

120: Low energy communities with district heating and cooling

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Abstract

Minimizing the use of primary energy for heating and cooling purposes in buildings requires good understanding of the entire energy system and interactions between the different energy subsectors.

To provide a better understanding of the heating and cooling markets, Euroheat & Power, in cooperation with 13 partners across Europe and with support from the Intelligent Energy Europe programme, has launched at the beginning of 2005 the ECOHEATCOOL project. The project covered 32 countries including EU 25 Member States, four (then) accession and three EFTA countries.

The project results show that district heating and cooling systems can significantly contribute to system optimisation as they allow to recycle heat which otherwise would be wasted or would be difficult to use.

The project also demonstrates that disjointed analysis (or focus on a single energy source or use) can result in sub-optimal urban planning and inefficient use of resources. Only an assessment encompassing the whole supply chain - from conversion to delivery - will give a fair picture. An approach based on primary resource factors (PRF) makes it possible to have a comprehensive assessment on the resource efficiency of all heating and cooling options.

Keywords: low energy communities, district heating and cooling, resource efficiency, heat recycling, urban planning, primary resource factors

1. Introduction

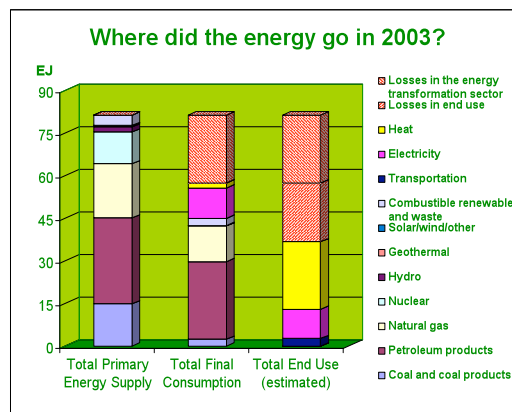
Energy used for heating buildings represents almost 70% of end-use demands and 40% of primary energy demands. For cooling demand it is estimated that it presently accounts for 8% of the annual electricity generation and continues to grow rapidly. This is the order of magnitude of what is at stake when we talk about sustainable cities, eco-districts, passive houses, zero energy buildings, low or no carbon buildings (1,2).

At the same time, cities often dispose of a huge untapped potential of sustainable heat: heat which is generated as inevitable by-product of electricity, of industrial processes, of waste management – with no or only little additional primary energy input. In many cases, there are also opportunities for using renewable energies: from geothermal and solar energy to biomass, or sea- and river-water for cooling purposes.

District heating and cooling enable optimal use of these resources. New projects taking shape throughout Europe today show that sound economic and environmental choices are not mutually exclusive, but instead are compatible to the point of being interdependent, if focus is placed on primary energy savings in the urban system instead of final energy savings in single buildings.

2. The European energy balance (1,7,8)

Figure 1: Energy balance of 32 European countries



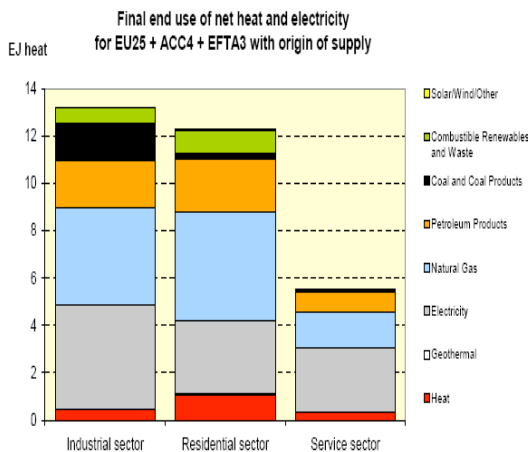
Europe wastes more heat than it consumes. The total primary energy supply of 81.1 EJ (1936.7 Mtoe) contains the calorific value of all fuels and other energy amounts supplied to satisfy the total energy demand. The second added bar contains all energy commodities used by all community sectors. The difference between the two added bars reflects what occurs in the energy transformation sector, including power generation, oil refining, central heat generation for district heating systems, and distribution losses in electricity and heat distribution systems. In particular, losses from the energy transformation sector are huge: 23,8 EJ (568,3 Mtoe), corresponding to 29% of all primary energy supply. Most of this heat was lost in thermal power stations due to low conversion

efficiencies. Adding losses from final to end-use, total heat losses in the balance correspond to more than half of the total primary energy supply. A future European energy system must reduce these losses in order to increase the energy efficiency, reduce the carbon dioxide emissions, and increase the security of supply. The heat sector in general and the district heat sector in particular could contribute to meet these objectives, by recycling existing heat losses in the energy system to satisfy local heat demands on the European heat market.

