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Intelligent Energy Europe

ECOHEATCOOL

Work package 3

Guidelines for assessing the efficiency of district heating and district cooling systems

This report is published by Euroheat & Power whose aim is to inform about district heating and cooling as efficient and environmentally benign energy solutions that make use of resources that otherwise would be wasted, delivering reliable and comfortable heating and cooling in return.

The present guidelines have been developed with a view to benchmarking individual systems and enabling comparison with alternative heating/cooling options.

This report is the report of Ecoheatcool Work Package 3

The project is co-financed by EU Intelligent Energy Europe Programme. The project time schedule is January 2005-December 2006.

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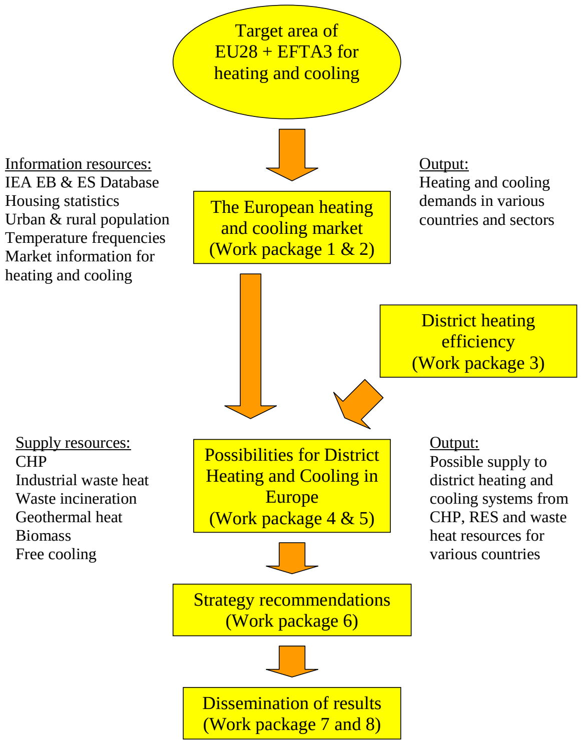
Produced in the European Union

ECOHEATCOOL

The ECOHEATCOOL project structure



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1 Executive summary

Great losses characterise the European energy supply: more than half of total primary energy supply is wasted in heat losses – as shown in ecoheatcool work package 1. The logical conclusion is that a policy aiming at developing efficiency and reducing emissions shall use instruments to identify and measure these losses and turn them into useful energy. The point of district heating and cooling is precisely to use heat sources that otherwise –without the district heating and cooling (DHC) infrastructure- would be wasted. Waste heat includes heat from CHP processes, heat from municipal waste incineration and industrial surplus heat. Likewise, at a moment where demand for comfort cooling is growing - generally met with electricity devices, district cooling provides a cost-effective and efficient alternative. DHC also allow an efficient use of renewable energy sources (RES).

However, most of the benefits of DHC occur well in the upstream to the delivery to the final users. They are therefore fully accounted, when measured in a comprehensive manner.

These guidelines aim at defining a set of criteria to assess the efficiency of district-heating and district- cooling systems; they define a methodology, building on primary resource factors, to measure all savings from production to delivery to the final users. By shifting from end-use KWh savings to the measure of all primary energy savings, and by moving from a building-bound analysis to a broader systemic-perspective the guidelines offer a valuable tool for policy-makers to benchmark the competing technologies on the heating and cooling market. Given the fact that 74% of the European population live in urban areas, and that industries with heat needs are close to these areas, the guidelines provide valuable information about the role of district heating and cooling in further increasing energy efficiency or '*Doing More with Less'*.

The guidelines will also offer a sound basis for eco-labelling of heating and cooling technologies to provide information for final users.

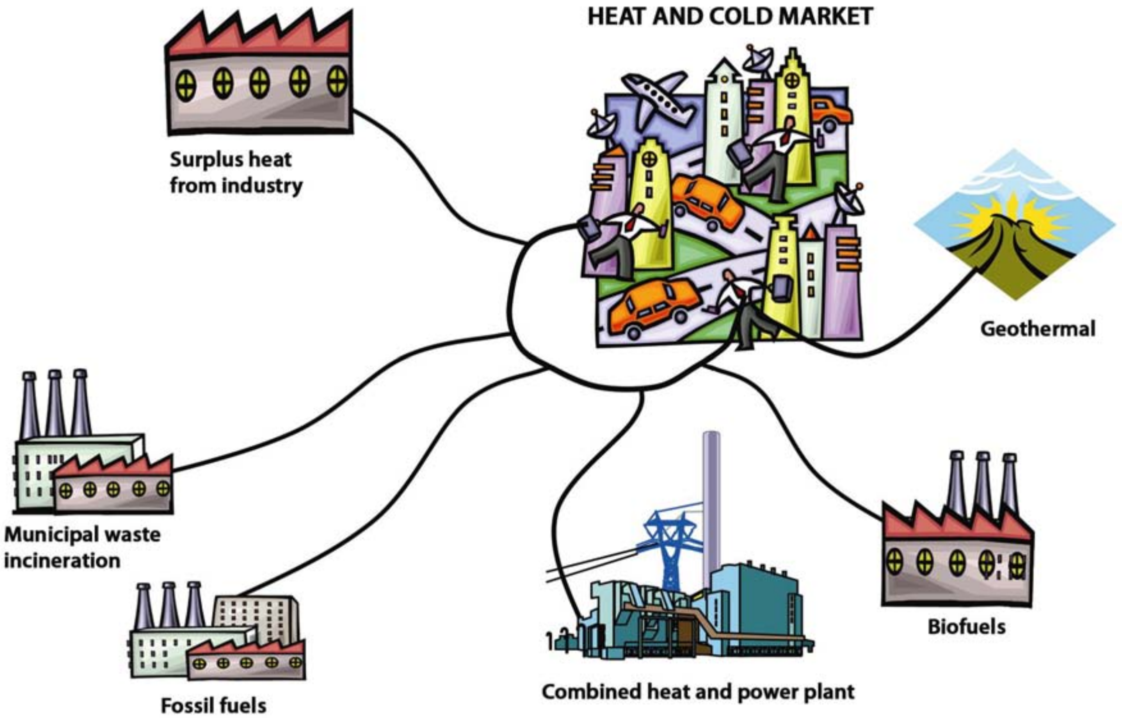
2 Introduction

2.1. District heating

District heating can be described as a system in which water is heated in one or several larger units and is then delivered via pipes to the residential/commercial/industrial customer's premises where the heat is extracted for heating purposes or hot tap water preparation.

District heating systems make it possible to optimally use and combine a large spectrum of energy inputs as illustrated in the diagram below: surplus heat from electricity production based on conventional or renewable fuels, heat from waste incineration and/or from industrial processes as well as different forms of renewable heat (i.e. geothermal, heat/cold from deep-sea or lake water).

