Presented at "Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization", organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 23-29, 2014.

UNITED NATIONS
UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

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# UTILIZATION OF GEOTHERMAL RESOURCES FOR SPACE HEATING

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## ABSTRACT

Space heating is among the most successful geothermal direct applications in countries with cold climate and is often achieved via a district heating system. Geothermal district heating systems are not conventional district heating systems, although they share certain features with them. If geothermal heat is used in an unsuitable system, the utilization of the energy source will be poor and the resource will not be used responsively. Among other things, the overall design of such systems should be set up to optimize energy extraction for the geothermal fluid and encourage energy saving behaviors. In addition to presenting the main components of a geothermal space heating system, the paper focuses on critical issues for the design of space heating systems from geothermal with focus on the space heating system at the end users and metering and tariff design.

## 1. INTRODUCTION

Geothermal district heating systems are not conventional district heating systems, although they share certain features with them. The nature of the source of energy has to be taken into account when planning such system. The geothermal fluid is extracted and re-injected at given capital cost – drilling and geothermal fluid gathering and pumping equipment - and operational cost – mostly pumping whenever required. Geothermal resource management furthermore implies controlling the energy extraction from a geothermal resource so as to maximize the resulting benefits, without over-exploiting the resource. It is therefore important for the economy of geothermal heating systems and for the reservoir management sustainability to optimize the energy extraction for the geothermal fluid and encourage energy saving behaviors. Another aspect to be taken into account is the fact that geothermal systems often come in replacement of existing systems. To be able to use low temperature geothermal fluid, i.e. 70-80°C the overall size of a radiator must be larger than in conventional systems.

This paper is an introduction to the main features of a geothermal district heating system. It also draws light on the design of house heating devices and of the metering and tariff system with the overall purpose to obtain a sustainable district heating system.

## 2. GEOTHERMAL DISTRICT HEATING SYSTEMS – OVERVIEW

### 2.1 Geothermal district heating system components

In general, geothermal district heating systems receive geothermal energy coming either from a low-temperature geothermal resource, with temperatures expected to range from 30°C to 125°C, or from co-generation from high temperature geothermal resource.

A geothermal district heating system aims at providing the end users with energy for space heating and, depending on the context, for domestic hot water. The energy is usually delivered to the end users in the form of hot water via a distribution system.

As of the energy production itself, it is usually produced on one hand by the geothermal energy production, relying on the geothermal resources located under the production site, and by the additional energy production system on the other hand. Depending on the local conditions, it is often advisable to make use of this last production system in order to provide the peak energy. The heat central(s) constitute(s) the connection point between the energy production systems and the end users.

The distribution system carries the energy in the form of hot water to the end users, connecting them to the heat central(s). Each of the elements above mentioned has to be assessed thoroughly in order to evaluate the suitability of the area for geothermal district heating and the feasibility of the projects (Figure 1).

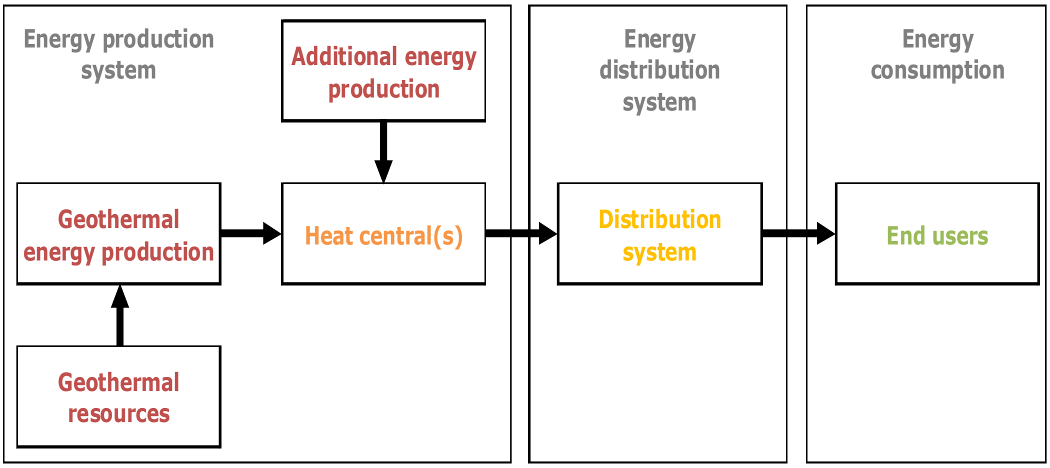

FIGURE 1: Main elements of a geothermal district heating system

### 2.2 General considerations and planning

The preferred water temperature for space heating from geothermal is in the range 60-90°C. Geothermal heat pump can be used if the temperature of the resource is too low for direct application. Common return water temperature is 25-40°C.