3. The European Heat Market (1)

The project showed very clearly that heat and electricity dominate the total end use and represent approximate 55% of the total energy use (57.3 EJ). The domestic hot water consumption remains an unknown factor in spite of its relevant share in the total heat demand. The use of natural gas and electricity for heat (accounting for 66%) dominates in the industrial, residential and service sector while district heating represents only 6% of the total heat market.

Fig. 2: Final end use of net heat and electricity in EJ

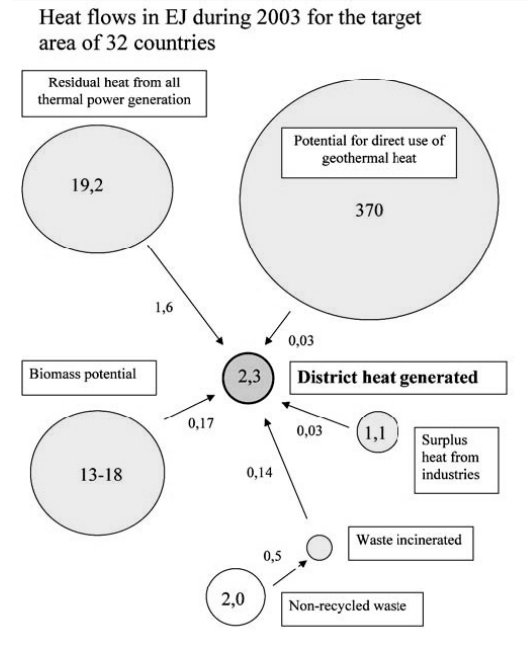


3.1 Possibilities with district heating (4)

As 74% of the population lives in urban areas, most of the heating and cooling demands are located in these dense populated areas. Multifamily buildings represent 48% of the total number of dwellings in Europe 32. At the same time service sector buildings are also located there. These conditions provide the possibility to reach a large fraction of the total space heat and cooling demands with urban district heating and cooling systems.

3.2. Strategic resources (4)

Fig. 3: Strategic heat resources and flows in EJ



The five suitable strategic local heat and fuel resources for district heating include:

- **CHP** : The potential of residual heat resulting from the thermal power generation is 19.2 EJ/year (out of which only 1.6 EJ/year was used for DH and 1.3 EJ/year in the industry). The cumulated present use represents 15% of the potential
- **Waste to energy plants**: Out of the 2 EJ/ year non recycled waste, ¾ are placed in landfills that produces methanol, the gas with the highest greenhouse effect and only 0.5EJ/year are incinerated. The present use represents 7% of the potential.
- **Surplus heat from industries**: The available resources is 1.1 EJ/year and the present use is 0.03EJ/year and mainly in Sweden, resulting in a current use of 3% from the total potential.
- **Biomass**: The potential for biomass in Europe is approximately 13-18 EJ/year. Most of the potential is related to agriculture. The present use in DH is 0.17EJ - 1% of the potential
- **Geothermal**: The total technical potential is approximately 15 times higher than total heat demands in Europe (370 EJ). Presently, only 0.03 EJ/ year are used (0.008% of the potential). Geothermal heat represents a long term option for the district heating sector in Europe.

3.3 Effects on the energy balance (4)

The Ecoheatcool study shows which possibilities arise if the energy performance of existing district heating and cooling systems is improved and heat sales doubled / new systems built:

- Higher energy efficiency, since primary energy supply for local heat demands are mainly replaced with recovery of heat losses

