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GEOTHERMAL SPACE COOLING

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ABSTRACT

The paper will propose an introduction to the heat pump technology applied to geothermal space cooling and give examples of how it can be used. Geothermal ground source heat pumps are currently the most widespread form of geothermal utilization. They usually require rather low enthalpy geothermal resources and can be used for both heating and cooling purposes as their cycle is reversible. Such equipment required a significant electrical input. On the other hand, geothermal heat pumps for cooling purpose is something completely different. Instead of using electricity for the heat pump compressor, like in a normal cooling machine or a refrigerator, the heat from a geothermal resource is used as the driving energy in an absorption heat pump, often named geothermal absorption chillers. Market prospects for residential and space cooling indicate that a steady increase can be expected in the coming years. The paper will indicate potential cooling demand in various places in around the African rift where geothermal energy is available. In addition to presenting and comparing the most common cooling methods, a basic business case will be developed.

1. INTRODUCTION

Geothermal ground source heat pumps are currently the most widespread form of geothermal utilization. Geothermal heat pumps for decentralized applications are rather common in Europe.

As the cycle on which the heat pumps are based is reversible, they can be applied for both heating and cooling purposes. During winter time the ground source delivers heat into the heat pump and the sink is the space to be heated. During summer time the ground source is the sink and the space delivers heat into the heat pump.

Geothermal heat pumps for cooling purpose is something completely different. Instead of using electricity for the heat pump compressor, like in a normal cooling machine or a refrigerator, the heat from a geothermal resource is used as the driving energy in an absorption heat pump, often named geothermal absorption chillers.

2. MARKET PROSPECTS

The projection to 2040 by the EIA for residential space cooling energy consumption indicates a steady increase in space cooling energy use worldwide of about 1.5% annually, from 0.85 PJ 2010 to 1.25 PJ. Electricity is currently the most common source of energy used for driving traditional space cooling machines. Rising electricity prices and the search for low CO_2 emission energy makes geothermal absorption heat pump an interesting option.

Cooling degree days give an indication on the measure of how much, and for how long, the outside temperature was above that of the base temperature.

Table 1 below gives an indication on potential cooling demand in various places in Africa.

Such information could be combined with information on potential geothermal resources to give an indication about the places where geothermal space heating could be applied.

Table 1: Cooling degree days for various locations (BizEE Software Limited, 2016)

Cooling Degree Days. For a base temperature of 22°C	**Celsius based 4 year average**
Addis Ababa, Ethiopia	82
Mafia, Tanzania	1666
Dodoma, Tanzania	828
Kakamega, Kenya	486
Eldoret, Kenya	126
Nairobi, Kenya	316
Mombasa, Kenya	1689

When a site for a space district cooling system has been selected, more detailed weather and load studies should be applied, similar as is done when geothermal district heating is designed.

Space cooling loads depend mainly on the building characteristics and on the local weather data. Weather records are usually provided by the local weather agency, preferably on an hourly basis, for a period of time as long as possible and are used to draw up the load duration curve.

The aim is to show with a load duration curve the number of days/hours per year that have an outdoor temperature lower or higher than a given temperature. The area under this curve is proportional to the number of degree-days required for heating or cooling and gives a measure of the amount of energy required for space conditioning. Figure 1 shows an example of load duration curves for various locations.

