevertheless, this study assumes that the selected plants are easily converted at a reasonable cost. This cost has been estimated by a number of experts to be that which should apply in most or a large number of cases. Technology data on the chosen power stations are presented in Table 17. The techno-economic parameters for the existing, power plant converted to CHP, and new CHP plants used in this study are presented in Table 17-4 and Table 17-5. The different parameters used are introduced above in Section 17.1.1.

Table 17-4. Existing power stations used in case studies.

City	Power plant type	Capacity [MW]	Fuel
Barcelona	CCGT	1050	Natural gas
Cologne	Steam turbine	965	Coal
Liverpool	CCGT	1420	Natural gas

Table 17-5. Techno-Economic Parameters used for selected power plants.

	Electric capacity	Heat capacity	I_t	Life Time	COM_{Fixed}	Availability	η_e	η_{BP}	η_h or η_c	Heat To Power ratio - Upper	z or CEH
	MW	MW	Euro/kW	Years	Euro/kW	-	-		-	-	-
Existing Plant - Barcelona	1050			60	32	0.9	0.55				
Existing Plant - Bonn	965			60	54	0.9	0.46				
Existing Plant - Liverpool	1420			60	32	0.9	0.55				
Conversion CHP - Barcelona	1050	584	158	60	38	0.9	0.55	0.52	0.29	0.56	0.115
Conversion CHP - Bonn	965	1476	270	60	65	0.9	0.46	0.39	0.60	1.53	0.115
Conversion CHP - Liverpool	1420	790	158	60	38	0.9	0.55	0.52	0.29	0.56	0.115
New CHP Coal			1620	60	65	0.9	0.46	0.39	0.60	1.53	0.115
New CHP Gas			948	60	38	0.9	0.55	0.52	0.29	0.56	0.115

Where: $\mathbf{I_t}$ - Over-night investment cost, **Life time** - over which we assume continuous refurbishment investment, $\mathbf{C_{OMFixed}}$ - Annual fixed Operation and Maintenance costs[195]. **Availability factor** - Annual technical availability factor, $\boldsymbol{\eta}$**e** - electrical efficiency in fully condensing mode, $\boldsymbol{\eta}$**BP** - electrical efficiency in Back Pressure (BP) mode, $\boldsymbol{\eta}$**h**- thermal efficiency in BP mode.

17.2.2. District heating and cooling grid

A report by Pöyry[196] investigated typical citywide housing in the UK has been the main source of data associated with both the construction of the district heating grid and with connection costs for the dwellings. In addition several experts in the field have been consulted. The assumed techno-economic assumptions are presented in Table 17-5. Several experts within the field have also been used for input to the different techno-economic assumptions for the individual appliances presented in Table 17-6.

[195] Regular O&M is considered to be 2%/y of the investment cost, and an additional 2%/y is added to cover the refurbishment to give COMFixed.

[196] Pöyrö, 2009, The Potential and Costs of District Heating Networks – A Report to the Department of Energy and Climate Change,

Table 17-6. Techno-economic parameters of individual and centralized appliances, networks and components needed to supply dwellings with heating and cooling.

	I_t	I_t	Life Time	$C_{OMFixed}$	Availability	ηh or ηc
	Euro/kW	Euro/Unit	Years	Euro/kW	-	-
Accumulator		50000000	50		0.7	1.00
Transmission pipe - Barcelona	73		60	0.4	1.0	0.99
Transmission pipe - Bonn	73		60	0.4	1.0	0.99
Transmission pipe - Liverpool	73		60	0.4	1.0	0.99
Centralized absorption unit for DC	420		50	10.5	0.9	0.90
Centralized Gas Boiler	68.1		60	2.7	0.9	0.95
DC grid - Barcelona		3650	60	36.5	1.0	0.90
DC grid - Bonn		3650	60	36.5	1.0	0.90
DC grid - Liverpool		3650	60	36.5	1.0	0.90
DH grid - Barcelona		3650	60	36.5	1.0	0.91
DH grid - Bonn		3650	60	36.5	1.0	0.91
DH grid - Liverpool		3650	60	36.5	1.0	0.91
Individual absorption unit	550		15		0.9	1.30
Individual air-conditioning unit	350		15		0.9	2.40
Individual fan coil unit	350		15		0.9	0.95
Individual electrical heater	350		20		1.0	1.00
Individual gas heater	51	3127	15	3.4	0.9	0.95
Individual heat exchanger		5520	20		1.0	0.95
Individual pressure valve		5520	20		1.0	0.95
Investment new wet system		345	20			0.95

Where: $\mathbf{I_t}$ - Over-night investment cost in either per installed kW or per unit, **Life time** - 60 year due to assumed continous refurbishment investment $\mathbf{C_{OMFixed}}$ - Annual fixed Operation and Maintenance costs [197], **Availability factor** - Annual technical availability factor, **ηh** - heat efficiency, **ηc** – cooling efficiency.

The analysis assumes that the entire district heating grid is built over night. A more realistic approach would be to assume that the grid would consist of increasing numbers of micro grids fed by gas engines and/or boilers during the initial build up phase providing a return on investment on each increment of heat load from close to the project start. Some of them would later be used as peak units, as the grid grows and became large enough to connect to the power stations. These steps would normally require around 5 years, which would have little effect on the economics for the life time of the district heating network or the CHP plant.

17.2.3. Demand

For each city the number of dwellings supplied by the district heating grid is estimated by matching it to the peak CHP heat output during the average daily peak hour in the coldest month (January) multiplied by a factor two[198], see Table 17-7. The peak heat demand is covered by a boiler. The dwellings are assumed to be single family houses whose characteristics (dimensions, type of insulation, number of windows etc.) are based on information from Nemry and Uihlein[199], which are good representations of the real mix of housing.

[197]Regular O&M is considered to be 2%/y of the investment cost, and an additional 2%/y is added to cover the refurbishment to give $\mathbf{C_{OMFixed}}$.

[198] The number of dwellings can be increased by a factor 2 due to that a boiler covers peak demand in addition to the heat that the CHP provides.

[199]Nemry, F., & Uihlein, A. (2008). Environmental Improvement Potentials of Residential Buildings (IMPRO-Building). Seville: JRC Scientific and Technical Reports.

TRNSYS software is used to estimate the heating and cooling demand in dwellings according to the specific climatic condition of each city or a nearby city (Bonn was used instead of Cologne). Estimated values during the average day of each month are presented in Table 17-7 and Figure 17-1 - Figure 17-3. This climatic database of TRNSYS contains hourly information about ambient temperature, relative humidity, solar radiation and other parameters, which affect the energy demand of dwellings[200]. Warm water consumption is estimated according to the hourly consumption profile from Biaou and Bernier[201] and the average inhabitant in a dwelling in each region.

In the cost benefit analysis the average losses over a year are assumed to be 10% between the CHP and the dwellings. Winter peak heat distribution losses are assumed to be 3%. Heat losses are lower in winter as a percentage because absolute heat losses are roughly constant year round but there is a much greater quantity of heat transported at winter peak.

Table 17-7. Calculation of the number of dwellings which can be served at peak, and the annual demand for heating and cooling.

	Barcelona	**Cologne**	**Liverpool**	**Unit**
CHP electric capacity (condense mode):	1050	965	1420	MW
CHP thermal capacity (back pressure mode):	584	1476	790	MW
Losses in winter peak:	3%	3%	3%	
Average daily peak hour demand in coldest month	9	14	14	kW/Dwelling
Dwellings:	121	203	106	Thousands
Annual Heat Demand:	2068	5859	3190	GWh
Annual Space Cooling Demand:	73	0	0	GWh

[200] TRNSYS 17. 2010, available at: http://sel.me.wisc.edu/trnsys/features/t17updates.pdf

[201] Biaoua, A.L., Bernierb, M.A., 2008, Achieving total domestic hot water production with renewable energy, J. Building and Environment, vol 43, pp. 651-660

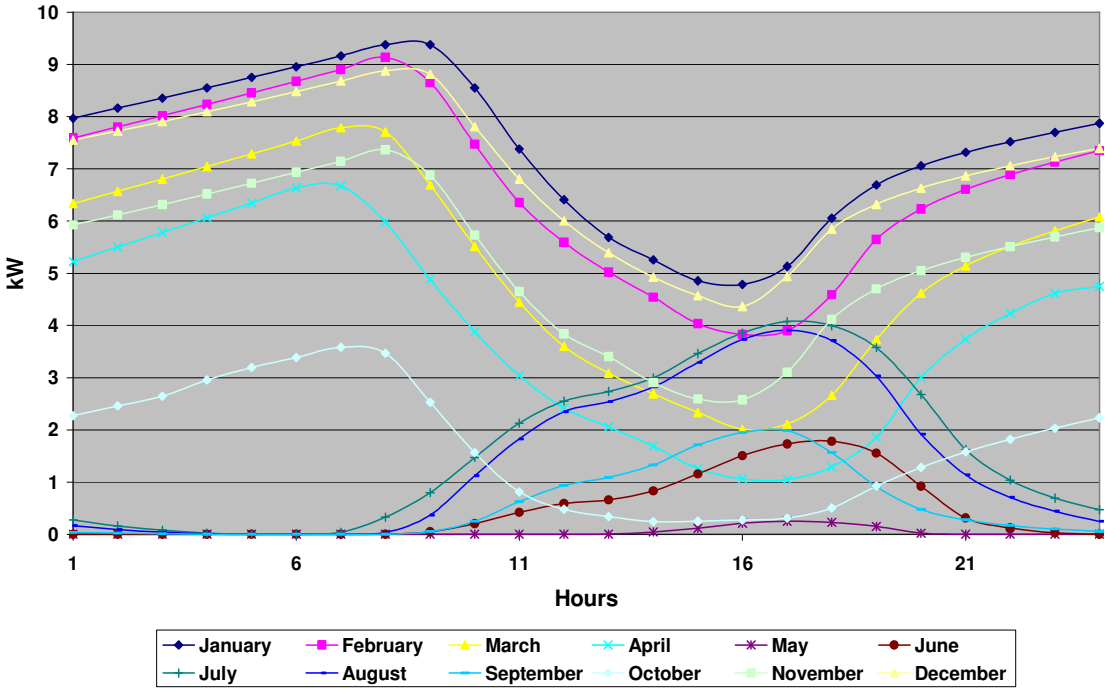


Figure 17-1. Heating and cooling demand for average day in each month in Barcelona.

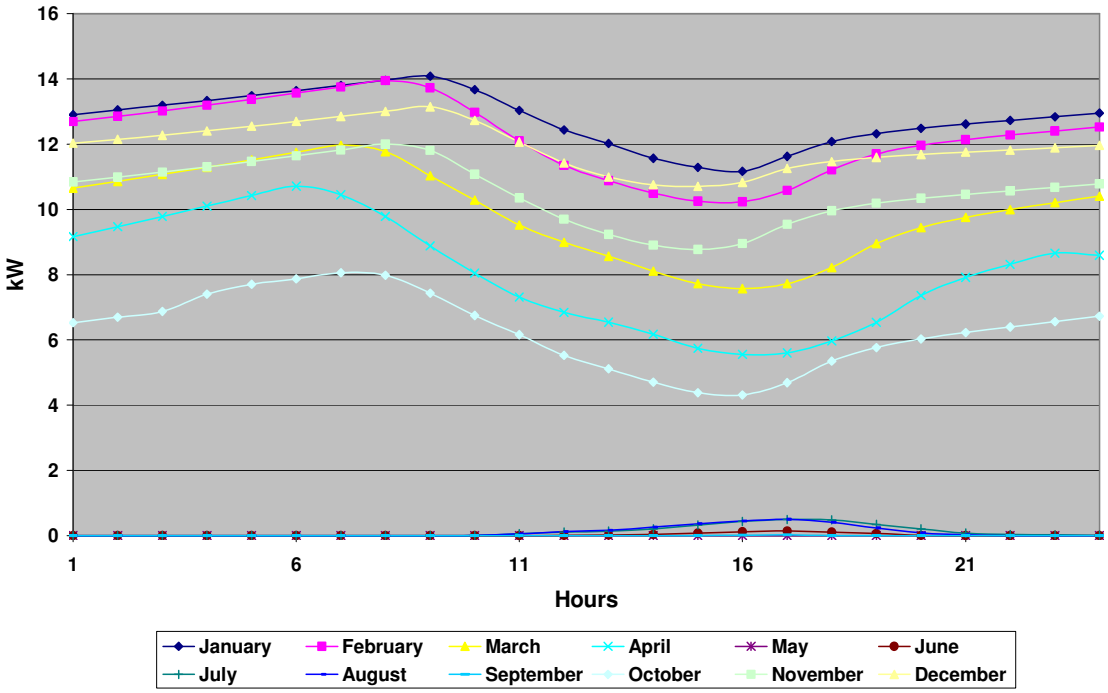


Figure 17-2. Heating and cooling demand for average day in each month in Cologne/Bonn.

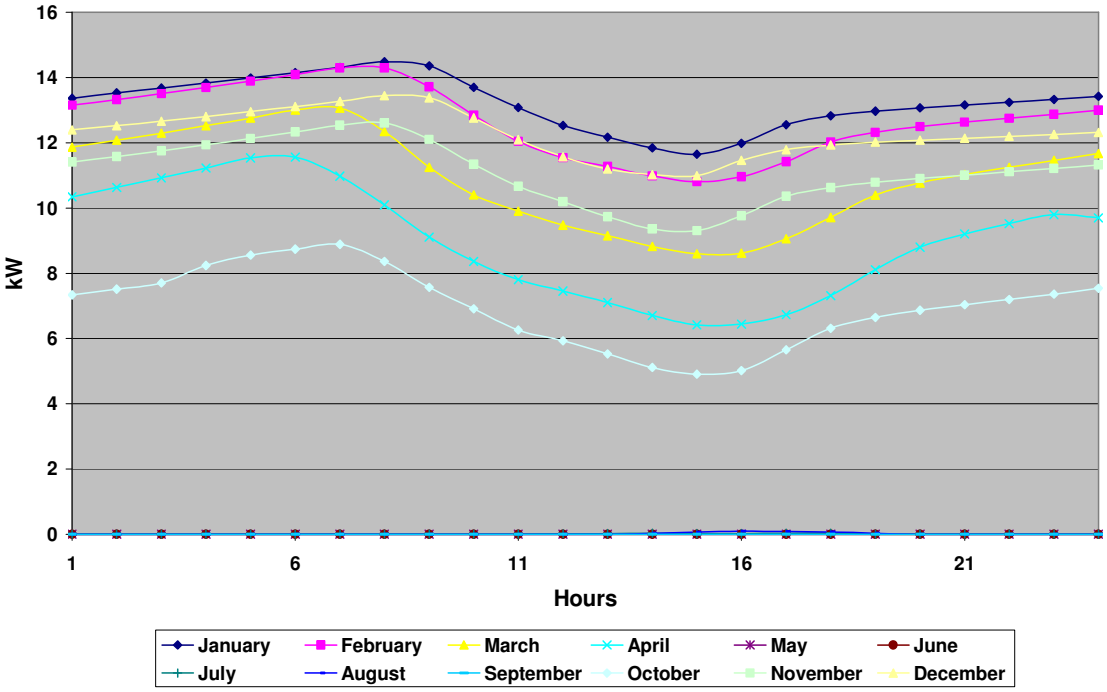


Figure 17-3. Heating and cooling demand for average day in each month in Liverpool.

17.3. Results

Results from the case studies of the selected cities are presented below. District heating was considered for all cities, CHP-I means that a power plant is converted for cogeneration by modifications / changes to the turbines. An alternative case when a completely new CHP plant is constructed has been considered too referred to as CHP-Ib. Different alternatives for the existing space cooling (air conditioning) has only been considered for Barcelona (case CHP-II and CHP-III), since the existing space cooling demand in dwellings is minor for Cologne and Liverpool.

17.3.1. Liverpool

The power plant in Liverpool is 1420 MW. Before conversion it is assumed to generate 8.4 TWh per year of electricity, which generates a considerable income. When the power plant is converted into a CHP, the revenues decrease slightly due to a lower electrical output for same fuel burn when the heat is recovered.
Table 17-8 – Table 17-11 present the annual costs of supplying dwellings in Liverpool with space heating, warm water and space cooling in addition to generating electricity from the existing power plant for the three different cases – Base Case, CHP-I and CHP-Ib. When comparing the Base Case with CHP-I it can be noted that annualised heating costs are reduced by 107 million Euros from implementing district heating. If a new CHP plant is built the annualised total costs would decrease by 64 million Euros.

Emissions and primary energy savings:
Primary energy savings of 1.47 TWh can be achieved by introduction of district heating. CO_2 emissions can be reduced by 0.39 million tonnes.

Table 17-8. Annualized costs for Base Case for Liverpool at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
Existing power plant	1420	1	-221	0	44872	8443	314691	588843
Individual. el. heater	337	23275	110	8298	0		101560	
Individual. gas boiler	1195	82520	137	22404	281		114206	
Individual. el. AC	0	11	0	0	0		52	
Total annual costs			26					

Table 17-9. Annualized costs for CHP-I case of Liverpool at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
Conversion CHP	1420	1	-181	8994	53846	8109	314691	566789
Centr. gas boiler	710		32	1938	1934	1233	26608	
Ind. heat exchanger	1532	105795	41	41090	0			
Ind. air-cond.	0	11	0	0	0		52	
Accumulator		1	2	2132	0			
DH grid	1532	105795	19	15480	3862			
Transmission pipe	1532		5	4452	555			
Wet system	337	23275	1	565	0			
Total annual costs			-81					

Table 17-10. Annualized costs for CHP-Ib case of Liverpool at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
New CHP gas	1420		-136	53966	53846	8109	314691	566789
Centr. gas boiler	710		32	1938	1934	1233	26608	
Ind. heat exchanger	1532	105795	41	41090	0			
Ind. air-cond.	0	11	0	0	0		52	
Accumulator		1	0	2132	0			
DH grid	1532	105795	19	15480	3862			
Transmission pipe	1532		5	4452	555			
Wet system	337	23275	1	565	0			
Total annual costs			-38					

Table 17-11. Summarized results for Liverpool.

	Base Case	CHP-I	CHP-Ib	
Annual Costs:	26	-78	105	MEuro
Annual Heat	3190	3190	3190	GWh
Annual Cooling	0	0	0	GWh
Net Primary Energy	10229	8753	8753	GWh
Net Electricity	-7741	-8135	-8135	GWh
Net CO_2	3349	2800	2800	k Tonne

Sensitivity analysis:
A sensitivity analysis was performed using three discount rates (3.5, 5.5, and 7.5%) for all cases studied, in order to understand how they influence the result. A significant impact on the absolute numbers is shown, see Table 17-12. To convert to CHP was profitable for all discount rates studied. To build a new CHP station would be profitable at discount rates of 3.5 and 5.5%.

Table 17-12. The total system cost for each case studied of Liverpool using three different discount rates.

Discount rate, %	Base Case, MEuro	CHP-I, MEuro	CHP-Ib, MEuro
3.5	169	101	160
5.5	174	124	197
7.5	180	149	237

As mentioned earlier it was estimated that 116 000 dwellings can be served in Liverpool. By some experts would be seen as a too conservative estimate. In one case an expert claimed that 325000 dwellings can be served. Economics would be further improved leading to annual costs savings of 252 MEuro compared to the base case. The CO_2 emissions would decrease by 1.29 Mtonne and primary energy consumption by 3.06 TWh annually. In the remainder of this chapter the standard way of estimating the number dwellings will be followed.

17.3.2. Cologne

Table 17-13- Table 17-15 presents the resulting annual costs of supplying dwellings in Cologne with space heating, warm water and space cooling in addition to generating electricity from the existing power plant for the same three cases.

The results shows that an annualised cost reduction of 415 million Euros can be achieved by introducing district heating in Cologne. The higher annualised savings compared to Liverpool is due to the lower electrical efficiency in a coal fired power plant compared with the gas fired power plant in Liverpool. Whereas the total efficiency (heat plus electricity) are similar in a coal versus gas fired CHP, and thus the total efficiency gains will be higher in Cologne compared with Liverpool.

The increased total efficiency gains in coal based Cologne compared with natural gas Liverpool makes it also profitable to invest in a new CHP. The reduction of annualized cost would be one fourth compared with Base Case.

Emissions and primary energy savings:
When converting the Cologne power plant to CHP and by employing a district heating network for heating primary energy savings of 4.45 TWh can be achieved. As a consequence CO_2 emissions are reduced by 1.7 million tonnes, see Table 17-16. Net electricity is reduced by 0.68 TWh.

Table 17-13. Annualized costs for investments for Base Case (Business as usual) of Cologne at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	*Fixed OM*	*Variable OM*	*Fuel costs*	*Revenue electricity*
	MW	units	MEuro	*kEuro*	*kEuro*	*kEuro*	*kEuro*	*kEuro*
Existing power plant	965	1	-88	0	52110	7274	219021	269159
Individual. el. heater	630	44747	332	15518	0		316464	
Individual. gas boiler	2234	158649	319	43073	540		275180	
Individual. el. AC	0	20	2	0	0		1996	
Total annual costs			565					

Table 17-14. Annualized costs for investments of CHP-I case of Cologne at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	*Fixed OM*	*Variable OM*	*Fuel costs*	*Revenue electricity*
	MW	units	MEuro	*kEuro*	*kEuro*	*kEuro*	*kEuro*	*kEuro*
Conversion CHP	965	1	-34	10445	62532	6590	219021	332324
Centr. gas boiler	483		53	1317	1314	1670	48696	
Ind. heat exchanger	2864	203396	79	78998	0			
Ind. air-cond.	0	20	2	0	0		1996	
Accumulator		1	2	2132	0			
DH grid	2864	203396	37	29762	7424			
Transmission pipe	2864		9	8325	1038			
Wet system	630	44747	1	1086	0			
Total annual costs			150					

Table 17-15. Annualized costs for investments of the CHP-Ib case of Cologne at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
New CHP gas	965		18	62671	62532	6590	219021	332324
Centr. gas boiler	483		53	1317	1314	1670	48696	
Ind. heat exchanger	2864	203396	79	78998	0			
Ind. air-cond.	0	20	2	0	0		1996	
Accumulator			0	0	0			
DH grid	2864		37	29762	7424			
Transmission pipe			9	8325	1038			
Wet system	630	44747	1	1086	0			
Total annual costs			200					

Table 17-16. Summarized results of Cologne at 3.5% discount rate.

	Base Case	CHP-I	CHP-Ib	
Annual Costs	574	203	258	MEuro
Annual Heat	5859	5859	5859	GWh
Annual Cooling	0	0	0	GWh
Net Primary Energy	2270	-2183	-2183	GWh
Net Electricity	-5977	-6658	-6658	GWh
Net CO2	5965	4237	4237	k Tonne

Sensitivity analysis:
A sensitivity analysis was performed on the three discount rates (3.5, 5.5, and 7.5%) for all cases studied in order to understand how much it influences the profitability. The results show a large impact from the discount rate on the absolute numbers, see Table 17-17. However, conversion or new construction of CHP with additional investment in infrastructure remain profitable also at high discount rates relative the base case..

Table 17-17. The total system cost for each case studied of Cologne using three different discount rates.

Discount rate, %	Base Case, MEuro	CHP-I, MEuro	CHP-Ib, MEuro
3.5	565	150	200
5.5	574	187	259
7.5	584	228	323

17.3.3. Barcelona

Table 17-18- Table 17-23 presents the resulting annual costs of supplying dwellings in Barcelona with space heating, warm water and space cooling in addition to generating electricity from the existing power plant for the same three cases. Details about the case description and technologies can be found in Section 16.1.1.

In the base case the annual costs for heating and cooling in Barcelona for the present situation is calculated. Table 17-18 presents the costs for different components. The income generated by the power plant comes from selling electricity to the open market.

The CHP-I case calculated the annual costs for heating and cooling in Barcelona when employing district heating. Individual cooling is provided through electrical air conditioning. Annualised cost savings were 70 million Euros.

If a new CHP plant was constructed (CHP-Ib) the annualised costs for heating and cooling would decrease by 36 million Euro, see Table 17-20.

The CHP-II case calculated the annual costs for heating and cooling in Barcelona when employing district heating and individual absorption cooling, see Table 17-21. Here cooling is achieved by providing heat to individual absorption units through the district heating network. Total annualized cost savings for heat and cooling were 66 million Euro.

The CHP-III case calculated the annual costs for heating and cooling in Barcelona when employing district heating and centralised cooling, see Table 17-22. Individual cooling was achieved through providing heat to centralized absorption units, which in turn provided cooling to a district cooling network. Total annualized cost savings for heat and cooling were 76 million Euro.

Emissions and primary energy savings:
When converting the Barcelona power plant to CHP and by employing a district heating and cooling network (CHP-III) primary energy savings of 1.26 TWh can be achieved. As a consequence CO_2 emissions are reduced by 0.46 million tonnes, see Table 17-23. Net electricity is reduced by about 0.34 TWh.

Table 17-18. Annualized costs for the Base Case (Business as usual) of Barcelona at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
Existing power plant	1050	1	-50	0	33180	4575	181324	269159
Individual. el. heater	249	26566	91	6136	0		84401	
Individual. gas boiler	883	94187	112	25572	321		85922	
Individual. el. AC	73	48301	16	2233	0		14197	
Total annual costs			169					

Table 17-19. Annualized costs for investments for CHP-I case (converted CHP) of Barcelona at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
Conversion CHP	1050	1	-28	6651	39816	4423	181324	260179
Centr. gas boiler	525		36	1433	1430	1363	31282	
Ind. heat exchanger	1133	120753	47	46900	0			
Ind. air-cond.	73	48301	16	2233	0		14197	
Accumulator		1	2	2132	0			
DH grid	1133	120753	22	17669	4407			
Transmission pipe	1133		4	3292	411			
Wet system	249	26566	1	645	0			
Total annual costs			99					

Table 17-20. Annualized costs for CHP-Ib case (new CHP) of Barcelona at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
New CHP gas	1050		5	39904	39816	4423	181324	260179
Centr. gas boiler	525		36	1433	1430	1363	31282	
Ind. heat exchanger	1133	120753	47	46900	0			
Ind. air-cond.	73	48301	16	2233	0		14197	
Accumulator			2	2132	0			
DH grid	1133		22	17669	4407			
Transmission pipe			4	3292	411			
Wet system	249	26566	1	645	0			
Total annual costs			133					

Table 17-21. Annualized costs for investments for CHP-II case of Barcelona at 3.5% discount rate.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	Fixed OM	Variable OM	Fuel costs	Revenue electricity
	MW	units	MEuro	kEuro	kEuro	kEuro	kEuro	kEuro
Conversion CHP	1050	1	-34	6651	39816	4526	181324	266359
Centr. gas boiler	525		61	1433	1430	2432	55807	
Ind. heat exchanger	1133	120753	47	46900	0			
Ind. abs. Unit	73	0	0	0	0		0	
Accumulator		1	2	2132	0			
DH grid	1206	120753	22	17669	4407			
Transmission pipe	1206		4	3505	437			
Wet system	249	26566	1	645	0			
Total annual costs			103					

Table 17-22. Annualized costs for investments for CHP-III case of Barcelona.

	Installed Capacity	Installed Capacity	Annual Costs	Annualized costs				
				Capital Cost	*Fixed OM*	*Variable OM*	*Fuel costs*	*Revenue electricity*
	MW	units	MEuro	*kEuro*	*kEuro*	*kEuro*	*kEuro*	*kEuro*
Conversion CHP	1050	1	-24	6651	39816	4365	181324	181324
Centr. gas boiler	525		30	1433	1430	1147	26313	
Centr. abs. unit			0	0	0	215		
Ind. heat exchanger	1133	120753	47	46900	0			
Ind. fan coil	73	48301	2	2233	0			
Accumulator			2	2132	0			
DH grid	1133	120753	22	17669	4407			
Transmission pipe	1133		4	3292	411			
DC grid	73	48301	9	7068	1763			
Wet system	249	26566	1	645	0			
Total annual costs			93					

Table 17-23. Summary of cases for Barcelona at 3.5% discount rate.

	Base Case	CHP-I	CHP-II	CHP-III	
Annual Costs	169	101	61	49	MEuro
Annual Heat	2068	2068	2068	2068	GWh
Annual Cooling	73	73	73	73	GWh
Net Primary Energy	-1449	-2491	-1909	-2709	GWh
Net Electricity	-4043	-4360	-4533	-4387	GWh
Net CO2	-549	-926	-718	-1005	k Tonne

Sensitivity analysis:

A sensitivity analysis was performed on three discount rates (3.5, 5.5, and 7.5%) for all cases studied in order to understand how much the discount rate influences the result. The results show a large impact from the discount rate on the absolute numbers, see Table 17-24. For discounts rate at 5.5% all CHP-I-III remained profitable compared to the base case. At 7.5% discount rate it was not profitable to construct a new CHP station (CHP-Ib).

Table 17-24. The total system cost for each case studied of Barcelona using three different discount rates.

Discount rate, %	Base Case, MEuro	CHP-I, MEuro	CHP-Ib, MEuro	CHP-II, MEuro	CHP-III, MEuro
3.5	169	99	133	103	93
5.5	174	122	170	125	118
7.5	180	147	210	149	146

17.4. Conclusions

Case studies were performed for three European cities representing northern, central and southern climates. The system cost assessment shows the potential costs savings for society from converting existing power plants into Combined Heat and Power (CHP) plants and to invest in district heating and cooling infrastructure. Assuming that all potential dwellings were connected to the district heating network the required infrastructure investments would in most cases be paid back within 4-10 years, from the point of view of total cost savings. However, various stakeholders will claim from the cost reductions made, so the savings for consumers will also depend on the competitive situation of a particular city. Adding centralised district cooling infrastructure was shown worthwhile only in Barcelona.

The case studies show that introduction of district heating reduced CO_2 emissions by 13, 12, and 19% for Barcelona, Cologne, and Liverpool, respectively. The primary energy savings were about the same. Further a reduction in net electricity consumption is shown (electricity purchased by the households minus electricity generated from the power plant) after converting the power plant to CHP by about 2.5-5% for all cities studied. The reason is a reduction in electricity used for heating of the dwellings. This implies a further saving on the cost of investment in power plants in the system.

The cost savings from converting a thermal plant into CHP is greatest in Cologne, the city with the coldest climate (hence longest heating period). The large potential cost savings are also due to the fact that coal-fired plants operate at lower electrical efficiencies, and thereby have a larger total efficiency improvement when moving from electric-only to combined heat and electricity generation (the total efficiency are similar for gas- and oil-fired CHP). When retrofitting the plants for CHP and investing in associated infrastructure needs, and assuming a social discount rate of 3.5%, the total annualised cost for heat decreased by 76, 257, and 71 million Euros in Barcelona, Cologne, and Liverpool, respectively. As expected, retrofitting a power plant for CHP was shown cheaper than constructing a new CHP plant for all cities. It would be cost efficient to replace the existing power plant with a new power plant in all cities both at 3.5 and 5.5% discount rates. At 7.5% discount rate the conversion was not worthwhile. In Barcelona combined district heating and centralised district cooling would improve the financial analysis further, compared to district heating only. This is explained by that the heating season of Barcelona is short and by adding a district cooling system utilization of the CHP will increase.

Finally, it should be noted that the cases incorporated only single family houses, which is conservative since multi-family houses and office buildings would have even larger benefits due to relatively less infrastructure needs, e.g. district heating pipe costs, and less heat losses.

18. CALCULATION OF THE POTENTIAL CONTRIBUTION FROM CHP DISTRICT HEAT (CHP-DH) IN THE EU

18.1. Calculate the CHP expansion per MS to meeting a 75 % target – referred to as "Vision" within this chapter. ..... **Error! Bookmark not defined.**

18.2. Calculate the heat generated per MS from the CHP expansion described **Error! Bookmark not defi**

18.3. Estimation of the potential uptake of DH from CHP . **Error! Bookmark not defined.**

18.4. Estimation of the investment needed to meet the vision **Error! Bookmark not defined.**

18.5. Conclusion ..... **Error! Bookmark not defined.**

In order to place the possible costs and energy savings in context, we have assumed a target (in the model), such that close to 75 % of the domestic and commercial low temperature heat load in the EU27 could be provided by waste heat from CHP-DH. This is then compared country by country with the available heat if all combustion power stations were converted to CHP-DH[202].