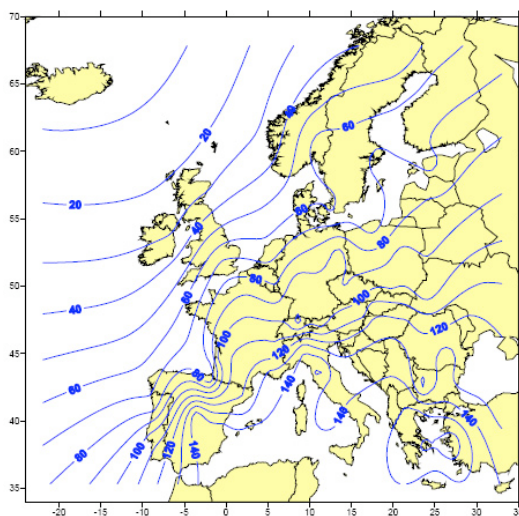
from the energy system. The current benefit is 21,3 Mtoe/year reducing the overall primary energy supply from 1943,1 to 1921,8 Mtoe/year. If the current district heating systems are improved and heat sales are doubled, this benefit will increase to 71,1 Mtoe/year. The possible reduction of 50,7 Mtoe/year is equivalent to the whole annual primary energy consumption of Sweden.

- Higher security of supply, since imports of fossil fuels are reduced and use of domestic renewable resources are increased when district heating systems are improved and district heat sales are doubled. This combined effect will reduce the current import dependency with 105,5 Mtoe/year or 5,5 % of all primary energy supply. This is more than the whole primary energy consumption for Poland.
- Lower carbon dioxide emissions, since fossil primary energy supply is reduced from improved and doubling district heat sales. The present avoided emissions (113 million tons annually) can be further increased to 516 mln tons, if district heating systems are improved and district heat sales doubled. The reduction will be 404 mln tons annually, corresponding to 9,3 % of all carbon dioxide emissions from fuel combustion in the target area or more than all annual carbon dioxide emissions from fuel combustion in France.

4. The European Cold Market (2)

The estimation regarding cooling demands has been carried out based on three main elements: European Cooling Index (developed within this project), buildings statistics and specific cooling demands analysis.

Fig. 4: European cooling index (ECI) in a contour map computed from information from 80 urban locations in Europe. The average space cooling demand should be proportional to this index.



According to ECI the specific cooling demand varies in the range of +/- 30% from Northern to Southern Europe.

The most striking is the picture of the accelerated growth of cooling demands in Europe 32. This is

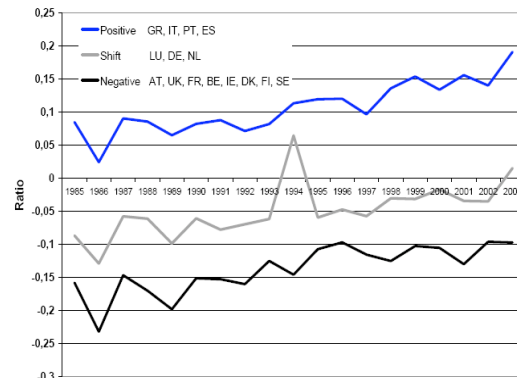
largely due to the fact that the space cooling demands are increasing rapidly in most European countries, as a result of higher availability and increasing customer pay ability. Electricity consumption increased in average by 50% during the last two decades in all European countries. Part of the increase in the electricity consumption must be attributed to cooling demands.

Consequently an estimate of electricity demand associated with comfort cooling based on monthly variation of the electricity demand was carried out.

$$\text{Ratio} = \frac{(\text{demand July}) - (\text{demand April})}{\text{annual average demand}}$$

The ratio is positive if the electricity demand is higher in July as compared to April. A high ratio implies that there is a peak in the electricity demand caused by comfort cooling needs. July was chosen as the warmest month of the year while April is considered to be a neutral month for cooling. In general the Mediterranean countries have higher ratio, and the summer electricity demand increases more than the average demand.

Fig. 5: Ratio according to Equation 1 for the three country groups with positive ratio, shifting ratio and negative ratio



Furthermore, the cooling demands assessment showed that firstly, for the same geographical location, the real specific cooling demands can vary a lot in terms of energy per square meter. This variation is mainly due to large variations in technical solutions, design guidelines and operational strategies. Nevertheless the specific cooling demands are higher in the service than in the residential sector. In the Nordic countries, public and office buildings are normally dimensioned for specific cooling demands of 30-60 W/m², while retail areas are dimensioned for 50-80 W/m². In Southern Europe, the specific cooling demands are approximately 20% higher. Secondly, there is a large variation in the full load hours. For the same geographical location a wide variation is registered in the load curve of the cooling demands for different types of customers especially in the public and service sector. This shows that a large proportion of the total cooling demand is due to non-climatic factors. Duration

times are usually within the range of 1100-1300 equivalent full load hours per year in northern and 50% higher in southern countries.