When considering a geothermal resource for space heating purposes, the chemical composition of the geothermal brine plays an important part and might impact the feasibility of the project depending on whether the brine can be used directly in the system or not. Radiators or floor heating systems are commonly used for geothermal space heating although air heating systems are also possible.

Another criteria for planning of geothermal district heating systems is the population density of the area being considered as it is important for the economy of the system. Large distance from the market increases the capital cost and the running cost (heat loss, pumping). The market should furthermore be checked for compatibility with a geothermal space heating system as discussed further in this paper.

In addition to this and apart from the geological aspects presented in other papers during the short course, the main steps for sketching the major elements of geothermal district heating at a preliminary stage include:

- Assessment of the main local factors: climate, population, market…
- Assessment of power and energy requirements of the community.
- Preliminary sizing of the energy production systems.
- Preliminary assessment of the distribution system.

Prior to presenting the main design steps of a geothermal district heating, the authors of this paper would like to draw the reader's attention to an issue which is often overlooked when planning geothermal space heating systems: the space heating system itself and its design.

### 2.3 System concept

Various concepts may be applied to use geothermal resources for space heating depending on the characteristics of the geothermal fluid, the elements of the system already in place or other technical or economical aspects. Figures 2 and 3 present the most common concepts: the single pipe systems and the double pipe systems.

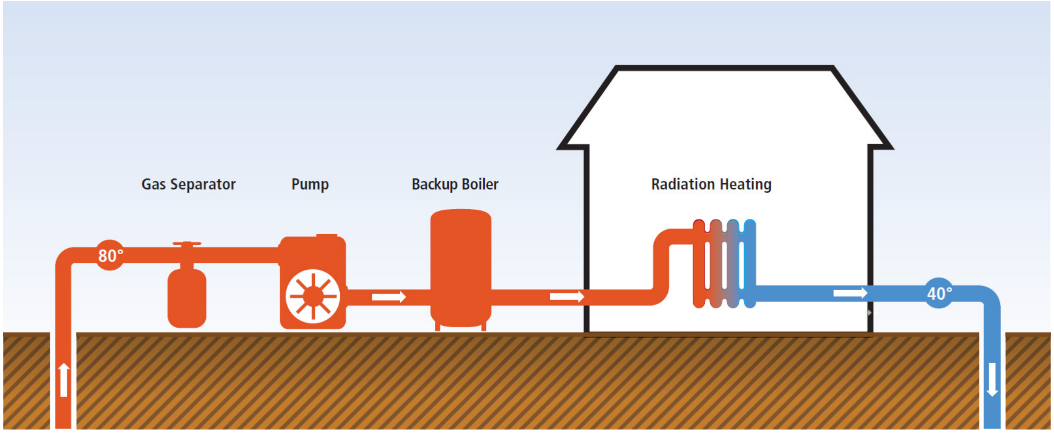

FIGURE 2: Single pipe system (Goldstein et al., 2011)

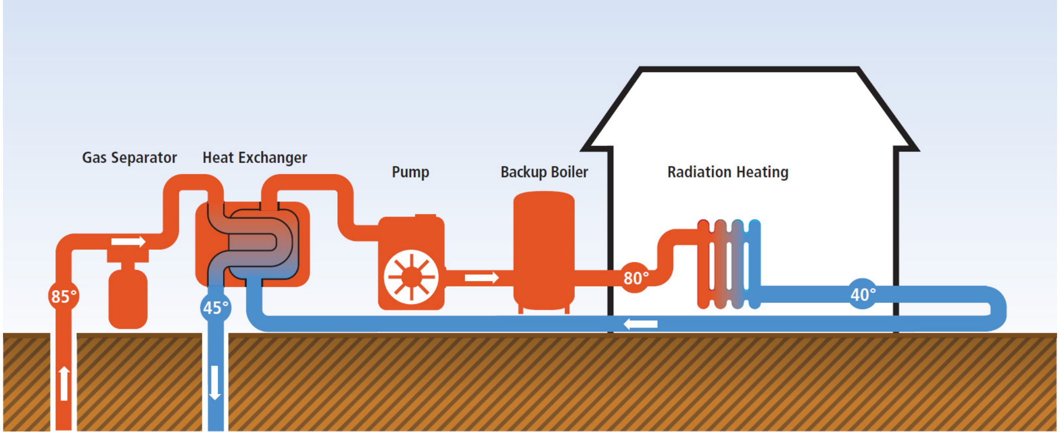

FIGURE 3: Double pipe system (Goldstein et al., 2011)

A single pipe system is an open system using the geothermal fluid directly in the space heating elements. A double pipe system is a closed system using the geothermal fluid via heat exchanger. Peak load boiler may be installed in both configurations, depending on the capacity of the geothermal resource and on the peak space heating demand.