We have performed this estimation in the following manner:

18.1. Calculate the CHP expansion per MS to meeting a 75 % target – referred to as "Vision" within this chapter.

1. Table 18-1 gives total installed electrical[203] capacity of thermal power plants using combustible fuels, per MS. – Column A.

2. Total installed capacity[204] of CHP per MS. Table 18-1 – Column B.

3. We make available 100% of the total EU installed electrical capacity of thermal power plants using combustible fuels, to be CHP (Although not all is used since it is greater than the actual heat demand). Thereafter the required conversion of existing CHP to reach the 100 % is estimated, Table 18-1 – Column F.

[202] There is no target for the market share of DH in Denmark. Currently it is 62% of all homes or roughly 50% of the heat demand. The aim is that the municipalities shall find the least cost zoning between DH and individual solutions. In Heat Plan Denmark, a report prepared by AUC and Ramboll and financed by heat consumers (a small non-profit organisation) it was estimated that it could increase from 50% to 70%.

[203] Source: Eurostat database.

[204] Source: Eurostat database.

Table 18-1. Estimated CHP per MS for meeting a vision of 100% CHP in total installed electrical capacity of thermal power, combustible fuels, in EU.

	A	B	C	D	E	F
	Total Thermal Combus. (GW)*	CHP Electrical capacity (GW)**	Share of CHP in Thermal Power combustible fuels		CHP Electrical capacity (GW)	Targeted Conversion of CHP (GW)***
	2009	2009	2009	Vision	Vision	Vision
AT - Austria	5,8	2,91	50%	100%	5.8	2.9
BE - Belgium	8,2	2,42	29%	100%	8.2	5.8
BG - Bulgaria	4,3	1,28	30%	100%	4.3	3.0
CY - Cyprus	1,4	0,01	0%	100%	1.4	1.4
CZ - Czech Republic	9,6	4,76	49%	100%	9.6	4.9
DE - Germany	69,4	22,49	32%	100%	69.4	46.9
DK - Denmark	9,2	5,28	57%	100%	9.2	3.9
EE - Estonia	2,5	0,42	16%	100%	2.5	2.1
ES - Spain	47,8	3,65	8%	100%	47.8	44.1
FI - Finland	8,2	5,79	71%	100%	8.2	2.4
FR - France	20,6	5,68	28%	100%	20.6	14.9
GR - Greece	9,7	0,51	5%	100%	9.7	9.2
HU - Hungary	6,5	0,20	3%	100%	6.5	6.3
IE - Ireland	5,3	0,29	5%	100%	5.3	5.0
IT - Italy	67,2	7,67	11%	100%	67.2	59.6
LT - Lithuania	2,3	1,09	47%	100%	2.3	1.2
LU - Luxembourg	0,4	0,11	28%	100%	0.4	0.3
LV - Latvia	0,9	0,26	28%	100%	0.9	0.7
MT - Malta	0,0	0,00	-	-		
NL - Netherlands	18,3	9,25	50%	100%	18.3	9.1
PL - Poland	28,3	8,63	30%	100%	28.3	19.7
PT - Portugal	7,2	1,30	18%	100%	7.2	5.9
RO - Romania	10,9	4,46	41%	100%	10.9	6.5
SE - Sweden	7,1	4,52	64%	100%	7.1	2.6
SI - Slovenia	1,2	0,33	26%	100%	1.2	0.9
SK - Slovakia	2,2	1,59	71%	100%	2.2	0.7
UK - United Kingdom	62,1	5,71	9%	100%	62.1	56.4
EU	417	101	24%	100%	417	316

Eurostat Database (downloaded 2011)
** Eurostat Technical Note on CHP in 2009 (year=???).
*** Targeting conversion of existing non electric-only thermal power stations

18.2. Calculate the heat generated per MS from the CHP expansion described

4. Table 18-2 – Column C represents the Calculated additional heat output from CHP available if 100% of all EU power stations were CHP (Table 18-1- Column F) based on the heat-to-power ratio per MS in 2009 (Table 18-2- Column B and C). We have assumed that after conversion the load factor is 0.6. Estimates of heat-to-power ratio are based on 'Main activity producers' when available, otherwise on the average CHP of MSs. We assume that

the heat output of the new or converted CHP will supply the district-heating grid. The reason is that the main stock of non CHP thermal power plants is public (non auto) producers. The future uncertainty in linking the heat to a district heating grid is lower compared with linking to an industry competing on a global market.

Table 18-2: Calculation of annual heat from additional CHP (= targeted Conversion).

	A	B	C
	Targeted Conversion of CHP (GW)	Heat to Power Ratio	Annum Additional Heat Output (TWh)
	Vision	2009	Vision
AT - Austria	2.9	3,0	24.7
BE - Belgium	5.8	2,0	62.2
BG - Bulgaria	3.0	3,1	47.7
CY - Cyprus	1.4	1,3	9.8
CZ - Czech Republic	4.9	2,6	39.9
DE - Germany	46.9	1,9	254.3
DK - Denmark	3.9	1,9	38.3
EE - Estonia	2.1	3,7	34.2
ES - Spain	44.1	2,2	0.0
FI - Finland	2.4	1,9	11.9
FR - France	14.9	1,6	43.7
GR - Greece	9.2	4,6	63.5
HU - Hungary	6.3	1.6	47.1
IE - Ireland	5.0	1.7	0.0
IT - Italy	59.6	1.2	160.2
LT - Lithuania	1.2	2.0	10.9
LU - Luxembourg	0.3	2.7	0.0
LV - Latvia	0.7	1.2	4.2
MT - Malta		-	
NL - Netherlands	9.1	1.7	44.4
PL - Poland	19.7	2.2	146.1
PT - Portugal	5.9	2.4	41.7
RO - Romania	6.5	2.8	79.0
SE - Sweden	2.6	2.6	17.4
SI - Slovenia	0.9	2.5	7.2
SK - Slovakia	0.7	1.2	3.5
UK - United Kingdom	56.4	1.8	286.1
EU	316		1478

[205]

[205] Eurostat Database (downloaded 2011)

18.3. **Estimation of the potential uptake of DH from CHP**

The demand for useful energy in these (rough) estimates is assumed not to increase substantially between 2005 and 2009.This assumption can be justified when the buildings are being improved (decrease the need) while more houses are being built (increases the need).

5. In order for DH to be useful there must be a demand for heat. For different reasons DH will never be available for all buildings. We have focused on the demand for space heating and warm water in the residential and the service & commercial sector. The potential market for district heating could increase considering that the district heating grid can be used for space cooling (through an absorption machine). Each step in calculating a rough estimate of the technical potential of DH in each MS is presented in Table 18-3. We assume that DH can supply 75% of the useful energy demand for heating in the residential and in the service & commercial sector (Column F).

6. A summary of the existing heat form CHP and the additional heat gained from conversion of existing electric-only power plants is presented in 18.4

7. The next step is to calculate the resulting DH from CHP from combining the estimated potential DH demand (step 5) and the heat available from public CHP after 100% of the existing thermal plants have been converted into CHP (step 6). The result is presented in Table 18 4.It is assumed that maximum 90% of the DH heat supplied in a year will be supplied by CHP (remaining will be supplied by peak boiler, waste heat etc.).

18.4. Estimation of the investment needed to meet the vision

8. Finally the investment costs for converting the thermal power stations into CHP and for an expansion of the district heat grid are calculated (see Table 18-3 to Table 18-6). The expansion costs include both the large ‘bulk pipe’ costs and the ‘city-grid’. The grid expansion cost will differ depending on the region. Regions with a high annual heat demand per dwelling will have a lower grid cost compared with regions with regions with a low heat demand, when fewer buildings need to be connected to the heat grid to supply the same amount of heat from the CHP. Northern (N) countries are assumed (from the study in Chapter 17) to have an investments cost of 70 Euro/GJ annual heat demand, while the same cost for the southern (S) countries is assumed to be 108 Euro/GJ.

Table 18-3. Analysis of the technical potential of DH.

	A	B	C	D	E	F
	Total Final Energy Consumption (PJ)*	Total DH (PJ)*	Share of DH in FEC for Heating	Useful Energy for Heating (PJ)**	Share of DH in Useful Energy for Heating	Assumed 75% potential demand for DH (PJ)
	2005	2005	2005	2005	2005	Vision
AT - Austria	419	28	7%	188	15%	141
BE - Belgium	590	1	0%	433	0%	325
BG - Bulgaria	126	18	15%	80	23%	60
CY - Cyprus	20	0	0%	11	0%	8
CZ - Czech Republic	406	49	12%	391	13%	293
DE - Germany	3844	154	4%	2808	5%	2106
DK - Denmark	269	63	24%	241	26%	180
EE - Estonia	54	16	30%	43	37%	32
ES - Spain	983	0	0%	442	0%	332
FI - Finland	282	60	21%	210	29%	158
FR - France	2700	0	0%	1746	0%	1310
GR - Greece	311	2	1%	82	2%	62
HU - Hungary	413	29	7%	458	6%	343
IE - Ireland	199	0	0%	132	0%	99
IT - Italy	1942	7	0%	1785	0%	1339
LT - Lithuania	82	22	27%	68	33%	51
LU - Luxembourg	32	1	5%	22	7%	17
LV - Latvia	88	18	21%	53	35%	40
MT - Malta	6	0	0%	4	0%	3
NL - Netherlands	727	7	1%	796	1%	597
PL - Poland	1041	190	18%	794	24%	596
PT - Portugal	226	0	0%	98	0%	73
RO - Romania	404	61	15%	339	18%	254
SE - Sweden	488	105	22%	389	27%	292
SI - Slovenia	59	5	8%	33	14%	24
SK - Slovakia	177	26	15%	197	13%	148
UK - United Kingdom	2502	2	0%	2662	0%	1997
EU	18387	8865	5%	14505	6%	10878

* Eurostat Database (downloaded 2011)
** JRC-IE Heat and cooling database (2011)

Table 18-4. Calculating of annual heat from additional CHP

	A	B	C
	Annual Heat out available for DH from CHP (PJ)	Additional Annual Heat out available for DH from converted CHP (PJ)	Total Annual Heat out available for DH from CHP (PJ)
	2009	Vision	Vision
AT - Austria	53.8	88.8	142.6
BE - Belgium	26.8	223.8	250.6
BG - Bulgaria	42.9	171.8	214.7
CY - Cyprus	0.1	35.2	35.3
CZ - Czech Republic	71.7	143.5	215.1
DE - Germany	343.3	915.3	1258.6
DK - Denmark	109.8	138.0	247.8
EE - Estonia	9.7	123.1	132.8
ES - Spain	0.0	0.0	0.0
FI - Finland	120.5	42.7	163.2
FR - France	67.3	157.2	224.5
GR - Greece	3.1	228.5	231.6
HU - Hungary	39.0	169.6	208.6
IE - Ireland	0.0	0.0	0.0
IT - Italy	76.9	576.8	653.7
LT - Lithuania	13.7	39.3	53.0
LU - Luxembourg	0.0	0.0	0.0
LV - Latvia	4.8	15.2	19.9
MT - Malta	0.0	0.0	0.0
NL - Netherlands	121.8	159.8	281.6
PL - Poland	164.2	525.9	690.1
PT - Portugal	34.6	150.1	184.7
RO - Romania	54.7	284.5	339.2
SE - Sweden	80.7	62.6	143.4
SI - Slovenia	6.9	26.0	32.9
SK - Slovakia	15.3	12.6	27.9
UK - United Kingdom	85.1	1030.0	1115.2
EU	1547	5320	6867

* Eurostat Database (downloaded 2011)

Table 18-5. Calculating of annual heat from additional CHP (=targeted conversion)

	A	B	C	D	E	F	G
	Usefuel Energy for Heating (PJ)	DH (PJ)	Assumed potential demand for DH (PJ)	Total Annual Heat out available for DH from CHP (PJ)	VISION - Share of heat from CHP in the DH	VISION - Share of heat from CHP in the DH - ADJUSTED	Annual Heat DH from CHP (PJ)
	2005	2005	Vision	Vision	Vision	Vision	Vision
AT - Austria	188	28	141	143	101%	90%	127
BE - Belgium	433	1	325	251	77%	77%	251
BG - Bulgaria	80	18	60	215	360%	90%	54
CY - Cyprus	11	0	8	35	427%	90%	7
CZ - Czech Republic	391	49	293	215	73%	73%	215
DE - Germany	2808	154	2106	1259	60%	60%	1259
DK - Denmark	241	63	180	248	137%	90%	162
EE - Estonia	43	16	32	133	410%	90%	29
ES - Spain	442	0	332	0	0%	0%	0
FI - Finland	210	60	158	163	104%	90%	142
FR - France	1746	0	1310	225	17%	17%	225
GR - Greece	82	2	62	232	374%	90%	56
HU - Hungary	458	29	343	209	61%	61%	209
IE - Ireland	132	0	99	0	0%	0%	0
IT - Italy	1785	7	1339	654	49%	49%	654
LT - Lithuania	68	22	51	53	105%	90%	46
LU - Luxembourg	22	1	17	0	0%	0%	0
LV - Latvia	53	18	40	20	50%	50%	20
MT - Malta	4	0	3	0	0%	0%	0
NL - Netherlands	796	7	597	282	47%	47%	282
PL - Poland	794	190	596	690	116%	90%	536
PT - Portugal	98	0	73	185	251%	90%	66
RO - Romania	339	61	254	339	133%	90%	229
SE - Sweden	389	105	292	143	49%	49%	143
SI - Slovenia	33	5	24	33	135%	90%	22
SK - Slovakia	197	26	148	28	19%	19%	28
UK - United Kingdom	2662	2	1997	1115	56%	56%	1115
	14505	**865**	**10878**	**6867**	**63%**	**54%**	**5875**

Table 18-6. Calculating of grid and CHP conversion costs.

	A	B	C	D	E
	Annual Heat DH from CHP (PJ)	Present DH from CHP (PJ)	Additional DH from CHP (PJ)	Region	GRID and CHP Conversion Cost
	Vision	2009	Vision		CAPEX (billion €)
AT - Austria	127	54	89	N	5.1
BE - Belgium	251	27	224	N	15.7
BG - Bulgaria	54	43	172	S	1.2
CY - Cyprus	7	0	35	S	0.8
CZ - Czech Republic	215	72	143	N	10.0
DE - Germany	1259	343	915	N	64.1
DK - Denmark	162	110	138	N	3.7
EE - Estonia	29	10	123	N	1.4
ES - Spain	0	0	0	S	0.0
FI - Finland	142	121	43	N	1.5
FR - France	225	67	157	S	17.0
GR - Greece	56	3	229	S	5.7
HU - Hungary	209	39	170	S	18.3
IE - Ireland	0	0	0	S	0.0
IT - Italy	654	77	577	N	40.4
LT - Lithuania	46	14	39	N	2.2
LU - Luxembourg	0	0	0	N	0.0
LV - Latvia	20	5	15	N	1.1
MT - Malta	0	0	0	S	0.0
NL - Netherlands	282	122	160	N	11.2
PL - Poland	536	164	526	N	26.0
PT - Portugal	66	35	150	S	3.4
RO - Romania	229	55	285	N	12.2
SE - Sweden	143	81	63	N	4.4
SI - Slovenia	22	7	26	N	1.1
SK - Slovakia	28	15	13	N	0.9
UK - United Kingdom	1115	85	1030	N	72.1
	5875	**1547**	**5320**		**319**

18.5. Conclusion

According to our estimation if all EU combustion power stations were converted to CHP-DH an additional 5320 PJ of low carbon heat are likely to be made available at an investment cost of €319 Billion. In most countries the restricting factor appears to be the availability of combustion power station heat rather than the lack of potential heat load, although this may not be true if there are clusters of power stations in remote locations or at non-economic distances for heat transmission.

To put these figures into context, we may make further estimates of the relative annual cost of heat from boilers or CHP-DH as follows:

From table 3.1 to provide this heat from a boiler would require 1.11 units of heat per unit of heat delivered, and from CHP 0.27 units of heat.

Therefore if this heat were provided by natural gas boilers the annual fuel cost, based on Eurostat domestic gas costs for 2009 of around €11.5/GJ would be 11.5 x 5320PJ x 1.11 = €67.9 Billion. From CHP the annual fuel cost of this heat would be 11.5 x 5320PJ x 0.27 = €16.5 Billion. Thus €51.4 Billion difference in (fuel cost only) for a spend of €319 Billion gives an approximate idea of the savings. This calculation is given to place the numbers in context and the accurate estimation of all costs and benefits is to be found in Chapter 17.

Clearly this figure is an upper bound and subject to considerable uncertainty as to the total size of the saving but the ratio costs to benefits is likely to be reasonably accurate. Many of the existing power stations will not be able to be converted to CHP or are too far from heat loads. But if policy encourages this growth in CHP-DH then over 20 years we can expect more stations to be built close to heat loads and those remote closed down and the total potential to move closer to the upper bound.

The above calculation only includes fossil energy fired power stations. As Stephen Tindal[206] has noted ""Switzerland got 7.5 per cent of its district heat from nuclear power stations in 2009. Within the EU, Slovakia got over 5 per cent of its district heat from nuclear stations in 2009. Hungary and the Czech Republic also use nuclear heat. But in the EU's main nuclear players, such as France and the UK, the heat is simply expelled into rivers and seas". Much of this nuclear waste heat could be used for building heating. And since nuclear energy provides about 1/3 of the heat into EU power stations, this if used would represent a significant further increase in the amount of heat available to heat European buildings.

[206] (Energy Efficiency: made in Denmark, exportable to the rest of the EU?- Stephen Tindale. April, 2012.

19. COMBINED HEAT AND POWER AND STEAM TURBINE / COMBINED CYCLE POWER STATIONS – BACKGROUND AND CONCEPTS. CONVERSION OF EXISTING STATIONS TO CHP. COMPARISON OF CHP WITH HEAT PUMPS.

19.1. Combined Heat and Power – CHP ..... **Error! Bookmark not defined.**
19.2. Carnot's Law and the Z factor ..... **Error! Bookmark not defined.**
19.3. Thermodynamics of CHP – the Iron diagram..... **Error! Bookmark not defined.**
19.4. The Z-factor and the Iron Diagram for specifying CHP performance and its application to extraction condensing unit (also called a pass out turbine):**Error! Bookmark not defi**
19.5. Exergy..... **Error! Bookmark not defined.**
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19.8. Conversion of existing electricity only power stations to CHP**Error! Bookmark not defined.**
19.9. Heat to power ratio and range of practical Z factors: . **Error! Bookmark not defined.**
19.10. Co-efficient of Performance (COP) of heat pumps compared to (COP) –Z factor for CHP. The importance of low DH temperatures to maximise efficiency of CHP.**Error! Bookmark n**
19.11. Load following and back up to variable / intermittent renewable energy sources such as wind. ..... **Error! Bookmark not defined.**

19.1. Combined Heat and Power – CHP

When an operating power plant provides the heat which is normally rejected to the environment, instead to a process or other heat user, then this is known as Combined Heat and Power (CHP) or cogeneration. The terms CHP and cogeneration are used interchangeably, which can be from the very large – (4GWe) to the very small – (1 kWe).

All power plants which operate with thermal energy as an input – fossil fuel, nuclear energy or geothermal, inevitably produce waste heat or more correctly reject heat. This is a consequence of the 2nd Law of Thermodynamics. Essentially a power generating plant works by subjecting a working fluid – typically a gas to a thermodynamic cycle – thereby converting energy at a high temperature into work plus energy at a lower temperature; the 1st Law of Thermodynamics dictating that energy is always conserved (you have the same total amount of energy before the cycle as after). In the context of power generation, a thermodynamic cycle typically means subjecting a volume of gas to a process of typically compressing, heating, expansion (coupled with work extraction) and cooling (or heat rejection).

19.2. Carnot's Law and the Z factor

For a power station based on heat input (nuclear, fossil, waste heat or biomass) the larger the difference between the temperature of the heat input and the temperature of heat rejection, the greater the efficiency of the power station. Efficiency here means how much electricity output is produced for a given fuel input (note the existence of two confusingly different methods of defining this important ratio – see Annex 2)

This relationship between heat input and heat rejection temperatures and efficiency is embodied in Carnot's Law after the French physicist and military engineer who proved it in

1824.[207] Carnot's Law states that the maximum efficiency that any heat engine can achieve depends on the difference between the hot and cold temperature between which the engine is working[208].

Formulae: $\eta_c = 1 - T_c/T_h$ (Hot (h) and cold (c) temperatures in Kelvin).

In an engine these are the temperatures of the gases in the cylinder at the point of ignition and the temperature at which they leave the engine. In a steam cycle power station, they are the temperature of the steam leaving the boiler and entering the high pressure HP turbine, and the temperature of the steam at which it leaves the low pressure LP part of the steam turbine. This temperature depends on how the steam is condensed, e.g.: by sea water, cooling tower, low temperature district heating or high temperature district heating.

Clearly in a conventional electricity-only power station, whether or not the heat is rejected to the environment in a cooling tower at *a certain temperature* or is used for other purposes such as horticulture *at the same temperature* there is no effect on the electrical efficiency of the power station because the heat is still being rejected at the same temperature.

Thus using the waste heat from a given plant has no effect on the efficiency of power generation, unless the reject temperature is changed.

Where the waste heat from a power generator, is needed at a higher temperature than that at which it is currently rejecting – a cooling tower or the sea, instead to heat cities perhaps, or some process, this will inevitably lower the efficiency of the power plant in converting heat to electricity. However in the right circumstances this is a loss worth taking because the quantity in MWh of the heat so gained, is much greater than the value in MWh of the loss of electricity and taking into account the cost of whatever apparatus such as pipes and heat exchangers, is needed to convey this heat to potential users.

The loss of electricity is normally described by the Z factor which represents the useful heat gained in kWh for electricity lost in kWh – this can vary from about 4 -10 in power stations, and can be theoretically much higher depending on the exact circumstances. (or the Cv-factor, which represents 1/Z) The Z factor is a function of

1) the temperatures of the water to be heated before and after (supply and return temperature of the DH water)
2) the total load of the turbine
3) the capacity of the rejected heat, as the Z factor has a maximum for the combination at which the steam flow is divided between the normal seawater condenser and the district heating condenser without pressure reduction

The important point here is that the lower the temperature at which heat can be rejected, then generally the more efficient the power generator will be. This is why power stations are sited if possible close to cooling water such as the sea or river where the heat is rejected at the temperature of the water. The world's most efficient coal power plant at Nordjylland,

[207]Carnot, Sadi (1824). Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance. Paris: Bachelier

[208] To be pedantic, it could be argued that the power plant process is not a Carnot process but a Rankine process and we cannot necessarily be sure that Carnot's law (which only says something about a MAXIMUM theoretical efficiency, that is never achieved if at all applies for the Rankine cycle in the real world . Nevertheless in practice Carnot Efficiency is a good guide and is widely understood. The lower the temperature difference, the lower the efficiency.

Denmark is 47% LHV, (see Annex 2) and achieves this because it uses cold North Sea water for cooling at certain times of the year.

Thus it is important that DH systems use the lowest possible supply and return temperatures.

By rejecting heat to DH at low temperatures, e.g. in two steps, e.g. from 40 to 65°C and further from 65 to 90°C the Z-value will be larger[209].

Moreover, by producing the DH at a capacity equal to the "pressure less point[210]" and at the time of the day and week at which the plant is running due to the need for heat and not at the time there is maximal daily electricity prices, then the Z-factor is even larger and more important, the productions costs of DH will be lower and the DH obligation will not reduce the capacity value of the power plant.

Thus it is important that DH systems are connected to power plant via a large heat accumulator, eg. Having a capacity equal to 10 hours of maximal heat load. Such accumulators can be semi pressurized to contain water up to e.g. 130°C, but it will be much simpler and cheaper if the maximal temperature is below 100 or 95°C.

For these reasons Danish experts recommend that it is important that the return temperature of the DH is as low as possible, e.g. 40°C and that the maximal demand for supply temperature is below 95°C. In fact all the heat sources of the future energy efficient society will benefit from low return temperature, e.g. heat pumps, solar water, geothermal, condensing biomass boilers, condensing biomethane CHP.

Danish experts also consider it important that building codes and standards also set requirements to the building level heating installations and e.g. require 35°C return at a

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[209] The reason why two extractions are theoretically better than one is as follows:
1. There must always be an extraction at the pressure necessary to supply the design flow temperature.
2. If part of the heat can be supplied by a lower pressure extraction, then the steam required for that part of the heat stays in the turbine for longer and therefore generates more electricity.
3. The lower the return temperature, the greater the temperature range and therefore the greater the separation of pressures when multiple extraction is employed.
4. The corollary is that the highest Z factor would correspond theoretically with an infinite number of extractions - so the more the better, having due regard to practical considerations. (Robert Hyde, RHEnergy Limited, 28 Tilmore Road Petersfield, Hampshire.

[210] **Presureless point.** When extracting steam for heating the DH water it is most optimal to bleed a small amount of steam along the expansion line in order to approach a situation as close as possible to a counter current heat exchanger; (Appendix 5) that is, with as small a temperature difference between the condensing steam (condensing steam temperature is determined by the pressure at which it was bled from the turbine) and the corresponding temperature of the DH water, as possible. This is of cause impossible to realize in a power plant. In particular the fact that steam condenses at a constant temperature (given the pressure) makes it difficult to have more than just a few (1, 2 or maybe three) heat exchangers in the DH production process. (note, that the turbine steam is not mixed with the DH water.)
In the real world, steam can only be bled from the turbine between stages; in the design of the turbine, if the maximum amount of DH is very small, one may bleed steam from between several stages. The typical situation with large DH production requires bleeds of a size that requires them to be made between turbine cylinders. Such a bleed for ONE DH heat exchanger is typically made with one valve to open up for the steam to the DH heat exchanger and another valve to shut off the steam from going to the next (low pressure) turbine. These valves normally operate such that for increased DH production the first valve opens fully and then the second valve shuts (almost completely). The point where both valves are fully open is called the loss-less point (or **pressure less point**) and in this point throttle-losses from either of the valves are avoided. To have two (or more) heat exchangers involved, it will normally require that the main steam mass flow is divided into separate flows and each flow has a bleed like the afore mentioned. Other solutions to this problem do exist depending on the actual situation (turbine sizes, DH temperatures, annual DH production etc.).

supply temperature of e.g. 65°C, which also is sufficient for hot tap water. This is not difficult, buildings with floor heating can achieve e.g. 25°C in normal operation and may be 30°C on a cold day.

As regards the energy performance of buildings they consider it as important that the building can be cooled by "high temperatures", e.g. 15°C instead of 5°C. This will increase the free cooling significantly and increase the performance of chillers.

Also this is possible to a large extent by using the same floor tubes for basic cooling.

The above mentioned can be studied in Denmark and at[211]

Danish experts also recommend that in order optimise future CHPs:

- In calculating the gross energy demand of the building to be lower than a certain low demand, the ratio between electricity, fuels and DH based on CHP and/or renewable should be: 2,5 : 1,0 : 0,5 to take into account the incremental costs and use of fossil fuels in the EU for these services to buildings.
- Heating installations should be designed for low temperature hot water, e.g. to hot water heated from 35 to 65°C
- Cooling installations should be designed for high temperature cooling
- Electricity consumption for heating and cooling should be interruptible in certain peak periods.

19.3. Thermodynamics of CHP – the Iron diagram

This section of the report goes into a small amount of detail on the thermodynamics of CHP and discusses the conversion of condensing power plants into condensing extraction units (also known as pass out units). Normal electricity only power plants are referred to as condensing – for obvious reasons. If they are either designed or subsequently modified to retain the condensing possibility, but also to permit extraction of the steam from higher up the turbines (i.e. closer to the high pressure part of the steam circuit) are referred to as extraction condensing units or for short extraction units with the condensing implied.

Most of the charts in this section unless otherwise stated have been kindly provided by Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator.

19.4. The Z-factor and the Iron Diagram for specifying CHP performance and its application to extraction condensing unit (also called a pass out turbine):

The diagram overleaf shows an extraction-condensing steam chp plant.

[211] http://www.stateofgreen.com/Profiles/Ramboll

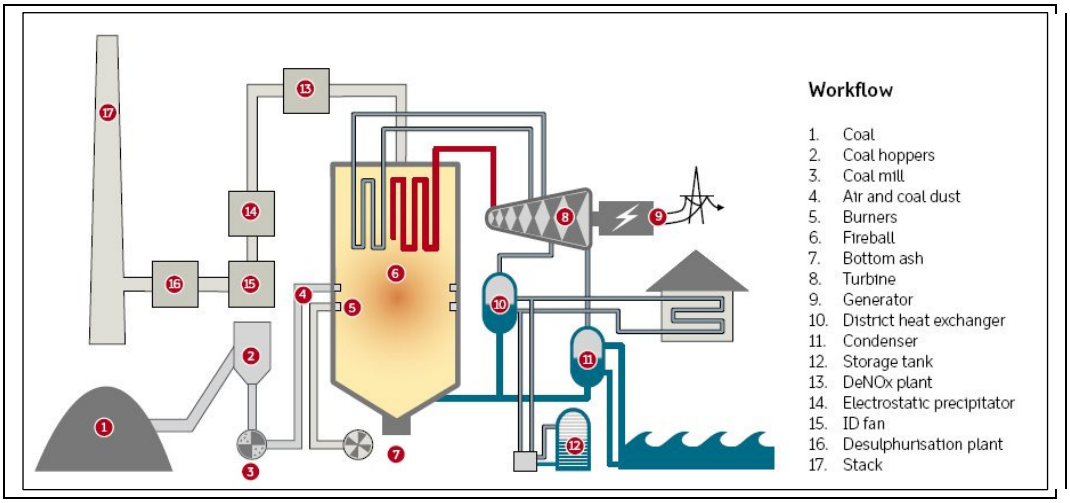


Figure 19-1 Diagram of an extraction unit. Heat is extracted for heat exchangers (10) at suitable temperature levels. In condensing mode all steam goes to the condenser[212]

The diagram below is used for describing the operation of an extraction condensing unit such as the unit in the figure above.

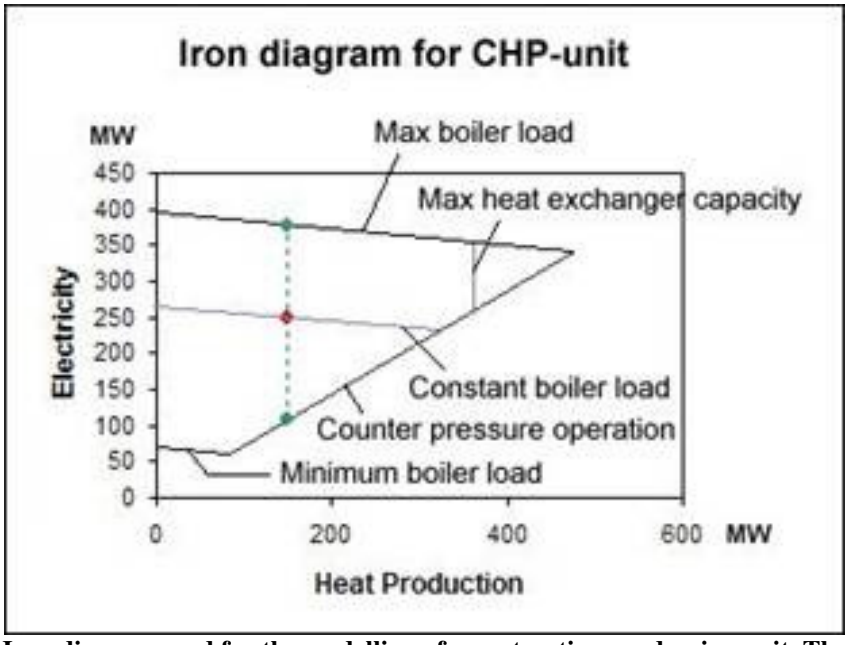


Figure 19-2 Iron diagram used for the modelling of an extraction condensing unit. The vertical axis indicates the power output MWe, and the horizontal axis the heat output MWth[213].

