District Cooling Application on an Existing District Heating Infrastructure: Technologies and Potential

Ioannis Tsigkas, Giorgos Panaras*
Mechanical Engineering Department, University of Western Macedonia, Kozani, Greece
*Email: gpanaras@uowm.gr

Abstract. The proposed work attempts to examine whether district cooling is a sustainable solution for cooling applications in a modern urban area where there is already a district heating system network installed. In order to make a complete and objective assessment about the aforementioned topic, the majority of factors affected by or affecting such a project is taken into consideration, namely energy, environmental, socio-political or financial issues. The analysis uses as reference system that of the district heating of the city of Kozani, Northern Greece, operating since 1993; the system uses heat produced by the nearby coal power plants. In conclusion, district cooling is assessed as a feasible and sustainable choice for Kozani with multiple benefits for the region. For example, the increase of the pipeline network lifespan by minimizing corrosion due to oxidization, the extended utilization of waste heat, the reduction of the load on the electric power network as more and more customers will shift from air-conditioners to District Cooling and the creation of a variety of either short term or long term jobs during the construction phase and during the lifetime of the installation. Moreover, a variety of suggestions is given for prospective researchers on the topic as well as proposals on the development of the project further than the pilot phase.

1 District Energy Systems (DES) and Technologies

1.1 Introduction
District Heating and District Cooling along with any related technologies comprise what is often referred to as District Energy Systems. Namely, the systems that allow the production of energy on a large scale at a remote location and its distribution to multiple small-capacity end users.

A great variety of DES technologies has been developed and tested for decades worldwide and they are believed to be highly promising, taking into regard their proven benefits on multiple levels[1, 2], as described below:

- On environmental level, benefits include reduced heating and cooling carbon footprint, improved air quality, decreased use of CFCs, higher contribution of renewable energy sources to the energy mix, and lower dependence on fossil fuels.
- On finances and energy strategy, the presence of low limitations regarding the choice of energy sources, and reduction of energy production costs are mentioned.
On society and local economies level, local communities are granted the ability to manage and exploit their own energy resources more independently and efficiently, construction and operation of DES facilities create job positions, while funds that are spent on energy can be absorbed by the local market.

For landlords and tenants, benefits include reduced heating and cooling costs, reduced operational costs, greater security and reliability, reduced spatial demand.

However, there are a few challenges that need to be taken into consideration in order to evaluate DES, such as limited technical knowledge on DES, the requirement of large initial investment is required, the difficulty to find the ideal space for such a facility, especially in densely populated urban areas, as well as the fact that monopolies might emerge in favor of the network’s administrator due to lack of specific legislation regarding DES.

Considering the socioeconomic conditions of the few last decades (e.g. urbanization, the need for air quality improvement, global warming), the reasons for the continuously growing number of DES applications become obvious. Many countries have recently set goals and specific guidelines for further development of DES. Thus, the above conditions provide a fertile ground for the modernization of DES and any related technologies as well as the optimization of their integration with various other systems, such as electricity production or waste management.

1.2 District Heating
The fundamental idea of district heating is the utilization of waste heat in order to satisfy local heating demand\(^3\). A district heating system comprises of a network of insulated pipes that serve the purpose of transferring heat, by means of hot air, hot water or low-pressure steam, from a production plant to the network end users. Such networks may vary in size, ranging from a few hundred meters, taking for an example a hotel or a large residential complex, up to tens of kilometers, supplying whole communities and industrial areas.

District heating systems can be powered by a great variety of energy sources\(^4\), such as:
- Steam power plants
- Waste incineration plants
- Industrial processes
- Combined heat and power plants
- Fuel cells
- Heat pumps
- Geothermal energy
- Solar thermal energy

The ability to utilize multiple energy sources guarantees fuel independency, reliability and continuous operation of the district heating network.

1.3 District Cooling
District cooling is the cooling equivalent of district heating\(^5\). They share many similarities technically and their main and most obvious difference is the circulation of chilled water in the case of district cooling instead of hot water. Accordingly, district cooling refers to the process of distributing cooling energy by means of chilled water, from a large cooling plant to the end users, for the purpose of cooling spaces or dehumidification.