### 2.4 Cost estimate for geothermal district heating system

Cost estimates for geothermal district heating systems and possible energy price will be highly dependent on the local conditions. Table 1 indicates possible cost and price ranges.

TABLE 1: Investment cost and energy price for geothermal heat applications, including energy production system and distribution system

| **Heat application** | **Investment cost, USD/kW** | **Energy price, USD /kWh** |
|---|---|---|
| Geothermal district heating system | 800-2000 | 0.036 – 0.090$^{1)}$ |
| Individual ground source heat pumps | 1000-4000 | - |
| Reykjavík Energy | 1000 | 0.022$^{2)}$ |

$^{1)}$ Number of utilization at max power pr. year = 2200
$^{2)}$ Number of utilization at max power pr. year = 4500

## 3. GEOTHEMAL SPACE HEATING DESIGN

This section introduces the space heating design theory.

House heating systems in geothermal district heating systems are among the most critical components for using a geothermal heat source. If geothermal heat is used in an unsuitable house heating systems, the utilization of the energy source will be poor and the resource will not be used responsively.

Many places in the world have a single piping system to connect district heating system to in-house radiator systems. The main principle is that water is led up to the highest floor and the radiators are connected in series so that the return water from a high level radiator is led to the next floor supply below (Figure 4). A throttle valve is sometimes installed parallel to the radiator to ensure that the water runs through the radiators on each floor. As a result, the supply water to radiators situated on lower levels will be colder than the supply water to radiators higher up in the building. This means that radiators on the lower levels must be installed larger than the radiators higher up. The overall temperature drop can be measured from top to bottom of each building. A common temperature drop is from 90°C to 70°C during periods of maximum heat load for an average apartment building.

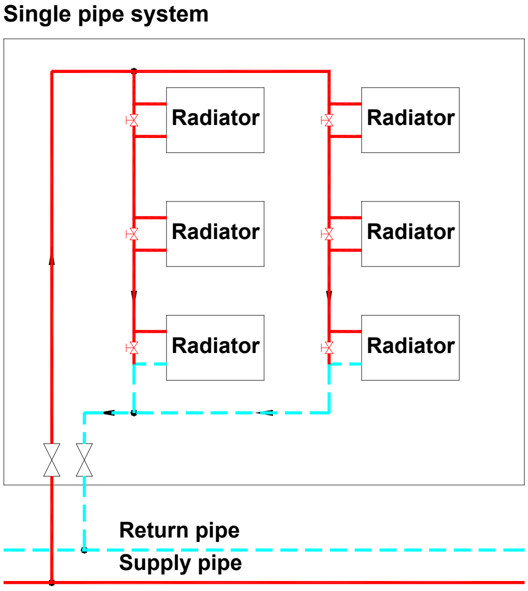

FIGURE 4: Typical space heating system with heating elements connected in series

To be able to use low temperature fluid, i.e. 70-80°C the overall size of a radiator must be large. A preferred and more efficient way of connecting heating elements is the connection in parallel as shown in Figure 5. All heating elements can be sized based on the same design parameters and the system is more balanced.