This diagram simply shows the range in which such an extraction condensing unit (also known as a pass out unit) can be operated and it enables the designers and promoters to look at various cost options and to model the economic value of various options. Starting at top left we can see that at max fuel burn / boiler load the unit will produce 400 MWe and no useful heat (a lot of low temperature heat of course which goes to atmosphere or sea).

[212] Dong Energy

[213] Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator.

As heat is extracted from the Low Pressure, LP turbine, by progressively opening valves at extraction points along the turbine, the power output drops and heat becomes available at a higher temperature, and the operating point of the turbine moves along the top line, here marked Max boiler load.

Eventually a limit is reached on the right hand side of the diagram at about 480 MW of heat and 350 MW of electricity.

If boiler output is now reduced, i.e. less fuel is fed into the boiler and we still want the maximum amount of heat possible, then the operating point (i.e. the behaviour of the plant) starts moving down and to the left along the line marked Counter pressure (or back pressure) operation. Heat and power will both reduce until we reach the lowest point in the diagram at about 85 MW of heat, and 65 MW of electricity. The boiler is now operating at its lowest permissible fuel burn rate and steam output.

If we now reduce the heat taken, by further limiting steam extraction, then power rises, with the operating point moving to the left and up until we reach the left hand vertical axis and producing 70MW of electricity but no heat.

If fuel supply (and therefore boiler load) is increased sufficiently, and still in the no heat output condition then we would arrive at the point at the left hand end of the Constant boiler load line producing 260 MW and with no heat (we could of course increase fuel burn until we were again at the max electrical output 400 MWe). If heat is extracted once again, and with the fuel load remaining constant, the heat available is indicated by this line, which is parallel to the original upper line of the diagram.

Thus we can choose any point on the left hand axis, and increase heat output, but diminish electricity whilst holding fuel burn / boiler output constant, and the operating point will move along the Constant boiler load line. This line is also called an iso-fuel line. There is an infinite number of these lines to choose between the upper and lower limit, thus it is clear that the extraction condensing turbine can be operated anywhere within this envelope.

The slope of the Constant boiler load line is known as the Z factor and is in the above case a constant (typically 10 to 5 MWth/MWe) and specifies how much heat is gained is lost for every unit of electricity lost.

The slope of the Counter (or back) pressure operation line is called the cM constant (0.5 to 1 MW/MW).

19.5. Exergy

There is a term called Exergy or in some books: Availability. In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with the environment. Thus exergy is for our purposes a measure of the usefulness or value of energy. This term expresses the fact that energy may have different values (to customers); i.e. high temperature heat is more valuable than low temperature heat (for the same amount of energy). Though a thermal power plant discharges large amount of (waste) energy, it has low exergy and has virtually no value (who will pay for 20°C warm water?); by sacrificing a little bit on the power production it is possible to add just a little bit

more exergy to the discharged energy (giving it a higher temperature - 80/100°C - of the cooling water) and thereby make it a sellable/valuable product. It is then easy to make the comparison with a heat pump – it uses a little bit of electricity to produce a larger amount of heat (by taking heat out of the surroundings). For a very good heat pump the ratio between the electricity spent and the power produced is around 4. For a CHP-plant this ratio is the Z-factor and it is superior to heat pumps as is its size (the amount of heat produced) - 300-500 MW.

It is inappropriate to use high exergy energy for example gas, for uses which require low exergy heat, such as heating which can be met with low temperature waste heat.

19.6. Non-linear lines for constant load in the Z-diagram

We should make the reservation that the lines for constant load in the Z-diagram may be non-linear in some cases. Therefore the Z-factor is not always constant.

It further turns out that even within the sub-regions, the iso-fuel lines may not be linear straight lines. It will thus be possible to have either a local slope (or Z-factor) and a global Z-factor (always referring back to condensing mode). This is shown in the figure below.

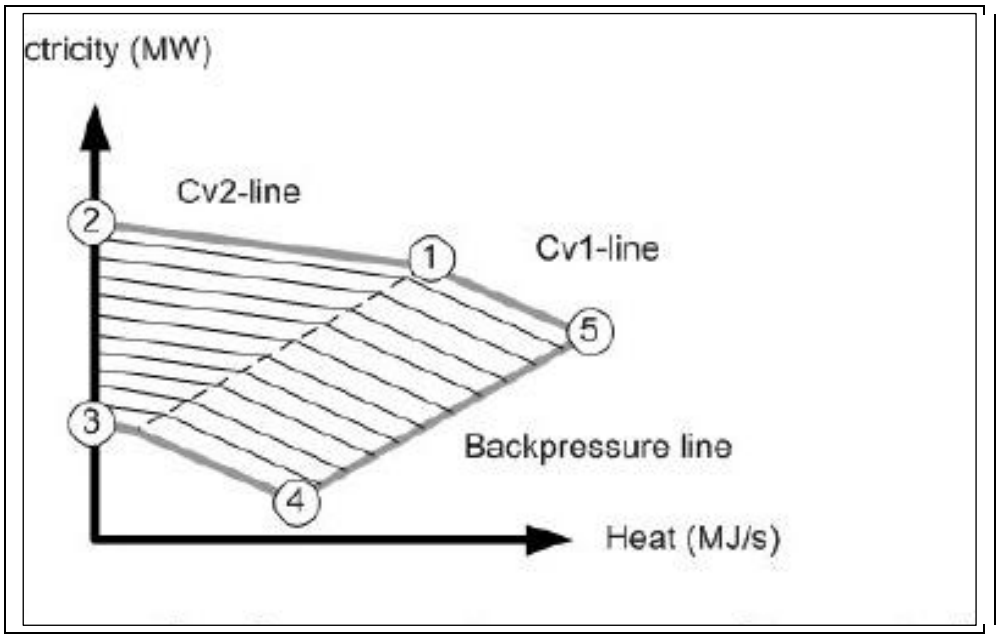


Figure 19-3 Iron diagram for the extraction steam turbine unit AMV3 with special characteristics[214]

19.7. Counter (or back) pressure turbine:

A backpressure turbine is a turbine operated between high pressure steam and lower pressure steam which means the exiting steam encounters the pressure of the lower pressure steam. The pressure in the low pressure end of the turbine is determined by the saturation pressure of steam at a temperature related to the highest coolant water temperature. If this temperate is (way) above the ambient temperature, the back pressure is much higher than the lowest possible pressure that could have been obtained in case the ambient had been used for heat

[214] Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator.

discharge. A back pressure turbine is a simple construction and since it is the same steam mass flow that both results in the electricity production and the heat production these two will be almost linearly dependent on one another. Thus this operational line is the only condition that a Counter (or back) pressure turbine can operate along. The back pressure turbine can only control the amount of heat extracted by changing boiler fuel input or throttling steam output and hence reducing electricity output whereas the extraction condensing unit can independently vary both within limits. Thus an extraction turbine has a much better operational flexibility than a counter pressure turbine but since it is generally more complex it more often used on larger turbines.

A back pressure steam turbine is typically used:

- in industry which often requires high temperature heat and
- in medium scale CHP plants (gas CC plants or biomass steam turbines) for district heating, which are too small to be competitive in the power market as a condensing plant, but large enough to be competitive against smaller CHP plants of the gas engine type

Different applications will have different CHP turbine solutions depending on heat and power demand and process types, i.e. some industries are more suitable than others for back pressure, others for extraction.
The design of the turbine, including choice between heating in one, two or three steps depends on the local conditions and has to be optimized.

19.8. Conversion of existing electricity only power stations to CHP

If a perfect CHP unit is desired starting from an existing generating set, then the entire turbine[215] may need to be replaced. This is an expensive solution (but still a lot cheaper than building an entirely new CHP station). In many cases the limitations of converting existing turbines were accepted and many such conversions were carried out in Denmark. According to one expert[216] "Most power stations can be converted" But in most of these Danish cases better units have been installed over time on the same site as the old ones, and the converted units were used as backup or decommissioned.

However there are many examples such as the Prague CHP power station conversion, and the Flensburg one (See Annex 1), where successful conversion have been carried out with many of the original components still in use. So conversion of existing turbines can be a practical option.

The diagram shown earlier figure 21.2 is an example of a new CHP unit with cM =0.7 and Z = 0.1 (approximately).

The Danish unit below was successfully converted with cM =0.6 and cV =0.14, and we can see that the maximal CHP potential could be utilized. Nevertheless, the unit is no longer in operation for other reasons.

[215] This is not always be the case and a replacement of the turbine (alone) may not always give a perfect result; boiler re-heat pressure limits may apply.

[216] Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator.

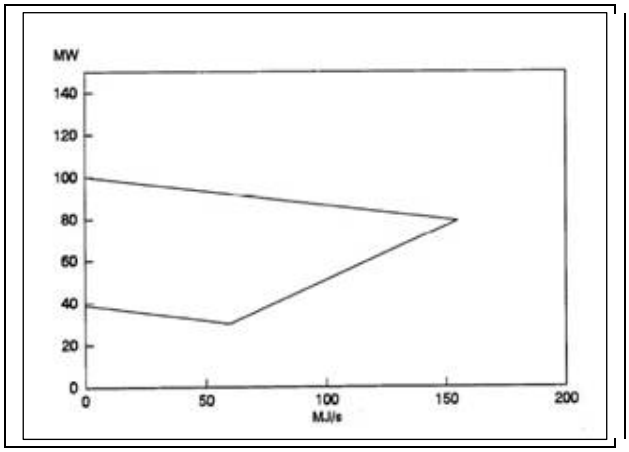


Figure 19-4 Successfully converted Danish unit - no longer in operation (this was considered a good interim solution since replaced by a purpose built CHP unit) [217]

The diagram below (cM =3.5 and cV =0.13) indicates that there has been a large condensing plant next to a smaller town and that only part of the CHP potential could be utilized. Therefore, although in principle it is a CHP plant, the total efficiency of the unit is almost as low as the efficiency of a condensing plant.

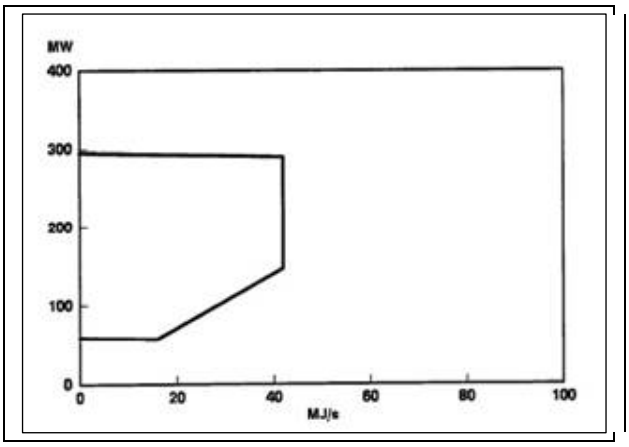


Figure 19-5 A less successful Danish conversion (cM =3.5 and cV =0.13) [218]

The conversion cost depends on the specifications of the existing turbine and the properties specified for the unit after the conversion. Generally the conversion into CHP need not be expensive compared to Flue Gas Desulphurisation (FGD) (deSOX and deNOX) and switching to another fuel (and the cost of DH transmission).

It should be noted that the amount of extraction can be chosen at will in a conversion, in other words it is not necessary to fully convert a given turbine and extract all the heat – any desired fraction can be made available – i.e. power stations can be partially converted.

217 Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator

218 Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator.

19.9. Heat to power ratio and range of practical Z factors219:

The coal fired CHP plant, Avedore Vaerket unit 1 (AVV1), commissioned in 1991 had a full load back pressure point (212 MW electric, 330 MW district heat) giving a heat to power ratio of 1:0.64. This plant has a Z-factor of (app.) 330 / (250-212) = 8.68. At that time probably best available technology.

In the design of the unit AVV2 (commissioned in 2001 and running on wood-pellets, oil and NGas) other considerations resulted in a solution with a much worse heat to power ratio (1:0.73 without gas turbines and 1:0.86 with GT) and the Z-factor being (6.93 and 7.19, respectively). The crucial point is the way the contracts on heat delivery are set up. In case the prices of the two products (power and heat) are commercially independent there could be an incentive to produce as much heat as possible with a Z-factor as high as possible. This need not be the case when the heat market is regulated.

(Numbers are obtained from the 'read more' point at:
http://www.dongenergy.com/EN/business%20activities/generation/electricity%20generation/Primary%20power%20stations/Pages/Avedore%20Power%20Station.aspx)

The important thing to observe here is that it may not always be BAT that is preferred even when building new plants since it might be beneficially to make other choices. Also, in particular for retrofit which most probably will be the case in Europe, the thermodynamics of the original plant will to a large extent determine what could at all be achieved when retrofitting to CHP. The three most critical points for the steam turbine are: 1) the location of the expansion line (most preferably it should pass close by the 1 Bar saturation point – how close depends on the DH forward temperature), 2) is there a possibility (or possibilities) for making steam extraction(s) from the turbine group near or (pressure-wise) above this point, and 3) can most of the expansion steam mass flow be diverted from the extraction point(s) to DH production.

19.10. Co-efficient of Performance (COP) of heat pumps compared to (COP) –Z factor for CHP. The importance of low DH temperatures to maximise efficiency of CHP.

A useful paper[220] illustrates how similar CHP is to electric heat pumps. In both cases power is used to upgrade heat. In the case of the heat pump the power drives the heat pump upgrading the heat. In the case of the CHP the power to upgrade the heat comes from a reduction in the electrical output from the power station, as a result of rejecting the heat at higher and more useful temperature.

The loss of electrical output in the CHP case, or electricity used in a heat pump case, is associated with the provision of heat at a higher temperature which as a result can perform more useful functions such as heating buildings.

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[219] Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

[220] "Why heat from Combined Heat and Power (CHP) Vilnius 3 is as renewable as heat from electric heat pumps" Presented to the 11th IAEE European Conference arranged by the Lithuanian Energy Institute (2010). WRH Orchard of Orchard Partners London Ltd. The title of the paper was subsequently revised to "Exergy & marginal fuel use an analysis of heat from CHP and heat from electric heat pumps."
http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf.

The paper analyses these effects and the effect of the temperature of heat networks on the effectiveness of heat pumps and CHP. It further analyses the effect of heat and electrical network losses on the effectiveness of the different technologies to reduce CO_2 emissions and reviews an EU Exergy method for the analysis of renewable CHP.

Both electric heat pumps and CHP have the potential to deliver large amounts of heat for the amount of electricity used to upgrade the heat. The measure of this ratio of electricity or power used per unit of heat obtained is known as its "Coefficient of Performance or "COP"

Due to the technologies having their own history and symbols in the case of CHP the use of electricity per unit of heat has been known as its "Z factor".

In comparing Coefficients of Performance it is important to know about the quality of the heat and its usefulness reflected by its temperature. As an example whilst heat at around 40°C can be used for under floor heating, for domestic hot water heat at over 60°C is required.

Electric heat pumps typically have Coefficients of performance (COP) of 3 – 4 when upgrading heat in the environment to deliver heat to buildings at relatively low temperatures suited particularly for under floor heating.

The following chart illustrates the effect of network temperatures and the number of stages of extraction[221]. Commonly two stages of extraction are used for large scale CHP. The Vilnius 3 power plant however was designed with three stages of extraction so the chart illustrates this effect. The reason more stages of extraction deliver a higher COP is that less power is used to provide the heat.

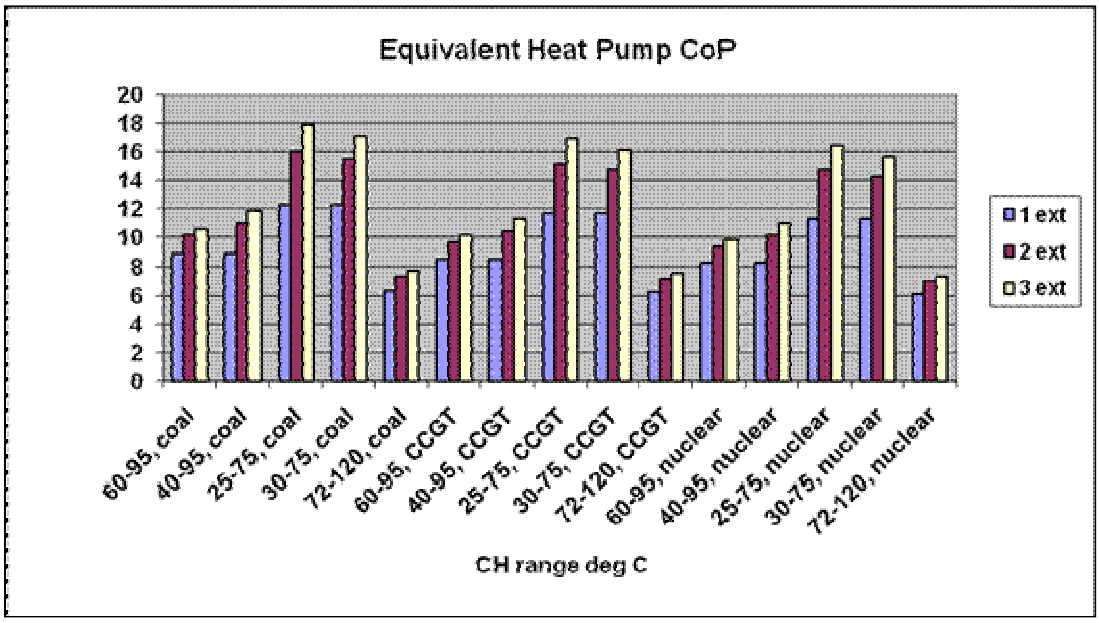


Figure 19-6 the equivalent COP of various power generating systems with different DH temperatures and one, two or three stages of steam extraction.

[221] Steam can be extracted in 1,2 or 3 stages in a CHP plant. Generally the more stages, the better the Z or COP.

One should note that the quality of the heat from all these options is greater than 75C making this source of heat suitable for feeding existing buildings with radiator system designed to accept heat from boilers.

The reason the COP for the heat from the CHP is superior to the heat from heat pumps whether directly driven or electrically driven is due to the much higher source temperature of heat for the CHP typically 28-30°C summer and winter compared to 8°C for ground source heat pumps and say minus 10°C for air source heat pumps in winter.

The approach to considering CHP as a "Virtual Heat Pump" is also explored in Professor Robert Lowe's[222], paper "Combined heat and power considered as a virtual steam cycle heat pump"

In his paper he provides a clear theoretical explanation in some detail as to why steam turbine CHP can be considered a "virtual steam cycle heat pump.

His paper also illustrates the effect of the temperature at which heat rejected in power generation in relation to its use.

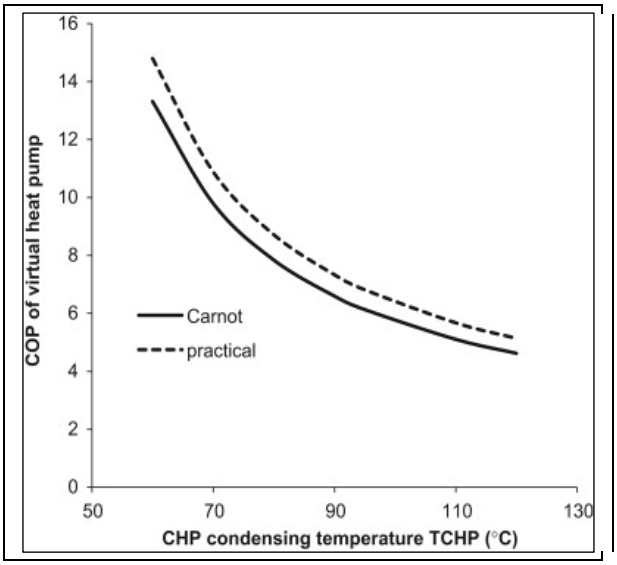


Figure 19-6 Graph showing theoretically how the COP or Z-factor of a steam cycle power station increases with lowering condensing temperature[223]

In the case of horticulture or aquaculture where heat normally rejected to the environment through cooling towers is at a high enough temperature to be useful.

Under this condition if there is no impact on the power stations efficiency to produce electricity, then the COP for the heat is infinite.

[222] Energy Policy 39 (2011) 5528–5534.

[223] Professor Robert Lowe, Combined heat and power considered as a virtual steam cycle heat pump, Energy Policy 39 (2011) 5528–5534.

19.11. Load following and back up to variable / intermittent renewable energy sources such as wind.

Optimisation of the role of electric heat pumps and CHP and the integration of heat networks with electrical networks and renewable sources of electricity and heat appears to offer considerable potential particularly due to the ability to store heat and the ability of heat networks to diversify the demand for heat. This ability to store heat offers significant benefits for scenarios to resolve heat sector decarbonisation solutions through heat networks whatever the heat source.

The reason for this is linked to the fundamental difficulties of economically storing electricity to meet peak heating demands. A further factor relates to the electrical generating capacity required to meet heat demands on the coldest days and the high losses on electrical networks at times of peak demand compared to their average losses over a year.

A benefit of large scale extraction condensing CHP is its ability to vary its electrical and heat outputs. This makes the system particularly attractive for meeting diurnal variations in electricity demand which for a normal electricity generating station will reduce its efficiency and performance on part load. Such plant when operated in the CHP mode continue to operate their boilers of gas turbines at maximum efficiency and by delivering heat at night to large heat accumulators provide benefits to both electrical and heat consumers from more effective conversion of fuel to useful products.
In Denmark the thermal storage capacity is increased and adjusted to an optimal level based on current trading signals. Fynsværket started in 1975 with 15.000 m^3 and now it is 75.000 m^3. In 2020 it is expected that there will be even more storage capacity due to more electricity from wind and questions as to how best to integrate such capacity. One option may well be if the electricity cannot be readily stored to use it in electric heat pumps to raise the temperature from very large heat stores to feed heat in to heat networks.

See Chapter 10 for more details of storage.

20. TYPES OF POWER PLANTS THAT CAN BE OBTAINED EITHER AS ELECTRICITY-ONLY OR CHP

20.1. Internal combustion, Stirling engines and gas turbine power generators**Error! Bookmark not defin**
20.2. Back or Counter pressure turbine .....**Error! Bookmark not defined.**
20.3. Large Single Cycle Steam Power stations .....**Error! Bookmark not defined.**
20.4. Example - Nordjylland 3, Denmark.....**Error! Bookmark not defined.**
20.5. Differences Needed To Enable Large Single Cycle Power Stations to Be Able To Provide Heat for CHP-DH.....**Error! Bookmark not defined.**
20.6. Z factor for Nordjylland (Nordjyllandsværket) power station**Error! Bookmark not defined.**
20.7. Large Combined Cycle Power stations: (CCGT also referred to as NGCC – Natural Gas Combined Cycle).....**Error! Bookmark not defined.**
20.8. Application of CHP to a CCGT.....**Error! Bookmark not defined.**
20.9. CCGTs specifically designed for CHP.....**Error! Bookmark not defined.**

Almost all types of power plants, from a few kW to several GW can be obtained as electricity only, or with some modification or additions as CHP – this section briefly reviews them.

20.1. Internal combustion, Stirling engines and gas turbine power generators

With these type of devices, which range in size from a few kWe for internal combustion (large ship engines can be up to 40 MW) and Stirling engines, to 100s of MWe for gas turbines then the extraction of waste heat for CHP has little or at least insignificant effect on the power generating efficiency. It is a matter of common experience that utilising the heater on a car, which is driven by a small internal combustion engine, has no impact on the fuel consumption of the car. With gas turbines there may be some efficiency and power loss due to the back pressure exerted by the heat exchanger (but this back pressure is normally independent of the amount of heat extracted)

This is because these devices consist of the prime mover such as the engine or turbine which drives the generator. Any heat recovery will be achieved by attaching a heat exchanger to the engine or turbine through which the exhaust gases pass. This has little if any effect on the performance of the power cycle apart from possibly a slightly increased power loss due to the obstruction of the exhaust gases. In the engine case, additional heat can be picked up from the engine jacket and this has absolutely no effect at all on the efficiency of the engine.

There will be slightly increased losses due to the extra pumping power needed to circulate water around the various heat exchangers, but these are marginal losses. These losses are known as parasitic losses and are generally 1 or 2 %.

The great advantage of these ICE and GT devices is that the heat can be taken at a very high temperature – thus steam or hot water can be made available at several hundred °C. This is in part a consequence of the inefficiency of these devices, which from Carnot means the exhaust gases are at high temperatures compared to more complex and efficient plants.

A lifetime maintenance cost of this type of unit is around 0.001 EUR/kWh which compares with a CCGT of around 0.003 EUR/kWh.

LCV efficiencies of 43% can be compared with a CCGTs efficiency of up to 60%, peak in both cases.

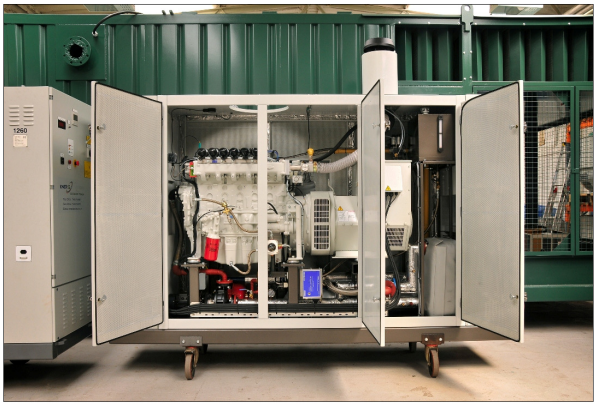


Figure 20-2 Aprox 150 kWe gas engine chp unit



Figure 20-1Approx 500 kWe gas engine chp unit

20.2. Back or Counter pressure turbine

A back pressure turbine is a very common device found in many large industrial locations. Typically in an oil refinery or chemical plant, steam is raised centrally in a boiler house, or energy centre, at high pressure and distributed around the site where it can be used at a variety of pressures either that at which it was generated or lower. Where lower pressure steam is needed in a process below the maximum pressure this can be achieved using a throttling device, but this wastes the pressure energy of the steam. So it is normal if the quantity of steam is large to employ a back pressure turbine to lower the pressure. This operates between a high pressure steam line and a lower pressure line. This device then simply captures the pressure energy and generates electrical power by driving a generator. The electricity is either used on the site or exported. This is relatively inefficient in terms of power generation, due to the relatively higher temperature of the steam at the turbine outlet, and the back pressure on the exiting steam. It is a fact that having several minor turbines for an expansion is generally much more inefficient than one large. Nevertheless, no energy is wasted and the simplicity and high overall (heat plus electricity) efficiency and the cheapness of these devices make their use very widespread.

This type of turbine was commonly used in CHP-DH schemes but is relatively little used except in legacy systems.

20.3. Large Single Cycle Steam Power stations

Most large steam cycle power stations which are typically coal or heavy fuel fired, consist of several generating units each typically around 500 - 650 MW. (The maximum size is around 900MW). The fuel is burnt, raises steam in a boiler, which drives a turbine to produce electricity.

This arrangement which has evolved over many years, gives rise to the most efficient means of converting difficult fuels such as coal and heavy oil into electricity. These are fuels which due to their nature – solids or liquids with a range of contaminants which renders them unsuitable for burning in other plant such as engines or gas turbines. Solid fuels and heavy

oils are not useable in Gas Turbines (GTs) and Internal Combustion Engines (ICE); large ship engines may run on heavy fuel oil.

For example Drax Power Station, in Yorkshire, UK is around 4 GWe and has 6 x 660 MWe generating sets. Each generating set consists of:

- A means of feeding coal into a boiler
- Fans to blow air into the boiler
- A boiler to generate steam
- An exhaust gas duct and chimney fitted with dust removal and sulphur dioxide extraction equipment
- A high pressure turbine
- Steam pipe from the boiler to the inlet of the high pressure HP, turbine and which may be at a temperature of 582 ^{0}C and a pressure of 290 Bar or 290 times atmospheric pressure.
- Steam piping, which conveys the steam from the exit of each turbine, to the inlet of the succeeding, and lower pressure turbine, often with a means of re-heating steam to dry the steam exiting from the lower pressure end before it is fed to the next turbine
- A medium pressure turbine
- A low pressure turbine
- A condenser fitted at the outlet of the low pressure turbine. This is fed with cold water from either the sea or a cooling tower (isolated by a heat exchanger) and is a heat exchanger designed to immediately condense steam leaving the turbine to warmish water. This arrangement provides a near vacuum at the LP turbine exit, which ensures there is no "back pressure" on the steam leaving, thereby ensuring maximum efficiency.
- A means of cooling the warmed water exiting the condenser – this may be a cooling tower, or a convenient river or sea water body.
- A single generator driven by the turbines which are all mounted on a single shaft and rotating at 3600 / 3000 revolutions per minute (typically)

20.4. Example - Nordjylland 3, Denmark

Nordjylland 3 is a sea water cooled Ultra-Super Critical (USC) plant. This means it operates well above the critical pressure/temperature (221 Bar / 374 C)). Opened in 1998, the plant is situated near the town of Aalborg, Denmark. In power-only mode, the net efficiency (see Annex 2) is 47%, on a fuel LHV (see Annex 2) basis (44.9% on an HHV basis), and is the most efficient coal-fired unit in the world. The high efficiency comes from use of a double reheat steam cycle at very high conditions (29 MPa/582°C/580°C/580°C) plus a low condenser pressure from the availability of cold sea water for cooling. The steam conditions took full advantage of newly available materials when the plant was designed but also necessitated the use of flue gas re-circulation and advanced water treatment as well as care in start-up to ensure integrity of boiler components.[224] It can operate in CHP mode as well.

[224] Professor Robert Lowe, Combined heat and power considered as a virtual steam cycle heat pump, Energy Policy 39 (2011) 5528–5534.

20.5. Differences Needed To Enable Large Single Cycle Power Stations to Be Able To Provide Heat for CHP-DH

The technical difference between the electricity only version of these plants and a version which can deliver heat at a temperature suitable for DH, is that there must be some means of condensing the steam at a higher temperature than for electricity only. This is achieved by extracting steam from the turbine higher up i.e. towards the higher pressure end (there may be several steam extraction points), and diverting it to a district heating heat exchanger. By allowing the steam to condense at a higher temperature say 95°C - 75°C, rather than the lower temperatures at Nordjylland heat is made available at a sufficiently high temperature to permit building heating.

As we would expect from Carnot's Law, this comes at the price of a reduction in the efficiency at which power is generated. At Nordjylland the operators have means to divert steam from the low temperature condenser to a higher temperature condenser. The more steam is diverted to the higher temperature district heating condenser, the less electricity is generated, because there is less steam passing through the LP turbine, and thus less power transmitted to the generator.

Note that during this transition, there is no change in the fuel consumption of the power station, unless for other reasons the operators decide to lower fuel burn.

20.6. Z factor for Nordjylland (Nordjyllandsværket) power station

The Nordjylland power station is a sea water cooled power station fuelled by imported international bituminous coal. In power-only mode, the net efficiency (see Annex 2) is 47%, on a fuel LHV (see Annex 2) The power station is situated on the north bank of the Limfjord, about 10 kilometres North East of the Northern Danish town of Aalborg. The short distance to an urban area with some 200,000 inhabitants offered the opportunity to establish a pipeline for hot water to an existing grid for district heating. Commissioned in 1998, the net electrical output of Unit 3 for no heating load is 384 MWe and gross electrical output is 411 MWe. At nominal heat output of 420 MJ/s MJ/s (MWth), gross electrical output is 340 MWe according to published figures[225].

We can estimate the Z factor for this plant as follows:

411 – 340 (loss of electricity when shifting to heat output, MWe) divided by 420 MWth (gain in heat) give a Cv value of 0.169, corresponding to a Z value of 5.915. This is equivalent thermodynamically to a heat pump with a COP of 5.915. The actual figures are confidential but we understand that in the normal optimized operation, the Z-factor is in fact around 8.

This Cv of 0,169 is the value at maximum heat load. The dynamic Cv, which is the average during the year is probably 20% lower thus the average z is nearer 7. Since the liberalization these are considered confidential.