Similarly to district heating, district cooling can utilize most types of renewable energy sources\(^6\). These are mainly:
- Deep water source cooling
- Seasonal energy storage cooling
- Waste cold energy (e.g. LNG stations)
- Absorption cooling
- Adsorption cooling
The two latter technologies are the most widespread and most promising due to their easy integration to any heat producing process and their flexibility to utilize any type of heat source to generate cooling power.

1.4 Absorption Cooling

Absorption chillers are the most widely used type of thermal chillers; absorption is a physical or chemical phenomenon or a process in which atoms, molecules or ions enter some bulk phase – liquid or solid material[7]. The main difference of absorption chillers in comparison to conventional chillers is that the coolant undergoes thermal compression through heating a liquid solution of coolant and absorption medium, replacing the work of a mechanical compressor. To achieve water temperature slightly higher than 0 °C, which is the most common for air-conditioning applications, a liquid solution of water and lithium bromide (H\textsubscript{2}O/LiBr) is used. The lack of large moving parts and the ability to exploit any heat source are their main advantages compared to conventional chillers[8].

The main components of an absorption chiller are the generator, the condenser, the evaporator and the absorber, can be seen also in figure 1.

![Figure 1. Schematic drawing of an absorption chiller][8]

Absorption chillers are mainly supplied with district heat, waste heat or heat from co-generation. The required heat source temperature is usually above 80 °C for single-effect machines and the coefficient of performance (COP) is in the range from 0.6 to 0.8. Double-effect machines with two generator stages require driving temperature of above 140 °C, but the COP’s may achieve values up to 1.2[9].

1.5 Adsorption Cooling

Adsorption chillers use solid sorption materials instead of liquid solutions; Adsorption refers to the adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface[10]. Market available adsorption chillers use water as refrigerant and silica gel as sorbent[11].
Figure 2. Schematic drawing of an adsorption chiller\cite{12}

The machines consist of two sorbent compartments (Figure 2) – one evaporator and one condenser. While the sorbent in the first compartment is regenerated using hot water from the external heat source, e.g. the solar collector, the sorbent in the second compartment adsorbs the water vapor entering from the evaporator. \cite{12}.

Under typical operation conditions with a driving temperature of 80 °C, the systems achieve a coefficient of performance (COP) of about 0.6, but operation is possible even with temperatures of approx. 60 °C. The capacity of the chillers ranges from 5.5 kW to 500 kW chilling power \cite{13}.

2 District Cooling Applications

As expected, its many advantages make district cooling a very attractive solution. The first district cooling plant started operating in Denver, Colorado, in 1889 and it has been advancing and spreading rapidly since. However, what is of greatest importance is the ease of district cooling integration with renewable energy systems and this is the main area of focus of the present work. The six most important examples of urban district cooling applications in Europe are\cite{14}:

1. Paris (290 MWc) \cite{16}
2. Vienna (67 MWc)\cite{17}
3. Stockholm (280 MWc) \cite{18}
4. Solna/Sundbyberg (43 MWc) \cite{19}
5. Helsinki (180 MWc) \cite{20}
6. Växjö (13 MWc) \cite{21}

In the following table (Table 1), the main characteristics of the respective installations are summarized. Although district cooling is generally a very attractive solution for efficient and sustainable cooling, the following factors contributed into making these specific examples successful\cite{14}:

- On all 6 cities there was a district heating network already in operation for years before the installation of district cooling. So, the consumers were familiar with district energy systems and there was adequate experience and technical knowledge regarding them.

- The fact that there was an existing district heating network, helped on reducing the district cooling network building costs.

- In every case there where thorough studies conducted prior to the construction of the system in order to achieve optimal exploitation of local resources, minimal network length and minimal intervention to the urban and extra-urban environment.