Figure 1: District heating and cooling: a holistic approach linking energy supplies to local needs



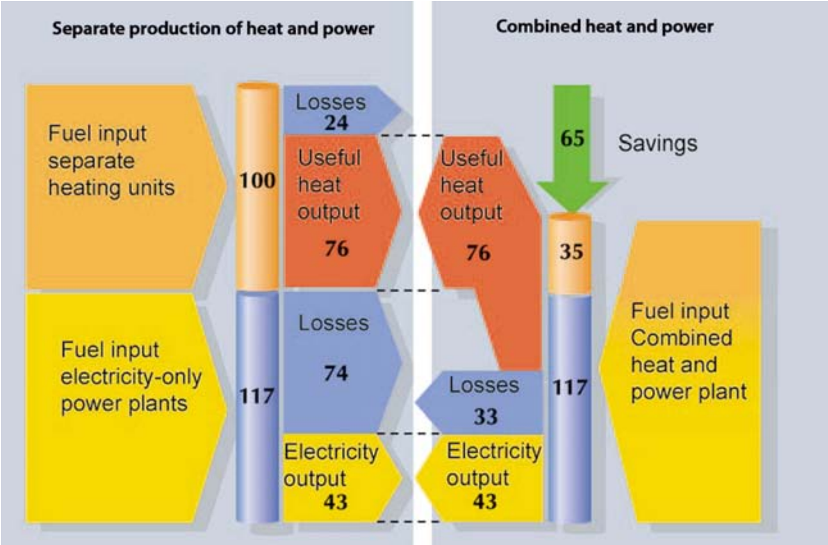
Combined Heat & Power

The share of district heat produced in CHP mode reaches around 64% to 94%[1] in 'old' EU 15 and between 35% (Baltic States) to 72% (Hungary) in new Member States of the Union. As illustrated in the diagram below, with the recovery and use of the heat produced during the generation of electricity, CHP production reaches much higher efficiencies (at least 80%) than separate production of heat and electricity (European average below 40% for electricity production).

This diagram illustrates that in order to produce the same output of energy, 43 units of electricity and 76 of heat, the CHP plants needs 30% less fuel input than separate productions. Both plants in the example are coal-fired.

Figure 2: comparisons of CHP and separate production

[1] Figures for 2003, source: 'District heating and cooling in Europe country-by-country-survey', Euroheat & Power 2005



Fossil fuels and Renewables

The second point is the possibility for a district-heating scheme to use different fuels depending on prices, fuel availability and local conditions. At European level, fossil fuels have still an important position but the share of renewables is growing. District heating will be instrumental in the development of renewables on a large scale; the use of CHP will allow to reach high level of efficiency and optimally use natural resources.

Incineration of Municipal waste

In modern societies incineration of waste is justified by the need to avoid environmentally harmful landfill. Burning waste in CHP plants coupled to district heating networks replaces fossil fuels, and provides environmental benefits due to very tight procedures that limit noxious emissions in comparison to landfills.

District heating and CHP provide the right infrastructure and technology to turn a potential environmental threat into an opportunity to produce and distribute energy.

Surplus heat from industries

Like heat from municipal waste incineration, surplus heat from industrial processes is heat that without the district heating/cooling infrastructure would be wasted.

2.2. District cooling

Like district heating, district cooling[2] is offering solutions tailored to local conditions and using the flexibility of the district infrastructure. Compared to conventional electricity-driven chillers, district cooling will increase the environmental standards/overall efficiency of energy systems as it:

- Contributes to the phase-out of Hydrochlorofluorocarbon - HCFC's. (Traditional compression cooling machines use HCFC's, which are harmful to the ozone layer and significantly contribute to the greenhouse effect.)
- Reduces summer peak loads in electricity grids, as explained below;
- Opens the possibility to better exploit existing production capacities (use of surplus heat), reducing the need for new thermal (condensing) capacities.
- Opens the possibility to use renewables.

There is an ongoing shift of structure in the supply of energy. It is evident in Europe, USA and Japan and is valid - for instance in Europe - both in the North and in the South. For different reasons, there is a steadily growing demand for air conditioning or comfort cooling, mainly in commercial and institutional buildings. In the United States and Japan, more than 80 % of buildings in these categories have comfort cooling. In Europe, the figure is less than 50 %, but it is rapidly increasing. The trend is European-wide and related to the need for comfort cooling in households, and in the tertiary sector.

It is noteworthy that the cooling demand is only to a certain extent related to summer conditions. In fact, between 40 and 60 % of the total cooling demand runs all year round for cooling of computers and other equipment, office and meeting areas etc.

Traditionally, comfort cooling is based on electricity to run the individual appliances. Consequently, electricity demand will continue to grow even faster if traditional cooling expands. On top of that, there is a European peak load dilemma: between 1990 and 2002, average peak loads in the EU15 countries have increased by 20 %. In Greece, the corresponding increase was 54 % during the same period. The average peak-load increase is expected to continue at the same rate - at least. In the Mediterranean countries, the forecasted increase is even higher. In the years between 1990 and 2020 generation capacity in Spain and Italy is expected to double. In Greece and Portugal capacity is forecasted to increase three times during the same period.

Until recently, electrical peak loads in many European countries have typically occurred during winters, but lately the highest peaks in many regions and countries have been registered in the summers - in many cases touching capacity limits with risks for outages. Between 1990 and 2002, the annual electricity consumption in EU15 rose by 30 %, while the increase for July was 38 %. The reason for this trend is often the increased need for comfort cooling.

District cooling provides an alternative route allowing to convert this potential threat to the environment and to electricity supply infrastructure into opportunities for the energy business, its customers and society.

Different technologies for cooling associated to a district network can be used:

Combining district heating and cooling

"Surplus cooling" can be used from heat pumps that are originally intended for production of district heat, operating on for instance, sea-water or waste water. By connecting the cold side of the heat pumps to a district-cooling system, the heat pumps can be used for the production of both heat and cold. In some instances these heat pumps have to be supplemented with chillers to meet cooling demands in the summertime when there is not the corresponding need for heating. In a similar way, big chillers can be used for producing heat when needed.

[2] More on district cooling, *'District cooling – A proven technique for enhanced business and improved environment.* Paper by Tomas Bruce, Ake Petersson and Par Dalin for the World Energy Congress in Sydney, 2004'.

Absorption chilling

Absorption chillers use heat as primary energy and not electrical power as is the case for conventional compression chillers. The benefits of this technology compared to conventional chillers are that the electrical power consumption is dramatically reduced and primary energy is used more efficiently. Surplus heat from e.g. municipal waste incineration, industrial processes and power production may be utilized for cooling production by integration of an absorption chiller to the plant.

For CHP plants where the heat demand's profile is the bottleneck during summer, district cooling enable to increase the efficiency of the plant by using excess heat that is available while displacing less environmentally friendly alternatives.

Free cooling

The concept is based on extracting deep cold seawater. Via heat exchangers the cold is transferred to the distribution network. Still another exchange takes place at the customer, where the cold is used in the cooling infrastructure of the buildings. The maximum cooling temperature delivered to customers can be guaranteed with if needed additional cold added from different sources. Such a technology is used in Stockholm, Helsinki, Amsterdam and Toronto.