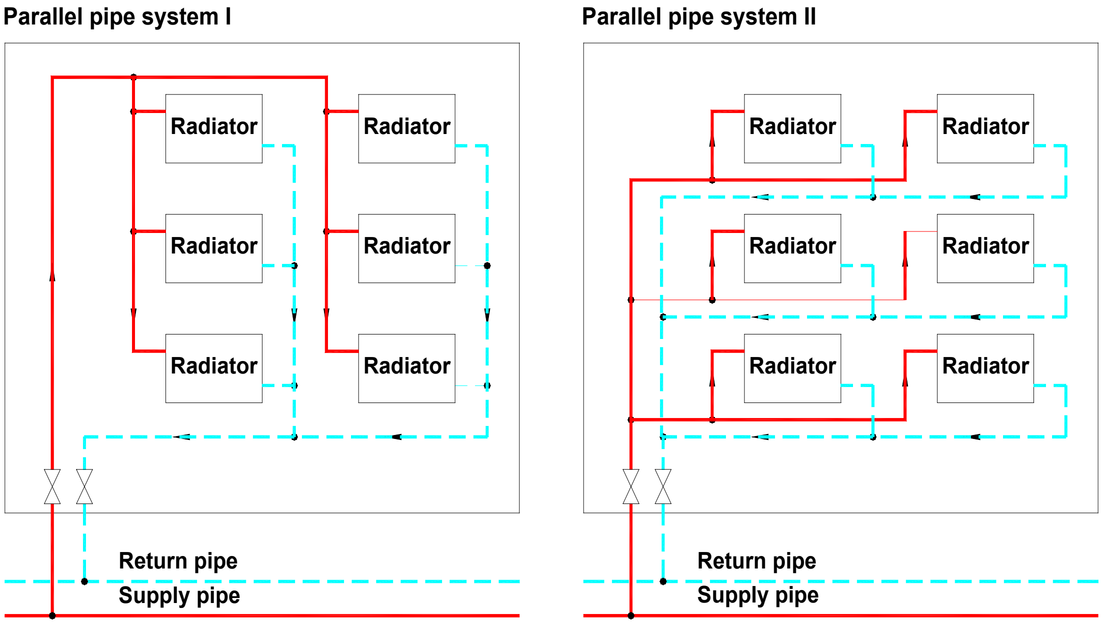

FIGURE 5: Typical space heating system with heating elements connected in parallel

Furthermore, the type of heating system used in houses should be carefully chosen, in adequacy with the enthalpy level of the fluid provided by the district heating system. Possibly cascaded system using radiators with supply/return temperatures 80/40 combined to floor heating system could be installed.

### 3.1 General guidelines for geothermal space heating system design

House heating with water, without any phase change, is not very complicated. The most basic heat transfer is from the water to the space being heated via house heating equipment at the consumer. The formula describing the matter is as follows:

$$Q = c_p \cdot dm/dt \cdot (T_{in} - T_{out}) \tag{1}$$

where $Q$ = Heat released (kW);
$c_p$ = Specific heat of fluid (kJ/(kg·°C));
$dm/dt$ = Mass flow (kg/s);
$T_{in}$ = Temperature of fluid into the heating system, supply temperature (°C); and
$T_{out}$ = Temperature of fluid out of the heating system, return temperature (°C).

It is specially noted, that the following notation for mass flow might be suitable in further context:

$\dot{m}$ = Mass flow (kg/s) (another notation).

The maximum temperature utilization is when the return temperature approaches the temperature inside the heated space, or $T_{out} \rightarrow T_{\text{inside space}}$. That is:

$$Q_{\max temp,utlization} = c_p \cdot \dot{m} \cdot (T_{in} - T_{inside\ space}) \tag{2}$$

This is never reached in practice, though, as it would result in an infinitely slow flow through any heating device.

When the upcoming temperature is limited, as is the case in geothermal heating, $T_{in}$ is rather low, especially when compared to coal heating. To utilize the temperature further down, $T_{out}$ has to be lowered closer to $T_{inside\ space}$ than before.

As the sought outcome when utilizing geothermal energy is an optimized energy extraction, design of space heating systems should always follow the principles introduced below:

- Utilize the temperature as much as possible, or economically feasible in one step;
- Keep the systems simple; and
- Get as high DT as possible in the first step.

The water coming back from the space heating system should in most cases be pumped back to the heat central as 100% re-injection is always the future goal, especially when renewal of water occurs slowly in the reservoir. As discussed further in section 6, metering and tariff systems might also be designed to contribute to serving these purposes.

### 3.2 Power and energy demand for space heating

Energy consumption of space heating depends mainly on:

- Climate (indoor / outdoor); and
- Insulation of the building

Table 2 presents typical power and energy demand for space heating depending on the type of building.

TABLE 2: Space heating power and energy demand for various type of buildings

| **Building type** | **Power demand ($W/m^2$)** | **Energy demand ($kWh/m^2$ p. annum)** | **Energy demand kWh per annum pr. dwelling unit (80 $m^2$)** |
|---|---|---|---|
| Old | 100 | 210 | 16,800 |
| Modern | 50 | 105 | 8,400 |
| Energy efficient | 20 | 42 | 3,360 |

These figures actually vary greatly depending on the country, its customs, climate and history:

- Old European/China – 210 $kWh/m^2$ per annum;
- Norway – 140 $kWh/m^2$ per annum;
- Sweden – 120 $kWh/m^2$ per annum;
- Germany – 125 $kWh/m^2$ per annum;
- UK – 100 $kWh/m^2$ per annum;
- Denmark – 80 $kWh/m^2$ per annum;
- Reykjavík 2010 – 200 $kWh/m^2$ per annum; and
- Europe low energy target: 40-60 $kWh/m^2$ per annum.

