Smart thermal grids, geothermal integration into smart cities

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ABSTRACT

The future of our current energy is moving towards Smart Cities and Smart Rural Communities, where the integration of combined technologies using renewable energy sources reduces the environmental impact and offers citizens a better quality of live. Geothermal has a particularly important role in smart electricity and thermal grids, since it can deliver both heating and cooling and electricity.

Shallow geothermal, assisted by heat pumps, is a key energy source for smart energy systems. It provides solutions for the future energy system by coupling smart thermal and electricity grids via underground thermal storage (UTES) and by ensuring a reliable and affordable heating and cooling supply to both urban and rural areas.

Deep geothermal technologies will also fit perfectly with smart cities as they can provide heating, cooling and power.

As both of these technologies, deep and shallow geothermal, can be installed in grid and off-grid heating and cooling systems, they perfectly fit the new smart cities and rural communities approach.

In addition, there is also an important role for geothermal energy in connections with and management of smart electricity grids. Geothermal heat pumps can provide demand response services, thereby contributing to grid stabilisation, whilst UTES is an excellent storage solution. Combined heat and power plants are also a solution for making the electrical grid more flexible.

Smart Thermal and Power grids will use renewable energy like geothermal to ensure a reliable and affordable heating and cooling, electrical supply to various customers. This is possible because they are:

- Flexible, adapting: In the short-term to the energy supply and demand situation. In the medium-term by adapting to the temperature level in existing networks and the installation of new distributed micro-networks. In the long-term by aligning the network development with urban planning.

- Intelligent: they are intelligently planned and operated, and enable the end-user to interact with the heating and cooling system. They can, for instance, supply heating or cooling back to the network and to off-grid applications.

- Integrated: they are integrated in the whole urban energy system from a spatial point of view (related to urban planning parameters and processes), and from an energy system point of view (e.g. optimising the interfaces to other urban networks – electricity, sewage, waste, Information & Communication Technologies-ICT, etc).

- Efficient: they are designed to achieve the highest overall efficiency of the energy system, by choosing the optimal combination of technologies and enable a maximum exploitation of available local energy resources by cascade usage.

- Competitive: They are cost effective in a way that makes operation affordable, both for consumers and businesses. They increase the cost efficiency of heating and cooling supply, and create opportunities for customers to participate.

- Sizable: These systems can be both applied for neighbourhood level or city-wide, according to the demand of heat and cold.

- Securing energy supply: They increase security of energy supply at a local level by using local sources of energy for heating & cooling.

1. INTRODUCTION

The providing of a sustainable solution for the energy consumed in our cities and rural communities, can not only focus on smart grids for electricity.

Heating and cooling represents some 50% of European Union (EU) 's final energy consumption. Thermal energy is the biggest energy end-use sector. Heat users quite often have specific demand profiles comprising issues of temperature, capacity, and timing. Therefore, a variety of applications and sources are required to cover this demand.

Heat temperatures can be classified as follows:

- Low temperature (up to 95° C);

- Medium temperature (between 95° C and 250° C)
- High temperature (above 250° C)

Technologies used should match as closely as possible the temperature levels required by the thermal energy demand. Furthermore, it is important to distinguish between primary, final and useful energy when considering energy efficiency in buildings and to bear in mind that additional conversion steps are needed to convert a “final” form of energy into a ”useful” form of energy. A distinction should be made between energy sources (gas, heating oil, biomass, geothermal, solar thermal, aerothermal), enablers (heat pumps, boilers, stoves, district heating) and end-users (households/residential, commercial/services, and industry.

The heating and cooling end-users are:

Residential sector

Energy demand for H&C in the residential sector is strongly dependent upon climatic conditions and follows a clear seasonal pattern. However, domestic hot water is essential in all climates. Capacity demand varies from only a few kWth for small and well-insulated buildings, to some 100 kWth for blocks of flats. Cooling demand is expected to increase, not only in Southern Europe but also in Central and Eastern Europe. Geothermal heating and cooling technologies can cover this demand, including through district heating and cooling.

Service sector

In the service sector, H&C demand is strongly influenced by the type of building and its use. Loads are typically higher, starting with some 10 kWth to 1MWth or more for larger installations; space cooling and ventilation is almost a standard, while H&C loads can vary widely in a short timeframe. Geothermal heating and cooling technologies can cover this demand but must be rather flexible in size, adaptive to quick changes, and able to supply substantial amounts of cooling.