2.3. Objectives of the guidelines

When considering heating-and-cooling systems we need to distinguish between building-integrated- on-site solutions based on a single fuel/energy input and designed for a single building (i.e. oil or natural-gas fired boilers, heat pumps...) and supply of heat as end-energy via an external 'district' grid based on one or several fuel/inputs and generation sources. The assessment of the performance of heating and cooling systems can thus not be limited merely to the final customers or the buildings where the energy consumption takes place. A comprehensive approach to end-user efficiency calls for a framework that defines final savings as savings carried out along the whole energy chain.

Final savings shall encompass all savings – i.e. from the primary energy savings occurring during the CHP process to the point of delivery of the final product to the customers.

A comprehensive approach is thus needed to fairly evaluate all existing options. The principles set in these guidelines allow to assess the efficiency of district heating and cooling via a methodology of primary resource factors (PRF) encompassing all savings and losses from the energy conversion to the delivery to the final customers. The use of primary resource factors allows to compare the different heating and cooling technologies available on the market and offers the possibility to assess the efficiency of complex infrastructure and make benefits visible – those benefits that in the case of district heating and cooling occur well in the upstream of the delivery to the final customers.

Additional to savings in terms of final energy, the guidelines consider environmental criteria. The guidelines present a methodology that builds on PRF values to evaluate the impact of heating and cooling systems.

A method reflecting the overall savings will provide transparency, and will thus be an indispensable tool for policy-makers with a view to rating each option's contribution to EU policy goals such as:

- Reduced primary energy consumption
- Improved security of supply and reduced dependence from energy import
- Reduced environmental impact and achievement of the Kyoto objectives
- Better customer's information

It is worth noting that the guidelines will also be valuable for operators to upgrade systems and reach higher PRF values. As they reflect the efficiency of the whole system, operators are therefore able to use them to evaluate where they should take action to reach higher PRF values. With higher customers' information, it is expected that operators may pay increasing attention to their respective ranking.

2.4. Strategic use of guidelines

2.4.1. Policy-making

The guidelines reflect and support European Union policies with regard to the improvement of the efficiency of energy production and its end-use; the further development of the use of new and renewable energy sources/technologies and the mitigation of emissions resulting from energy production and use.

The guidelines will enable a coherent implementation of existing and future Directives related to energy efficiency (see below). They will bring useful information on the heat market and thereby be a valuable tool for policy-makers. By providing information on the efficiency of heating and cooling options, the guidelines will provide a basis to monitor efficiency developments in the heating and cooling market.

2.4.2. European legislation

The guidelines directly relate and refer to the following pieces of European legislation:

Directive 2004/08/EC 'on the promotion of cogeneration based on a useful heat demand in the internal energy market'

The European Union has since its communication on CHP, in 1997, recognised the importance of the technology and of district heating, which provides a heat load to support its development. The benefits of CHP arise from a higher efficiency, which leads to fuel savings and consequently emission reductions. This efficiency and also the fuel flexibility of CHP bring as well significant benefits in terms of security of energy supply.

The Directive 2004/08/EC on 'the promotion of cogeneration based on a useful heat demand in the internal energy market' will provide a framework for Member States to support the technology. The guidelines allow making visible the benefits of expanding CHP in district-heating systems. The principles of the calculation method outlined in the guidelines take full account of and build on the principles set out in Annexes II and III of the Directive.

Directive 2002/91/EC on 'Energy Performance of Buildings'

The aim of this Directive is to reduce the environmental impact of the energy use for buildings. It foresees different instruments such as the setting of minimum requirements on the energy performance of new buildings and for large existing buildings that are subject to renovation (Articles 4.5 and 6); energy certification of buildings (Article 7) and inspection of boilers and air conditioning systems (Articles 8 and 9).

In a recent communication on renewable energy, the Commission stated that:

> 'The Community has already adopted Directives on the energy performance of buildings and cogeneration. These will encourage greater use of renewable energy in heating. There is a need for the buildings directive to be implemented in a way that stimulates the integration of efficient biomass systems, geothermal heat pumps and solar thermal heating in residential and tertiary-sector buildings. The decentralised energy supply based on renewable energy that is envisaged under the Buildings Directive should look to the potential of using renewable energy for heating and cooling, ... Micro-turbines fired by biomass are another possibility for using renewable energy in buildings. There is also a need to encourage a greater share of biomass in cogeneration and in district heating systems, especially where existing systems can be economically refurbished (which is the case in many of the new Member States).'

A framework laying down standardised calculations methods is required and foreseen in the Directive's article 3 and the Annex of the Directive. The Commission has mandated CEN to develop these standards. Among the new standards being drafted, a standard directly addresses DHC.

The CEN pre-standard on 'The performance of quality of district heating and large volume systems' will be instrumental in the implementation of the Directive, especially of article 5 requiring Member States "to ensure that the technical, environmental and economic feasibility study of systems such as decentralized energy supply systems based on renewable energy, CHP, district or block heating or cooling (..), heat pumps (..) is considered and is taken into account before construction starts for new buildings with a total useful floor area over 1000 m^2."

Euroheat & Power's Task Force Eco-labelling has been consulted on the drafting of this standard. The present guidelines build on this standardisation activity, and will serve as further input to continue the dialogue with standardisation bodies.

Proposal COM (2003) 739 final for a Directive on 'Energy End-Use Efficiency and Energy Services'

The proposed Directive on 'energy end-use efficiency and energy services' is intended to stimulate energy end-use efficiency, energy efficiency programmes and measures. The draft Directive puts strong emphasis on integrated energy end-use services combined with the delivery of energy. In its Annex III it mentions 'heating and cooling' as well as 'hot water preparation' as eligible areas where energy efficiency programmes and other energy efficiency measures may be identified and implemented.

To be effective the Directive will need to be complemented by tools allowing to quantify and compare the energy savings potential of different options. The guidelines will provide a methodology to enable the assessment of savings i.e. related to the conversion from individual boilers to district heating and/or the efficient upgrading of district heating and cooling systems (fuel switching, efficiency improvements in both the production and distribution of DHC).

Labelling of heating systems

The European Union Eco-labelling Board recently launched activities on eco-labelling of water heating systems. The work will focus on the labelling of heat pumps while developing comprehensive criteria to label all water heating systems on the market.

The principles of the guidelines will provide input on how to develop indicators to label different technologies and assess their respective environmental efficiency.

3. Information sources

The present guidelines have been established by a group of six district heating experts from five major district heating countries (Austria, Denmark, Italy, Germany, Finland, the Netherlands, and Sweden). The group had four meetings during the project period, worked electronically between the meetings and continuously liaised with Euroheat & Power's working group 'Energy Policy' and Task Forces 'district cooling'

The group has worked in close contact with other interested parties and organisations, i.e. EUEB, CEN, national eco-labelling and standardisation bodies. The work performed is intended to prepare the grounds for larger consultation and agreement involving a maximum number of stakeholders.