While the demand in the year 2000 was only 150 TWh, corresponding to a saturation rate of 14%, space cooling demand in 2020 was forecasted to be 2,4 EJ, with a saturation rate of 60 % in the service sector and 40 % in the residential sector.

4.1 Possibilities with District Cooling (5)

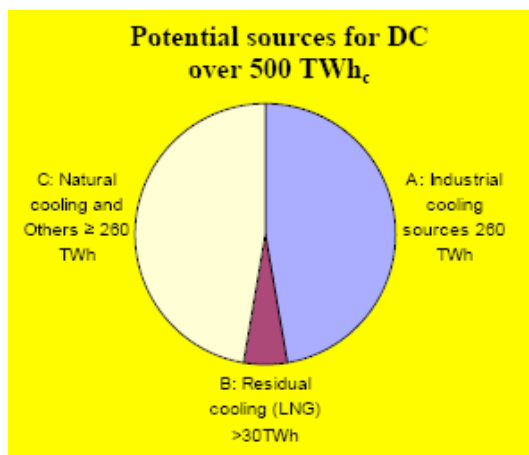
The main idea of district cooling is to use local sources that otherwise would be wasted or not used, in order to offer the local market a competitive and high-efficient alternative to the traditional cooling solutions. The centralisation of cooling production is a prerequisite to reach a high efficiency, as it makes possible to use “free cooling” or waste heat sources.

A district cooling system can reach an efficiency rate typically 5 or even 10 times higher than traditional local electricity-driven equipments. Similar to district heating, strategic sources can be identified for district cooling: natural cooling from deep sea, lakes, rivers or aquifers; industrial cooling sources where absorption chillers are used: waste heat from industry, CHP, waste to energy plants or residual cooling from re-gasification LNG.

The current market share for district cooling is almost 2 %, corresponding to district cold deliveries of about 9 PJ/year. Currently, about 100 district cooling systems exist in European high dense city centers and commercial areas. Most of them are located in France, Sweden, Germany, and Italy.

A district cooling market share of 25% would give district cold deliveries of 0,6 EJ/year which can cover 35% of the service cooling needs and 15% of the residential demands. The technical potential for district cooling sources is 3 times higher than the forecasted district cooling supplies (500TWh). Over 260TWh/year could be natural cooling sources (free cooling including the possibility for seasonal storage), the residual cooling (especially from LNG) represents more 30TWh/year while the industrial cooling such as CHP, waste incineration, surplus heat from industries would account for more than 260 TWh.

Fig. 6: Potential sources for District Cooling



4.2 Effects on the energy balance (5)

For Europe 32 a district cooling market share of 25% of the total cooling supply corresponds to:

- A cooling energy demand of about 165 TWh_c, a peak cooling capacity demand of about 140
- GW_c and investments in new district cooling infrastructure of 55 to 80 billion Euro.
- With a typical DC system we could estimate an efficiency that is 5-10 times higher which suggests that about 50 to 60 TWh_e electricity could be saved.
- These savings gives the potential of 40 to 60 million tons CO₂ savings/year for the Europe 32 (around 15% of the EU commitment in the Kyoto protocol).
- The potential of natural industrial and residual cooling sources that today are available exceeds the needed input for an assumed 25% district cooling market share.
- If the marginal investment impact is 20% of the total avoided electricity capacity (50 GWe), the avoided investment will be about 30 billion Euro or 40-50% of the investment for new district cooling infrastructure.

5. Primary Resource Factors (3)

Traditionally demand and supply side are considered separately. However, if the aim is to optimize the entire energy system, such disjointed analysis is insufficient to fully exploit the possibilities of urban planning. Although useful for modelling purposes, this approach (or similarly, a focus on a single energy source or use) often results in a suboptimal and inefficient use of resources.

Intelligent urban energy solutions must combine reduction of end-use, use of more efficient technologies at all levels and increased use of locally available renewable. To compare integrated solutions, these must be assessed in terms of their resource efficiency, i.e. their ability to reduce the consumption of fossil primary energy. Only an assessment encompassing the whole supply chain - from conversion to delivery - will give a realistic picture.