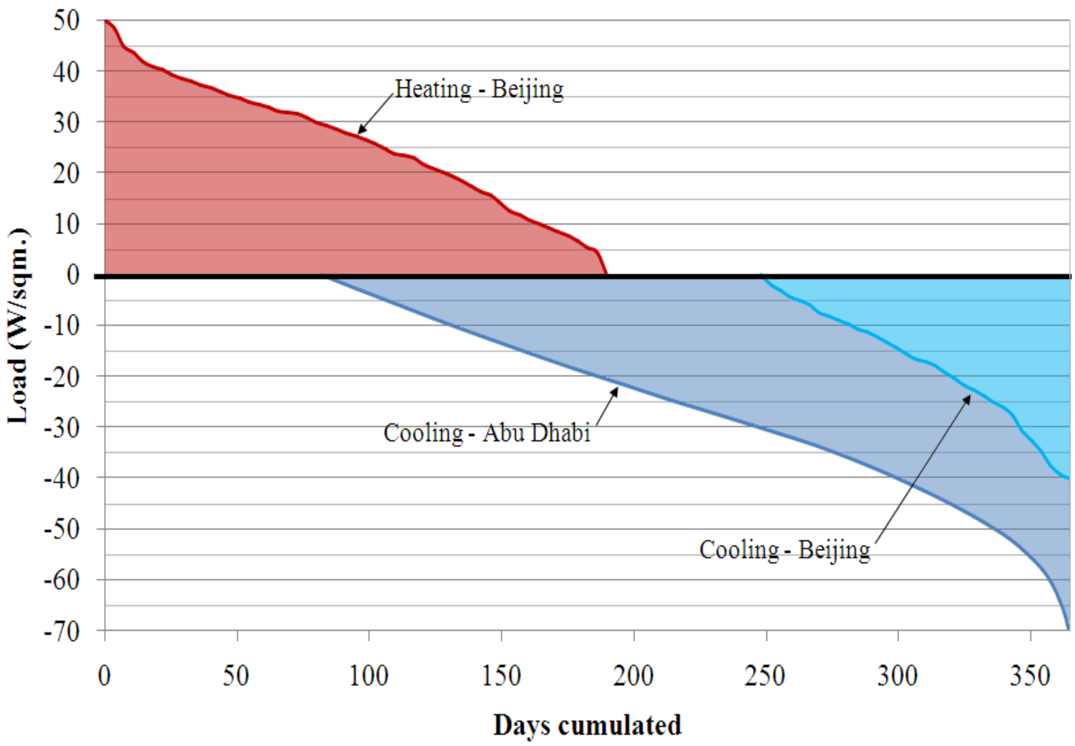

Figure 1: Heating/cooling load factors in various locations

Heating and cooling load factors are summarized in Table 2 below.

Table 2: Heating/cooling load factors

	Cooling load	Heating load
Abu Dhabi	2,650 h/year @ 25°C 2,850 h/year @ 22°C	-
Beijing	1,250 h/year @ 25°C	2,400 h/year @ 18°C
Reykjavík	-	4,300 h/year @ 20°C

3. COOLING TECHNOLOGY

3.1 Heat pumps

The heat pump's theoretical cycle proceeds from the Carnot cycle. Heat pumps are reversible machines that transfer heat by absorbing heat from a cold space and releasing it to a warmer one, and vice-versa. The heat is transferred by a working fluid media and requires additional energy input as shown in
Figure 2.

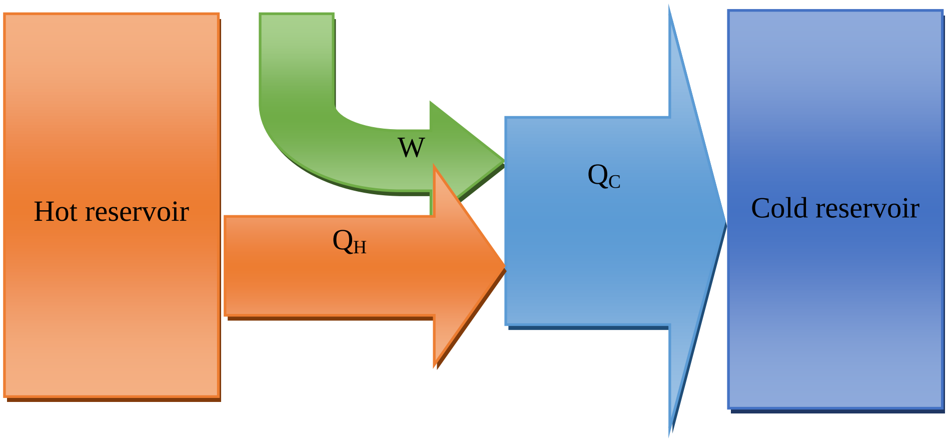

Figure 2: Heat pump – heat flow principle

Heat pumps are characterized by a coefficient of performance (COP) corresponding to the number of units of energy delivered to the hot reservoir:

$$COP = \frac{Q_C}{W} = \frac{Q_C}{Q_C - Q_H} \qquad (1)$$

where Q_C = Heat released to the cold reservoir, cooling capacity (W);
W = Work consumed by the heat pump (W); and
Q_O = Heat extracted to the hot reservoir (W).