[225] http://www.vattenfall.dk/da/file/NordjyllandUK080121_7841588.pdf

20.7. Large Combined Cycle Power stations: (CCGT also referred to as NGCC – Natural Gas Combined Cycle)

This kind of power station is a development of the gas turbine and steam turbine plant. They are generally only suitable for clean fuels because of the gas turbine's requirement for clean fuel. (However Integrated Combined Cycle Gasification – (IGCC) plant where the coal is gasified and cleaned have been developed, but these are not in widespread use as of yet).

In simple terms, with this type of plant, the fuel gas is first burnt in a large gas turbine which may be up to 200 MWe (or even more for H technology machines) where electricity is generated at an efficiency of perhaps 40% LHV The exhaust gas from the GT is then fed into a steam boiler/exhaust gas heat exchanger, and steam is raised and used in a steam turbine generally of around half the output of the GTs feeding it, much as in the standard steam plant described earlier where it may generate power at around 20% LHV electrical efficiency. Plants of this type at utility scale typically have a combined output in the range 200 – 440MW.

From the Carnot point of view the benefits are obvious – the fuel is burnt in the GT at a much higher temperature than the steam entering the HP end of the steam turbine simple cycle described earlier, whereas the heat from the steam turbine is rejected at as low a temperature as in the fully condensing steam plant. Therefore the total temperature difference between the heat supply temperature and heat rejection temperature is much greater leading to a much higher efficiency.

The most efficient CCGTs can achieve LHV efficiencies of 60% which is the sum of the separate efficiencies of the gas turbine and the steam turbine, which compare to the best coal plant mentioned earlier which is 47% LHV.

20.8. Application of CHP to a CCGT

The CCGT can readily be purchased or converted to CHP-DH as shown in the figure below by the addition of various heat exchangers and other relatively minor changes.
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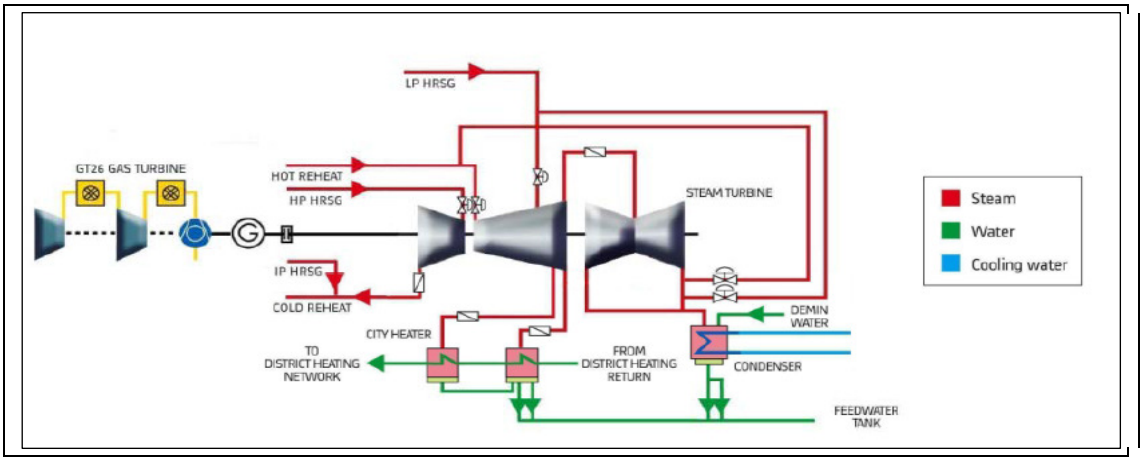


Figure 20-3 Water steam cycle of the Alstom KA26 ecoHEAT CCGT for district heating – with controlled steam extraction feeding two district heaters for flexible and efficient cogeneration[226]

20.9. CCGTs specifically designed for CHP

Below is the performance envelope of one of the latest CCGTs specifically designed for CHP operation. (It is the Iron Diagram shown earlier, but with the axis reversed) This unit is up to 60% efficient in electrical only mode.[227]

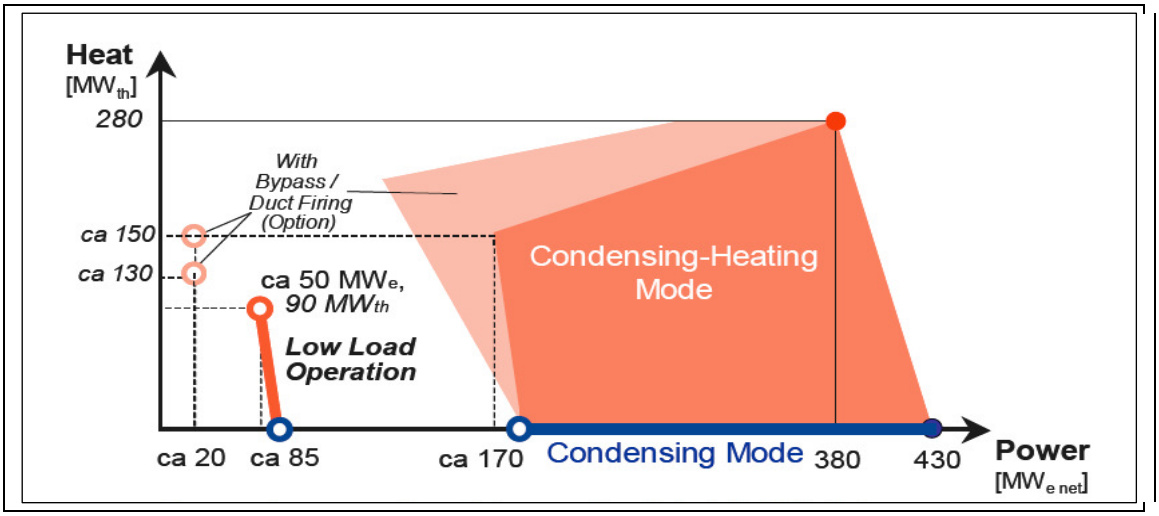


Figure 20-4 Large operation window provides highest flexibility between power (horizontal axis) and heat production (vertical axis) [228].

We can easily calculate the Z factor for this CHP station. It clearly loses 430 - 380 = 50 MWe, to provide 280 MWth, and therefore the Z factor is 5.6.

[226] http://www.alstom.com/Global/Power/Resources/Documents/Brochures/ka26-ecoheat-combined-heat-power.pdf

[227] http://www.alstom.com/Global/Power/Resources/Documents/Brochures/ka26-ecoheat-combined-heat-power.pdf

[228] http://www.alstom.com/Global/Power/Resources/Documents/Brochures/ka26-ecoheat-combined-heat-power.pdf

21. METHODS OF ALLOCATION OF CARBON SAVING AND FUEL SAVING IN CHP PROCESSES

21.1. The Orchard Convention ..... **Error! Bookmark not defined.**

21.2. The extent to which the economic benefit of insulation is reduced by low carbon / fuel content heat. ..... **Error! Bookmark not defined.**

21.3. Impact on incentive design ..... **Error! Bookmark not defined.**

21.4. Carbon footprint of CHP-DH and biomass ..... **Error! Bookmark not defined.**

21.1. The Orchard Convention

A very important issue mentioned earlier in Chapter 3 is how to we allocate the benefit of CHP. Should the energy and carbon savings be allocated to the benefit of electricity consumers and the electricity sector, or to heat consumers and the heat sector, or some arbitrary split between sectors?

It can be argued that it doesn't matter where the benefit is allocated. But actually this is very important. It can have a significant effect on policy and how to signal and incentivise maximisation of the useful energy and income from fuel. Where incentives are being offered to reduce primary energy use and or the CO_2 overhead of that primary energy is it better to encourage the development of low carbon heat supply through low temperature piped heat networks through an incentive on the electricity from the CHP, or is the incentive more appropriate on the low carbon waste product i.e. the heat?

There are a number of different methods for analysing CHP, and each has its advantages and disadvantages. As an example of the different approaches, which may be taken and the different results which occur, the Orchard Convention can be considered, which is described in two papers[229],[230]. It reasons that the laws of thermodynamics mean that no fuel savings arise for electricity consumers when heat rejected in electricity generation performs a useful function. The paper reasons that whilst incentives may well be appropriate on the electricity the primary incentives need to be on the heat with a mechanism to encourage investment in the heat networks essential if this method of decarbonising our existing building stock is to be optimized.

The "Orchard Method" allocates all the increased cost, essentially the extra fuel burn to the heat consumers. The principle behind the analysis is that the fuel use per unit of electricity stays the same as the electricity from a reference generator, for all CHP's and electricity-only generators which can be thought of as CHP's where the heat is just not used.

When it is decided to use heat at higher temperature from the CHP's its electrical efficiency reduces. To maintain the same cost and fuel use for electricity sold to other consumers, whether we reject the heat at 30°C or need to use some electricity to upgrade the heat to say

[229] BIEE Academic Conference St Johns College Oxford Supplementary Paper W R H Orchard MA MBA CEng FIMechE MCIBSE MIEE FinstE "Discussion of defects in current UK and proposed EU conventions for allocation of fuel burn for power and heat rejected in power generation" http://www.orchardpartners.co.uk/Docs/005-Orchard-Convention-BIEERef8.pdf

[230] 11thIAEE Conference Vilnius 2010 "Why heat from Combined Heat and Power (CHP) is as renewable as heat from electric heat pumps. W R H Orchard MA(Oxon) MBA CEng FIMechE MCIBSE MIET FEI http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf

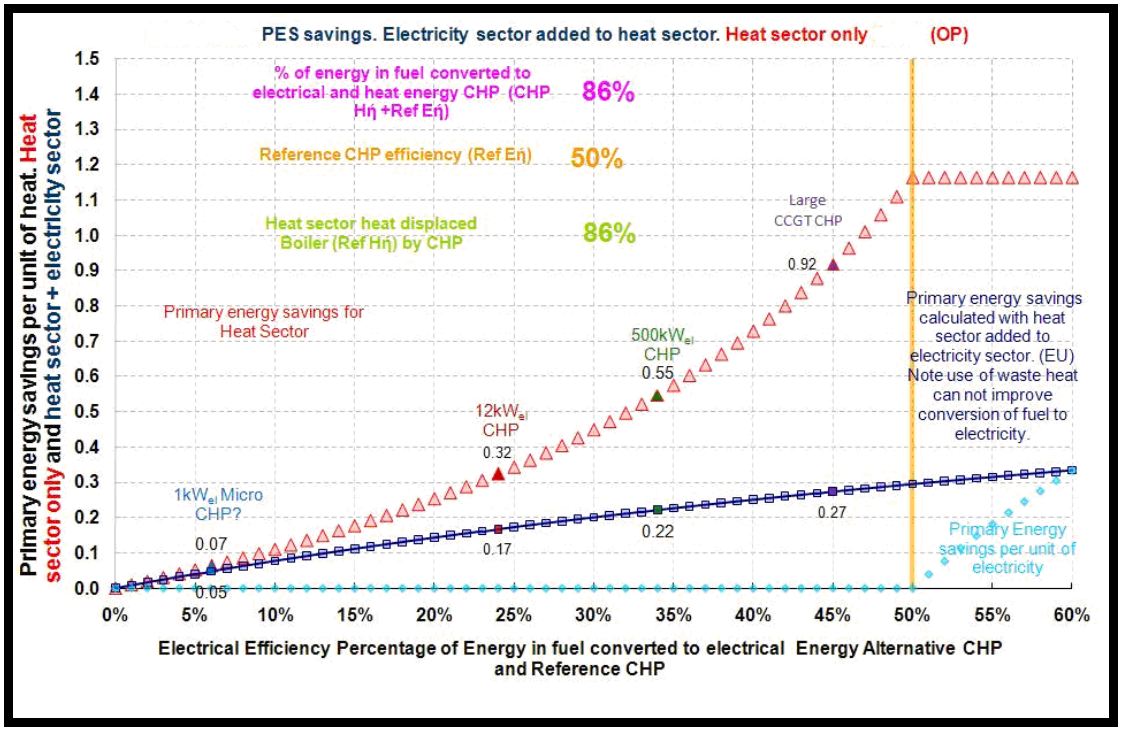
90°C the fuel is allocated to the heat. The effect of this is that one can see what the benefit is to heat consumers by operating any electricity only generator as CHP without its operation affecting the costs to electricity consumers.

The following chart from the paper[231] illustrates alternative methods of presenting the savings achieved from the operation of CHP on the heat sector, and some combination of the heat sector with the electricity sector (the Primary Energy Savings method, Chapter 3.5). It uses reference electricity generation from 50% HHV efficient CCGT for comparison in the electricity sector, against lower efficiency electricity generators operating either as CHP or electricity only generation.

Clearly if we decide to reduce the output of electricity by using the waste heat, other electricity has to come from an alternative electricity generator which is represented by the reference generator. This generator which will typically be a large CCGT may well feed into another part of the system. In practice this reference generator and its electrical efficiency will change depending on what type of other generation is operating on the electrical network to meet demand when electrical output is reduced to produce heat.

The following chart compares primary energy savings from lower electrical efficiency CHPs operating at a time on an electrical system when the reference plant is a 50% HHV efficient reference CCGT. The overall efficiency for the both the CHP and heat from a boiler treated as the alternative source of heat in the heat sector in the diagram is 86% HHV to estimate the savings in this example. However the method works equally well for other alternative sources of heat such as direct electric heating where if the source was electricity then the relevant figure would be as an example 38% HHV for electricity from coal and 50% HHV for electricity from CCGT. The figure for electric heat pumps then depends on its COP and the electricity source for the electric heat pumps.

[231] 11thIAEE Conference Vilnius 2010 "Why heat from Combined Heat and Power (CHP) is as renewable as heat from electric heat pumps. W R H Orchard MA(Oxon) MBA CEng FIMechE MCIBSE MIET FEI http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf



When reject heat from CHP is used for horticulture at 28°C our primary saving is all the fuel that would otherwise be burnt either in the green house boiler, or burnt to provide electric or other forms of greenhouse heating. The chart shows this as a primary energy saving of 1.16 units of fuel where the red curve with triangular symbols cuts the vertical yellow line representing the reference power plant and its electrical efficiency.

When a CCGT or other steam turbine power, moves to operation as virtual heat pump with less electricity generated and heat upgraded when rejected to a temperature suitable for district heating, this electricity use is reflected by the lower electrical efficiency shown on the diagram on the x axis by a change from 50% to say 45% for the CCGT in CHP mode. 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 reject heat is now at over 70°C instead of 28°C and can be used to heat cities.

The blue curve shows a different type of saving. This is the overall saving for electricity and heat. It is calculated by adding heat as a product, to electricity as a product. It illustrates the benefit of CHP to the country as a whole if as in this case the whole country was otherwise heated with 86% efficient boilers using the same type of fuel as the CHP. It does not reflect actuality due to the varied nature of other methods of currently heating a country or the differing fuels.

A further matter to consider is the effect of combining the electricity sector where no saving can be obtained from CHP with the heat sector where all the savings are realised. It is easy to understand that if heat normally rejected at 32°C is used for horticulture, e.g. growing tomatoes, then a 100% saving arises of the alternative fuel or heat source. Looking at the chart one can see that combining the heat with the electricity signals a saving of only 30%.

Information from this blue curve can result in planners being misled in relation to the technological potential of CHP for heat sectors, as an example, in using this figure to compare the relative benefit of insulation, with a heat sector specific solution to CHP and low

carbon piped heat supply.

The chart also shows how the greatest savings arise with CHP where the electrical performance of CHPs is as high as possible in relation to the useful heat they can produce.

The relatively low primary energy savings from micro CHPs tested by the Energy Savings Trust in the UK for units with electrical efficiencies on a HCV basis of between 6 and 20 % confirm this effect.

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 the Primary Energy saving method commonly used in formulas for assessing savings from CHP obscures the benefits of the higher electrical efficiency CHP for the heat sector and the lower primary energy overhead of the heat and its associated CO_2 footprint.

In agricultural terms the paper [232] argues that the blue curve is similar to adding information about "apples" to information "oranges" on the basis that both are fruit, then estimating savings for a "apples and oranges" mix.

Some models and statistics view the use of heat from a CHP plant as lowering the carbon content of the electricity. The reasoning is based on an idea held by some economists that there has to be a joint benefit when two products arise from a single source. This is illogical to many engineers and scientists[233], with knowledge of thermodynamic laws, who have studied this in detail. They agree that the carbon and energy savings from CHP should be allocated to the heat sector (i.e. building or process heating). That is, the reject heat is treated as a low primary energy / low carbon source, and by using this heat to heat buildings, we displace high carbon, high primary energy content sources such as oil, gas or electricity. Thus low energy / low carbon reject heat saves primary energy / carbon in the heat sector (building or process heating).

Consider a large power station, which is electricity only and dissipates low temperature heat to water in cooling towers. Assume it is operating at maximum output, and therefore maximum fuel burn. The electricity will have a certain carbon foot print and primary energy content.

If the waste heat, without altering its temperature, is now used for example to heat a fish farm or a greenhouse – which is possible with this type of low temperature heat, this has absolutely no effect on the fuel burn in the power station (it is still burning the same, maximum rate of fuel) and hence the energy content or carbon content of the electricity remains unchanged. It will perform exactly the same as a power station not heating a fish farm. We can say with assurance that the primary energy and carbon content of the heat is zero and that the carbon content of the electricity is the same as before we started using the waste heat.

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[232] 11thIAEE Conference Vilnius 2010 "Why heat from Combined Heat and Power (CHP) is as renewable as heat from electric heat pumps. W R H Orchard MA(Oxon) MBA CEng FIMechE MCIBSE MIET FEI http://www.orchardpartners.co.uk/Docs/IAEEVilniusPaperWhyHeatFromCHPisRenewableMarginalExergyAnalysis2011-09-14.pdf

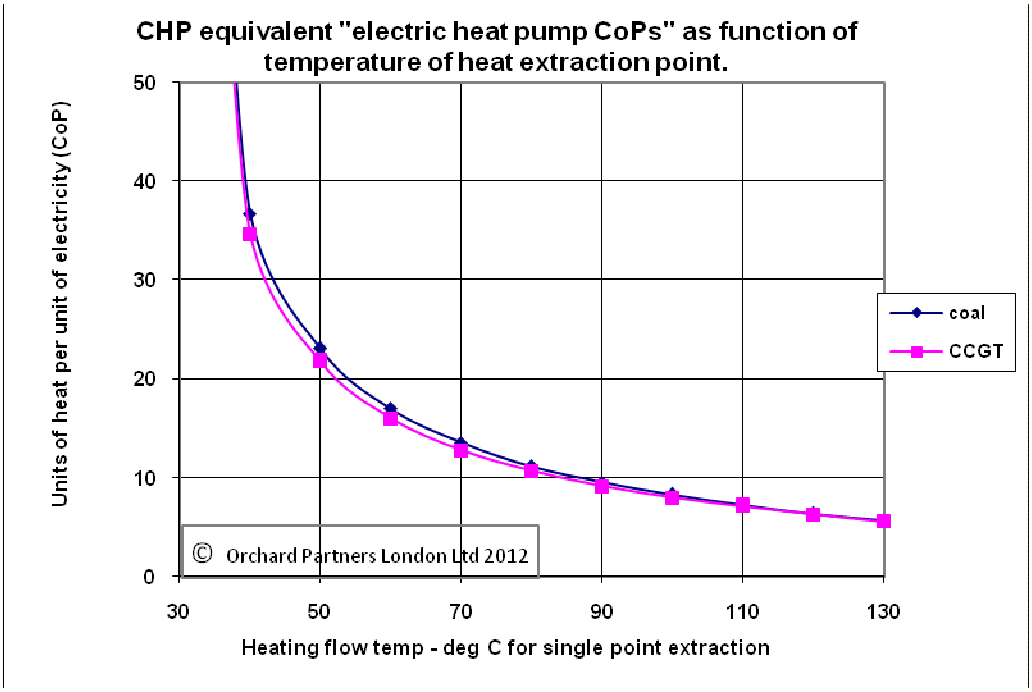
[233] e.g. Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

If we now start to raise the temperature of the heat we extract from the power station by extracting steam, and becoming a CHP stations, the boiler fuel burn will remain constant (at its maximum rate), We now get more heat at a higher temperature but less electricity (as noted earlier which can be calculated from the Z factor - i.e. how many heat units we gain for each unit of electricity we lose, typically 4 – 10. See Section 19.3.1). This Z factor CHP terminology is identical to the Coefficient of Performance (COP) for electric heat pumps.

If we want to maintain the electricity output of the station and the electricity system (ie that particular national grid system) as a whole as before, we need to produce more electricity from an identical unit operating on part load elsewhere and below its maximum output. We then burn a small amount of additional fuel to produce more electricity in this power plant. One way of understanding how we calculate the fuel use per unit of upgraded waste heat is to consider this fuel as the fuel required to upgrade the quality of the heat from the CHP.

This extra power station fuel burn should be allocated to the heat sector, since it is the extra fuel burnt to maintain the electrical output of the entire electricity system at the same level as before. This extra fuel burn can readily be calculated from the known efficiency of the electricity-only plant, and Z factor of the CHP plant in question

The carbon and fuel content of power station waste heat can be very low. How low depends on the temperature of the heat from the steam turbine CHP. This measured by the COP of the heat varies from infinity when the heat is used at the lowest temperature for agriculture as illustrated in the following chart which shows how steeply the curve is rising to infinity as the temperature of the reject heat approaches 30°C



These theoretical COPs can be compared with COPs for electric heat pumps using electricity from the same electricity generator of 3-4 when heating buildings using heat in the environment at say 8°C for ground source units and temperatures varying from 10°C to below minus 10°C for air source units.

This method permits comparison between alternative methods to decarbonise heat sectors. It

can compare heat from CHP to other low carbon supply sources, heat pumps; high efficiency boilers direct electric heating and demand side measures such as insulation.

The papers describing the method also explain why the method conforms to principles of economic analysis for joint products.

Where there are joint products, such as electricity and heat, it is easy to determine the fuel use for the respective products. You simply alter demand for one product with no change in demand for the other product. This method reflects real life market situations.

For the two main types of CHP this principle can be readily applied to steam turbines and diesel and gas engines.

Where CHP is a large extraction condensing turbine the amount of heat extracted and the amount of electricity generated can be varied in a way that demand for one product can be held constant and demand for the other product increased. A diagram of the characteristics of specific turbine generators is used to determine detailed information about the marginal fuel use for electricity and heat production for load changes.

In practice it is found that extraction of heat benefits the supply of electricity when small amount of electricity output are required. Under these conditions for electricity only production are constrained by minimum operating conditions for boilers.

By extracting heat the additional load on the boiler permits operation to the benefit of electricity and heat consumers.

21.2. The extent to which the economic benefit of insulation is reduced by low carbon / fuel content heat.

Where CHP is a diesel or gas engine the heat is rejected at useful temperature for immediate use to heat buildings and cities with no change in electrical efficiency of conversion fuel to electricity. In this case the signal for an increase in demand for heat delivers a signal of zero incremental fuel burn for increases in demand for heat. The fuel use for the power does not change.

This principle is understood by motorists with internal combustion engines in cars.

They find that turning their car heater on in winter makes no difference to fuel use for a journey.

As a result there is no economic case to insulate a motor car to reduce its fabric heat loss.

This same principle applies when optimising investment in lowCO2 heat supplies to existing buildings and the evaluation of the cost and economic case for adding insulation to reduce the fabric element of a buildings heat demand taking into account the other building heat loads that also require decarbonisation the domestic hot water and ventilation load. See also Chapter 15.

The method therefore could be considered for the evaluation of the retrofitting of district heating to existing cities as one option for decarbonising the heat sector.

1

21.3. Impact on incentive design

In Europe most incentives for CHP are applied to the electricity generated. Logically any incentive, rather than being a bonus for the electricity, could be applied instead to the heat from a CHP station which is where the benefits occur. This would have the benefit of driving the heat recovery to the highest limit.

21.4. Carbon footprint of CHP-DH and biomass

CHP-DH has one of the lowest carbon footprints of all typical heat sources, significantly lower than electric heat pumps as indicated by the table below. [234]

(In the below table, reproduced in its entirety, the biomass footprint is controversial see * below)

[234] William Orchard Partners. 2009. http://www.claverton-energy.com/wp-content/uploads/2009/02/footprinttaxheatforbuildings1.jpg

Table 21-1CO_2 footprint of CHP-DH and biomass. Footprints for heat and energy supplies to buildings in descending order worked out according to the Orchard Convention. (Courtesy of Orchard Partners)

		Distribution losses		
Heat supply options gross (higher) calorific value (CV) basis and efficiency (eff)	**kg CO_2/kWh per unit of Energy**	**Energy Average loss %**	**CO_2 Average loss kg**	**kg CO_2/kWh Energy delivered**
Hydrogen fuel from electricity(coal) 80%(eff)	1.046			
Biogas burnt in 86% (eff) domestic boiler.				1.008
Electricity from coal 36%	0.837	10	0.084	0.920
Biogas as a fuel 40% (eff) conversion from biomass (Lund University Maria Berglund Pal Borjesson)	0.850	2	0.017	0.867
Biomass wood boiler 78%? (eff). *	0.436	5	0.022	0.458
Electricity from gas 48% (eff) *	0.397	10	0.040	0.437
Biomass (dry wood) as a fuel	0.340			0.340
Air source heat pump COP 2.9 (Electricity from coal)				0.317
Coal as fuel	0.301			0.301
Old gas boiler 75% (eff)				0.255
New condensing natural gas boiler 86% (eff)				0.222
Heat micro CHP 1kWel 6% (el) (eff) 86% (eff) overall				0.212
Natural gas as a fuel	0.191	2	0.004	0.195
Heat pump good geothermal winter heat source, COP 4 electricity from gas.				0.109
Piped heat from gas fired condensing 500 kWel CHP 34.7 % (el) (eff) 86% (eff) overall	0.103	10	0.010	0.113
Piped heating from very large biomass CHP co fired with coal.	0.075	20	0.015	0.089
Piped urban district heating from coal fired CHP equivalent COP 12.7	0.066	20	0.013	0.079
Piped urban district heating from gas fired CCGT CHP equivalent COP 12	0.033	20	0.007	0.040
Electricity from wind, DTI Future of Nuclear Power page 49	0.020	10	0.002	0.022
Electricity from nuclear 0.006 to 0.026 DTI Future of Nuclear Power page 49	0.010	10	0.001	0.011
Piped district heat from nuclear fired CHP equivalent COP 10	0.001	20	0.000	0.001

*(Some experts find it questionable to accept that there is a substantial net CO_2 emission from using biomass for generating electricity and heat. Arguing thus "that despite the fact that there is some CO_2 in the flue gases from burning biomass, the same amount of CO_2 was actually withdrawn from the atmosphere during the growing season and the CO_2 would anyway be emitted as the wood rot in the forest. Although there are huge biomass resources, which are CO_2 neutral as they can be harvested in a sustainable way, the resource is limited and should therefore be used efficiently. That could be in CHP plants and in DH boilers with condensation in smaller communities in which CHP is not cost effective. As a rule, an individual wood boiler should never replace heat from an efficient CHP plant although this plant is based on fossil fuels, as the biomass could be used better elsewhere. In case the biomass is waste (like straw) from making crops, it is suggested that the CO_2 is allocated to the crops").[235]

[235] Pers Com. Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy. Professor at the Technical Univ. of Denmark.

22. CAPITAL COSTS OF NEW POWER STATIONS, CHP POWER STATIONS AND THE COST OF CONVERSION OF POWER STATIONS TO CHP

22.1. Capital cost of New CHP power stations ..... **Error! Bookmark not defined.**

22.2. Partial conversion of existing power stations to CHP to provide heat for DH networks..... **Error! Bookmark not defined.**

22.3. Barking Reach Power London..... **Error! Bookmark not defined.**

22.4. Investigations by the UK's CEGB – the Central Electricity Generating Board into converting existing stations to CHP ..... **Error! Bookmark not defined.**

22.1. Capital cost of New CHP power stations

For a given location, a new power station can be ordered from the manufacturer, as either electricity only or CHP – usually with the option to shift to fully condensing mode in the latter case. The cost is between 5 and 20% extra for the CHP version, depending on the plant type, size and location; and in fully condensing mode there is no loss of efficiency

A financial analysis is carried out in Chapter 17 where the total cost of converting three typical stations to CHP, building the attendant connection pipeline, the heat grid and house connections is included.

Note that whilst the analysis, which shows in the 3 cases a positive economic case, was based on conversion, the same applies to a new station. That is, if a new station were proposed adjacent to a heat load such as the 3 cities considered, since the cost of making a new station CHP is also in the same range – 10 – 20%, extra then the same sort economic benefit would be expected to apply.

One study[236] states "The obviously and most important is simply that the conversion of existing electric-only power stations to CHP operations is usually feasible, and well worth looking at in any specific case where a heat load is existing within any reasonably distance of an existing station."

Conversion of existing power stations to CHP to provide heat for DH networks
As an alternative to purchasing a new power station, existing electricity only power stations can be converted to CHP and there are a number of examples of this:

- Amercentrale, power station - 1245 MWe of power. Section 23.3
- Prague (Malice) 480 MWe Section 23.2
- Flensburg 205 MWe. Section 14 1.1.1
- Many examples of conversion from Denmark

This cost of conversion of a station is around 10 – 25%[237] of the original cost of such a station, where as noted earlier a new station might cost 20% more than a power plant. If the most efficient (in overall terms) CHP unit is desired then the entire turbine will probably be

[236] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

[237] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

replaced. This is an expensive solution but still a lot less than a new station. In some of the cases above the limitations of converting existing turbines have been accepted as being relatively insignificant.

In the Prague case, which had various turbine sets, some were replaced as new and some modified, whilst others were relegated to standby or peaking duty.

Over time in Denmark, many of the converted units have been replaced by better, new units installed on the same site and the converted units were used as backup or decommissioned. Thus conversion of a power station can be viewed as a convenient interim solution which can be phased out over time as the heat load is built up, which as mentioned earlier can take decades.

With the results of the Financial Analysis in Chapter 17 (which shows the CHP-DH based on existing power station conversion is economic) and the foregoing examples it is likely there are many good economic cases for CHP-DH, but each case is different and has to be studied in detail. Non technical factors come into play such as expected lifetime of any industrial facility, planning regime and so on. By no means can all existing power stations be economically converted to CHP operation. Each one has to be analysed on its merits and the trade-offs considered.

22.2. Partial conversion of existing power stations to CHP to provide heat for DH networks

It is possible to partially convert existing power stations to a high standard of CHP at low cost compared to building a new one. This strategy would apply if converting the whole station would provide too much heat for any adjacent heat load.

For example, if we considered Drax power station in UK it would be possible to convert only one 660 MW unit out of the 6 to CHP if desired. If low temperature district heating were the destination of the heat then the full conversion of one unit would probably be the best solution, and, this would be achieved by modifying (removal or changing of some of the blades for example) or exchanging the entire low pressure turbine and modifying the existing condenser and replacing it with a district heating condenser. In this case this would amount to a partial conversion of the whole station – 1/6th in fact.

Alternatively one of the units could be partially converted to give heat at a higher temperature than available by extracting some heat at high temperature and pressure from the cross over between the HP and LP turbines. This would be overall less efficient than the LP option. In this case in effect only a small fraction of 1/6th of the station has been converted to CHP. This same procedure could be applied to all 6 units, which would still give a lot less heat than if the whole station had been converted to a high standard.

Thus there are many options to convert a particular power station. Exactly which is the best option would depend on a detailed study of the particular plant and the purposes for which the heat was required and how much heat was required.

22.3. Barking Reach Power London

Another potential conversion example for which costs are partly available is Barking Reach

Power Station which already exists as a 1000 MW CCGT. This unit has around 350 MW of low grade waste heat available at around 35°C - too low for any practical use except for heating horticultural establishments such as green houses or fish farming which is a strictly limited market. To capture up to 100MW of heat from the medium pressure steam header, a budget conversion cost was given around £10 million - 4% of the new capex. This is with a Z-factor of just under 5 (which as noted earlier is an indication of the efficiency of the CHP) which is quite respectable and better indeed than Nordjylland power station. This conversion is only capturing part of the available heat but at a low price and low efficiency. Full conversion to condensing / extraction turbine would be much more costly as it would require modifications to the low-pressure section of the steam turbine. Costs for this are not publicly available.[238] This would give more heat, and at a higher Z factor.