Industry

Industrial heat demand varies by temperature levels, sectors, etc. According to the study Ecoheatcool, around 30% of the industrial heat demand is required at temperatures below 100° C, for instance for washing, rinsing, and food preparation. Some heat is also used for space heating and on-site hot water preparation. Medium temperatures are required to evaporate or to dry. High temperatures are required for the manufacture of metals, ceramics, glass etc. Temperatures above 400°C can be created by using hot flue gases, electric induction and other combustion processes.

Being in small or large cities or in less densely populated rural communities, heating and cooling is consumed by these three end-users: circa 40% is consumed by households, same share for the industry, services consumed around 15% of the h&c, the rest is divided between the agricultural sector and other sectors.

2. CITIES AND BUILDINGS IN EUROPE

Heating and cooling is largely dominated by fossil fuels (more than 80%). This sector is therefore heavily responsible for EU’s GreenHouse Gases (GHG) emissions and its reliance on energy imports from unstable regions, with eight Member States (Finland, Lithuania, Latvia, Estonia, Czech Republic, Slovakia, Hungary, and Bulgaria) having more than 95 % of their total gas supplies coming from Russia.

Together with energy efficiency, renewable heating and cooling technologies, including geothermal, are the only options to reverse these trends.

Through the use of RES, heat and cold generation will become sustainable and secure with significant societal benefits by:

- Improving EU’s security of supply: given the variety of RES for H&C, EU member states will further benefit from an increased security of supply through the diversification of the energy sources used, when compared with today’s fossil fuel dominated energy mix.
- Stabilising energy prices: RHC technologies are able to provide a competitive alternative to fossil sources, and price volatility is reduced
- Creating local and sustainable jobs and fostering the European industrial leadership
- Sustainability: As highlighted in the European Commission’s Energy Roadmap 2050, RHC will be vital to decarbonisation of the EU’s energy system.

Most of the heat consumed in cities lies in the buildings sector, mainly for space heating and domestic hot water. Addressing the building sector, and particularly the existing building stock, is therefore of crucial importance.

Buildings have enormous energy efficiency and decarbonisation potential, because Europe’s building stock is old and mostly inefficient, with almost 40 % of houses built before 1950. Buildings consume more than two thirds of the thermal energy in Europe. The sector is expanding, which is bound to increase its energy consumption. Around 60 % of building’s heat is produced from natural gas, and heating oil or kerosene is still widely used in the residential sector. Moreover, the residential and tertiary sectors account for approximately 40 % of gross inland consumption of gas. This consists mainly of direct use for heating and domestic hot water preparation for households and commercial buildings (using individual or central boilers).

Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the European Union's energy dependency and greenhouse gas emissions. These ambitions are consistent with the objectives of the new Energy Union. It is necessary to lay down more concrete actions with a view to achieving the great unrealised potential for energy savings in buildings and reducing the large differences between Member States' results in this sector.

It exists several favourable applications for geothermal in cities. It can be installed for single buildings or building complexes: large office buildings, shopping malls, theaters, cinemas, congress, etc., appartments, hotels, etc. or in networks for heat and/or cold: water-loop at low temperature (10-20 °C) and heat pumps for individual buildings; local heating/cooling network fed by shallow geothermal and shallow geothermal for storage in district heating/cooling (ATES/BTES).

3. GEOTHERMAL IN BUILDINGS, CITIES, GRIDS

Per definition, Geothermal Energy is the energy stored in the form of heat beneath the earth's surface. This energy can be found at different temperatures in the ground and the ground water, depending on local geology and depth. With geothermal energy for heating and cooling, two main resource types are distinguished:

• The first one (very low temperature in the range of the annual mean air temperature on site, up to about 30 °C) is based on the relatively stable groundwater and ground temperatures at shallow depth (the limit is typically set at 400 m). Typically, heat pumps are used to extract energy from the ground and raise the temperature to the level required by the heating systems.

• The second one (low and medium temperature, ranging from 30 °C to over 100 °C) extracts the heat from ground and groundwater at higher temperature, and typically at greater depth.

A third category, high temperature (high enthalpy) resources of well over 100 °C to some >300 °C, is primarily used for electric power generation. However, residual heat from such applications can still provide energy for heating, and some high-temperature industrial processes could be supplied directly with heat from this type of resource.