### 3.3 Radiator systems

Heat loss from buildings can be expressed by the equation:

$$Q_{loss} = k_l(T_i - T_o) \tag{3}$$

where $Q_{loss}$ = Heat lost from building (W);
$k_l$ = Overall building heat transfer coefficient (W/°C);
$T_i$ = Indoor temperature (°C); and
$T_o$ = Outdoor temperature (°C).

This equation can be expressed in terms of the reference/design conditions of the radiator. The relative heat loss form the building is

$$\frac{Q_{loss}}{Q_{loss,0}} = \frac{(T_i - T_o)}{(T_{i,0} - T_{o,0})} \tag{4}$$

where $T_{i,0}$ = Reference indoor temperature (°C); and
$T_{o,0}$ = Reference outdoor temperature (°C).

The heat emission by hot water radiators can be expressed as

$$Q_{rad} = \dot{m}c_p(T_s - T_r) \tag{5}$$

where $Q_{rad}$ = Heat emitted from radiator (W);
$\dot{m}$ = Mass flow through radiator (kg/s);
$T_s$ = Water supply temperature to the radiator (°C); and
$T_r$ = Water return temperature from the radiator (°C).

Relative heat duty of the radiator, in terms of reference/design conditions, can therefore be written as

$$\frac{Q_{rad}}{Q_{rad,0}} = \frac{\dot{m}(T_s - T_r)}{\dot{m}_0(T_{s,0} - T_{r,0})} \tag{6}$$

Where $\dot{m}_0$ = Reference mass flow through radiator (kg/s);
$T_{s,0}$ = Reference water supply temperature to the radiator (°C); and
$T_{r,0}$ = Reference water return temperature from the radiator (°C).

There is a relationship between the load on a water radiator system and the mean temperature difference. This relationship can be specified as

$$\frac{Q_{rad}}{Q_{rad,0}} = \frac{UA\Delta T_m}{U_0A_0\Delta T_{m,0}} = \frac{A}{A_0}\left(\frac{\Delta T_m}{\Delta T_{m,0}}\right)^{4/3} \tag{7}$$

Where $U_0$ = Overall heat transfer coefficient of radiator at reference/design conditions (W/(m$^2$·°C));
$U$ = Overall heat transfer coefficient of radiator (W/(m$^2$·°C));
$A_0$ = Surface area of radiator at reference /design conditions (m$^2$);
$A$ = Surface area of radiator (m$^2$);
$\Delta T_{m,0}$ = Mean temperature difference at reference/design conditions (°C); and
$\Delta T_m$ = Mean temperature difference at other conditions (°C).

If the radiator surface area remains unchanged and this equation can be simplified to

$$\frac{Q_{rad}}{Q_{rad,0}} = \left(\frac{\Delta T_m}{\Delta T_{m,0}}\right)^{4/3} \tag{8}$$

The radiators may be regarded as counter-flow heat exchangers for which the mean temperature difference is determined by the equation

$$\Delta T_m = \frac{(T_s - T_r)}{ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} \tag{9}$$

Assuming steady state, the heat emission by the radiators is in equilibrium with the heat loss from the building. Furthermore it is assumed that the walls have no heat capacity; that is no heat is stored in the walls.

$$\frac{Q_{rad}}{Q_{rad,0}} = \frac{Q_{loss}}{Q_{loss,0}} \tag{10}$$

Combining equations (4), (8) and (9), a relationship can be found for the return temperature of the radiator. Here the return temperature, T<sub>r</sub>, can be obtained with iteration.

$$\left[\frac{\frac{T_s - T_r}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)}}{\frac{T_{s,0} - T_{r,0}}{ln\left(\frac{T_{s,0} - T_{i,0}}{T_{r,0} - T_{i,0}}\right)}}\right]^{4/3} = \left[\frac{T_i - T_o}{T_{i,0} - T_{o,0}}\right] \tag{11}$$

The building heat loss coefficient can be calculated directly from reference conditions

$$k_l = \frac{\dot{m}_0 c_p (T_{s,0} - T_{r,0})}{(T_{i,0} - T_{o,0})} \tag{12}$$

In Iceland, the most common geothermal radiator design is 80°C/40°C/-15°C/20°C (supply temp./return temp./outdoor temp./indoor temp.). Figure 6 illustrates how such radiator system functions with varied supply temperature. Given 80°C supply water the radiators would return 40°C water at -15°C outdoor temperature, as the reference/design condition indicates. If water is supplied to the radiator at lower temperature the radiator would return water at higher return temperature than at reference/design conditions. This yields lower ΔT through the radiator, resulting in poorer efficiency of the radiator and utilization of the geothermal water.