3.2 Heat pumps – various technologies for geothermal utilization

The most common applications of heat pumps are refrigerators and freezers. Heat pumps are also very common as chillers for space heating and cooling. Table 3, below, proposes an overview of the most common cooling methods.

Table 3: Overview of the most common cooling methods

Chiller type	**Compression**	**Absorption**
Compression type	Mechanical	Thermal absorption loop
Energy source	Electric power	Heat energy 85°C–150°C
Refrigerant agent	Halons, chlorinated CHC, Chlorine free hydrocarbons	Water with lithium bromide as an absorption agent
COP	4-6	0.6–1.0

A few machines that can be applied to geothermal space cooling are briefly introduced below.

3.2.1 Conventional compressor driven chiller for space cooling

The compression cycle requires an electrical energy supply. Figure 3 proposes a schematic view of the process.

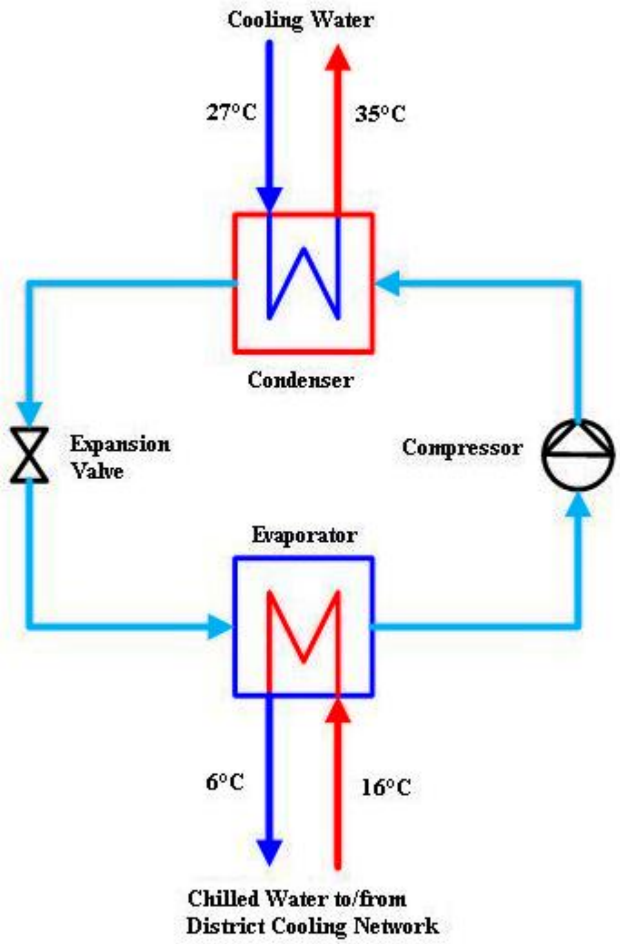

Figure 3: Compressor driven chiller – typical working process

The typical operation ranges for compressor driven chillers is:

- Electricity.
- Cooling water: 27/35°C, i.e. from cooling tower.
- Chilled water: 16/6°C, used for space cooling.
- Working fluid.
- COP: 4–6.

3.2.2 Absorption chiller machine

Absorption chillers present various advantages. They are cost effective with a high efficiency, long lifetime and low operation and maintenance costs. The investment cost of such equipment is, however, rather high, or about twice the investment cost required for a compressor driven chiller.