4. References

Directive 2004/08/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market

Directive 2002/91 EC on the energy performance of buildings

Proposal for a Directive on energy end-use efficiency and energy services - COM (2003) 739 final

Green paper Towards a European strategy for the security of energy supply - COM 2000 (769) final

Green paper on "energy efficiency or doing more with less" – COM (2005) 265 final

Communication on the share of renewable in the EU COM 2004 (366)

Communication final report on the green paper "Towards a European strategy for the security of energy supply" - COM 2002 (321)

Communication on a Community strategy to promote combined heat and power (CHP) and to dismantle barriers to its development –COM (97) 514 final

CEN prEN 15315 Heating systems in buildings - Energy performance of buildings - Overall energy use, primary energy and CO2 emissions

CEN prEN 15316-4-5 Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems

DIN V 4701-10

Energieeinsparverordnung EnEV (German regulation on energy conservation)

5. System boundaries

The performance of a district-heating system is evaluated by considering the balance of primary energy consumption of heat generation and heat distribution of the district heating system.

When comparing different heating options, it is indispensable to clearly establish the boundaries delimiting what is being considered and to apply these symmetrically and coherently to all systems under consideration.

The current guidelines correspond to an end-energy formulation and ignore the effect of the internal distribution system.

They serve to evaluate/certify the performance of individual district-heating systems and to allow comparison with other systems - but they are not intended to assess the performance of the heating system in each individual building. Distribution losses in the individual building are basically independent of the heating system in question. The system borders are thus drawn after the house substation. Analogously, in the case of solar heating, the system borders should be drawn at the connection after the expansion tank, for heating boilers after the boiler's own circulation, etc.

It is, however, necessary to describe the distribution system as a restricting criterion for each heating system because the specifically determined values are only valid under certain conditions. For example, the primary energy requirement of Heating System X only applies in the case that the in-house heating system corresponds to a low temperature system, or Heating System Y is only to be considered in connection with passive houses.

In the case of cooling, the same system boundaries as for heat and electricity apply.

System boundaries are further explained in chapter 6.

6. Energy Efficiency

6.1. Primary energy and primary resource factor (PRF)

Primary energy refers to energy that has not been subjected to any conversion or transformation process (e.g. oil in the oil fields). Primary energy may be resource energy or renewable energy or a combination of both. Resource refers to a source depleted by extraction (e.g. fossil fuels) and renewable energy to a source that is not depleted by extraction (e.g. biomass, solar).

The use of the primary resource factor (PRF) enables to measure the savings and losses occurring from energy generation to the delivery to the building. The primary resource factor f_P expresses the ratio of the non-regenerative resource energy Q_P required for the building to the final energy supplied to the building Q_E.

$$f_P = \frac{Q_P}{Q_E}$$

The primary resource factor represents the energy delivery but excludes the renewable energy component of primary energy. The proposed CEN-standard (CEN Draft Standard TC 228 WI 00228 027, as described below) suggests an approach where a primary resource factor is introduced. This primary resource factor is equivalent to the suggested EHP definition of primary energy factor f_P.

The advantages of district heating and cooling become visible in the frame of such a broad analysis based on the use of fuel input. In effect the PRF shed light on the benefits of using fuel and energy (in the form of waste heat) that would be emitted into the atmosphere unused if it were not possible to use the heat in district heating and cooling systems. Such fuels and energy streams include, for example: biomass, biogas, blast furnace gas, landfill gas, residual waste, sewage sludge, solar and geothermal heat, and surplus heat from industrial processes.

6.2. Determination of the different PRF for different fuels

In order to calculate the PRF of a district-heating scheme, different fixed values are needed for different fuels.

Figure 3: Table for PRF values of different fuels

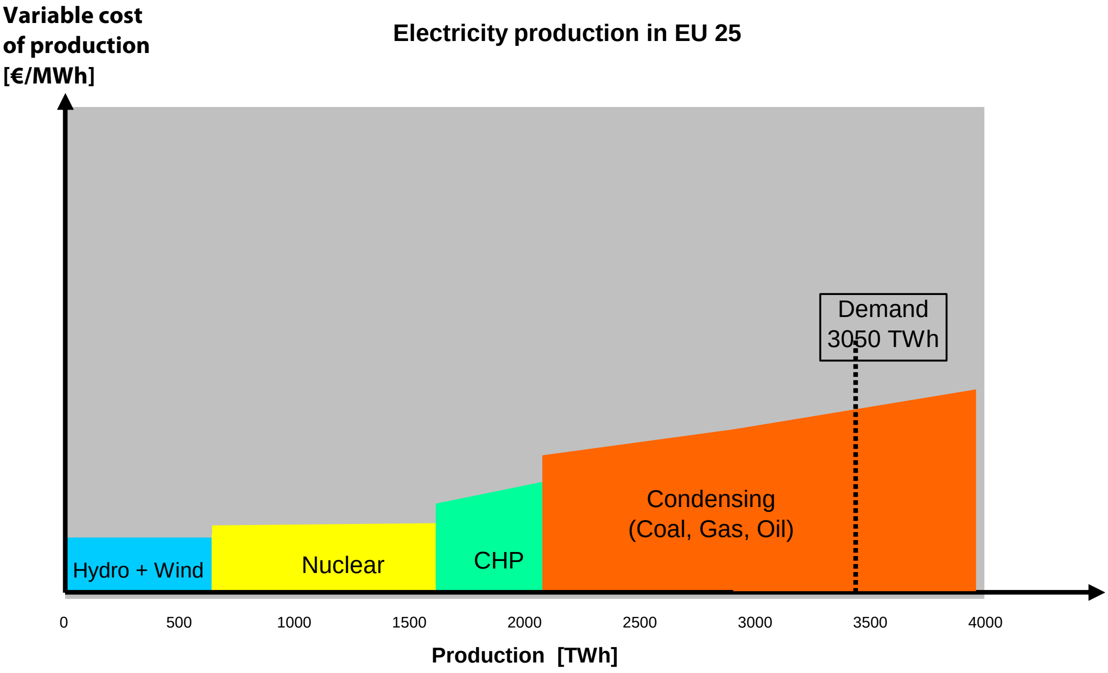
Fuel	Primary Resource Factor
Lignite Coal	1.30
Hard Coal	1.20
Oil	1.10
Natural Gas	1.10
Excess heat e.g. from industrial proc.	0.05
Renewables (e.g. Wood)	0.10
Waste as Fuel, Landfill Gas	0.00
Free Cooling	0.00
Electrical Power, European Average	2.5

6.2.1. Value for electricity

The value for electricity is fixed at 2.5 in order to be consistent with European legislation. The draft Directive on energy services refers to this value in its annex 1.