Figure 7 shows the mass flow ratio of the water through the radiator as a function of the outdoor temperature. The mass flow ratio expresses how much more water a radiator would need if run at other conditions than reference/design conditions. As an example, 80/40/-15/20 radiator with 65°C supply temperature would need 2.5 times more mass flow at -15°C outdoor temperature than if the radiator would be run at 80°C supply temperature. If the supply temperature would be much lower than 60°C, the radiator would most likely not be able to deliver the desirable heat to the building at -15°C, since at 60°C supply temperature the radiator would need almost 6 times more mass flow than at reference/design conditions.

It is interesting to see how the return temperature changes as the radiator size increases. Figure 8 illustrates this phenomena for various supply temperatures. If the raditator size increases by 40%, the radiator would return water at 34°C, if supplied with water at 70°C, and 39°C, if supplied with water at 60°C. This is is a clear gain as the utilization of the geothermal reservoir would be much better. Instead of cooling the geothermal water down to 53°C (if supply temperature is 60°C) it could be cooled down to 39°C, given that the radiator is sized properly.

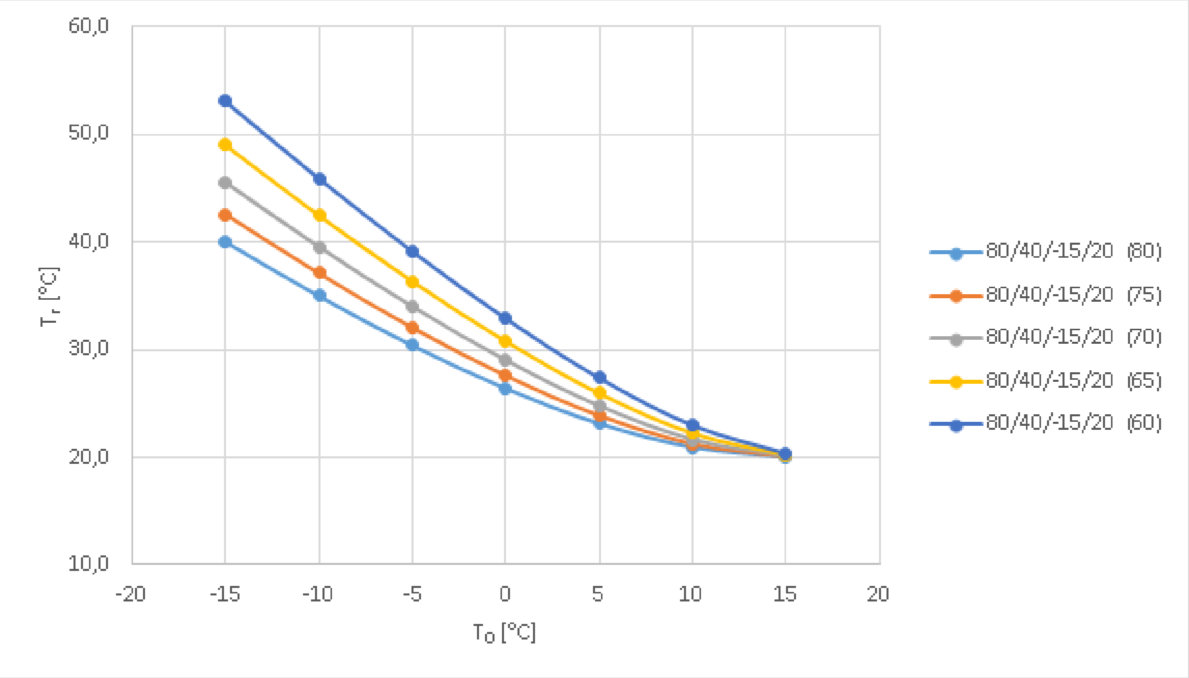

FIGURE 6: Return temperature for 80/40/-15/20 radiator design as a function of outdoor temperature for various supply temperatures (Ts)