This station is currently planning to add a third 470 MW CCGT block. Provision to extract heat in the form of low pressure steam could be made so that the new CCGT block could operate as a combined heat and power (CHP) plant. Space could be allowed for heat exchangers enabling hot water to be made available to new developments and associated district heating schemes in the area.

In effect then, the new turbine, if the others were left untouched, would amount to converting 1/3 of the station to CHP and would be relatively cheap, as this would add at most about 20% to the cost of the new CCGT block.

One of the 400 MWe CCGT blocks if new would cost approx. 250 million Euros.

These two examples show what is quite typical that any large power station complex evolves through its life as 1 or more units are modified and refurbished, there will be multiple opportunities for converting power stations, in all or in part, and that these opportunities will emerge through the life of a given population of power stations.

22.4. Investigations by the UK's CEGB – the Central Electricity Generating Board into converting existing stations to CHP

During the early 1980's the CEGB carried out detailed investigations[239] into converting selected power stations to CHP. Note they would only have looked at the ones more likely to be suitable and economic for conversion, which would of course be the case for any Europe wide investigation.

They looked at a range of power station ages (16 – 32 years) and methods of conversion (back pressure or extraction condensing). The results are shown in the table below.

[238] Alastair Young, Buro Happold. London.
[239] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

Table 22-22-1 The old UK Central Electricity Generating Board looked at a range of power station ages (16 – 32 years) and methods of conversion (back pressure or extraction condensing)

Power station	Nechells	Stella North	Ferrybridge C	Cockenzie	
Built	1953	1956	1968	1969	
Age	32	29	17	16	
No of sets	4	4	4	4	
Size, MW	56	60	500	300	
Pipe distance from power station	1	4	38	16	

The study included:

- Technical feasibility of taking steam from the turbines
- Effect upon thermal performance
- Fuel type and price
- Operating and maintenance costs
- Environmental standards
- remaining lifetime of plant
- Distance from the heat load and cost and reliability of heat transmission.

The study[240] conclusion says "The obviously and most important is simply that the conversion of existing electric-only power stations to CHP operations is usually feasible, and well worth looking at in any specific case where a heat load is existing within any reasonably distance of an existing station. Too many parameters are involved to reach any generalised conclusions, but it should not be difficult in such instances to carry at least a back of the envelope type of calculation to begin with, and then to go on to successive degrees of refinement if matched by commensurate interest by the heat consumers of a distribution authority."

It also notes that "a phased programme of CHP development is also possible; for example, Edinburgh might be served initially from Cockenzie and ultimately from Torness a nuclear station presently under construction, located some 35 km further on from Cockenzie."

It discusses heat transmission from the power station to the DH site: "….the capital cost of long distance heat transmission must be included, together with the heat distribution and consumer connections as appropriate……..a major pipe connection from Ferrybridge to Sheffield - a potential route was surveyed by CEGB as being 38 km with a direct line of 30 km - could cost as much as 50 millions pounds. A city the size of Sheffield or Edinburgh would also incur some 150m pounds of capital expenditure for a full district heating system spread over some 15 – 20 years of construction…."[241]

With around 500,000 population; this would amount to capital cost of say 410 Euros per head, which over a 60 year life at 3.5% discount would amount to around €7.5 per person, or €22.5 per household per year in 1980 money. In today's value of money that would be around €59 per household per year.

[240] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

[241] Postelthwaite, A.f., Waterton, J.C., 6th National Conference chp'85 Developments in converting Power Stations to chp operation

Table 22-22-2 Data for 3 conversions.

Station	Ferrybridge	Cockenzie	Ferrybridge E
Scheme reference	C	D	E
Water supply temperature, C	170	95	90
Heat Output MW	71	200	250
Loss of electricity sent out MW	21	56	36
Z factor	3.33	3.57	6.66

Note the Z factor for the E scheme is 6.66, which is comparable to the Nordjylland power station with a Z of 6 -7. Also that the E scheme, for Ferrybridge, with the higher Z, would be expected to have a lower water forward temperature of 9 ^{0}C, compared to the alternative C scheme which has a Z of 3.33. This stems from the fact that the steam is taken at a higher temperature and pressure. Note also the scheme is only 71 MW compared to 250 MW for the "proper" scheme, indicating how partial conversion to CHP is possible.

23. EXAMPLES OF DISTRICT HEATING AND CHP-DH SCHEMES PARTICULARLY WHERE EXISTING STATIONS HAVE BEEN CONVERTED

23.1. Stadtwerke Flensburg Germany ..... **Error! Bookmark not defined.**

23.2. Prague Combined Heat and Power and District Heating **Error! Bookmark not defined.**

23.3. The Amercentrale power plant, in Geertruidenberg, Netherlands **Error! Bookmark not defined.**

23.4. District heating in Canavese, Milan – an example of a gas engine plus heat pump district heating scheme ..... **Error! Bookmark not defined.**

23.5. 1.1 MW Spark Ignited gas engine - Biogas fuelled district heating in Polderwijk, Zeewolde, The Netherlands. Example of a very small, successful CHP-DH system based on natural gas. ..... **Error! Bookmark not defined.**

23.5.1. New district energy scheme ..... **Error! Bookmark not defined.**

23.5.2. Data Polderwijk 2009 2010 ..... **Error! Bookmark not defined.**

23.6. Danish District Heating and Heat Plan Århus, Denmark **Error! Bookmark not defined.**

23.6.1. Danish District Heating ..... **Error! Bookmark not defined.**

23.6.2. Heat Plan Arhus ..... **Error! Bookmark not defined.**

23.7. The Odense Denmark CHP-DH scheme ..... **Error! Bookmark not defined.**

23.8. Schemes in Eastern European states **Error! Bookmar**

23.1. Stadtwerke Flensburg Germany

This is an outstanding example of an existing 200 MW power stations being converted to CHP-DH by the local municipality with 98% of the local population linked up to an extensive district heating network.

According to the operators[242] "Flensburg boasts the most favourable district heating prices at a connection density of more than 98% (of heat loads connected). Work started on expanding the supply network as early as 1969. The city's own electricity-only power station was converted in 1971 into a co-generation plant providing 170 megawatts of electrical and 800 megawatts of thermal output. Four reserve co-generation plants guarantee supply security".

Of note is the fact that the city is most unsuited to CHP-DH – being of a topologically difficult shape, with historical and narrow streets and congested services.

An article with a full technical description of this interesting and successful scheme is included in Annex 1.

23.2. Prague Combined Heat and Power and District Heating

Another outstanding example of CHP conversion is the Prague DH system in the Czech Republic. District heating systems are sometimes perceived as remnants of collectivism of the communist era. In this context it is very interesting that, even though essentially conceived before the revolution, most of the development of Prague district heating system actually took place after 1990, under the conditions of market capitalism and without investment subsidy or grant of any kind.

[242] Hans-Jürgen Prinz Stadtwerke Flensburg/. Pers Com. 23.11.2010

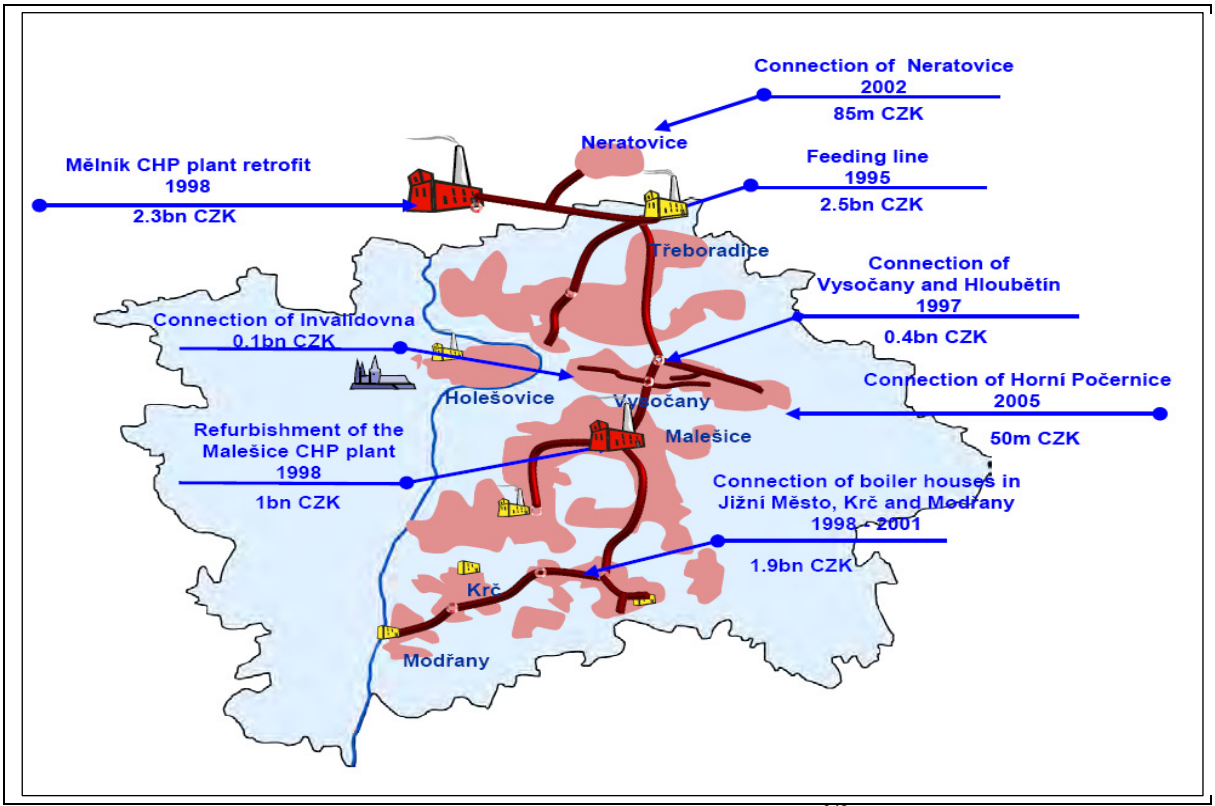


Figure 23-1 Prague district heating system[243] .

The CHP station was originally electricity only, but was converted to CHP and is connected to the DH system by a 1m diameter, 64 km[244] pipeline. The Prague District Heating Company, Pražská teplárenská (PDHC) was established in 1992. Foundations to what now forms Prague district heating system were laid in the 60s when new concrete blocks of flats started to be built in Prague and district heating was preferred as the most suitable way to provide heating to the newly constructed buildings. Several areas supplied with heat from district heating were formed in this way. Initially, these systems were based on domestic brown coal, and later on heavy fuel oil and natural gas. In the 80s, poor air quality in the city gave rise to the idea of using waste heat generated in a power plant in the nearby town of Mělník and supplying it as clean heat to Prague. The project was launched in 1987.

After 1989 PDHC decided, together with the owner of the Mělník power plant, to go ahead with the project in the new market economy environment. Heat supplies were no longer considered a social service and subsidies on heat prices were quickly cancelled. The construction was finished in 1995, when the first gigajoules of heat from Mělník arrived in Prague.

Both coal-fired plants in Prague and in Mělník had to undergo complex retrofitting in order to fulfil new stringent air pollution requirements starting in 1998. The system is now one of the largest interconnected district heating systems in Europe. The system has been instrumental

[243] Prague District Heating System. Application for 1st Global District Energy. Climate Awards. September 2009.http://www.copenhagenenergysummit.org/applications/Prague,%20Czech%20Rep-District%20Energy%20Climate%20Award.pdf

[244] http://www.copenhagenenergysummit.org/applications/Prague,%20Czech%20Rep-District%20Energy%20Climate%20Award.pdf. Prague District Heating System. Application for 1st Global District Energy Climate Awards

in the abatement of air pollution while providing affordable and safe heat to more than 200 thousand households and thousands of other customers from the public as well as private sector in the city of Prague and the nearby town of Neratovice. The system will be further expanded by the connection of the Libuš area which is under construction and expansion to Holešovice is being considered.

Table 23-1 Brief Description of the Prague District Heating System:

Heat transporting medium	hot water (in some parts of the system up to 140°C)
Boiler capacity	1963 MW
Installed power capacity	480 MW
Available power capacity	350 MW
Length of the system (from the CHP plant in Mělník to Modřany)	63.6 km
Total length of the pipelines	1365.5 km
Total heat sales in 2008	10 PJ (2.8 TWh)
Share of CHP heat on total supply	83 %
Share of the annual heat consumption in the Prague district heating system from the municipal waste incineration plant	11 %
CHP power production in 2008	966 GWh
Households served -	More than 200 thousand

Other technical details

The Melnik CHP plant (today's main plant of The Prague DH system) was originally designed as a conventional condensation plant in the 60's (put into operation 1957 - 1960). The idea of the project Prague DH system arose in half of 80's.

At the end of the 80's and in the beginning of the 90's 6 steam boilers (6 x 250 tonnes per hour; brown coal) were refurbished (6 x 270 tones/hour; higher calorific brown coal), today they are interconnected through a double steam bar. Condensation turbines 1 and 2 (2 x 55 MWe) were substituted by 2 back pressure turbines (2 x 60 MWe) in 1988. Condensation turbines 3 and 4 (2 x 55 MWe) were converted to extraction machines (2 x 60 MWe) in 1988. And condensation turbines 5 and 6 remained. In 1994 - 1995 the pumping station in Melnik CHP plant and backbone feeder Melnik - Prague (2 x DN1200; 34 km) were built (2.5 bn CZK). In 1998 an FGD unit (deSOx) in Melnik CHP plant was added (2.3 bn CZK).

23.3. The Amercentrale power plant, in Geertruidenberg, Netherlands

The Amercentrale power plant, in Geertruidenberg, Netherlands, owned by Essent, part of the international RWE Group, is one of Essent's larger generating facilities. Heat from the power stations is fed to homes, businesses, institutions and market gardening greenhouses. The plant has been in operation since 1980.

This is an example of another electricity-only power station conversion to CHP-DH and this is interesting because originally power only, it is only partially converted. The overall efficiency is only around 60% since not all of the waste heat potential is captured – merely sufficient to meet heat load on DH network. There are two significant power generating units at the power station:

Unit 8: With a power generating capacity of 645 MW and a heat production capacity of 250 MW, unit 8 is the second-largest coal-fired combined heat and power plant (CHP) in the Netherlands. The unit has been in use since 1980.

Unit 9: With a power generating capacity of 600 MW and a heat production capacity of 350 MW, unit 9 is the largest coal-fired CHP unit in the Netherlands. The unit consumes 1.5 million tons of coal per year, and can also be fired with natural gas and (partly) biomass. Unit 9 also has a wood gasification unit, where 150,000 tons of building timber and salvaged wood can be converted into 'wood gas'. After thorough cleaning it serves as a sustainable fuel, replacing roughly 70,000 tons of coal.

23.4. District heating in Canavese, Milan – an example of a gas engine plus heat pump district heating scheme

DH service in Milan started in the early 90s, mainly based on heat production from WTE - Waste to Energy plants - and from natural gas fuelled CHP plants (CCGT and CHP engines). The heat produced is fed to the buildings by means of several large district heating networks of which Canavese is the most recent one. At present these networks are separated but there is a program to interconnect them in the next few years to better optimize and develop the whole system. The City of Milan has a population of about 1,300,000 inhabitants.

In December 2010 the district heating distribution network had an extent of about 100 km and serves about 265,000 inhabitants, corresponding to a peak power demand of 530 MW. Discussions are underway to convert an existing CCGT to combined heat and power.

The Canavese DH system, pictured below, is one of the sub groups of the Milan District Heating system. The district heating system consists of a natural gas fuelled high efficiency 15MW gas engine CHP plant and heat pump fed by groundwater for the production of hot water at a maximum temperature of 90°C.

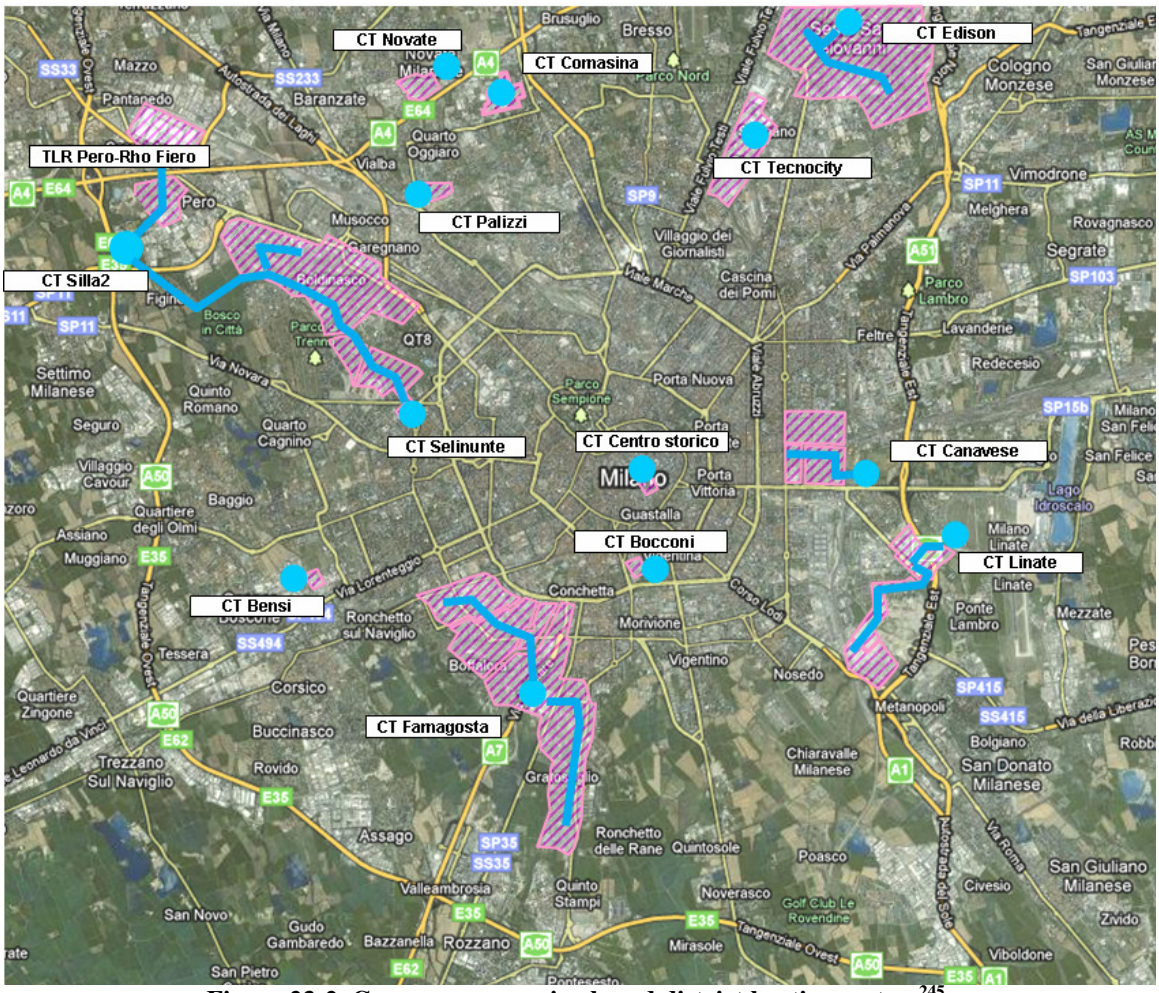


Figure 23-2 Cavanese gas engine based district heating system[245].

23.5. 1.1 MW Spark Ignited gas engine - Biogas fuelled district heating in Polderwijk, Zeewolde, The Netherlands. Example of a very small, successful CHP-DH system based on natural gas.

23.5.1. New district energy scheme

The district heating grid in the Polderwijk started in 2007 and now more than 1,000 are connected to the heating grid. The generation of renewable energy started at the beginning of 2009.

The distance between this farm and the Polderwijk is 5 km. In 2008 a pipeline of 5.5 km was realized from farm to Polderwijk for transport of raw biogas to the CHP at the energy station of the Polderwijk. The CHP was commissioned 2008.
In a tender procedure the municipality gave in 2006 a concession for 30 years to the company who offered a climate neutral district energy concept at reasonable price.

[245] CANAVESE DISTRICT HEATING SYSTEM. City of Milan, Italy, a2a Calore & Servizi s.r.l. Lorenzo Spadoni,Via Caracciolo, 58 20155 MILANO. ITALY

Essent Local Energy Solutions won the tender. The offer of Essent was based on cooperation with the dairy farm Van Beek in Zeewolde. Essent invests in a district heating grid and an energy station for the Polderwijk. Van Beek installed a 1.1 MW cogeneration unit at the energy station of the Polderwijk. Raw biogas is transported from the dairy farm to the

23.5.2. Data Polderwijk 2009 2010

Table 23-2 Data For Polderwijk

Average number of households	710
est. electricity consumption households	2,485,000 3,050,000 kWh
Heat consumption households	7,930,000 9,350,000 kWh
Electricity generated on biogas	6,700,000 7,500,000 kWh
Utilisation of heat from biogas	CHP 5,900,000 7,100,000 kWh
Natural gas peak boilers	3,610,000 4,735,000 kWh

23.6. Danish District Heating and Heat Plan Århus, Denmark[246]

23.6.1. Danish District Heating

One expert Danish practitioner[247] states

> "a strong development of CHP plants and district heating networks is very important to reduce total energy consumption (CO_2 emissions) in Europe; doing this, together with an increase in the requirements to building energy conservation are the single most important reasons for Denmark being able to avoid an increase in its energy consumption despite a 2-3% annual economic growth over the past 30 years.
>
> It is important to be aware of the timing in the story when telling it. Much of the Danish CHP conversion took place before the electricity market was liberalized; this made a lot of things easier in that the consumers (both heat and power) paid what was agreed to be a fair price covering in a fair way both investments and running costs, and they hardly went into a debate about what they were paying for because it was fair and nobody was supposed to make a profit. After the liberalization of the power market, the heat market is still a regulated monopoly and by law, the heat suppliers can require the heat prices, when buying heat from the power plants, to be cost-determined plus only a reasonable profit.
>
> It is my personal opinion, that if a conversion to CHP is to take place in a liberalized market I think that it is important that all players affected get their fair share of the profit if they should go for it. This requires transparency between the involved parties with respect to technology, management, and economy."

[246] Heat Plan Denmark. Low Carbon Urban Heating. Anders Dyrelund, Market Manager. Rambøll (consultants).Denmarkhttp://www.copenhagenenergysummit.org/Low%20Carbon%20Urban%20Heating,%20Heat%20Plan%20Denmark%20paper.pdf

[247] Niels Houbak MSc, PhD Civ.Ing. Ramboll Energy – Power. 20+ years professor at the Technical University of Denmark (DTU).

After the energy crisis in 1973 Danish district heating started to develop from the existing CHP plants, and in 1979 a nation wide heat planning process began in accordance with the Heat Supply Act. Some areas were selected for gas supply and others for district heating and local CHP plants were built. This also included conversion of a existing power stations, and there are many examples in Denmark where this has been carried out. These conversions are often considered a good interim solution.[248]

23.6.2. Heat Plan Arhus

In 1981 Heat Plan Århus was the first heat plan for use of CHP from an extension of an existing power plant to be approved by the Minister in accordance with the Heat Supply Act. The heat transmission system is owned by the local community in Aarhus. TVIS is a municipal partnership company which owns a transmission network in the Triangle area, Kolding, Vejle, Fredericia and Middelfart.

Aarhus municipality has 311,222, inhabitants. The starting point of Heat Plan Århus was an urban area with an old CHP station centrally located and a number of DH systems in the surrounding country. Heat supply from the new power station Studstrup was thought to be the right solution. The existing units (150 and 250 MW) were not considered suitable for conversion. Instead two new 350 MW units were designed and built for CHP.

[248] Personal communication. Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator

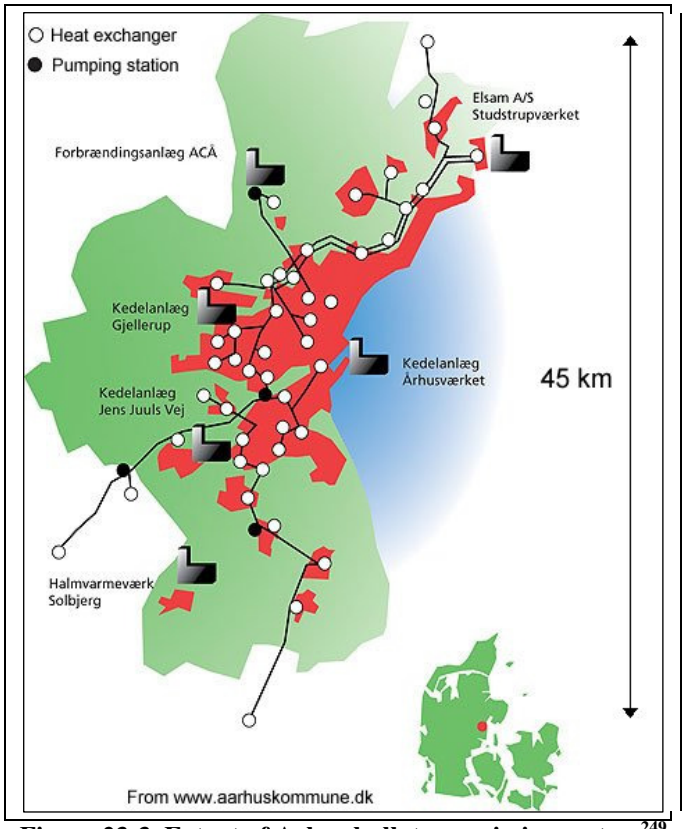


Figure 23-3 Extent of Arhus bulk transmission system[249]

The total length of the continuously connected transmission pipes is 130 km.[250] This is part of a network with a power station (Studstrupværket) in one end, a waste incinerator (ACÅ) along the line, and decentralised peak boilers.

23.7. The Odense Denmark CHP-DH scheme

This scheme has been operated for many years and could be said to exhibit many features of best practice[251]:

- Low heating supply temperatures given a Z factor of 8 (4 times better than a heat pump)
- Water metered rather than heat metered which encourages low return temperatures for higher Z
- Direct connection minimising pumping power, and again lowering temperatures maximising Z.

See **Annex 6 for** an article describing the technical details of the Odense CHP-DH scheme.

The above studies referred to in previous articles did not assume the performance parameters (Zs of 8, direct connection etc.) of Odense so it is likely that the economic returns calculated

[249] Claverton Energy Group conference in November 2007, Bath. - Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator
[250] Claverton Energy Group conference in November 2007, Bath. - Dr Paul Frederik-Bach, ex director of ELTRA the West Danish Transmission operator
[251] Odense Kommune, Fjernwavmeforsyningen. Article published by Danish District Heating Association "A remarkable district heating system. Per Rimmen.

are conservative and likely to be improved with modern. low temperature schemes and high Z's.

Odense claims to have heating costs 30% lower than that of oil or gas.

23.8. Schemes in Eastern European states

Eastern European (EE) states have often inherited poor (i.e. high average losses as compared to modern systems) CHP-DH systems from the old planned economy era. They have also fallen into disrepair due to inadequate maintenance with the conditions of the pipes and heat and power generating apparatus being poor as a result. Many of these systems have no controls at the dwelling with customers being charged by floor area and thus have no incentive to conserve energy. There are examples of where these decrepit systems have been turned into successes.[252]
Overall the European heat losses in CHP-DH systems are estimated to be 14%,[253] with about 10% in West European (WE) networks and 20% in East European (EE) networks. However many EE systems have succeeded in lowering the heat losses such as in Riga where losses are now at 13% and according to some experts Riga can be seen as a model city for upgrading old Soviet DH systems. Today, they have better benchmarking parameters than many West European DH systems. Many of these modernizations have been largely paid for by the World Bank. [254] Many others have been successfully upgraded. A tentative classification according to Werner[255] is:

High degree of rehabilitation: Estonia, Latvia, Lithuania, Poland, and former DDR in the current Germany.
Medium degree of rehabilitation: Czech Republic, Slovak Republic, Hungary, and Slovenia
Low degree of rehabilitation: Bulgaria and Romania.

[252] Metamorphoses of cogeneration-based district heating in Romania: A case study. Flavius Iacobescu a, Viorel Badescu bna Department of Applied Thermodynamics, Polytechnic University of Bucharest, Spl. Independentei 313, Bucharest 060042,Energy Policy 39 (2011) 269–280
[253] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden
[254] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden
[255] Dr Sven Werner, Professor, Energy Technology, Halmstad University (Högskolan i Halmstad), SET, PO,Box 823, SE-30118 Halmstad, Sweden

24. FINANCIAL AND INSTITUTIONAL BARRIERS TO CHP-DH AND MEASURES OF PROMOTION

24.1. Market capital rates versus utility capital rates.....**Error! Bookmark not defined.**
24.2. The need to focus on core business .....**Error! Bookmark not defined.**
24.3. Electricity market volatility .....**Error! Bookmark not defined.**
24.4. Energy Utilities – their business model is to sell more, not less energy**Error! Bookmark not define**
24.5. The example of the water industry of heavy regulation leading to successful outcomes .....**Error! Bookmark not defined.**

There are no technical barriers to CHP-DH, the technology is well known and there are numerous examples across Europe of all sizes

A review of literature relevant to the cost comparison of CHP-DH with other heat sources has been performed in Chapter 4. In general it reveals that for large cities in much of Europe it is likely to be the lowest cost heating. This has been confirmed by the detailed study carried out by JRC in Chapter 17. Since it is not widely implemented, then the main barriers to CHP-DH are therefore financial and institutional.

24.1. Market capital rates versus utility capital rates

The high costs of initial investments, particularly for heat transport and distribution, have been identified as a serious obstacle to the expansion of district heating by many member states.

Typically infrastructure projects such as water supply, waste treatment and electricity generation, whilst in the hands of governments and municipalities have historically to used a relatively low discount rate of 3 – 4 %/yr real for assessment purposes. This is the rate recommended by for example the IEA and the UK Treasury in its Green Book[256] and the EU[257]for assessing infrastructure projects.

Typically a government will assess the viability of an infrastructure project such as a new road, railway or airport and if it meets the 3.5% rate of return (amongst other criteria) then it may wish to see it built. It will then adjust the market environment in a variety of ways so that private sector firms can build the infrastructure, but they will expect to actually make much higher rates of return. Thus important infrastructure is routinely assessed at 3.5% and then the market is adjusted so that private sectors can make the much higher returns they require. This is discussed further in Annex 5.

Private sector business demand much higher rates of return than 3.5% for CHP-DH schemes because in general they are inherently risky in a free market environment. Unless a developer can be sure he will have close to 100% of the heat market he is not likely to invest in CHP-DH. Thus in successful DH countries the business has been de-risked by for examples governments granting monopoly powers to DH companies. This means they are then not only willing to invest but can also borrow capital at very low rates, because effectively they are government backed.

[256] "THE GREEN BOOK" Appraisal and Evaluation in Central Government. Treasury Guidance.LONDON:TSO, July 2011

[257] European Commission (EC), 2008, Guide to Cost Benefit Analysis of Investment Projects,

Thus the key to removing this barrier is granting by governments of the kinds of powers enjoyed by other natural monopolies such as water companies and electric distribution companies. This essentially means monopoly of supply of heat, ability to lay pipes where they are deemed necessary, ground entering, compulsory purchase procedures, and pre granted planning permissions.

Also the companies need the right to set a fair price based on value of assets; again these are all typically enjoyed by utility companies. These prices when set will be such that they can make a return greater than 3.5% typically but not much greater since the whole project will have been de risked. This means they can then access lower rates for borrowing capital. Unless governments have granted these sorts of powers to would be CHP-DH operators, then this is likely to be an insuperable barrier.

This is covered in more detail in Annex 5.