Absorption chillers can easily be operated by geothermal energy as they are driven on a heat source with a broad temperature range of 85°C–150°C. It is furthermore to be noted that such equipment is much more silent than the conventional compressor driven chillers.

Typical operation range for absorption chillers is:

- Driving heat: 95/60°C.
- Cooling water: 27/35°C.
- Chilled water: 16/6°C.
- Coefficient of performance: 0.7 single stage, 1.2 double stage.
- Cost: 20–50% more expensive than a standard compressor machine.

Figure 4 proposes a schematic view of the process.

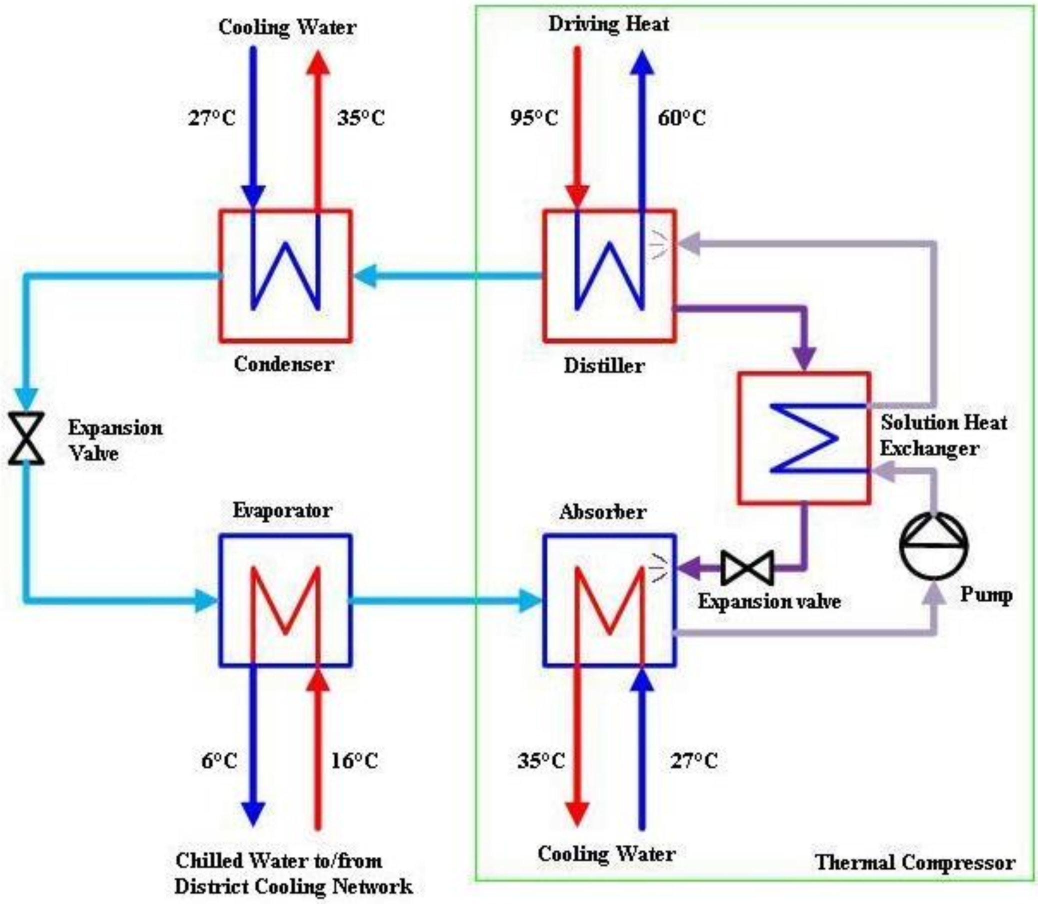

Figure 4: Absorption chiller – typical working process

An absorption chiller does not use an electric compressor to mechanically pressurize the refrigerant. Instead, it uses a heat source to evaporate the refrigerant. The absorption cooling cycle can be described in three phases:

- Evaporation: the liquid refrigerant evaporates in a low partial pressure environment, thus extracting heat from its surroundings.
- Absorption: the gaseous refrigerant is absorbed – dissolved into another liquid - reducing its partial pressure in the evaporator and allowing more liquid to evaporate.
- Regeneration: The refrigerant-laden liquid is heated, causing the refrigerant to evaporate out. It is then condensed through a heat exchanger to replenish the supply of liquid refrigerant in the evaporator.