The value 2.5 reflects an efficiency of 40%, which is the average efficiency of electricity production according to Eurostat. This value should be used for the purpose of a European-wide labelling that fits with the internal energy market where additional change of demand is typically met by the most expensive production. What matters for an additional electricity demand is the cost of marginal production, determined by fossil fuels and efficiency in the range of 40%. It means practically that in Europe, an extra demand is systematically met by fossil as illustrated in the picture below.

Figure 4: electricity production in the EU 25



In Norway for instance where electricity is mainly produced from hydropower, an extra demand is typically met with coal-fired electricity generated in Denmark or Finland. A second example is France. If nuclear provides the main part of electricity generation (around 80 %), any peak demand in winter is met by fossil fuels.

6.2.2. Value for fossil fuels

The different values for fuels are justified by the losses occurring during extraction, and transport of the fuels. For instance, in the case of gas the value is justified by losses occurring from the point of extraction to the delivery to the customers (mainly transport losses, occurring from the energy needed to compress the gas in gas pipelines). In the case of lignite coal, the 1.30 value is justified by the more extensive energy losses needed for lignite compared to the 1.20 value for hard coal.

6.2.3. Excess heat from industrial processes

Burning wastes and landfill gases avoid the use of fossil fuels and make use of energy flows that otherwise would be lost. Hence the 0 value.

6.2.4. Values for renewables

This value is important to incentivise the use of biomass. The 0.10 value reflects the energy used to harvest the biomass and the transport needed to carry the fuel to the installations.

6.2.5. Values for Waste as fuels and landfill gases

Burning wastes and landfill gases avoid the use of fossil fuels and make use of energy flows that otherwise would be lost. The value is therefore 0.

6.2.6. Value for free cooling

Free cooling is produced with renewable input such as deep cold sea/lake water. Its value is therefore 0.

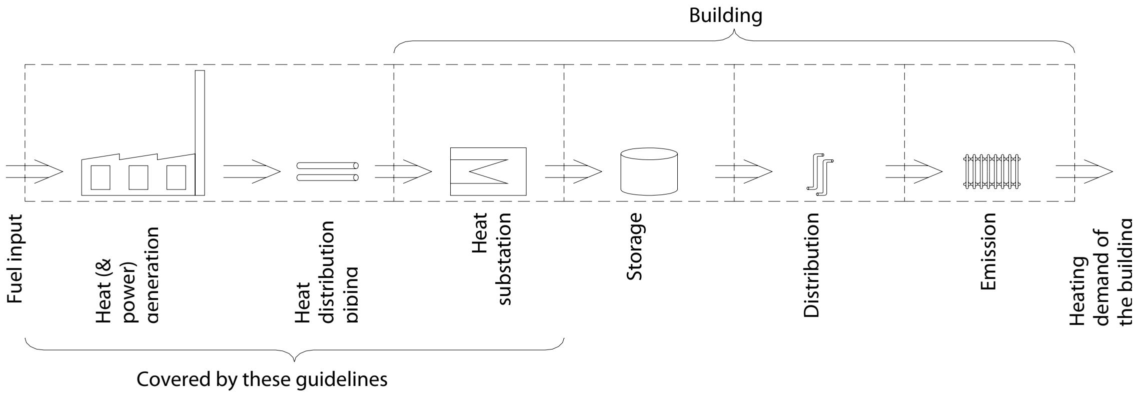
All input additional to free cooling needs to be taken into account, see 6.4 on the calculation rules for cooling.

6.3. District Heating

6.3.1. Calculations Methods

The performance of a district-heating system is evaluated by dividing the system into two parts, outside and inside the building (cf. figure 4).

Figure 5: Systematic of rating the performance of district heating systems



The outside part is rated by the balance of primary energy consumption of heat generation and heat distribution, the inside part is rated by the additional energy requirements of the heat substation. Thus the substation can be considered to replace the heat generator within the building (e.g. heating vessel).

For existing district heating systems usually all needed inputs are known by measurements. Figure 2 shows the method of the calculation.

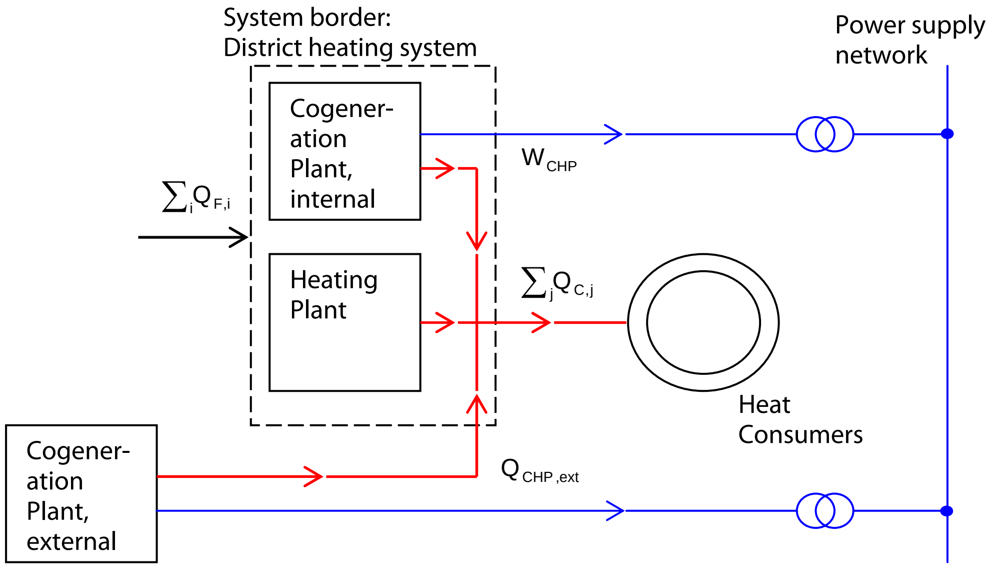


Figure 6: Method of the balance for an existing district heating system

The inputs to the calculation are:

$Q_{F,i}$ Fuel (final energy) input to the heating plants and to the cogeneration plants within the considered system within the considered period (usually one year). The amount of this energy is measured at the point of delivery.

$Q_{CHP,ext}$ Heat delivery to the considered system from external cogeneration power plants.

$f_{P,F,i}$ Primary resource factor of the fuel (final energy) inputs.

W_{CHP} Electricity production of the cogeneration plants of the considered system.

$f_{P,elt}$ Primary resource factor of electrical power. This factor is given by the European average - in accordance to principles laid down in annex III of Directive 2004/08/EC – cf Figure 3.

$Q_{C,i}$ Heat energy consumption measured at the primary side of the substations of the supplied customers within the period of interest (usually one year).