24.2. The need to focus on core business

It is standard business practice to focus on the "core business". Thus a water company will invest in water treatment, a pharmaceutical company in a new drug plant or drug, and an engine company will invest in technology. The Boards of these companies are well aware that long term real returns are low (3.5%) and are quite happy to invest in core business at these low rates of return, such as a new drug factory, providing long term security is provided – and this security tends to come from governments who can provide the framework by means of various laws and regulations. Financiers are happy to raise capital for these well run, long term sound business, supported by a sound regulatory and legal framework.

Anything outside this core business is considered non-core by a drug company board. So an energy manager who wants to install a new chp plant at a drug plant which is not actually necessary for the production of drugs, will be required to show it meets a much tougher financial hurdle. This is typically a 3 – 5 year payback time.

Thus it may therefore be unrealistic to expect power generating utilities or other energy providers to invest in CHP-DH – it is not their core business –generating and selling electricity is their core business.

24.3. Electricity market volatility

This volatility of electricity and fuel price makes it very difficult for new entrant CHP plant not owned by one of the existing major utilities to get funding because they cannot go to a source of funding with any certainty and say what the power price will be and therefore what the returns will be 30 years ahead. Incumbent players do not face this difficulty because to a very large extent they are able to control their income 30 years ahead (by raising power prices) and because they have large captive markets of existing customers so in effect they can sell from their own power stations' output to their own customers. Customer turnover – churn - is relatively low, and since all the large players have the same business model they are all offering similar deals to final consumers.

This helps to explain to a certain extent the reluctance of existing utility investors to invest in CHP-DH.

24.4. Energy Utilities – their business model is to sell more, not less energy

A paradox with all energy conservation schemes is that the business models of the large utilities, is to sell more, not less energy. CHP is capital intensive, and in the absence of a proper governmental framework, a risky investment. So there is a dis-incentive for utilities to become involved in something which harms their existing business model by selling less of a commodity, gas and or electricity and at the same time introducing more risk. They could sell the heat but this is a much more cumbersome and problematic prospect from the utilities' point of view because they already have the infrastructure – gas and electricity distribution and metering - so there is an understandable reluctance to invest in a further distribution and metering scheme.

24.5. The example of the water industry of heavy regulation leading to successful outcomes

The water industry has many obvious similarities with DH systems and has many statutory powers which need to be granted to CHP-DH operators in order to remove institutional barriers. It is therefore an instructive example showing how a market need (clean water and a sewerage system) was not met by the market and required government intervention.

In the late 19th Century in London and other major cities there were major epidemics of water borne disease and terrible odours. After much argument and debate the Government very reluctantly provided the cash and the whole of London and progressively all other cities had sewers and water supplies laid on. It is clear that this could not have happened incrementally house by house. Widespread powers of road breaking and house entry etc. had to be granted to a monopoly holder – the Metropolitan Water Board - who had to know in advance that they could invest on the basis that all customers would be connected. It is also clear that this was carried out by government decision and would not have happened by the operation of private capital alone, even though a of cost benefit analysis would have shown a better net benefit in terms of the reduced cost of ill health and death. To be successful water supply and treatment requires everyone to be connected by law for the greater benefit of the society.

This is precisely the situation facing CHP-DH in many non-traditional CHP-DH countries.. To be economic, CHP-DH must get at least 60% of the heat market in a given area. (In many schemes in Denmark the uptake is 95%, and in the large ones often close to 100%) Furthermore; it cannot grow incrementally street by street and house by house, since if a city takes 35-40 years to connect, the capital charges would be too high to be borne by the initially small customer pool.

The steep increase after 1980 of CHP-DH in Denmark is e.g. due to the oil price increase and the heat supply planning and subsidy schemes to new networks). The steep increase after 1990 is e.g. due to an agreement in the parliament that all municipalities should use the power in the Heat Supply Act to enforce all boiler plants larger than 250 kW (defined as a "public heat supply plant" of interest for the society) to connect within one year to the approved heat supply, which could be either DH or natural gas. Parallel to this the price commission decided that the heat price should not exceed the cost of heat from an individual boiler.

The water companies in England, although privatised,operate under a strict model of regulation. They are allowed to make about 6%/yr nominal on capital employed, but can issue debt at 3-4%, and have to submit detailed investment plans every 5 years – for cutting flooding, improving treatment and so on. In return for this, they are granted effectively an indefinite monopoly. The low business risk has meant that they increasingly finance their investment via debt, not equity. This is a successful model and could easily be applied to CHP-DH, as it is in Denmark.

There are other examples of how a CHP-DH business can be run successfully and the IEA publication "Coming in from the cold"[258] includes a chapter on different ownership/business models.

It is noteworthy that Water Companies have virtually unlimited powers when it comes to their ability to lay pipes anywhere they choose if they deem it to be in pursuance of their license conditions. Private developers can also call upon the water companies to exercise their powers and lay pipes if they need to on their behalf – all without seeking planning permission which is deemed to be already granted. These sorts of powers need to be given to DH companies to de risk this sector and remove the other major barrier, which is the lack of pre – granted planning permission to lay pipes, and widespread road breaking, compulsory purchase and land entry rights.

[258] "Coming In From The Cold ". Chapter 7. http://www.iea.org/textbase/nppdf/free/archives/cold.pdf.

25. LOCATIONS OF POWER STATIONS POTENTIALLY SUITABLE FOR CONVERSION TO CHP STATIONS – THEIR PROXIMITY TO LARGE CITIES.

25.1. Large coal and other fossil fuel fired plants that are above 20 year old and are located close to large cities of over 600,000 inhabitants**Error! Bookmark not defined.**

25.2. The coal and natural gas plants 300MW – 4000 MW within 25, 50 and 100 km from cities with a population above 500.000 inhabitants and between 100.00 and 500.000 inhabitants. ..... **Error! Bookmark not defined.**

25.3. Coal and natural gas plants between 50 and 299 MW within 25, 50 and 100 km from cities with a population above 500.000 inhabitants and between 100.00 and 500.000 inhabitants. ..... **Error! Bookmark not defined.**

25.4. Estimated Potential ..... **Error! Bookmark not defined.**

This section contains four separate analysis. Section 25.1 looks at large fossil fired plants over 20 years old and their proximity to large cities with a population of 600,000. Section 25.2 at all fossil stations in the range 300 MW and above and their distances (25, 50 and 100 km) from cities with a population above 500,000 inhabitants, and between 100,000 and 500,000 inhabitants. Section 25.3 looks at all fossil stations between 50 and 299 MW within 25, 50 and 100 km from cities with a population above 500,000 inhabitants and between 100,000 and 500,000 inhabitants. Section 1.4 estimates the number of power stations that are close to large cities.

25.1. Large coal and other fossil fuel fired plants that are above 20 year old and are located close to large cities of over 600,000 inhabitants

Assumptions of the analysis:

- Plant size (i.e. total installed within a site): larger than 900 MW
- Plant age: Older than 20 years for any of the power units of the plant
- Distance: Measured as a straight line between plant location and the centre of the closest city with a population of at least 600,000.

Methodology

- Plant data: JRC database based on Platts
- Plant coordinates: EPER/ E-PRTR database
- City coordinates: Google Earth

Results

- In EU27, there are 168 fossil fuel plants with capacities above 900 MW, with total capacity of 284 GW.
- 139 of these plants (244 GW) have units older than 20 years. This is 59 % of the EU thermal power fleet.
- 9 of these plants were not considered in the analysis as they were located in islands without large cities or could not be located on the map.

96% of this capacity (130 plants, approx. 234 GW) is within 110 km from a significant heat load that could be provided by the waste heat produced.

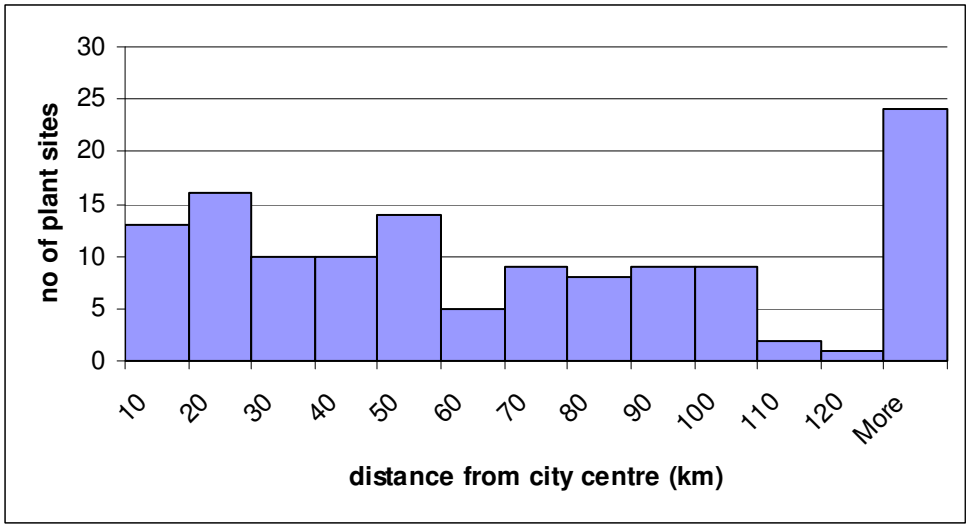


Figure 25-1 The relationship between distance and number of plants.

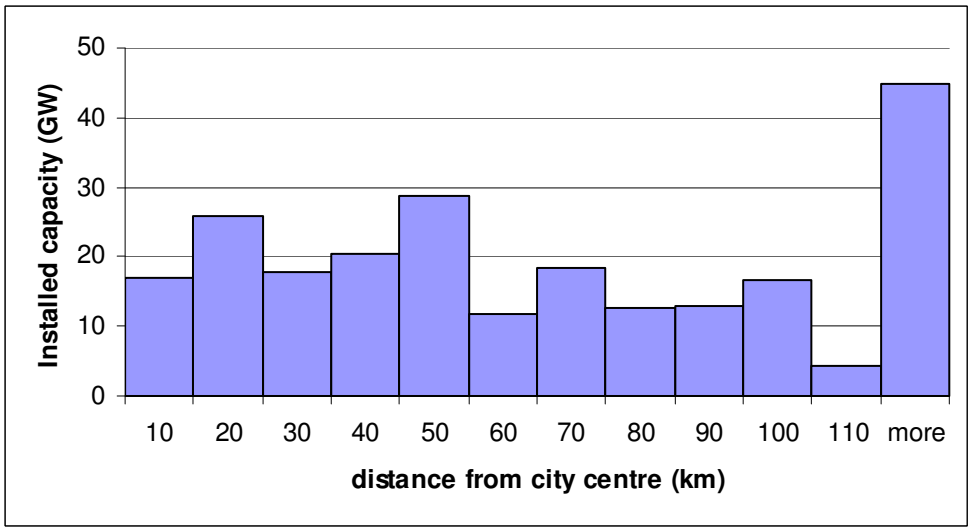


Figure 25-2 The relationship between distance and capacity of plants.

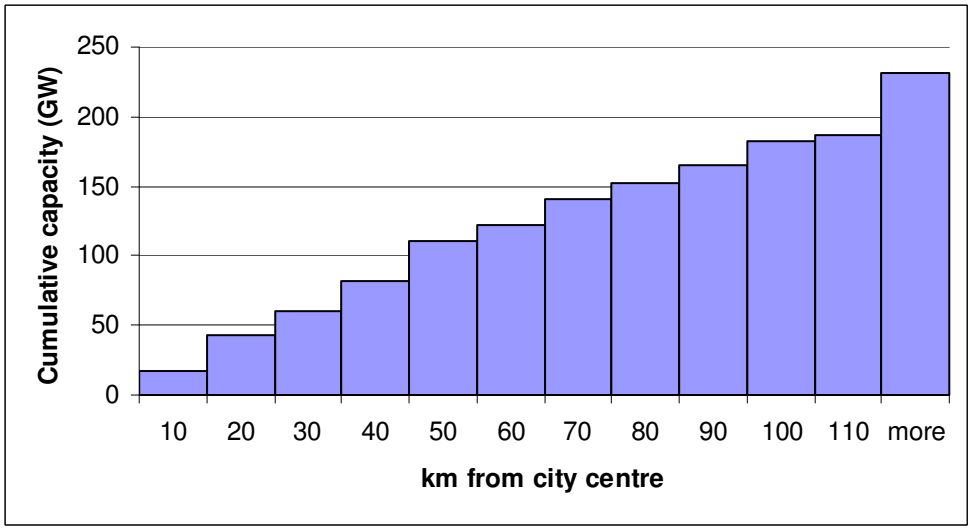


Figure 25-3 The relationship between distance and cumulative capacity.

Analysis
The longest distance between an existing CHP plant and a city centre, the JRC is aware of, is 67 km (the Melnik plant serving the city of Prague). The distance between this CHP plant and the Prague city centre, measured based on the methodology above, is 35 km, whereas the actual pipeline is 47 km in length. If this characteristic distance is considered as an indicative upper limit for economically viable heat transport then, 44 plants with a total capacity of 70 GW are located within 35 km from the closest city centre. It is noted however that the threshold distance of 35 km is arbitrary, given that there are studies indicating that heat can be transported at longer distances – even up to 140 km in some circumstances. Moreover, it needs to be further assessed on a plant level, which of these plants can be converted to CHP in view of the local climatic conditions and topography.

25.2. The coal and natural gas plants 300MW – 4000 MW within 25, 50 and 100 km from cities with a population above 500.000 inhabitants and between 100.00 and 500.000 inhabitants.

Tables 7 and 8 show the coal and natural gas plants above 300 MW within 25, 50 and 100 km from cities with a population above 500,000 inhabitants and between 100,000 and 500,000 inhabitants.

The grouping of the countries in the 3 zones was done according to the 3 climatic areas defined in the IMPRO-building report based on the heating degree day measurements.

- Northern Europe includes Sweden, Finland, Estonia, Latvia and Lithuania.
- Central Europe includes Ireland, United Kingdom, Netherlands, Belgium, Luxembourg, Germany, Denmark, Poland, Czech Republic, Austria, Slovakia, Romania, Bulgaria, Hungary and Slovenia.
- Southern Europe includes Portugal, Spain, France, Italy, Greece, Cyprus and Malta.

Table 25-1.Coal and natural gas plants above 300 MW within 25, 50 and 100 km from cities with population above 500,000 inhabitants

	Distance (km)					
	25		50		100	
Zone	Nr. plants	Capacity GWe	Nr. plants	Capacity GWe	Nr. plants	Capacity GWe
Northern Europe	1	0.8	1	0.8	2	1.8
Central Europe	47	34.6	78	57.6	128	103.4
Southern Europe	10	5.7	22	19.2	44	36.0

Conclusion: There appears to be significant potential for Central Europe and to a lesser extent in Southern Europe, but there is very little potential in Northern EU.

Table 25-2. Coal and natural gas plants within 25, 50 and 100 km from cities with population between 100.00 and 500.00 inhabitants

	Distance (km)					
	25		50		100	
Zone	Nr. plants	Capacity GWe	Nr. plants	Capacity GWe	Nr. plants	Capacity GWe
Northern Europe	2	1.0	2	1.0	3	2.0
Central Europe	103	96.1	151	142.9	194	171.4
Southern Europe	40	20.8	64	50.8	96	78.3

Conclusion: It appears that the potential is significant for Central Europe and to a lesser extent in Southern Europe, but there is very little potential in Northern EU.

25.3. Coal and natural gas plants between 50 and 299 MW within 25, 50 and 100 km from cities with a population above 500.000 inhabitants and between 100.00 and 500.000 inhabitants.

Table 25-3. Coal and natural gas plants between 50 and 299 MW within 25, 50 and 100 km from cities with population above 500.00 inhabitants.

	Distance (km)					
	25	25	50	50	100	100
Zone	Nr plants	Capacity GWe	Nr plants	Capacity GWe	Nr plants	Capacity GWe
Northern Europe	9	1.5	9	1.5	13	2.0
Central Europe	60	9.3	79	11.5	142	19.1
Southern Europe	14	1.5	21	2.1	39	4.4

Conclusion: It appears that the potential is significant for Central Europe and to a lesser extent in Southern Europe. There is some potential in Northern-EU.

Table 25-4. Coal and natural gas plants between 50 and 299 MW within 25, 50 and 100 km from cities with population between 100.00 and 500.00 inhabitants.

	Distance (km)					
	25	25	50	50	100	100
Zone	Nr plants	Capacity GWe	Nr plants	Capacity GWe	Nr plants	Capacity GWe
Northern Europe	15	2.4	19	2.8	21	3.1
Central Europe	142	18.4	199	26.3	247	32.0
Southern Europe	44	5.1	57	6.6	78	9.3

Conclusion: It appears that the potential is significant for Central Europe and to a lesser extent in Southern Europe. There is some potential in Northern -EU.

25.4. Estimated Potential

To perform a proper analysis of the true potential for connecting existing power stations to city district heating networks via a bulk heat pipeline requires a detailed study of each case. Terrain, geography and land use will affect the cost of bringing heat to a city, and also the type of housing will affect the cost of any heat distribution network. This is beyond the scope of this background report.

If we note the length of the Prague heat main which is 47 – 65 km, for a 200 MW station, we can surmise that there will be cases where a station larger than 900MW could be connected at 110km. (As the power station size increases, the cost of heat transmitted comes down disproportionately) Work already cited indicates that heat from a 2 GW station can economically be transmitted 140km. However the longer the length, the greater the chances of a "show stopper" such as a mountain or other impenetrable obstacle occurring.

If we conservatively assume that 50 km is a reasonable distance to transmit heat then it appears from the tables 7 – 10 that there are about 75% of European power stations are in range of a reasonable sized heat load.

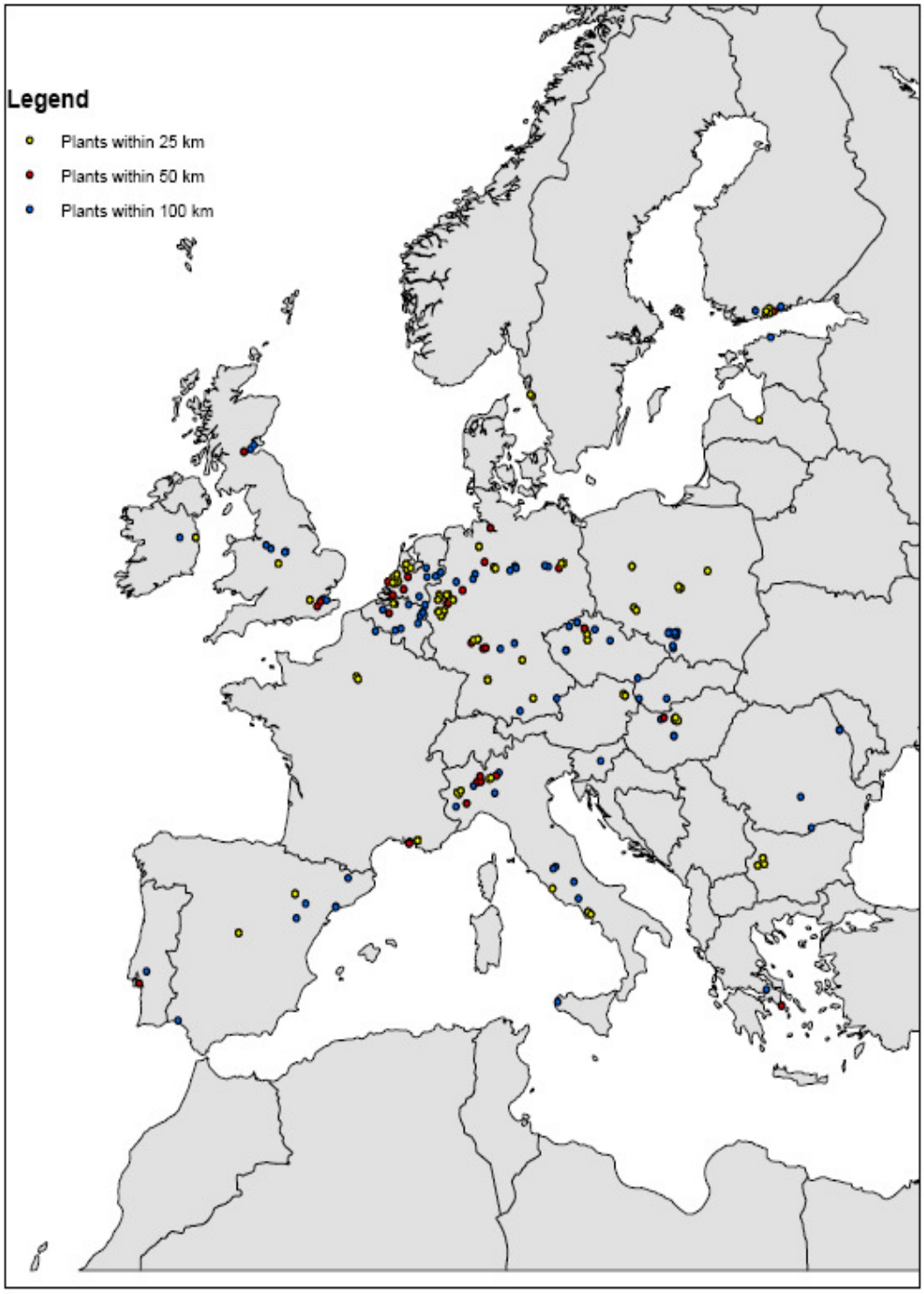


Figure 25-4 The coal and natural gas plants above 300MW close to + 500,000 population

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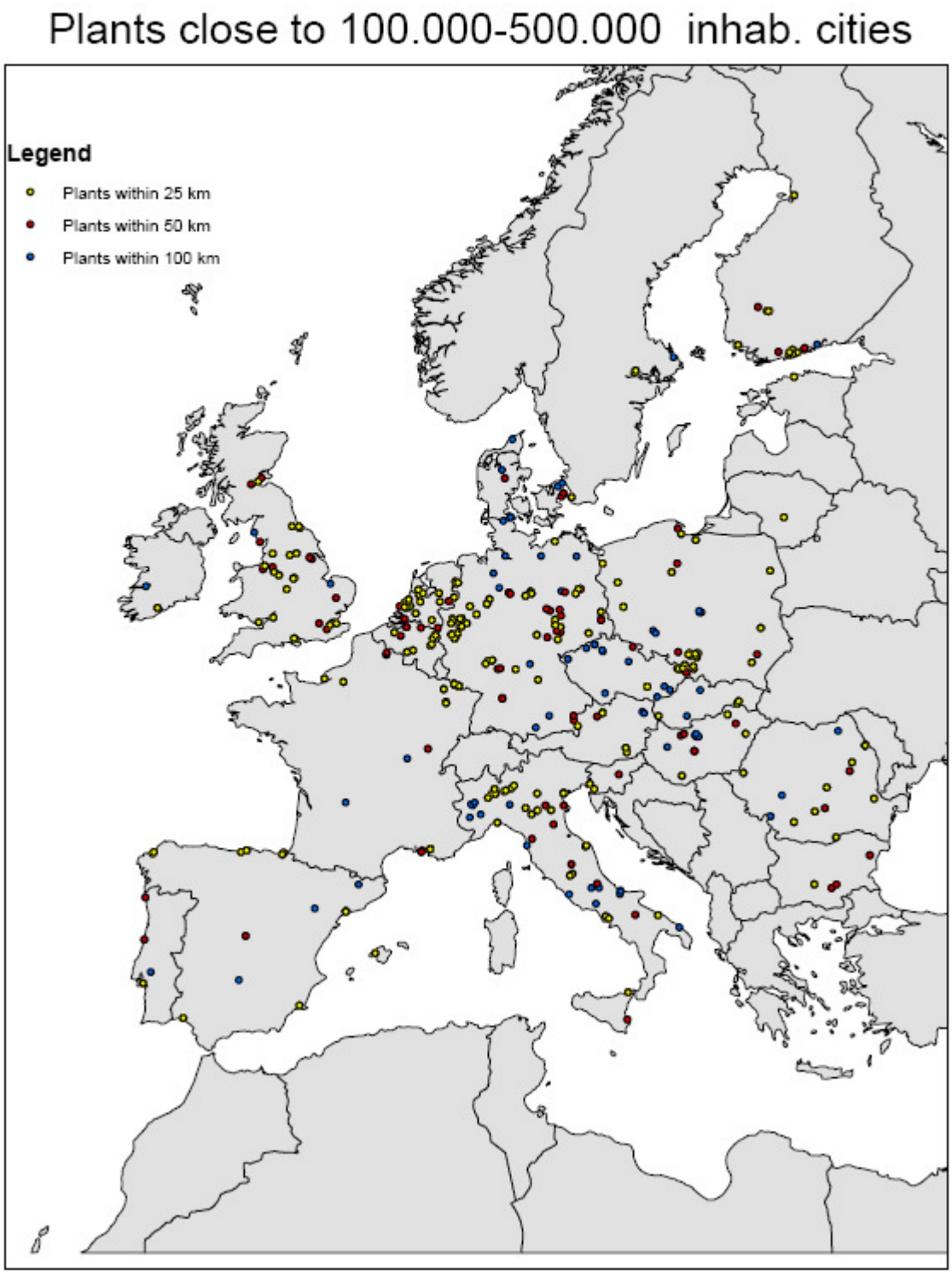


Figure 25-4 Plants close to 500,000 pop. cities

ANNEX 1 - FLENSBURG CHP-DH

"How we brought District Heating to Flensburg" An article written by Wolfgang Prinz, The then Technical Director, Flensburg Heat and Power Utility.

(This article was kindly provided by Wolfgang Prinz, The then Technical Director, (1985) Flensburg Heat and Power Utility. Personal Communication and is reproduced verbatim)

At one time thought completely unsuitable for district heating because of its narrow streets and its position around a fiord, the town of Flensburg in North Germany now has a CHP system supplying over 70 per cent of its buildings.
All this in less than ten years! The following account is based on a paper read by Wolgang Prinz to the conference of the German district heating association (AGFW) in Flensburg. The material is reproduced by permission of the author and the AGFW in Frankfurt.

FLENSBURG'S district heating project began in 1968 when the decision was taken to use energy from the town's coal fired power station to supply a hot water network. By using a number of relatively small turbo-alternator sets instead of one or two large ones, heating and electricity loads could be better balanced. There are now five sets each with an output of around 30 MW of electricity, and 65 MW of heat.

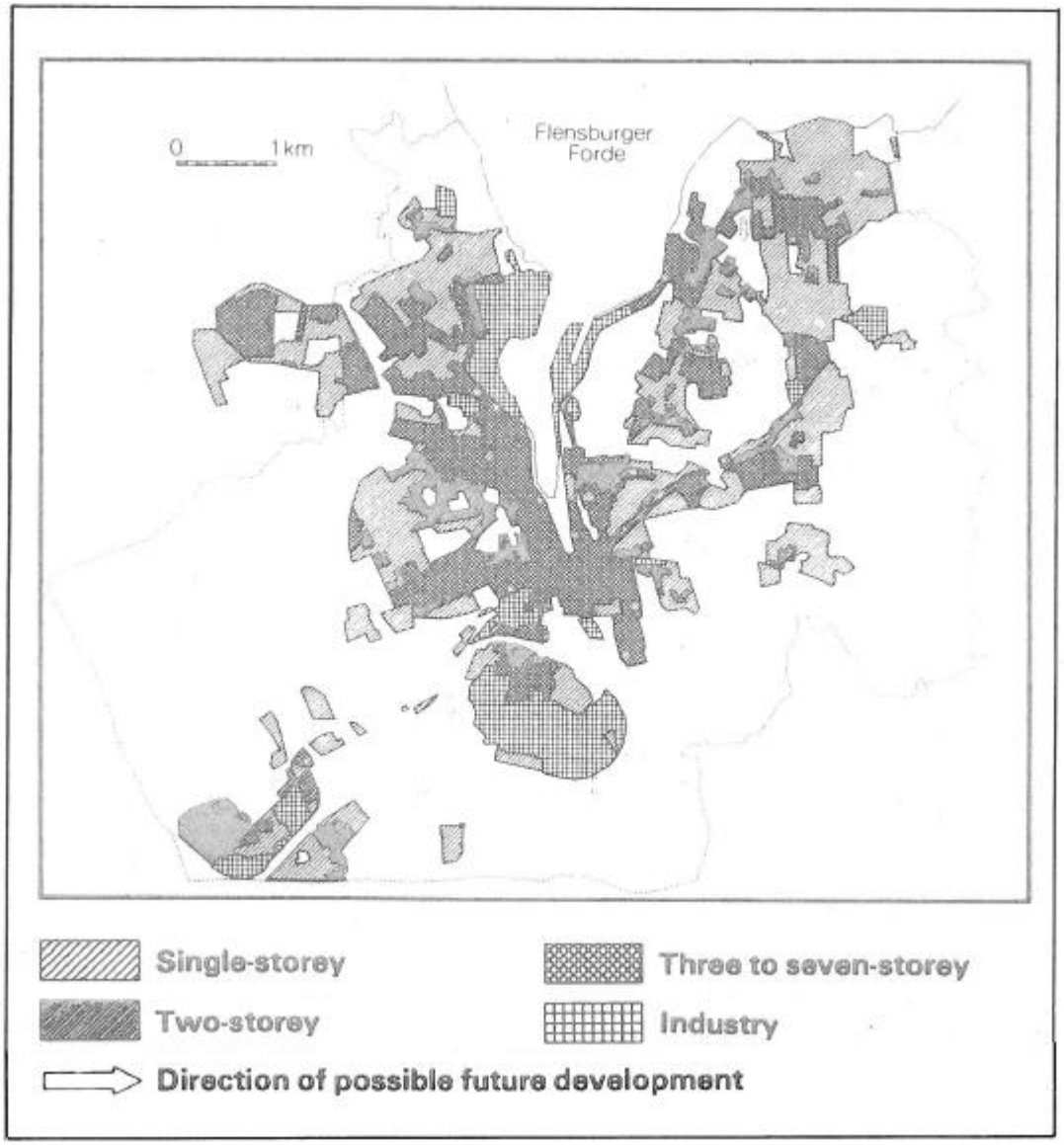
Today over 70 per cent of buildings take heat from the network and by 1985 nearly all buildings will be district heated.

The supply area of the Flensburg power and gas utility is around 100 000 inhabitants, 90 000 living in the town itself and some l0 000 in the neighbouring district of Glücksburg. There is no heavy industry in the area. The largest single energy user is a paper mill, but this has its own heat/power source. Apart from this there is a shipyard and engineering works with some 2000 employees. All other industry is small.

The heat load for Flensburg is therefore mainly in space heating and service hot water.

The design project began with a town plan on which buildings have been divided into groups according to the number of storeys to give an indication of building density. Later on, heat loads were analysed and also plotted on the town plan.

Trunk mains were designed at the outset to pass through the areas of highest building density. Although this had the disadvantage of involving work in the busiest streets with the additional complication of existing services, it gave the shortest route to the larger consumers, reduced the initial cost risks, and gave the lowest unit cost of heat as delivered. This follows from the principle that the economics of a district heating system depends more on the heat load per lineal metre of mains than on the heat load per unit area.