Concerning the application side, a distinction can be made between systems using additional energy and devices to match the temperature requirements, and those using the geothermal heat directly:

• If the geothermal heat is at a level of temperature lower than the temperature required by the heating system, further system components are installed:

- Heat pumps can be used to raise the temperature to the required level (ground source heat pumps, GSHP). In this case ground and ground water might also be used for cooling; directly in cases with the right boundary conditions, or by using a heat pump as cooling machine if lower temperatures are required

- The ground could also be used for heat or cold storage, UTES (Underground Thermal Energy Storage), e.g. for combined heating and cooling in commercial and institutional buildings

• If the geothermal heat is at a level of temperature compatible with the temperature required by the heating system, the energy from the ground or the ground water can be used directly (without any thermodynamic device). Direct applications are found in:

- district heating or combined heat and power installations
- agriculture (horticulture, aquaculture, drying)
- industrial processes
- balneology
- absorption heat pumps for cooling purposes

Also in the low to medium temperature range UTES is an option, making use of available surplus heat from building cooling or from heat and power cogeneration, or of renewable heat as from geothermal or solar thermal sources.

Currently, geothermal energy sources provide more than the equivalent of 4 million tonnes oil (Mtoe) per year for heating and cooling in the European Union, equivalent to more than 15 GWth installed capacity, where geothermal Heat Pump systems contribute the largest part. But still the potential is huge. Geothermal can be used virtually anywhere in residential and tertiary sectors, but also in industry up to temperatures in the range of 200-250°C.

Following current trends, in the European Union (EU-28), the contribution in 2020 will amount to around 40 GWth installed, corresponding to about 10 Mtoe. The total installed capacity for geothermal power in the EU now amounts to around 946 MWe, producing some 5,56 TWh of electric power yearly. Combined Heat and Power (CHP) plants are marginal, with less than 1 GWth capacity for heating, but the development of Enhanced Geothermal Systems (EGS) will provide further opportunities for CHP systems.

During the next 10 years, new geothermal combined heat and power plants with low temperature installations and Enhanced Geothermal Systems will be developed. The sector is forecasted to reach an installed capacity for geothermal electricity of 3-4 GWe in the EU-28. A binary system (Kalina or Organic Rankine Cycle or similar) at low temperature has a simultaneous electrical and thermal capacity of ca. 5 MWe and 10 MWth, respectively.

A typical EGS plant today has a capacity of 3-10 MWe, but future commercial plants will have a capacity of 25-50 MWe and 50-100 MWth (producing from a cluster of 5 to 10 wells, as currently found in the oil & gas industry).

CHP installations could provide heating representing 2 Mtoe by 2020 at high temperature, suitable for energy intensive industry.

The technological challenges for an accelerated deployment of geothermal heating & cooling across Europe are to develop innovative solutions especially for refurbishing existing buildings, but also for zero and plus energy buildings, as the systems are easier to install and more efficient at low temperature for both heating & cooling.

Secondly, to develop geothermal District Heating (DH) systems in dense urban areas at low temperature with emphasis on the deployment of Enhanced Geothermal Systems. Finally, the third goal is to contribute to the decarbonisation of industry by providing competitive solutions for heating & cooling.

Promising areas are the development of smart thermal grids (1st generation) with the building of new district heating & cooling networks (Geothermal District Heating & Cooling, with ca. 5 €-cent/kWh, is one of the most competitive energy technologies), optimisation of existing networks, and the increase of new and innovative geothermal applications in transport, industry and agriculture. The first regions to develop will be those possessing the most accessible resources (for example the Pannonian, Tuscan or Parisian basins) as well as higher grade resources where combined heat and power projects will be developed (e.g. the Bavarian Malm reservoir and the Upper Rhine Graben).

To sum up, the main opportunities for deploying geothermal in cities are four:

- Heating and cooling demand is always nearby

- Potential for substantial reduction of energy demand and emissions

- Shallow geothermal for H&C baseload in combination with other RES and conventional technology

- Elevated temperatures in the underground under cities– favourable for heating, shallow geothermal can help control this.

The main constraints would be the limited area available (for work, BHE / well placement, etc.), the mutual impact of shallow geothermal installation which must be strictly observed, regulated and controlled and we should notice that numerous installations and workings in the underground, require cautious drilling.

4 SMART CITIES AND SMART THERMAL GRIDS

The challenges smart cities face are not only that each city has its own singularities but also they are composed by different areas and level of urban density (city centre, districts, suburbs, parks, etc.).

The coverage of the heating and cooling consumption in the smart cities has to pass through smart thermal grids for answering this challenge and the challenges of the energy transition into a low carbon economy. The approach suggested is to have to step in this transition:

- A first generation would aim at retrofitting and decarbonising existing district heating and cooling systems and at developing off-grid RES systems
- A second generation would consist in deploying intelligent and interconnected thermal grids, the main innovation would concern the use of low temperature systems, with a RES integration, a connection to electricity and the use of storage as a balancing facilities. In this new generation the role of ICT will be primordial.