- European guidelines regarding the limitation of CFC, HFC and HCFC emissions affected consumers positively towards district cooling and made state-funding the projects an appealing option for governments.
### Table 1. Main technical characteristics of selected district cooling applications in Europe \[^{[14]}\]

| Location         | Nominal Cooling Capacity (MW) | Annual Cooling Energy Production (GWh) | Network Length (km) | Total Connected Surface (m²) | Cooling Technologies Used                                      |
|------------------|-------------------------------|----------------------------------------|---------------------|------------------------------|----------------------------------------------------------------|
| Paris            | 290                           | 410                                    | 71                  | 5.000.000                    | Electric chillers, River-water cooling, Heat pumps              |
| Vienna           | 67                            | 72                                     | 4.8                 | 1.100.000                    | Electric chillers, Absorption cooling, River-water cooling     |
| Stockholm        | 280                           | 426                                    | 200                 | 7.000.000                    | Electric chillers, Seawater cooling, Heat Pumps                |
| Solna/Sundbyberg | 43                            | 60                                     | 32                  | -                            | Electric chillers, Heat pumps                                  |
| Helsinki         | 180                           | 130                                    | 65                  | 1.400.000                    | Electric chillers, Absorption cooling, Seawater cooling, Heat Pumps |
| Växjö            | 13                            | 11                                     | 13                  | -                            | Electric chillers, Absorption cooling, Deep-lake water cooling |

### 3 Planning of the District Cooling Application in the city of Kozani

#### 3.1 General characteristics of District Heating Network

District heating started its operation for the first users in the city of Kozani in 1993, with the connection of the first 360 building to the network. In 2012 it was serving 5329 buildings with a total heated area of 2,450,452 m² and. Administrator of the system is the Municipal Water and Sewage Service \[^{[15]}\].

Thanks to the locally installed steam power plants of Public Power Corporation (PPC), the citizens of Kozani have access to inexpensive and environmentally friendly heating. More specifically, heat is taken by steam extraction from the plants’ turbines and is fed to the network. However, there are future
plans for transitioning the system into the use of exhaust gas heat exchangers in order to reduce or eliminate steam extraction and eventually utilizing a part of the heat that would be otherwise wasted and increase the efficiency of the power plants \cite{15}.

During the summer season, district heating obviously ceases to operate. However, the water flow must not stop as it could result in high oxygen presence inside the pipe network, leading to its rapid corrosion. So, the network administrator has to keep operating the pump stations and deal with the extra cost of running the network for nearly 5 months without any income \cite{22}.

Eventually, financial downtime could be reduced to 2 months by installing absorption coolers who will in turn utilize heat extracted from exhaust gas heat exchangers and provide chilled water to the existing district heating pipe network and thus, creating a fully operational district cooling network.

3.2 Calculation of cooling loads and demand for the city of Kozani
The building models that were used for the calculations were selected carefully to represent the statistical average of residential and office buildings of Kozani accordingly, based on similar studies \cite{23}.

Calculations were conducted based on CLTD method for cooling loads \cite{7} and ELOT EN ISO 13790 E2 (2009) \cite{24} standard for cooling energy demand, resulting in 27.78 W/m² peak load in August for residential buildings and 30.94 W/m² in July for office buildings and a total annual cooling energy demand of cooling per surface unit of 23.5 kWh/m²/y and 31.83 kWh/m²/y for residential and office spaces accordingly; in figures 3-6 the respective results for residential and office buildings are presented.

Thus, the weighted average of these values would be 27.89 W/m² and 23.8 kWh/m²/y accordingly, given that residential buildings comprise 96.4% of the total number of urban buildings and office buildings 3.6% \cite{25}.

3.3 Costs and limitations
End-users need to make some additions to their residences in order to get access to district cooling. On average, these are: 1) replacement of heating radiators with fan-coils, 2) installation of a heating/cooling thermostat and 3) insulation of exposed pipes in order to avoid condensation, with an average cost of...
9.4€/m². Selling price of cooling energy has been set to 0.023 €/kWh in order to recuperate the investment in 6 years and make it an appealing option in comparison to conventional air conditioners.