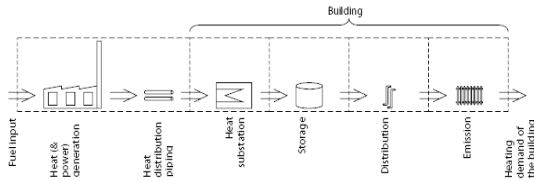
An approach based on primary resource factors (PRF) makes it possible to have a comprehensive assessment on the resource efficiency of all heating and cooling options.

5.1 Calculation principles (3, 9)

Primary resource factors express the ratio between the non-regenerative energy input and final energy used. The lower the PRF of a technology (in operation), the greater its contribution to reduce the use of fossil primary energy.

All energy used for extraction, preparation, refining, processing and transportations of the fuels to produce the heat, as well as – for district heating - the heat losses of the heat distribution piping system are taken into account in the calculation.

Fig. 7: From primary energy extraction to end use



The primary resource factor represents the energy delivery but excludes the renewable energy component of primary energy. It has to be determined within the thermodynamic system borders of the specific (district) heating system. For district heating systems this is usually the area supplied by one heat distribution piping system bordered by the primary side of building substations. Within this area, all energy inputs and all energy outputs are considered. Energy as input to the system is weighted by its specific primary resource factor.

5.2 Specific primary resource factors (3)

Fig. 8: Specific primary resource factors for fuels

Fuel	PRF
Lignite	1,3
Hard Coal	1,2
Natural Gas	1,1
Oil	1,1
Surplus heat	0,05
Renewables	0,1
Waste as fuel, landfill gas	0,0
Free cooling	0,0
Electrical power	2,5

- Value for electricity: The value 2.5 reflects an efficiency of 40%, which is the average efficiency of electricity production in the EU.
- 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.
- Excess heat from industrial processes: heat that otherwise would be lost. Hence the 0,05 value.
- Values for renewable: 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.

- 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.
- 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.

5.3 Resource efficiency of district heating and cooling systems (3, 8)

Fig. 9: District heating vs. building specific solutions

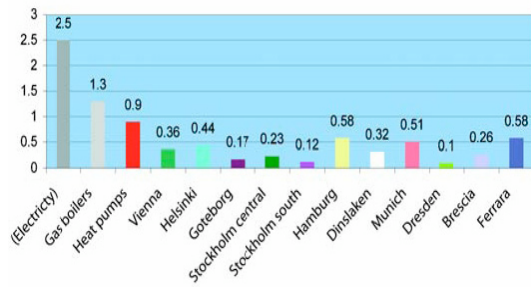
District heating	PRF	Building specific heating	PRF
CHP gas	0,5	Gas boiler	1,3
CHP coal	0,8	Coal fired boiler	1,5
Biomass	0,1	Oil fired boiler	1,3
Waste incineration	0,05	Electric heating	2,5
Oil	1,3	Heat pump	0,9

On the basis of the IEA energy balances, the average Primary Resource Factor was calculated for all district heating systems in EU-32. The result is a value of 0.82 which must be compared to values of 2.5 for electric heating (reflecting an average conversion efficiency of 40%), 1.3 for gas boilers and 0.9 for an average heat pump. National examples for district heating PRF values illustrate differences in the shares of recovered heat (from CHP) and renewables in the district heating systems. At the same time these values can serve as indicators for potential improvements.

- Finland – The PRF values of 0.60 reflects the use of a high share of heat from CHP based on fossil fuels in the district heating systems.
- Italy – The relatively higher value of 0.9 reflects the large dependency of district heating systems on fossil fuels (especially natural gas and coal) which are often, but not only burned in CHP plants. Still on average these systems provide better resource efficiency than individual boilers or electric heating.
- Sweden – The impressively low PRF of 0.25 reflects the high share of renewable fuels and surplus heat used in district heating systems.

The figures below shows examples of specific district heating systems.

Fig. 9: PRF values of specific systems



6. Conclusion

This paper illustrates the possibilities with district heating and cooling to improve the resource efficiency of European, national and local heating and cooling markets (down to the individual building performance), due to its capacity to reduce losses in the energy system and optimise urban energy supply and consumption.

Urban planners, building owners and architects have the choice of the energy used for heating and cooling (e.g. electricity, gas or district heating, conventional air-conditioning or district cooling). The impact on the environment, on the energy dependence of the country etc. will differ in accordance with this choice. Primary resource factors are useful tools to compare different options in planning and use (1, 2, 3). They can also serve as benchmarks for the performance of district heating systems.

7. Acknowledgement

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