The result of the calculation is the primary resource factor $f_{P,DH}$ of the considered district heating system. The calculation formula results from the above balance:

$$f_{P,DH} = \frac{\sum_i Q_{F,i} \cdot f_{P,F,i} - W_{CHP} \cdot f_{P,elt}}{\sum_j Q_{C,i}} \tag{1}$$

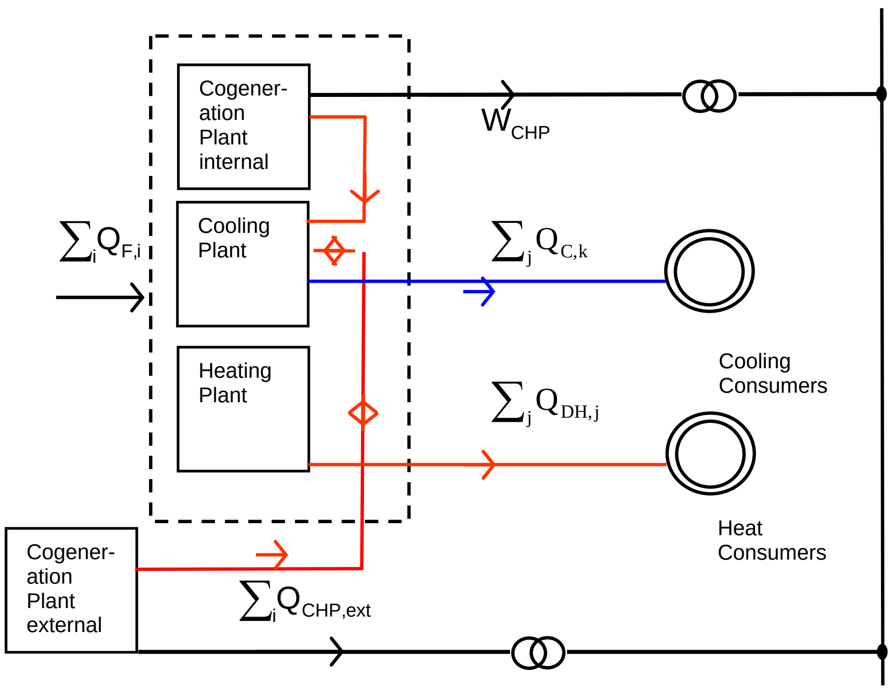
6.3.2. External deliveries

External heat deliveries to the considered system should be treated in the same way as a fuel input by weighting the external heat delivery Q_{ext} by its primary factor f_{ext}, which is calculated in the same way.

6.4. District cooling

For the production of cooling, the same system borders apply for the three products (heating, cooling and electricity) as illustrated in figure 6. Both district heating and cooling products have their own primary resource factor.

Figure 7: System borders



Before the calculation of the primary resource factor for district-cooling system, the fuels of district heating has to be determined. The formula of PRF for district heating system is the following:

$$f_{P,DH} = \frac{\sum_i Q_{F,DH} \cdot f_{P,f} - W_{CHP} \cdot f_{P,elt}}{\sum_j Q_{DH,j}}$$

$\sum_i Q_{F,DH}$ = Fuels of district heating system (Including fuels of district heat and CHP electricity)

$\sum_j Q_{DH,j}$ = Heat energy consumption measured at the primary side of customer's substations

All the fuels that not specially used for district cooling production are the fuels of district heating. Absorption chillers are using as input energy the heat produced in the installations. The formula needed for the calculation of district cooling system is the following:

$$f_{P,DC} = \frac{\sum_i Q_{F,i} \cdot f_{P,f} - W_{CHP} \cdot f_{P,elt} - \sum_j Q_{DH,j} \cdot f_{P,DH}}{\sum_k Q_{DC,k}}$$

$\sum_i Q_{F,i}$ = Total fuel input to considered system (Including fuels of DH, DC and CHP electricity)

$\sum_j Q_{DC,k}$ = Cooling energy consumption measured at the primary side of customer's substations

7. Auxiliary Energy Consumption

Auxiliary energy consumption is included in the above balance in that way, that only the net power production, i.e. the power production minus all auxiliary consumption e.g. for pumps etc., is used for the balance.

If there is no electricity production in the district heating system, than the electricity consumption of the auxiliary equipment has to be reported separately.

8. Recoverable Heat Losses

No losses are recoverable.

9. Calculation Period

It is recommended to use one year as the calculation period. For the winter and the summer period primary resource factors may be calculated additionally. According to this method it is as well possible to calculate monthly balances.

10.1. Use of PRF in benchmarking heating and cooling technologies

Value of the primary resource factor (PRF) defines the ratio between net fossil energy supply and heat energy used in building during one year. Consumption of non-renewable energy is the same as the use of fossil fuels. Every heating and cooling system has its own primary resource factor. If the value is less than one, the total consumption of non-renewable energy is less than energy transferred to building. Value that is more than one equals to greater total use of fossil fuels than heating or cooling energy delivered to building. Some of the most efficient heating and cooling systems have a PRF equal to zero. It means that heating or cooling is not causing the use of non-renewable energy sources.

10.1.1. District heating

Average PRF of district heating systems is lower than other common heating systems in Europe. Lower PRF means savings of fossil fuels.

Table 10.1. Typical PRF of different heating systems

District heating	PRF	**Building specific heating**	PRF
CHP gas	0,5	Gas boiler	1,3
CHP coal	0,8	Coal fired boiler	1,5
Biomass	0,1	Oil fired boiler	1,3
Waste incineration	0,05	Electric heating	2,5
Oil	1,3	Heat pump	0,9

10.1.2 District cooling

Average PRF of district-cooling systems is nearly the same as the average PRF of district heating. The main alternative for district cooling is cooling with building specific compressors. The average PRF of building specific cooling is more than doubled compared to the efficient district cooling systems. Penetration of district cooling means significant savings of fossil fuels.

Table 10.2 Typical PRF of different cooling system

Cooling system	PRF
District cooling (free cooling)	0,07
District cooling (absorption)	1,3 * PRF of Heat used
District cooling (heat pump)	0,8
Building specific compressor	1,0-2,0

11. Environmental efficiency assessment

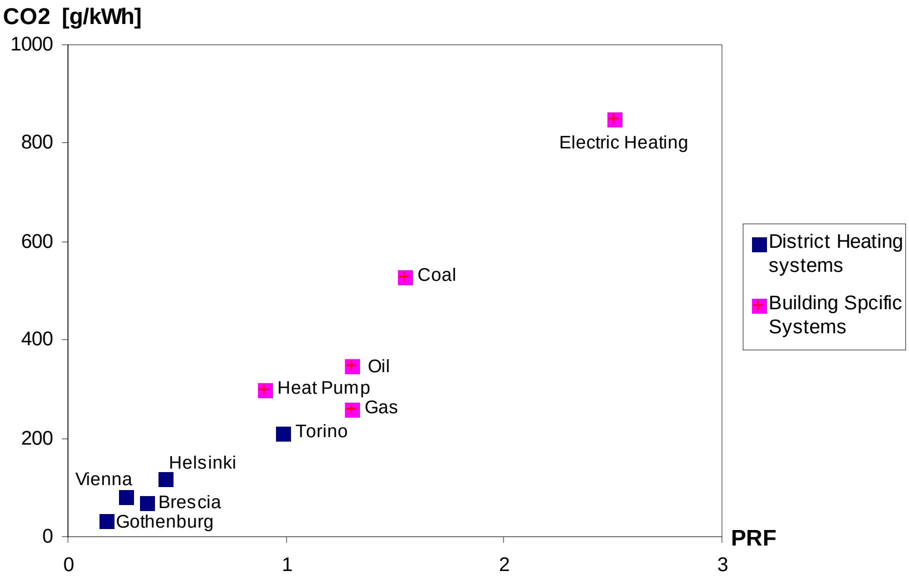
The environmental efficiency assessment of heating or cooling systems is based on the same principle as calculation of primary resource factor. CO2 emissions and air pollutants as well as the use of non-renewable primary energy resources are related to the heating or cooling energy transferred to the building. All savings and losses carried out along the whole energy chain are taken into account.