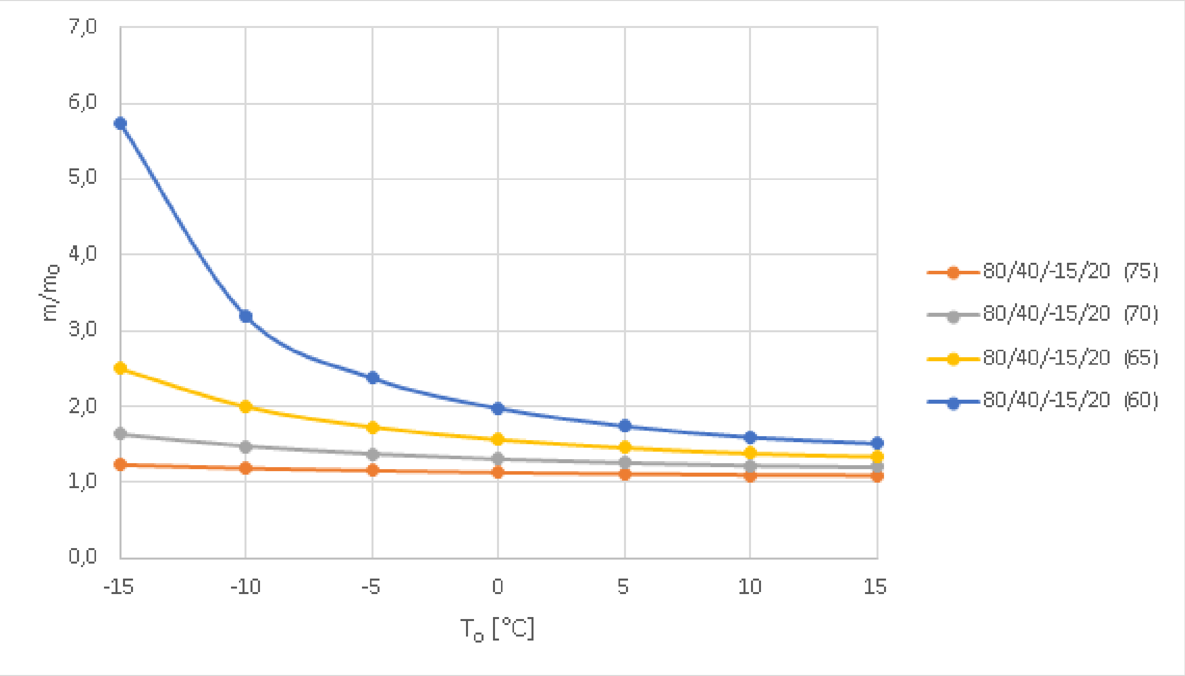

FIGURE 7: Mass flow ratio as a function of outdoor temperature for various supply temperatures, m0 is based on 80/40/-15/20 radiator design

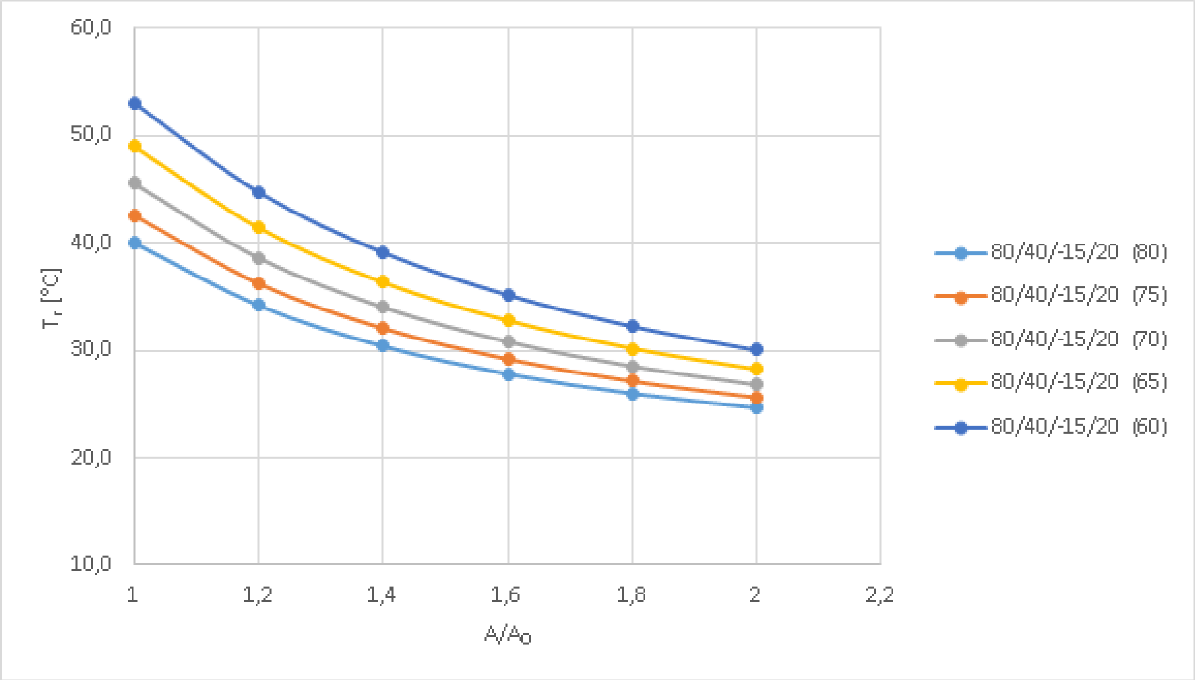

FIGURE 8: Return temperature as a function of area ratio at -15°C outdoor temperature and 20°C indoor temperature, $A_0$ is based on 80/40/-15/20 radiator design.