Lithium bromide is commonly used as the carrier fluid and water as refrigerant. Unlike CFCs and HCFCs, the working fluid used in absorption chillers is environmentally friendly and non-toxic. Lithium bromide can be easily transported, as white odorless salt, and stored.

4. THE USE OF GEOTHERMAL ENERGY AND HEAT PUMPS FOR COOLING

4.1 District cooling

A district cooling system distributes thermal energy in the form of chilled water or other media from a central source to multiple buildings through a network of underground pipes for use in space and process cooling. The cooling or heat rejection is usually provided from a central cooling plant, thus eliminating the need for separate systems in individual buildings. Figure 5 presents the main components of a district cooling system.

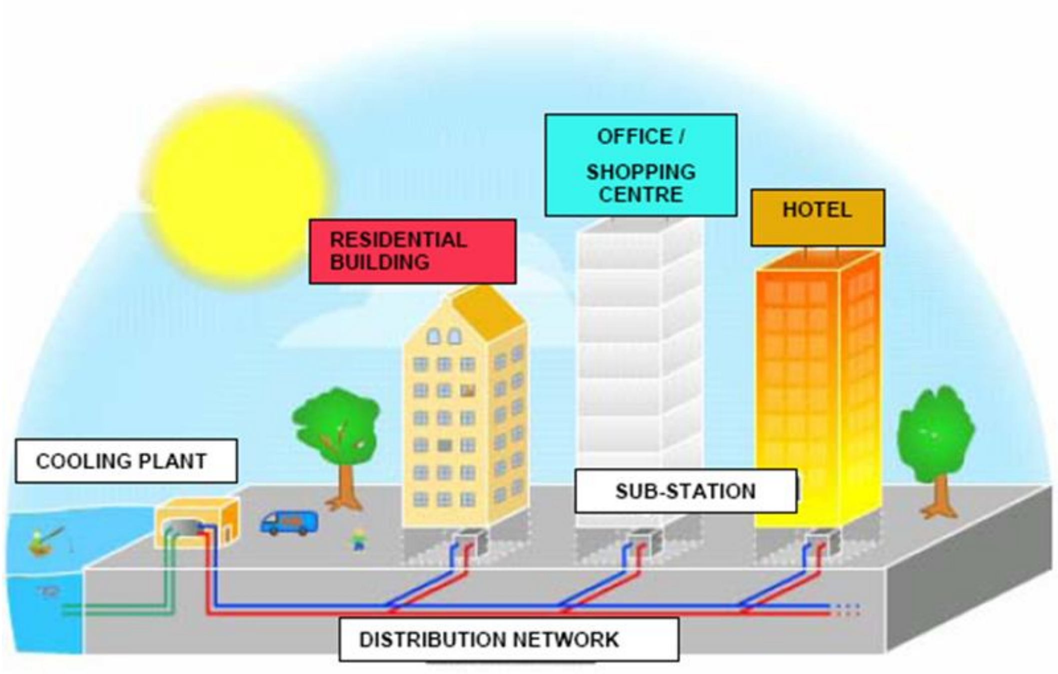

Figure 5: Main district cooling components

The main components of a district cooling system are further listed below:

- Cold Sink:
  - Cooling tower for air cooled systems.
  - Water for water cooled system: e.g. sea water, lake or a river.
- Cooling Plant producing chilled water at 6-8°C:
  - Compressor driven chiller, with electricity as an energy source, or absorption chiller requiring heat as energy source.
  - Storage tanks, accumulators and other typical equipment for district systems.