11.1. CO_2 emissions and CO_2 savings

CO_2 emissions are related to the use of fossil fuels and therefore CO_2 emissions are related to value of primary resource factor. Total CO_2 emissions of heating or cooling systems also depend on the specific emission factor of fossil fuel used. Using the following formula: CO_2= PRF. specific CO_2 factor, it is possible to benchmark different heating and cooling technologies. Because of low total use of fossil fuels, CO_2 emissions of district heating or district cooling systems are typically much lower than the emissions of alternative heating or cooling systems.

As shown in figure 10.1, lower primary resource factor value means lower CO_2 emissions. CO_2 emissions are almost directly related the value of PRF.

Figure 10.1. Relation between PRF and CO_2 of heating systems



11.2.1. District heating

CO_2 emissions of effective district-heating systems are at least twice lower than emissions of other common heating systems in Europe.

Table 10.3. Typical CO_2 emissions of different heating systems

District heating	CO_2 [g/kWh]	**Building specific heating**	CO_2 [g/kWh]
CHP gas	10	Gas boiler	260
CHP coal	270	Coal fired boiler	530
Biomass	30	Oil fired boiler	350
Waste incineration	20	Electric heating	850
Oil	360	Heat pump	300

The values of Table 10.3 are based on technology that is presently available. The values of existing heating systems are typically greater than values of Table 10.3. As efficient heating systems replace old technology, significant amounts of CO_2 emissions will be saved. Higher market share of district heating means lower CO_2 emissions of heating. CO_2 saving potential of district heating is really significant.

11.2.2. District cooling

CO_2 emissions of district cooling systems are typically lower than alternative cooling systems. Building specific compressor also has other greenhouse gas emissions due to leakages of refrigerants. Total greenhouse effect of a building specific compressor is more than the effect of CO_2.

Table 10.4. Typical CO_2 emissions of different cooling systems

Cooling system	CO_2 [g/kWh]
District cooling (free cooling)	25
District cooling (absorption)	1,3 * CO_2 of Heat used
District cooling (heat pump)	270
Building specific compressor	340-680

Penetration of district cooling reduces the greenhouse gas emissions significantly comparing to the alternative cooling systems.

11.3. Air pollutants

Air pollutants of heating and cooling systems are related to the final energy consumption of the building. Air pollutants are not related to the primary resource factor, because renewable fuels emit air pollutants as well as fossil fuels. The calculations of all air pollutants of heating or cooling systems are based on the same principle as the calculation of primary resource factor in Chapter 6. All the emissions and savings of air pollutants carried out along the whole energy chain are taken into account. Every heating and cooling system has its own factor for all air pollutants. Main air pollutants of heating and cooling are SO_2, NO_x and fine particles. There is a relation between air pollutants and quality of combustion technology. Small-scale combustion typically emits more air pollutants than large-scale combustion

12. Conclusions

Assessing the overall performance of DHC systems implies a broader view than the conventional measurement of savings at the end-user point of consumption. Provided all aspects of the energy chain are taking into consideration will the effective savings be measured. The interest of such a methodology lies in its ability to benchmark all heating and cooling options competing on the market. The methodology will therefore be instrumental in implementing European legislation aiming at developing energy efficiency in Europe. It should also serve as a basis to eco-labell heating and cooling technologies with a view to better inform users.

Last but not least, given the fact that 74% of the European population live in urban areas, and that industries with heat needs are close to these areas, the guidelines provide valuable information about the role of district heating and cooling in further increasing energy efficiency or *'doing more with less*.'

APPENDIX 1: CALCULATIONS OF PRIMARY RESOURCE FACTORS

1. Helsinki's district-heating system

	Q_F	f_p	f_p*Q_F
	GWh		
Coal	8487	1.2	10184
Oil	345	1.1	380
Natural gas	9507	1.1	10458
SUM	18339		21022

	W_{CHP}	$f_{P,elt}$	W_{CHP}*$f_{,P,elt}$
CHP electricity	7183	2.5	17958

Q_c	6930

Using the formula described above, the PRF of district heating in Helsinki is thus

$$f_{P,DH} = \frac{21022 - 17958}{6930} \approx \mathbf{0.442}$$

The specific CO_2 emission factor of fuel input to district heating system in Helsinki is 272 g/kWh. CO_2 emissions are thus

$$f_{P,DH} \times f_{CO2} = 0{,}442 \times 272 \frac{g}{kWh} \approx 120 \frac{g}{kWh}$$

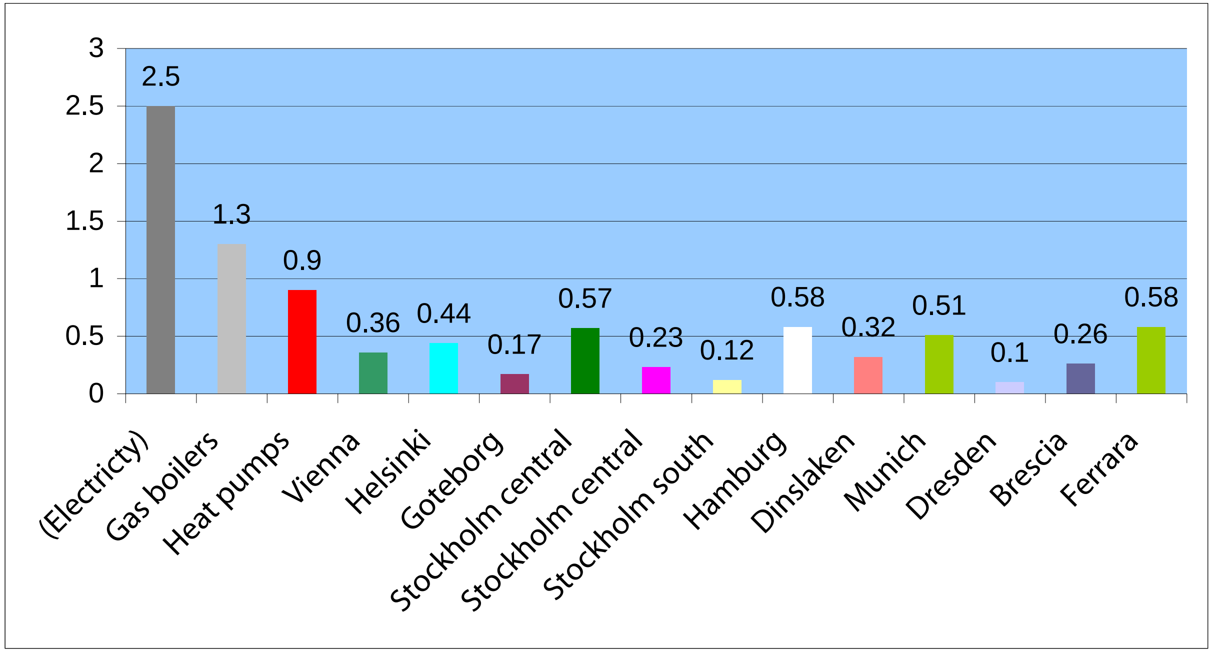
2. Göteborg's district-heating system (figures for 2003 and 2004)