Smart Thermal grids will use renewable energy like geothermal to ensure a reliable and affordable heating and cooling supply to various customers. This is possible because they are:

- Flexible, adapting: In the short-term to the energy supply and demand situation. In the medium-term by adapting to the temperature level in existing networks and the installation of new distributed micro-networks. In the long-term by aligning the network development with urban planning.

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- Efficient: they are designed to achieve the highest overall efficiency of the energy system, by choosing the optimal combination of technologies and enable a maximum exploitation of available local energy resources by cascade usage.

- Competitive: They are cost effective in a way that makes operation affordable, both for consumers and businesses. They increase the cost efficiency of heating and cooling supply, and create opportunities for customers to participate.

- Sizable: These systems can be both applied for neighbourhood level or city-wide, according to the demand of heat and cold.

For ten years, a geothermal project based on mine water in the Netherlands is giving a good example of smart thermal grid. Several development stages towards a smart grid have brought the project from Minewater 1.0 to Minewater 3.0. The heart and brain of this smart thermal grid is the intelligent control system.

The mijnwater project in the Netherlands uses groundwater in the town's abandoned coal mines to supply local homes and businesses, giving this former mining town a new life as an innovative, green, geothermal community, leading the way in smart thermal grids.

Beginning life as a project supported by the European Interreg IIIB programme and the 6th Framework Programme, Mijnwater B.V. is now a rapidly expanding private company owned by the municipality. It is continuing to diversify and develop and innovative concept, the success of which has been proved over nearly ten years.

<u>2008-2013</u>

The Mijnwater 1.0 was to prove the concept of using mine water as an energy source. The groundwater in flooded, abandoned coal mines at depths of about 800m is first used as a source of heating and cooling. Energy at low temperature is delivered to clusters of buildings via a grid, with heat pumps used to adjust the temperature. It leaded to 35% CO_2 emission reductions.

<u>2013- 2015</u>

The Mijnwater 2.0 then developed the system by using the Mine water as an energy balanced buffer. The mine water was no longer used as just a source of energy, but as a reservoir in a balanced system, meaning the resource is not depleted. Mijnwater works on a smart thermal grid system where users are grouped into clusters. Heat and cold from different sources (e.g. renewables and waste heat) is exchanged both within each cluster, and between clusters, with surplus energy transported in the Mijnwater reservoir for storage. In this way energy can be used several times in succession and customers become prosumers, supplying their waste thermal energy back to the grid. Three points of control are established; pressure is controlled at the Mijnwater wells, flow is controlled at cluster level, and temperature is controlled at building level. Unlike traditional thermal grids, which have a top down hierarchy with a heat plant at the top, the Mijnwater grid is based on equal connections in a decentralised system.

The power for transportation and heat pumps is increasingly supplied by renewable sources. In 2014, 125,000 m² were connected and 200,000 m² were contracted, leading to a CO_2 emission reduction of 65%.

<u>2015-ongoing</u>

Finally, Mijnwater 3.0 allows to have a demand and supply controlled system. The next stage of development will see the move to a demand and supply controlled system, which is optimises supply based on factors such as weather forecasts and user behaviour patterns. In 2016, 500.000 m2 would be connected and 800.000 m2 contracted. The objective is to have 80-100% of CO_2 emission reductions.

3. CONCLUSIONS

Our cities and rural communities will evolve in the future, participating to the transition towards a low carbon economy. This will largely be influenced by the energy system and the ICT.

Geothermal energy has the characteristics to play a crucial role in our future energy mix: decarbonised, providing affordable energy for society, and allowing competitiveness of European industry.

Geothermal heating & cooling can supply energy at different temperatures (low or high temperature), at different loads (it can be base load and flexible) and for different demands (heat and cold: less than 10 kWth to a tenth of a MWth). Geothermal is a renewable energy source which is local, manageable and flexible. It should be integrated in a regional approach which reduces costs for society (system costs: infrastructures and storage facilities, and externalities; Greenhouse Gas emissions etc.) and improves local security of supply. Smart thermal grids will, develop with geothermal as a key technology.

The next stage is then to go towards a full energy system integration in the cities. It means firstly a combination of heat/cold and electricity, with for example storing excess electricity in form of heat. This combined energy grid will also be integrated with communication technologies using common infrastructure. A link with the transport sector is also planned with electric cars as power storage.

The key issues to make smart energy grids work are to develop the right system architecture and to develop the operation strategies and control hardware and software.

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