- Water distribution network: usually consisting of supply and return pipes.
- Consumer's substation.
- HVAC systems in buildings:
    - Forced air ventilation system.
    - Free cooling with panels.

District cooling systems are competitive systems and present various benefits. Their energy performance is significantly better than individual, decentralized, systems and a district system often contributes to a maximized cost effectiveness. Furthermore, the investment costs for the users are significantly reduced. Finally, such systems enable space to be saved for the users allowing them to allocate space in the buildings to other activities than for the installation of space demanding equipment.

From the environmental point of view, a district cooling system will contribute to reducing sound pollution and is expected to have less impact on the environment than many individual systems producing the same cooling effect.

Geothermal district cooling systems use geothermal resources as a source of energy instead of primary energy sources such as oil or natural gas. They are therefore expected to contribute to a significant cut of CO_2 emissions in addition to contributing to reducing dependency on fossil fuel exports.

Last but not least is the efficiency and flexibility of such systems. Large industrial equipment are by far more efficient than commercial equipment. They are furthermore flexible as different energy sources may be used, e.g.:

- Electricity;
- Natural gas;
- Waste heat;
- Solar; and
- Geothermal energy.

4.2 Energy efficiency considerations

Although an absorption chiller as a much lower COP than a compression driven chiller, it might be more efficient than the latter if the whole production process is taken into account. Table 4 proposes a comparison of the energy output for compressor driven chiller and geothermal heat driven absorption chiller with the same initial energy input, i.e. to produce electricity or from the geothermal field.

Table 4: Energy output vs. energy input

Machine	COP	Energy source	Initial energy input at the chiller	Output
Compressor driven chiller	5	Electricity	0.2 kWh to deliver 1 kWh chiller effect	1 kWh
Absorption chiller	1	Geothermal hot water, 120°C	1 kWh heat to deliver 1 kWh at the chiller. No losses are expected to occur between the well and the chiller	1 kWh
Electricity		Geothermal hot water, 120°C	2 kWh heat from geothermal used to produce 0.2 kWh electricity (10% thermal efficiency)	0.2 kWh

An absorption heat pump driven with hot geothermal driving fluid might deliver 2 times more cooling energy than a compressor chiller, driven with electricity produced with the same geothermal fluid.

4.3 Cost considerations

Geothermal space cooling is a competitive solution compared to existing cooling methods, even so an overview of initial costs and maintenance is needed. Table 5 shows estimated cost of production for a one well geothermal cooling plant. The major cost of a project like this is the initial cost of building a cooling plant and if needed setting up for the geothermal wells. Estimating energy prices at 0.1$ per kWh an absorption chiller is able to compete easily with electric chillers.

Table 5: Estimated costs of project

Cost factor	**$**
Initial Setup of Cooling Plant and Pipings	$45,000,000
Production value	$9,143,816/year

A cooling plant of this size and production capability should be able to produce 26,000,000 ton of refrigeration hours (TRh) which is calculated as roughly 91,438,165 kWh or 91,438 MWh.

The electricity operating cost is 0.048$/TRh for geothermal cooling, while for decentralized air cooling units it is 0.16$/TRh and for water cooled electrical chillers is 0.096$/TRh. These numbers show that there are considerable savings in energy usage with geothermal cooling, compared to other cooling distribution methods.

5. CONCLUSION

Geothermal space cooling is technically and in many cases a commercially competitive solution compared to space cooling from conventional sources of energy. It presents various advantages, the main ones being the cut of CO_2 emissions, and the reduction of dependency on fossil fuel exports. When utilized in a district system, efficiency and cost effectiveness will be enhanced.
Compared to current forms of cooling, geothermal energy uses far less energy or electricity. Geothermal cooling, absorption and adsorption chiller, uses about 70% less electricity than decentralized air cooling units. Geothermal cooling also uses around 50% less electricity than water cooled electrical chillers. From this we can conclude that geothermal cooling is competitive with known methods.

REFERENCES

BizEE Software Limited, 2016: Degree days – Weather data for energy professionals. Website: www.degreedays.net/