In terms of the equipment for cooling load provision, a commercial absorption chiller with a capacity of 7.3 MWc has been chosen, demonstrating nominal COP of 0.73. The initial investment for the network administrator would require 980,000 €, including the chiller cost and miscellaneous expenses such as electrical and mechanical equipment and the construction of the building to contain the cooling plant. PPC sells thermal energy at a rate of 5 €/MWh, in addition, annual costs, including maintenance and electricity costs are estimated at 60,980,36 €/y. The analysis has not included the administrator savings from the current pump operation for the network during summer.

The main hydraulic limitation is related to the maximum water supply rate of the main pumping station (3600 m³/h). On one hand, considering the inlet and outlet water temperatures of the chiller (12 and 7 °C respectively), this leads to a maximum cooling power of 21 MWc, which is acceptable given the cooling load capacity of the chosen chiller (7.3 MWc). Thus, it is obvious that the existing network could support greater than the discussed capacity. On the other hand, the cooling operation temperature difference is significantly lower to that of heating (inlet and outlet water temperatures of 70 and 120 °C respectively), questioning the capacity of the existing hydraulic network to serve similar loads. Given that, cooling loads, especially for Kozani, are significantly lower, this limitation could be elaborated, demanding though a detailed hydraulic analysis which exceeds the scope of this work.

3.4 Feasibility study

For the case studied, it is noted that the two existing (heated) water reserve tanks of 1650 m³ water volume each will be used for the storage of cooling energy; their capacity is 7 MWhc in terms of energy, and 1.5 MWc in terms of power each, increasing the cooling load capacity of the chiller to 10.3 MWc. Experience of similar systems has shown that peak power of the system is set by design to the 80% of peak demand. Eventually, considering the final load capacity of the selected chiller, maximum connected power demand will be 10.3 MWc ÷ 0.8 = 12.87 MWc and maximum surface of connected buildings 420,963 m² respectively.

The following assumptions have to be made: the investment will be subsidized by 35% (which is the minimum for such projects), loan interest rate will be 6.5%, tax rate will be 29%, inflation rate will be 1.5% for the next 20 years (cooling plant life expectancy) and thermal losses between terminal points and the cooling plant are negligible.
Regarding the results of the above analysis, in figure 7 the NPV is presented; demonstrated values are quite high, considering also the magnitude of the initial investment. Moreover, in figure 8, the pay-back period is presented for a range of cooling energy selling price. The results are optimistic for the reference value of 0.023 €/kWhc (8.63 years), while becoming unfavorable for a cooling energy price below 0.017 €/kWhc. Thus, the overall results can be characterized encouraging, proving that district cooling is a viable and sustainable solution for the city of Kozani.

4 Conclusions
District cooling is a tested and reliable solution, that can substitute conventional air conditioning in a financially beneficial way. In addition, it contributes massively in reducing CO2 and CFCs emissions.

The planning of a district cooling system in the city of Kozani demonstrated positive economical potential, accompanied by multiple benefits, as:

- Increased district energy network life expectancy
- Utilization of waste energy produced by local power plants during the summer
- Lower electrical load during the summer and consequently higher network stability
- High level job opportunities created during the construction and the operation of the cooling plant

The presented analysis should be treated as a basic approach on the specific problem, which is complex and demanding. Further work should concentrate on network operation and planning issues, mainly related to the fact of the different distribution of cooling loads on the network with regard to the heating ones, while the lower temperature operation difference of cooling, with regard to heating, could cause local network inability on coping with the demanding water flow rate; the detailed mapping of cooling load demand remains of course a prerequisite. The cooling technologies also comprise a basic issue, in order to select cost-effective solutions; the use of alternative energy sources, noting the existence of a near lake with satisfactory capacity, or combination with solar thermal could also be the case, while one should have in mind the solution of heat pumps as end-cooling appliances, powered by low temperature heat serving as a geothermal heat sink, rather than installing central thermal-powered chillers.

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