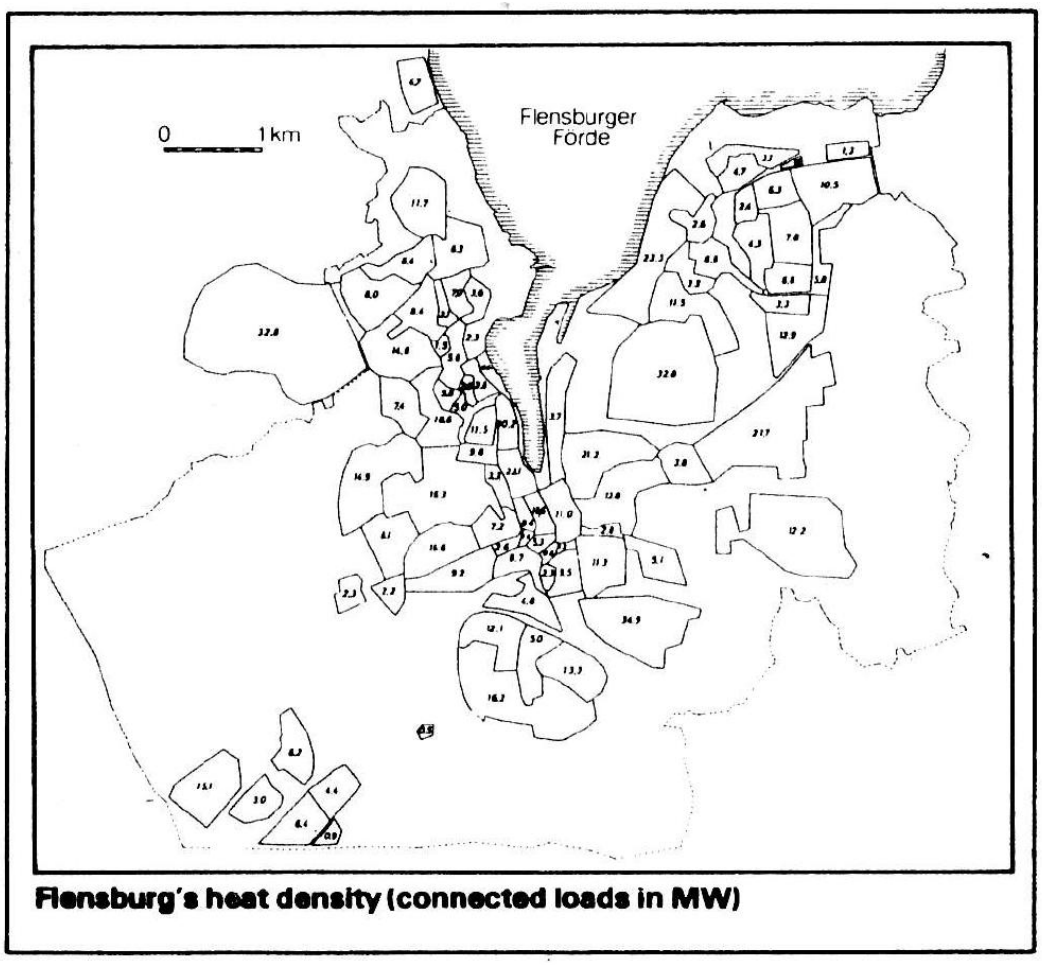


Plan of Flensburg

The heat load plan reproduced here is based on the state of construction in 1969/70 and gives a total connected load of 580MW. By l990 this will be in the order of 700 MW, if the town's building programme is realised.

The network was built as rapidly as possible to generate the load: for example, over 30km of mains were laid in the years 1976 and 1977, and 26km in 1978. The network now totals 180 km.

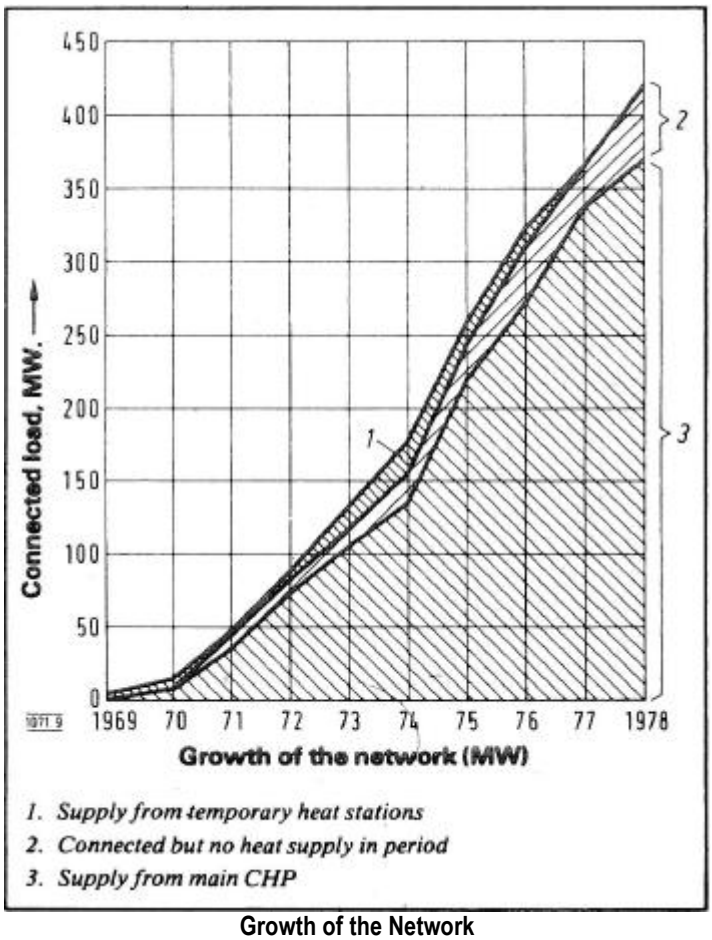
Problems with traffic flow meant that work sites had to be spread about and not concentrated for too long in one place: at times during construction over 30 sites were being worked simultaneously.



Flensburg heating density, MW

The chief steps in progress of the system were roughly as follows:

1967	Proposals discussed
1968	Go-ahead given
1969	First temporary heat station built
1970	First trunk mains (400 mm) from the power station to dwellings in the Northern parts of the town near the station itself.
1971/72	Extension of the trunk mains to the Western areas and increase in load on the first mains.
1973/74	Work on the Eastern part of the town through branches from the central trunk mains and the use of temporary boiler plants (15 in operation at one time). Second trunk main system (600mm).
1975/76	Further expansion on the East of the Fiord and the second trunk mains in this area. 50 per cent of the town now connected to the network.
1977/78	Mains to the South West of the town and attainment of the furthest North East point 13km from the station. Extensions to the network and further work on the main ring distribution in the East. Reserve heat station brought on line. 70 per cent of the town connected to the network.
1979	Further extension and linking of the main ring on the East side. This nearly completes the mains which will then be able to handle the final potential connected load of 700 MW.



Growth of the Network

The network is designed for a flow temperature range of 73 to 130°C, varied with the outside temperature.

The smallest possible pipe size had to be used because of the limitations of space under the narrow streets, and this meant fairly high water velocities leading to a pressure drop of about 2 m/bar on average. Combined with the variation in mains height over the terrain of about 60 m, this gives a nominal working pressure of 25 bar. The actual working pressure in the network however seldom exceeds 16 bar due to the staging of pumps along the mains-roughly one every 2.5 km. These pumping stations are mostly located underground. The pumps themselves are speed controlled through couplings which are cooled by means of the return water. The running speed is selected remotely from the central station switchboard.

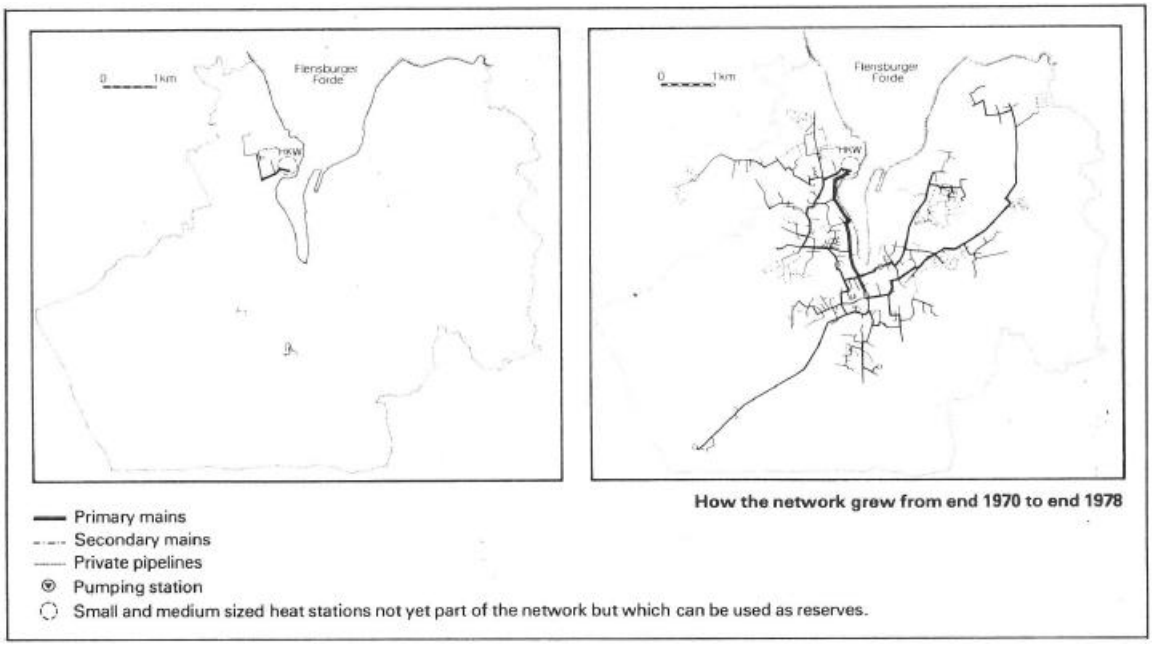
Because the network has to supply a great many existing heating systems in old buildings, each transfer point (sub-station) uses a heat exchanger to break down network pressure. To limit the cost of substations, small consumers are supplied by a secondary set of mains from a common substation. In this case, pressure is a maximum of 5 bar, and flow temperature varies from 65 to 100°C depending on the weather. The largest of these sub-stations is about 5MW.

Over 80 per cent of the network is accommodated in site-cast concrete ducts with pre-fabricated covers. The ducts are drained both inside and outside. Twin wall piping was not considered to be economic under the particular conditions, since a great many connections had to be made to the mains and direction was constantly changing. The concrete duct system also had the advantages that structural costs in the event of piping renewal are low, and the

ducts can be effectively protected against flooding.

A limited amount of steel twin wall piping was used in special situations for example where the water table was high, or space restricted. Plastics-wall pre-insulated piping was also used, mostly for making the connections between the network and the sub-stations. These alternative piping systems represent around only 10 per cent of the total network cost.

The responsibility of the district heat supplier ends after the stop valves and the substation connections from the network, although the supplier owns the heat meter and has the task of reading it. Originally, the heat meter was protected by a single strainer up-stream, but a great many meters failed because of debris entering from the return connections -the result of the very rapid extension of the network and frequent re-fillings. This was an important factor because of the number of sub-stations - in 1978 for example there were about 650 - and a second trap on the return connections had to be installed.



Growth of network 1970 to 1978

Two other important components in the sub-station are the differential pressure regulator and the flow stabiliser -both needed to provide the necessary conditions for heat metering.

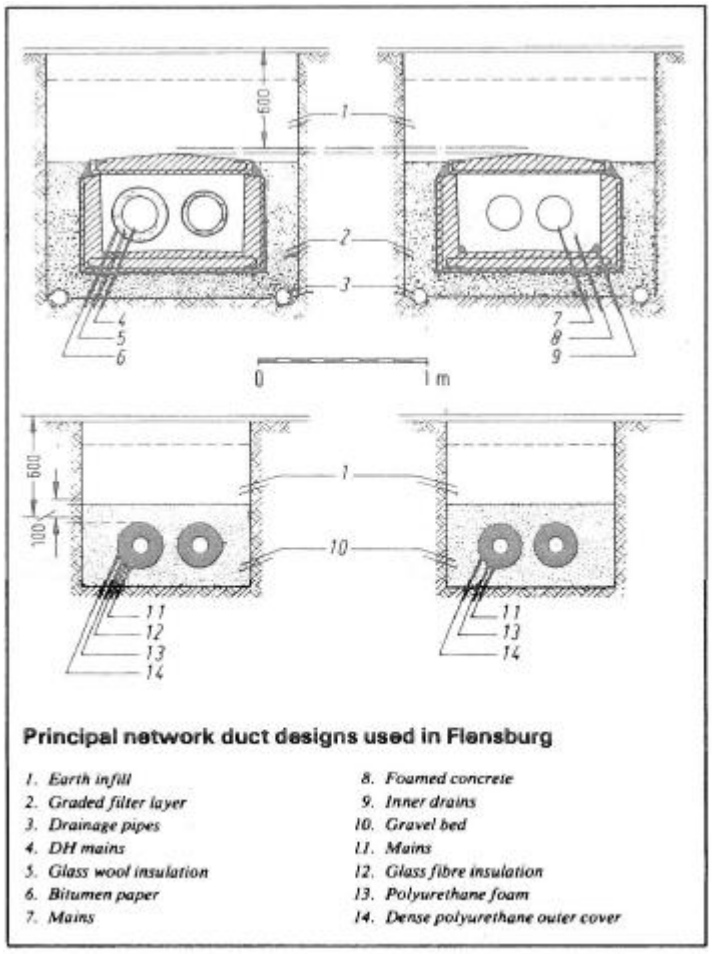
Corrosion has not so far been a significant problem with the network, which is for the most part relatively new. However, a standard procedure for checking the state of the mains has been developed. Apart from the regular twice-yearly inspection of the drainage pits, the whole of the network is checked externally for leaks at the beginning and end of the heating season by means of an infra-red imaging technique.

The specialist firm which does the work uses a small motorised trolley containing the camera equipment, and the trolley makes a complete tour along the line of the network. A temperature rise of 1.0K can be detected, and this is the signal from which it can be deduced that damage to the insulation has taken place. In this way potential sources of corrosion can be identified and corrected.

One great economic advantage of the Flensburg system is that the primary energy source is

almost entirely coal, with heavy oil used only for peak load boilers. In 1978 the amount of coal used totalled over 160000 tonnes against some 7000 tonnes of oil. About one third of the cost is indigenous; the rest is imported being shipped direct to the town's harbour. As an insurance against hold-ups in coal delivery-the harbour is ice bound for part of the year - large stocks are held. At the beginning of 1979 some 100 000 tonnes of coal were stockpiled, as well as 12 000 tonnes of heavy oil.

Although the generating station works in conjunction with the Danish and German grid system, both supplying and taking current depending on the season and the load, an emergency power facility is installed in the form of a 3 MW diesel alternator. The network is also protected from failure of the central station by the use of a ll5 MW standby heat station, and by other older decentralised units which give a further 25 MW. A second reserve station is due to be built within the next few years and will ensure a supply of about two thirds of the total load.



Principal network duct designs used in Flensburg

1. *Earth infill*
2. *Graded filter layer*
3. *Drainage pipes*
4. *DH mains*
5. *Glass wool insulation*
6. *Bitumen paper*
7. *Mains*
8. *Foamed concrete*
9. *Inner drains*
10. *Gravel bed*
11. *Mains*
12. *Glass fibre insulation*
13. *Polyurethane foam*
14. *Dense polyurethane outer cover*

Heating Duct details

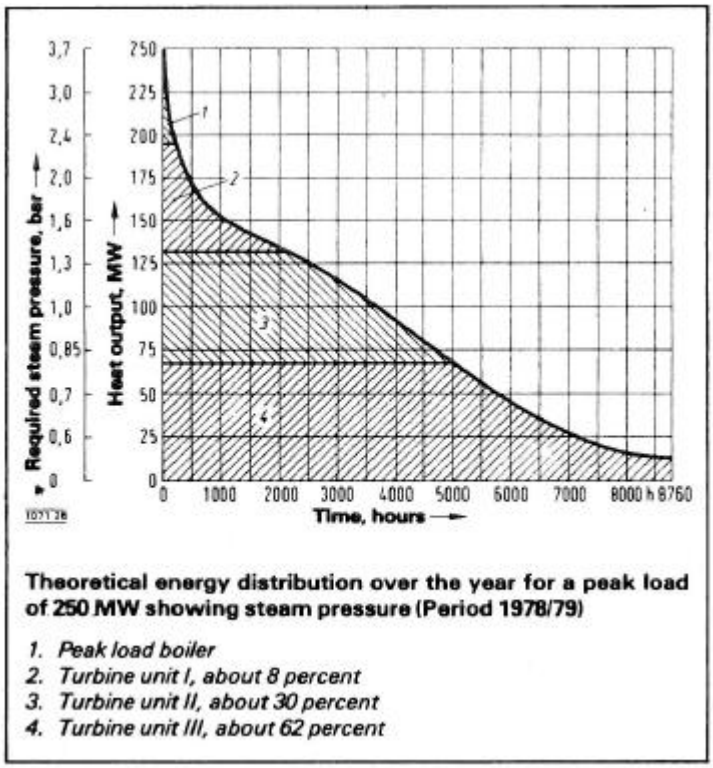
Since 1969 Flensburg's district heating has cost around 220 MDM, and by 1982 will have reached some 300 MDM.

All consumers are offered a basic heat price regardless of whether they are domestic, commercial or industrial. The price is made up from the DIN assessment of the building heat demand, which is more than the actual peak load. This is compensated for by the use of a load factor, which depends on the kind of building. For example, a hospital would have a load factor of 0.8, a dwelling 0.7 and a warehouse 0.5. From this is derived the annual connection tariff. At the moment this is rated at 26.23 DM/kW, and the heat price is 21.50

DM/kWh.

These prices are lower than any equivalent fuel, and were made possible by the very low specific costs of the installation.

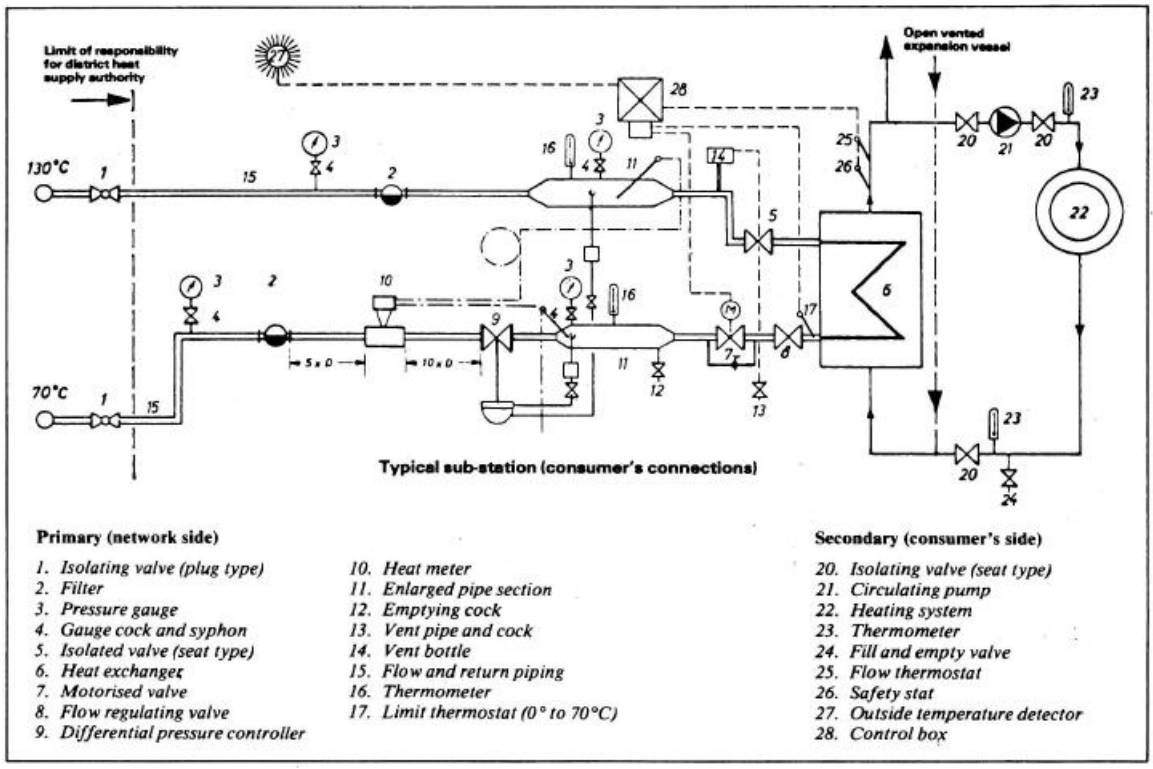
The success of district heating in Flensburg owes a great deal to the co-operation of all concerned -building owners, building contractors, housing associations, commerce and industry, and the establishment itself. One of the most important incentives was the very positive help given by the local press in promoting the system at every stage in its development.



Theoretical energy distribution over the year for a peak load of 250 MW showing steam pressure (Period 1978/79)

1. *Peak load boiler*
2. *Turbine unit I, about 8 percent*
3. *Turbine unit II, about 30 percent*
4. *Turbine unit III, about 62 percent*

Load Duration curve



Typical house connection

1.1.1. The Cogeneration Plants of Stadtwerke Flensburg [259]

- Since 1971 Stadtwerke Flensburg generates electricity and heat in cogeneration. For this purpose, the electricity-only power plant (existing in Flensburg since 1913) was converted into a CHP station in 1969-1971. The Stadtwerke Flensburg supplied district heating since 1969, initially on the basis of decentralized temporary mobile heating stations.
- Today the energy production of the Flensburg CHP station is based on six cogeneration plants (6 boilers that operate in conjunction with six turbo sets, each consisting of extraction condensing turbine (T3, T5) or back-pressure turbine (T6-T9) and generator. In addition, there is a smaller, light oil-fired "Steam block" serving as a reserve asset that only generates heat.
- At the heart of the CHP power generation are three large boilers (K9-K11) with "circulating atmospheric fluidised bed combustion". Usually they carry out most of the annual energy production. There are also two further - coal-fired - boilers (K7 + K8), and one oil-fired boiler (K5). The latter serves as a reserve asset.
- The fact that the CHP station consists of six and not just of one cogeneration plant is due to the fact that the district heating demand varies seasonally. (in the summer little and in the winter high demand). Therefore, depending on the seasonal demand for heat the number of cogeneration plants involved in the energy production varies strongly.
- The first cogeneration plant, the CHP station has started with in 1971, consisted of boiler "K3" and turbo set "T3". Boiler "K 3" does not exist anymore neither does

259 Hans-Jürgen Prinz Stadtwerke Flensburg/. Pers Com. 23.11.2010

boiler “K6” that had been operated since 1976. Today's cogeneration facilities have been completed shown in 23.1:

Table 0-1Technical history of the Flensburg CHP-DH schemes

Boiler	Year	Turbine	**Year**
K5	1975	T3	**1971**
K7	1979	T5	**1975**
K8	1982	T6	**1977**
K9	1986	T7	**1980**
K10	1989	T8	**1985**
K11	**1990**	**T9**	**1988**

Naturally quite a number of technical innovations have been realized in the CHP station over the decades. This includes e.g. the construction of flue gas desulfurization ("FGD") for the boilers K7 & K8 in 1984/85. In the end it is a matter of definition what should be considered as a modernisation measure rather than an innovation. For example in the time between 2006 and the end of 2008 the boilers K9-K11 have been converted in the scope of the project “KWKplus”. The measure is aimed at improving the emissions values significantly as well as implementing the co-firing of refuse-derived fuel in the previous coal-only boilers.

ANNEX 2 - EFFICIENCY CONVENTIONS

Lower Calorific Value (LCV) and Higher Calorific Value (HCV)

The reporting of efficiency is based on fuel energy content using the Lower Calorific Value (LCV) convention throughout this report. This method subtracts of the latent heat of the water vapour formed from evaporation of the moisture originally present in the coal or gas fuel, as well as that of the water vapour formed from combustion of the hydrogen present in the coal or gas.

With the Higher Calorific Value, HCV this latent heat is ignored. This use of the two methods causes much confusion. It makes a 10% difference in calculated efficiency for a gas plant – thus a 60% efficiency plant reported on the LCV basis, will in reality be 54% if reported using the HCV convention.

On a coal plant it makes about a 4% difference, thus a coal plant efficiency might be reported as 47%, but on a LCV fuel basis would be only 44.9% on an HCV basis).

Net or Gross Efficiency

A further complication is that efficiency can also be measured as Gross or Net. This is quite separate from the discussion in the preceding paragraphs.

Gross efficiency is the efficiency measured at the generator terminals. Net efficiency is the efficiency measured at the exit point of the power plant, and is based on the power generated at the terminals minus the power (also known as works power, self power, parasitic loads) needed to run the various auxiliary systems such as pumps, fans, coal handling and so on. These can be generally 3 – 7% depending on plant type.

ANNEX 3 - HEAT EXCHANGERS

Heat Exchangers are a device for moving heat from one fluid – typically in our case water or steam, to a physically separate fluid, in our case again likely to be water. This is achieved by physically separating the fluids by a thin sheet of thermally conductive material, such as copper alloy. This allows one fluid to heat or cool the other fluid. There are numerous types of heat exchanger, but of particular interest are counter flow heat exchangers and parallel flow heat exchangers.

It is worth noting that heat exchangers can be 100% efficient in terms of energy transfer, but not 100% in terms of exergy or temperature.

There have been enormous advances in heat exchanger technology, meaning costs and pressure losses have come down compared to 30 years ago.

Heat exchangers have a variety of uses for example separating fluids that have to be at different pressures – such as isolating a house internal heating system from the higher pressures of the DH main, or separating contaminated or chemical containing fluids – for example to isolate the ultra clean water used in the steam cycle of a power station turbine, from the more contaminated water of the DH network.

Clever modern designs can eliminate many heat exchangers which has many advantages as we will cover later.

Types of Heat Exchangers [260]

Because heat exchangers come in so many shapes, sizes, makes, and models, they are categorized according to common characteristics. One common characteristic that can be used to categorize them is the direction of flow the two fluids have relative to each other. The three categories are parallel flow, counter flow and cross flow.

Parallel flow Heat Exchangers

Parallel flow, as illustrated in figure 1, exists when both the tube side fluid and the shell side fluid flow in the same direction. In this case, the two fluids enter the heat exchanger from the same end with a large temperature difference. As the fluids transfer heat, hotter to cooler, the temperatures of the two fluids approach each other. Note that in this case, the fluid being heated can never attain the a temperature close to the initial temperature of the hot fluid – at best (with equal flow rates of both fluids), no matter how efficient the heat transfer, the cold fluid will rise by less than half the difference in temperatures of the two fluids and the cold fluid will also drop by about half the difference.

[260] From - http://openticle.com/2008/02/16/types-of-heat-exchangers/

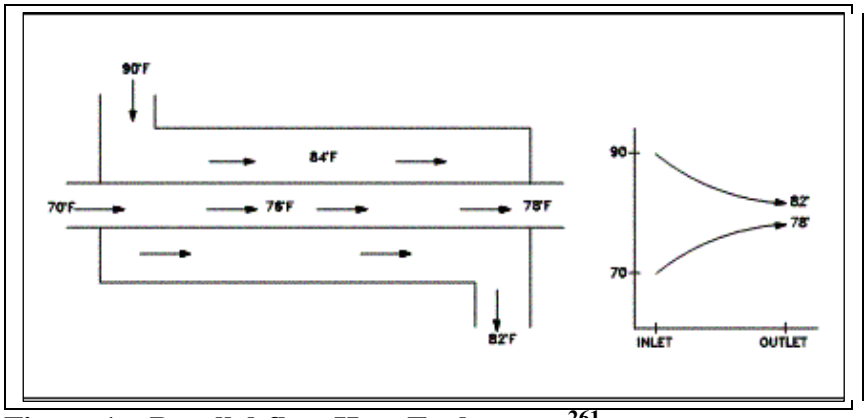


Figure 1 – Parallel-flow Heat Exchangers[261]

Counter flow Heat Exchangers

Counter flow, as illustrated in figure 2, exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger at opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. A well designed counter flow heat exchanger can have the outlet temperature of the cold fluid approach the inlet temperature of the hot fluid.

This will enable one fluid say at 80°C to heat an adjacent fluid to close to, but not exceeding 80°C – typically 79°C. This is important as in any heat exchange we do not want to lose temperature. Unfortunately, the closer the temperature approach, or Delta T; the higher the cost of the heat exchanger and therefore the greater the pressure loss and higher the pumping costs.

It is worth noting that a counter flow heat exchanger achieves this astonishing performance because at each point, there is only a small temperature difference.

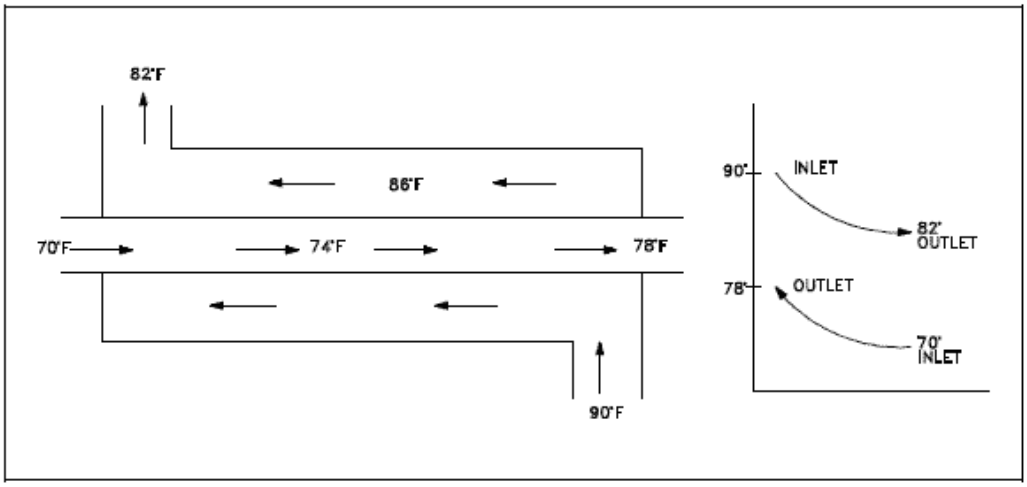


Figure 2 – Counter-flow Heat Exchangers[262]

[261] http://openticle.com/2008/02/16/types-of-heat-exchangers/
[262] http://openticle.com/2008/02/16/types-of-heat-exchangers/

Cooling towers

Cooling towers are a special type of heat exchanger. The familiar cooling towers seen at power stations are packed with a media, often timber lattice over which water is sprayed and trickles. The idea is to create as much surface area of water as possible. Heat is then lost from a cooling tower in two ways:

- By direct conduction between the warm water and the air which passes up the splash packing, by convection or in some cases with fan assist.
- By the effect of evaporative cooling. Any moist surface will be cooled due to the evaporation of the water, which has to extract energy to provide the latent heat of evaporation of the water. (This is known as free chill)

These provide very effective cooling but the disadvantage is they consume the water which they evaporate. An alternative which is not quite so effective is the air blast cooler.

Air blast cooler:

As the name implies, this consists of a bank of fine finned tubing through which the water to be cooled is passed and over which banks of fans blow air. These are not as efficient as cooling towers, needing fan power, and cannot reach quite as low temperatures, but do not suffer from the water loss penalty.

ANNEX 4 - 1977 EEC RECOMMENDATION ON ADVISORY GROUPS FOR CHP

Annex 6

EEC Recommendation on Advisory Groups for CHP

COUNCIL RECOMMENDATION
on the creation in the Member States of advisory bodies or committees to promote combined heat and power production and the exploitation of residual heat
(77/714/EEC) 25 Oct 77

THE COUNCIL OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Economic Community,

Having regard to the draft from the Commission,

Whereas in its Resolution of 17 September 1974 concerning a new energy policy strategy for the Community the Council accepted as an objective the 'reduction of the rate of growth of internal consumption by measures for using energy rationally and economically without jeopardizing social and economic growth objectives';

Whereas any improvement in the rational use of energy is generally beneficial to the environment;

Whereas in its Resolution of 17 December 1974 on a Community action programme on the rational utilization of energy the Council noted that, in its communication to the Council entitled 'Rational Utilization of Energy', the Commission had drawn up a Community action programme in this field;

Whereas a more rational use of energy can be obtained by greater use of combined heat and power production and the exploitation of residual heat in industry, electricity generating and remote heat supply systems;

Whereas implementation of this technique requires the solution of a number of complex problems of an economic, technical, administrative and legislative nature;

Whereas the solution of these problems depends to a large extent on local, regional and national factors;

Whereas the search for solutions at local and regional level is facilitated by an exchange of information and co-operation at national and Community level;

HEREBY RECOMMENDS TO THE MEMBER STATES:

(1) that they create one or more advisory bodies or committees, insofar as these do not already exist, to be responsible for giving an opinion on all measures likely to lead to increased efficiency in the supply of heat for industry and to promote the use of remote heat supply systems, in particular by:

- concentrating heat production and making greater use of combined heat and power production;
- greater thermal efficiency of power stations by exploitation of their residual heat;
- and improved efficiency of heat conduits and associated distribution installations in industrial establishments and in district heating systems, while taking into account the service life of the conduits;

(2) that to this end they invite the advisory bodies or Committees to consider the following measures:

- broadening of co-operation between electrical utilities and heat-consuming industries;
- identification and abolition of legal, administrative and price obstacles to the development of combined heat and power production to supply industry;
- reservation of sites on which industrial complexes and combined heat and power stations can be built side by side;
- encouragement, in accordance with Article 92 et seq of the Treaty, of combined heat and power production and of the transport of heat;
- provision of better information to small and medium-sized industrial undertakings;
- drawing up statements of heat requirements;

(3) that they encourage the advisory bodies or Committees to have regular exchanges of experience and to co-operate at Community level through procedures organized by the Commission;

(4) that they instigate and promote technical and economic studies with the aim of identifying new economically viable remote heat supplies; and that they promote the development, where justifiable, of existing district heating and industrial heat supply systems;

(5) that they inform the Commission regularly of the measures taken in the field covered by this Recommendation and of the effects obtained or anticipated.