		2003	2004	
Total heat consumption, measured at the primary side of the dwelling stations:	• Q_C	3450000	4075231	MWh/a
Annual gas consumption of the cogeneration plant, measured at the delivery point of the gas:		200 255	590 614	MWh/a
Annual gas consumption of the heating plant, measured at the delivery point of the gas:		768 603	209 000	MWh/a
Total gas consumption:		968 858	799 000	MWh/a
The unit of the gas consumption refers to the combustion energy inclusive the condensation enthalpy. Thus the total gas consumption has to be cor-rected according to the condensation enthalpy, which is 10 %. Corrected value of the total gas consumption:	• Q_F	871972,2	719100	MWh/a
Annual biofuel consumption of the heating plant, measured at the delivery point of the biofuel:		292 000	639 000	MWh/a
Annual electricity consumption of the heat pumps delivered to the district-heating grid			168 730	
Annual heat from heat pumps		698 400	539 405	
Annual industrial waste heat delivery		977090	1 129 240	MWh/a
Annual heat from waste incineration		945505	1 047 781	MWh/a
Annual heat from oil		92 000	41 000	MWh/a
Power production, total, measured at the input to the public power supply network:		180000	184868	MWh/a
Internal power requirements for pumps etc.:		75 000	75 000	MWh/a
Net power production:	W_{CHP}	105 000	109 868	MWh/a
Primary resource factor		**0,25**	**0,17**	

3. Vienna's district-heating system (2003)

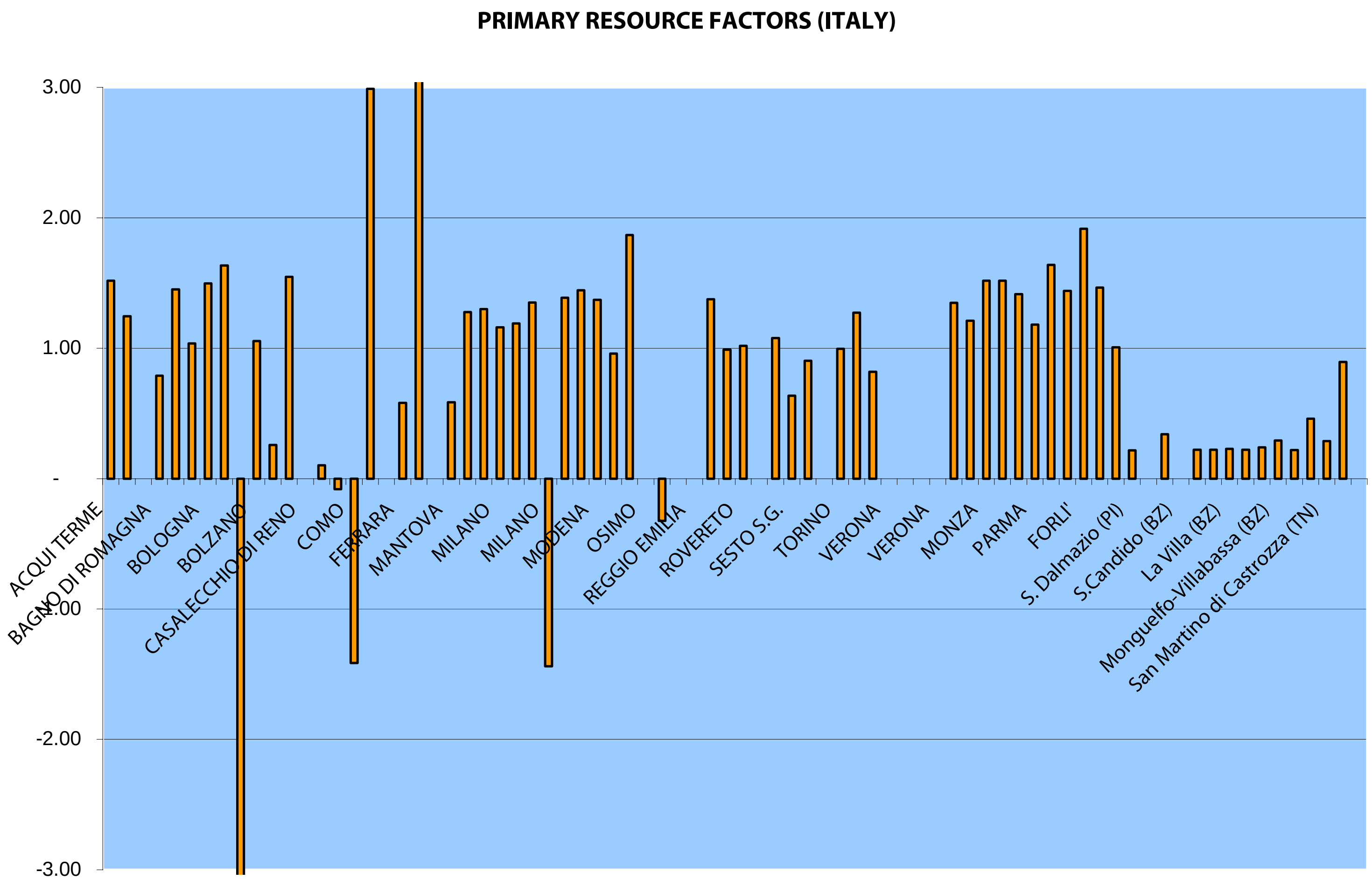
Heat; Q CHP (GWh)	5,407.1
Electricity; W Chp (GWh)	3,507.1
Energy input; QF (GWh)	12,039.8
PRF	
WCHP x fp el	8,767.7
Qf x fp	10,706.6
Qf x fp - Wchp x fp el	1,938.9
Primary resource factor	**0.36**

APPENDIX 2: PRF values for different district-heating networks



APPENDIX 3: PRF values for different district-heating networks (YEAR 2003)

1. ITALY



2. SWEDEN

PRIMARY RESOURCE FACTORS (SWEDEN)
(CHP not included)