66

ANNEX 5 – DETAILED DISCUSSION OF DISCOUNT RATES TO BE USED WHEN ANALYSING THE CASE FOR CHP-DH, AND THE ISSUE OF LICENSES COMPARABLE TO THOSE HELD BY OTHER NATURAL MONOPOLIES SUCH AS GAS AND WATER PIPES, AND ELECTRICITY CABLES

Reconciling the use of a 3.5%/yr (real) discount rate to assess the appropriateness of energy infrastructure schemes; such as Combined Heat and Power and District Heating (CHP-DH) networks with the private sector's need for a much higher rate of return.

1. Summary

The EU wishes to promote Combined Heat and Power District Heating (CHP-DH) Networks (and indeed low carbon energy projects generally) which can achieve a 30% primary fuel use reduction compared to separate heat and power production, because of the perceived need to cut carbon emissions and a desire to increase energy independence (which means reduced dependence on imported oil from the Middle East and gas from Russia).

The economic viability of such schemes is often assessed by governments[263, 264] who generally perform a cost benefit analysis to calculate a Net Present Values (NPV) at a real,[265] discount rate of 3.5%.

However in apparent conflict with this approach, private companies are reluctant to invest in such schemes if they cannot make the normal private sector rates of return – typically 4 – 9% (real) which translates to 6 -11% (nominal)[266]under the present market conditions. This note explains why this apparent inconsistency is illusory stemming from a failure to understand the role of government in promoting private sector business and suggests one way that it can be addressed specifically for District Heating and Combined Heat and Power; but the concepts are generally applicable to all low carbon investments and indeed any other infrastructure investment.

2. Introduction – the of DCF analysis by governments to assess investments in infrastructure

As is well known, Discounted Cash Flow (DCF) analysis is routinely used to assess the viability of an investment option. It allows the comparison of different projects which may have different capital costs and lifetimes, and different costs and benefits spread over long periods of time. DCF analysis is used to sum these different costs meaningfully to produce a single number, the Net Present Value or NPV. Broadly speaking, if the NPV is positive then the project is considered worth investing in, if negative, then not. (In some cases, where infrastructure has to be provided, say a water treatment plant, which always has a negative NPV, then the method is used to determine the option that has the least negative NPV.)

DCF analysis is based on the premise that investors perceive a unit of currency at the start of a project as worth more than the same unit of currency in the future because if the unit had been invested, then it would have increased in value by whatever increase could be expected

[263] European Commission (EC), 2008, Guide to Cost Benefit Analysis of Investment Projects,
[264] UK Treasury Green Book, the official UK guide to assessing investment for projects.
[265] i.e. inflation ignored – that is the unit of currency always has the same value whatever year is considered, whereas in reality the value will drop year on year due to inflation.
[266] i.e. the rate including the effects of inflation which is how company results are reported (that is, Company's always report £s or Euros, but each year the value is less due to inflation)

from a totally secure investment such as a bank backed by governments or governments bonds known in the UK as gilts[267].

Assuming for example that such a bank (or some other absolutely secure investment) offers 3% pa, then the investor (who by definition is not concerned to spend the money now, but merely saving) would perceive for example 1 € now as having the same value as €1.03 in one years time. Thus the offer of €1 in one year would be perceived as being equivalent to only €1/1.03 today, offered in two years time as worth €1/(1.03 x 1.03) and so on for succeeding years.

Thus NPV is the sum of all the terms in the series

$$\frac{R_t}{(1+i)^t}$$

Where
t - The year of the cash flow
i - The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital
Rt - The net cash flow (the amount of cash, inflow minus outflow) at time t.

This assumption is of course, only valid if the investor is absolutely certain that he will receive the unit of currency in one year, and over the 60 years if that is the life of the project.

In reality, economies over the long term grow at about 2 - 3.5 % real which is the same rate that government bonds are sold for, for this reason. This is taking into account all the various, booms, slumps and recessions which have occurred over the last two centuries. The average growth rate achieved by the UK economy from 1950-2005 was about 2.6% real, not 3.5%. A 3% growth rate has been exceptional. The Green Book states that 2% of the 3.5% is due to economic growth and 1.5% is other factors.

The average investor will therefore not make more than 3% per annum if they invested in a basket of projects and business in a given economy. This is why Governments (e.g. UK[268], the IEA, the European Commission etc. recommend the use of a 3.5% real discount rate to evaluate the Cost / Benefit of infrastructure projects – i.e. those projects which will last 60 years or more such as water supply, dams, drainage, roads, bridges etc. and which bring a range of benefits to the society as a whole and are deemed necessary for society to function and develop because this is the rate of return that business actually achieve in the long term..

For example the UK Treasury Green Book, the official UK guide to assessing investment for projects states:

> "**5.48** Discounting is a technique used to compare costs and benefits that occur in different time periods. It is a separate concept from inflation, and is based on the principle that, generally, people prefer to receive goods and services now rather than later. This is known as 'time preference'.
> **5.49** For individuals, time preference can be measured by the real interest rate on money lent or borrowed. Amongst other investments, people invest at fixed, low risk rates, hoping to receive more in the future (net of tax) to compensate for the deferral of consumption now. These real rates of return give some indication of their individual pure

[267] Short for Gilt Edged Investments
[268] UK Treasury Green Book, the official UK guide to assessing investment for projects.

time preference rate. Society as a whole, also prefers to receive goods and services sooner rather than later, and to defer costs to future generations. This is known as 'social time preference'; the 'social time preference rate'
(STPR) is the rate at which society values the present compared to the future.
5.50 The mathematical expressions used to calculate discounted present values are set out in the footnote below.9
The discount rate is used to convert all costs and benefits to 'present values', so that they can be compared. The recommended discount rate is 3.5%. Calculating the present value of the differences between the streams of costs and benefits provides the net present value (NPV) of an option. The NPV is the primary criterion for deciding whether government action can be justified.

What this essentially means, is that if a government thinks that investment in a bridge, or railway or road, shows 3.5%, then it should be built, because the investment will grow the overall economy at 3.5% and it will achieve the wider societal benefits such as mobility in this case. So if a government priority is to cut carbon emissions and fuel imports, then if this can be achieved with a 3.5%[269] rate of return then the government will probably decide the project should be proceeded with – the investment does not lose money and the country gets the low carbon investment. How it gets this investment to happen is another matter which the paper will consider later.

Higher rates of return are believed by investors to be available to those investors who think they have better market views than others, and who believe they can exploit a short term market boom (say construction, housing, art etc.) but there is always a risk, which is real, and this means in fact over the long term, they will not in general gain the higher return they anticipate because not all business ventures they invest in will be successful – as we have seen recently.

This is worth repeating, although investors demand higher rates of return than 3.5%, they do not in fact get them overall. They are illusory. This is because many ventures fail and this forces investors to diversify, which means that overall they will get the general rate of return of say the country as a whole, which is a basket of investments which is about 3% for mature economies, and which is the typical government bond rate. (For those countries not run by criminals)

Of course investors are aware of this, and make careful analysis of the risks of any given venture, and the more risky it is perceived as being, the higher the rate of return they expect but some of there investments will still go bankrupt. They are expecting that overall they will do slightly better than the 3.5%.

Generally it is a rule of thumb that investors will invest in business perceived as risk free, such as a utility (which is also a risk, but low), rather than buy government bonds, but need at least 6% nominal (i.e. not real) which is 2% inflation plus a one per cent risk premium on the assumed general growth rate of 3%, real.

3. The role of government legislation and regulation in assisting private enterprise to meet its higher than 3.5% real, financial goals.

A prime role for government once it has decided it wants a certain investment to happen in the market place is to manipulate affairs to enable this. In the past they would often simply

[269] If there is a shortage of investment funds, then of course the government may use DCF analysis to find the schemes with the highest NPVs and only proceed with those.

invest government money, i.e. raised on the bond market, where governments (non-criminal) are perceived as risk free, at say 3.5% to build power stations, bridges, roads and hospitals.

The French nuclear energy programme widely regarded as a successful venture was funded in this way by French sovereign debt which is 3.5 – 4%. Similarly prior to the break up of the UK Central Electric Generating Board, CEGB this was also funded by government debt.

However this is not current economic orthodoxy so generally the private market is expected to build these things. But since the investors in building and engineering firms know these can and do regularly go bankrupt, due to the risks they face – competition, incompetence, catastrophe etc. they demand higher rates of return than the 3.5% used by the government to assess the investment.

Clearly an investment, in say a power station, or water treatment plant that shows 3.5% really cannot make 6-9%, which would be enough to satisfy investors. Therefore the government steps in to alter the market structure in such a way as to ensure these returns. For example renewable energy projects receive in Europe a variety of support schemes to make it worthwhile for investors. This may be money coming from taxation, or it may be money which the government in the UK forces the electricity companies to levy on consumers – the Renewable Obligation Certificate or ROC scheme which can then be claimed as not being a tax…but it has the same effect – money taken from consumers to pay for something the government wants.

Similarly, the UK government has recently announced that it will set a Carbon Floor Price – and this will benefit all non carbon generators, but it has been shown to particularly benefit nuclear energy which is in line with the government's stated desire for more nuclear power stations which clearly, the free market is unwilling to build in the UK. The government also already underwrites the cost of decommissioning and insurance, which absent, would otherwise increase the price at which nuclear energy us sold.

So if a government is persuaded, by either cost benefit analysis, or pressure from lobbies, the personal views of influential government officials, or the whim of the Prime Minister of the day, that a given technology or course of actions has a broad range of benefits that are on balance beneficial, then it will adjust the market environment, by constructing laws and regulatory frameworks in such a way that an investor in the technology can achieve the rate of return needed. This may be 6% - 12% nominal or higher, even though the cost benefit of the scheme only meets 3.5%. For example according to professor Robert Lowe[270], who has studied energy conservation in buildings and Danish District heating system economics the Danish Government has clearly manipulated the commercial environment to favour a technology perceived as beneficial:

"…… we need to remember that energy supplied to dwellings in Denmark is roughly twice as expensive as in the UK due to various forms of energy taxation. A useful intro to the situation (for non-Danes) is contained in the IEA's ""Energy Policies of IEA Countries – Denmark – 2006 review…."" available at http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1694

It may also take steps to lower risk which mean investors can borrow money at lower rates – by granting monopolies – for example the Dutch municipality gave a 30 year monopoly on

[270] Professor Robert Lowe, University College London. Personal Communication.

the operation of a Biogas fuelled district heating in Polderwijk, Zeewolde, The Netherlands or providing other forms of backing which means that banks are more inclined to provide funds. Thus government intervention in markets in this way is quite normal. Sometimes government promote schemes in this way that do not even meet 3% real for a variety of often obscure reasons.

Another method available is to allow by legislation, businesses to set prices, which will guarantee a given rate of return. So typically in the UK, the government, or more specifically a regulation arm of government such as OFWAT may decide that the risks and benefit to society of the water, cable and gas pipes justify a 6% rate of return to their owners. It then allows the licensee (which also gains some monopoly powers) to have investment plans (for e.g. new treatment plants, new pipes) that achieve the licence conditions (e.g. provide services at mandated standards) and also allows the licence holder to set prices that can enable them to make that return, so long as they behave prudently.

Exactly the same logic can be applied to District Heating and Combined Heat and Power networks licences. Thus this does not imply any subsidy or taxation, merely the regulation of prices and the provision of such powers as may be appropriate, which lower borrowing rates, to permit a reasonable, typically 6% - 11%.

4. Role of government in lowering risk generally

One can see the whole panoply of government powers – the legislature, the law courts, the police, record keeping, enforcement of property and inheritance rights etc., in large part as fulfilling the vital function of risk reduction which in turn lowers the cost of funds and creates opportunity for investors. It is generally difficult to get investment funds for lawless countries such as Somalia, for example.

5. Government's historical and contemporary role in risk reduction for investors by the granting of certain powers to investors.

In order to allow investors to meet rate of return aspirations, the government has often ceded certain of its power to entities to fulfil specific roles. There are plenty of historical examples of networks such as the early coal-gas pipes, the railways, water and sewage pipes, power distribution and transmission cables, natural gas pipelines, the CHP-DH networks in Scandinavia and Germany which were all constructed as a result of the conditional ceding (either by gift, or selling and historically often including bribery of government officials or legislators which amounts to the investors buying a licence) by government of some of its powers which included typically:

- A monopoly, (only one company received the right to build the railway from London to Bristol for example)
- The ability to set prices to meet private sector required rates of return.
- Widespread powers of land entry and road breaking -
- Pre-granted planning permission (a water company does not have to apply for planning permission to lay pipes it deems necessary to carry out its licence obligations - even over multiple jurisdictions, or a railway to lay new tracks)
- Compulsory land acquisition powers
- All the above without any restraint other than adherence to the licence conditions or conditions set out in the Act of Parliament (in the UK), and reasonable compensation and to those who are affected.
- All these powers with effectively an indefinite lifetime, providing licence conditions

are observed.

This was because it was recognised by governments who wanted the railways / networks, and investors who wanted to build them, that without these powers, the networks and the wealth they created could not come into being. No one could have constructed a railway, water pipe or cable, which crossed many properties, without parliamentary or other power of authority, because it would.

a) Take too long and be too expensive to make the multiple planning applications / property negotiations
b) Any one conflict could have held up the whole process
c) And unless they knew no other entity could construct a parallel competing one they could not be sure of getting a return.

Thus the early railways and sewers in Europe were all constructed by the developer by obtaining from the power in the land - the parliament or the King/Queen and being granted rights to build the railway / pipe along the route prescribed.

Whilst these licences are often now in the hands of private companies and are therefore traded, they can in part still be seen as extensions of government since they have had many governmental powers ceded to them and if they are abused the government can take them back.

From a business point of view nothing beats owning a government guaranteed monopoly.

6. The creation of real wealth by the ceding of certain powers from government to private companies

If a developer borrows money from a bank to build infrastructure, the bank actually buys the money from the government at the bank rate which is normally close to the long term bond yield, and receives this money in the form of banknotes from the government. This money then gets lent to the investor. (Actually banks are allowed to electronically create money as a multiple of the actual bank notes they have)

Thus this ceding of power actually creates real wealth, i.e. the new bank notes in circulation as the result of building valuable infrastructure can be spent on real things, as opposed to government printing money via Quantitive Easing which merely dilutes the existing total wealth. Quantitative easing is not meant to create wealth in itself; it is intended to stimulate growth which will create wealth.

This actual wealth creation by ceding of power is powerfully illustrated by the construction of the trans-America Union Pacific Railroad where part of the funding came by giving the railway company and its backers blocks of land along the railway's path. Previously worthless land in the mid-West, once in the ownership of the railway, became enormously valuable real estate, but only once the railway had been built. (This is not of course the whole story, some of the original backers became extremely rich, and much of the history is controversial involving organised wholesale bribery of the legislature)

In a similar way, in recent years, large parts of the electromagnetic radio spectrum, once entirely owned and monopolised by government, have been auctioned (note we are not claiming that selling licences creates wealth based on the sale price) and sold off to enable telecom operators, radio and TV channels, to create value and previously non existent wealth

by the construction of mobile phone networks, radio and TV stations, thus transforming worthless radio bandwidth access into valuable commodities. (Unlike railways and pipes, radio is not a natural monopoly, but it can nevertheless be made one by government fiat).

Note that if the licenses had been given to all and sundry with no restriction, then there would have been less incentive for the operators to build the network. By restricting access to a select few via a monopoly, a low risk environment is created which simultaneously enables investors to borrow money more cheaply and to ensure they can charge enough, or sometimes more than enough to meet their return aspirations.

7. Funding District Heating and Combined Heat and Power networks

Against the background of existing energy networks, all operating with ceded quasi governmental powers, it is unrealistic to expect any entrepreneur to consider constructing a District Heating (DH) and Combined Heat and Power (CHP) network with the normal private sector model in competition with incumbent gas and electric operators, unless she is granted the same quasi governmental powers, since insurmountable challenges will be faced:

The incumbent is up and running with a sound business model, a good track record and any newcomer would face all sorts of inertia in terms of getting customers to switch to a new operator.

- The incumbent will have been, and will remain, funded at very low rates for the reasons explained
- The lack of property compulsory purchase, lack of pre-granted planning permission, lack of road breaking rights etc.
- The incumbent will have heavily written-down assets.
- The incumbent may have been heavily-subsidised to lay its original network, perhaps 50-100 years ago; this applies especially to electricity
- The new entrant will not have a monopoly, and could face competition.
- To be economic, such a network needs to have at least a 60% market share and preferably 90% which it is unlikely to get unless it is granted a monopoly on heat supply.

This all means that due to the high risks, the would-be DH operator could only borrow money at extremely high rates, if at all, and this would make the enterprise financially unworkable.

More attention could be paid to the very large one-sided competitive advantage that incumbent network operators have in comparison to would-be DH network operators.

This is what "Best practice in Danish district heating"[271] has to say on this subject:

> "
>
> **Efficient financing**
>
> Financing is a problem in many countries, but not in the district heating sector in Denmark. Most companies finance their investments in networks and CHP plants 100% by international credits at the lowest market based interest rate (for the time being around 5%* p.a. in USD). Banks compete to offer the best conditions so long as they can see that the security is high. And security is high, due to following reasons:
>
> • The national energy policy is stable
> • The municipalities guarantee for loans, also to the consumer co-operatives

[271] "Best practice in Danish district heating" News from DBDH 3/1999

• The consumers are obliged to remain connected and to pay at least the fixed tariffs
• The proven technology and maintenance management ensure long lifetime
• The consultants provide know-how on feasibility studies and project implementation
• There are clear roles of responsibility and efficient decision-making in the companies.

Therefore other private investors, ESCO's, BOOT concepts and the like offer no real competition."

*This is clearly a nominal rate and therefore the real interest rate is minus inflation about 2.5%

8. Rates of return achievable by District Heating and Combined Heat and Power networks

The European Commission's Joint Research Centre, (JRC) Institute for Energy and Transport has shown in an internal report that the construction of new Combined Heat and Power and District Heating networks (CHP-DH) based on either retrofitting existing power stations, or building new ones, is likely to easily meet a 6% real rate of return, and certainly 3.5% real, assuming 90% of dwellings can be connected, and give very large fuel and CO_2 savings - typically 30% which are seen to be worthwhile for society. This is why the European Commission passed the Cogeneration Directive (COM 2004/8/EC: Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market) and is currently going through the process of enacting a much stronger Directive to support cogeneration – (Proposal for a Directive on energy efficiency and repealing Directives 2004/8/EC and 2006/32/EC [COM(2011)370, 22/06/2011])

The question is what measures are needed to make these District Heating and Combined Heat and Power networks come about without resorting to unfashionable dirigiste measures? For even though they will make 6% real, they will not come about because the risks, under current circumstances, are still too high and unquantifiable for investors; this is principally the uncertainty of being able to achieve a 60% plus penetration, plus gain all the multiple planning permissions, building, road and property entry rights.

9. Free market solution – the creation of wealth by vesting certain powers in legal "license holders" entities and transferring them to the private sector.

One solution to this problem is to require Member States to create District Heating and Combined Heat and Power Network licences. These would be for areas which could be from city scale down to village scale, and which give precisely the same quasi-governmental rights as already enjoyed by existing network owners as well as any such other powers as may be necessary.

For example such a license might include:

- a monopoly for heat supply (with certain appropriate exceptions for example they could be restricted to gas supply areas).
- widespread powers of land entry and road breaking -
- pre-granted planning permission to lay pipes it deems necessary to carry out its licence obligations over multiple jurisdictions) – with specified compensation conditions

- compulsory land acquisition powers – with specified compensation conditions
- all the above without any restraint other than adherence to the licence conditions or conditions set out in the Act of Parliament (in the UK), and reasonable compensation and
- all these powers with effectively an indefinite lifetime, providing licence conditions are observed.

Similar licences could be created for bulk heat transmission pipelines, and for the waste heat from power stations which have been converted to CHP (as is intended to be required under the Energy Saving Directive)

These licences can then be auctioned to the highest bidders, which in most cases would probably turn out to be the existing utilities.

Auctioning these license is suggested not as a way of raising money for government (although it might) but because it is unlikely that the governments can simply hand them over in a democracy, so auctioning is a non-controversial way of handing these potentially valuable rights over. It may well be that these licenses are sold for a low or nominal value. The market will assign a value to each license and investment be raised for the best schemes.

Another method would be to set up a company with the licenses vested therein and then to sell shares in them. However they are disposed of is irrelevant – the point is that value is created merely by the vesting of licenses in a non-governmental body.

This of course already happens whenever an ESCO is given a contract by a municipality. It should be possible to require all jurisdiction to vest these necessary powers in a form of license and then to sell them to the highest bidder.

There is some evidence that these DH networks tend to raise property values in the same way as constructing a railway line.

Wealth is created by the substitution of otherwise wasted power station reject heat, and the consequent saving of fossil fuel meaning money previously spend on imported fuel can be spent within the economy and in the provision of jobs in the construction and maintenance of these enterprises.

10. Monopoly and a Natural Monopoly.

This is not to say monopolies are a good thing in general. It is generally accepted that one of the main reasons the West is rich with a low disparity of wealth is that monopolies are generally discouraged in favour of free-market capitalism. Monopolies are useful in a very limited set of circumstances and can very easily be abused. For example In Thailand the now exiled prime minister Thaksin Shinawatra, likewise Carlos Slim in Mexico, the worlds richest man, made a huge personal fortune and of course huge personal political power by obtaining a telecoms monopoly, significantly pushing up the costs of telecoms and all other services in these countries so such monopolies are not without dangers to the economy and democracy..

But we should note that there is a clear difference between a Monopoly and a Natural Monopoly. A simple monopoly occurs when one entity is given total control over a market sector, when it could easily be open to many. A Natural Monopoly occurs in cases such as railways, pipes and cables, where it is not feasible to have multiple players due to costs to

have parallel competing physical assets or in some cases where it is not physically possible to have duplication.

11. Conclusions

- There is no conflict between assessing societal benefits of infrastructure schemes at 3.5% (real) and the fact that business may require 6 – 11% (nominal) to invest because government can and do, post hoc, manipulate commercial environments to permit these returns.
- This has been routinely done in the past for network providers by effectively the granting or auctioning of licenses and this could readily be applied to district heating networks, or indeed any other form of energy infrastructure
- Incumbent utility suppliers such as gas and electricity pipe and cable networks have a huge competitive advantage over would-be competitors piped heat suppliers by virtue of the various rights such as pre-granted planning permission, ground and road breaking rights, not enjoyed by DH operators, and these rights must be created and assigned in some way to CHP-DH developers if private capital is to create these networks.
- Unless this is recognized by the EU and remedied, CHP-DH networks will not be built on the scale envisaged as part of the programme to combat climate change and reduce energy dependence.

ANNEX **6 - ARTICLE DESCRIBING TECHNICAL DETAILS OF THE ODENSE CHP DH SCHEME. (REPRODUCED WITH PERMISSION)**[272]

A remarkable district heating system



By Mr Per Rimmen Director of Odense Municipal District Heating Company

Odense, the third largest city in Denmark, is known for its efficient district heating system, and a heat price which is among the lowest in Denmark. Around 75 % of the heat are sold to one-family houses, which are much more expensive to supply than large apartment buildings. It is therefore remarkable that the heat price can be among the lowest, considering that in many countries it is impossible for the district heating to be competitive, especially in districts with one-family houses.

The district heating company is owned by the municipality of Odense. The city council acts as a board of directors of the company. The 53,000 consumers (buildings) that are supplied represent 97% of the population in the municipality. The company's natural aim is to provide the consumers, and thereby the population living in the buildings, with sufficient and reliable heat at the lowest possible costs. All profit made by the company is used to reduce the tariff.

A typical family in a 150 m² one-family house pays annually DKK 8,500, including taxes and VAT. This corresponds to 0.6 % of the price of the house or 1-2 % of the annual family income and is 30 % lower than the alternative of individual oil or gas boiler.

What is the reason for this successful market share? Is there any secret? There are many reasons for the success, but one of the most important is that we have very simple and cheap district heating substations to connect the 53,000 buildings, which are supplied. The internal heating systems in the buildings are directly connected without heat exchangers and, most importantly, without a mixing loop. Moreover, all meters are cheap mechanical flow meters - not heat meters. In fact, there are no heat exchangers in the heating circuits of the system at all, except a few, which separate the special heating tubes in the green houses. This is even more remarkable as the whole directly interconnected heating system, from power plant to the radiators of 53,000 consumers (buildings), includes 1600 km of pipes, with dimensions from 25 to 1000 mm, 150,000 m³ of circulating water and pressure levels up to 25 bar. Only the hot tap water is heated in each building substation via heat exchangers or hot water tanks in order to ensure high quality of the water to the consumers and in the closed heating circuit. We definitely have no open systems, which are typical in the NIS countries.

Let us look in greater detail at the main reasons for the low heat price and the most important preconditions for the large and directly interconnected heating system:

The district heating system started in Odense in 1929 utilising the low cost surplus heat from the local power plant and it has gradually developed subject to commercial conditions.

The heat supply law from 1979 and the integrated heat supply and urban planning have moreover boosted the development in the last 20 years. District heating today supplies 100% of all heated buildings in the 95% of the city's urban areas suitable for district heating.

The heat production is still based on CHP - 20 % come from a CHP waste incinerator, 75% come from a new coal fuelled extraction CHP plant and only 5% come from peak load boilers distributed in the network. Consequently, the heat production is based on low-grade fuels, and the fuel consumption is around 3 times smaller than it would have been if the heat were produced in heat-only boilers.

A 15,000 m³ pressureless heat accumulator tank at the CHP plant has been in operation since 1975. It was the first heat accumulator in Denmark. Now heat accumulators in the range from 1,000-50,000 m³ are a natural part of any modern CHP plant. The accumulator maintains the pressure of the system and allows the CHP plant to operate in power-only mode in 2-4 power peak hours, while the accumulator provides all the heat. In other words, the heat extraction does not reduce the capacity value of the power plant.

Apart from the 53,000 buildings, the district heating system supplies two neighbouring towns and a number of greenhouses, spreading on an area of about 150,000 m². In total, 5% of the heat production is sold to the other municipalities and 30% to the greenhouses.

The temperature level is very low. The normative design temperature is, in principle, 120°C. However, the maximal operational supply temperature is 95°C, due to the pressureless accumulator. On the coldest day, the normal maximal supply temperature from the CHP plant is around 90°C, which is sufficient to provide a suitable supply temperature directly to the radiator thermostatic valve at the other end of the network. In summer, the supply temperature is around 78°C. This is sufficient to produce hot tap water at 55°C to most consumers, whereas thermostatic regulated bypasses ensure that the consumers at the end of the network are also provided with a district heating temperature of at least 60°C. The return temperature to the CHP plant is around 40°C in the winter and 42°C in the summer. The low temperatures reduce the fuel

Peak load back-up boiler plant fuelled by light oil situated in the outskirts of the network. It is not staffed and it can be started by remote control. It is seldom in operation, but it guarantees the consumers a reliable heat supply on the coldest days and in the case of repair or planned maintenance of the network.



[272]Per Rimmen, former director of Fjernvarme Fyn, is from "News from DBDH", second issue 2002



A typical consumer substation to a one-family house in the show room of the district heating company. The consumers are able to ask for advice before they decide to invest. The flow meter and valves in the left corner below belong to Odense District Heating Company, whereas the heat exchanger for hot tap water, the differential pressure valve, and other components belong to the consumer.

consumption for the production of heat in the combined production and the heat losses.

The flow meters in the consumer substations are simple mechanical flow meters owned and maintained by the Odense DH company, but the consumer reads the meter and reports the result to the consumer department. The board has considered replacing all the flow meters by heat meters, but found that it would not serve the interests of the consumers. It would be very expensive and would not introduce a more reasonable share of the costs among the consumers. The flow balance of the system shows that 42 mio. m^3 are circulated whereas only 35 mio. m^3 are measured at the consumers. The difference is mainly due to the re-circulation in thermostatic by-passes, as mentioned above. Only a minor part is due to faults of meters and not registered consumption in low load periods.

The tariff includes 3 cost based price components:

- A fixed annual meter-fee per consumer
- An annual fee per m^3 of heated building volume to cover the fixed costs
- A variable fee per consumed circulated m^3 flow

The fixed meter-fee and the variable fee are the same for all consumers, whereas the fee per m^3 building volume includes a discount to large consumers. Thereby the one-family houses pay a higher average price, which reflects the fact that it is much more expensive to supply the small consumers. This tariff structure encourages the consumers to save heat and to reduce the return temperature.

As all other Danish DH companies, Odense DH company pursues an active and transparent information policy towards consumers. In publications and during campaigns, consumers are offered advice on how to use the heat wisely and save heat and flow. The consumer can also contact companies and ask for a visit of an expert.

Many of the old concrete ducts are still in operation many years after they have been paid back and they are only replaced with pre-insulated pipes when non-profitable. A strategy is developed (see *News from DBDH* 4 1995, page 22, Rehabilitation of district heating pipe network in Odense) for replacement of pipes, taking into account investments, heat losses, costs of repair, water losses and the inconvenience of disruptions.

The water loss of around 180 m^3/km pipe/year is high compared to Danish conditions, but still very low compared to water losses in Eastern Europe and NIS. It should, however, be taken into account that the make-up water is produced efficiently at a high quality at the CHP plant and that it replaces the losses in all consumer installations, thereby preventing internal corrosion of these installations.

There is a risk that radiators could burst and water could leak into the buildings, due to the direct system. However, experience shows that this happens very rarely (once in every 10 years) and the costs of the damage are far lower than the savings. This low risk is mainly due to 3 factors:
water quality.

The success and the low heat price are not a pretext for the company for doing nothing. New possibilities for saving costs are analysed and implemented. A fresh example is our decision to remove the heat exchangers between a 25 bar transmission line measuring 15 km and the distribution system in the neighbouring towns Munkebo and Kerteminde, which are supplied from the system. The decision was made on the basis of detailed water hammering analysis with a computer simulation system called SYSTEM RORNET, and various measures have been implemented on the basis of the analysis to prevent water hammering, including 5 m^3 air vessels.

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Title: **Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion**

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Abstract
This report reviews the technology, state-of-the-art, best practice, barriers, scope and measures for promotion of Combined Heat and Power District Heating and Cooling (CHP-DH) It indicates that CHP-DH is likely to have a key role in de-carbonising the building heating sector in Europe, due to the inherently low fuel overhead of any energy delivered, typically 1/4th of the fuel energy over-head of gas boiler heat and 1/3rd the fuel energy overhead of direct electric heating. The technology offers the flexibility to operate with most sources of renewable energy such as wind, solar, geothermal and biomass and waste industrial heat. A key feature is the already cost effective manner in which surplus wind energy can be stored as heat and delivered to consumers, and the ability of CHP power stations to back up variable output wind thus solving the intermittency/variability problem without expensive electricity storage. It points out that the impact of CHP is exactly the same as a heat pump but with a much better efficiency as measured by COP. It points out the need to develop and stimulate low temperature District Heating and Cooling networks due to the improved COP and the ability to readily take in other forms of lower temperature heat.

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