### 3.4 Floor heating systems

Floor heating systems are interesting for geothermal space heating. Such systems can be accommodated with district heating fluid at supply temperature ranging from 40-90°C. Floor heating systems are usually designed with a ΔT ranging from 5-15°C and it is common to have a return temperature from 25-35°C. Floor heating systems can be used alone or in combination with radiators to contribute to reducing further the return temperature.

## 4. DISTRICT HEATING SYSTEM PLANNING AND DESIGN

District heating end-users usually require energy for space heating and for heating of domestic hot water (DHW). There are two design approaches for the assessment of end-users' power and energy requirements.

The first approach, "microscopic", consists of detailed assessment of the peak demand of each potential end-user. This requires in-depth information of construction components of each building, existing or planned. Since it is extremely difficult and time consuming to compile information in such detail, the normal practice is to assess the overall heat demand of the community by means of key figures. This second approach, also called "macroscopic", is described below.

### 4.1 Weather data

Space heating loads depend mainly on the building characteristics and on the local weather data. Weather records are usually provided by 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.

What we aim at showing with a load duration curve is the number of days/hours per year that have an outdoor temperature lower than a given temperature. The area under this curve is proportional to the number of degree-days required for heating and gives a measure of the amount of energy required for space heating. Figure 9 shows an example of load duration curves for various locations.

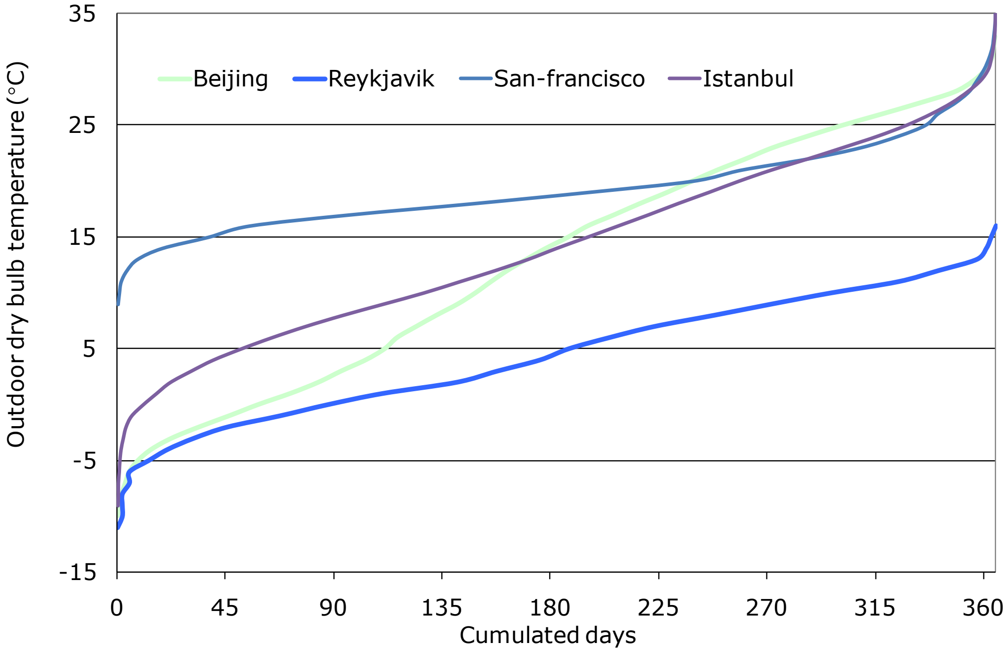

FIGURE 9: Temperature duration curve for various locations

The load duration curve is also used to indicate the heating period and the load factor, an important element of the geothermal district heating economics. Various considerations are taken into account when assessing the heat demand such as local habits and building standards. In western countries, it is quite safe to consider that buildings do not need heating when outdoor temperatures are above 18°C. On the basis of theses premises, space heating would be required in Beijing or in Istanbul about 200 days per year. In Iceland, where summer temperatures are seldom above 15°C, space heating is almost always in use.

On the other end of the load duration curve, severe cold waves are also carefully looked into. Severe cold waves are characterized by their rarity and by their intensity, i.e. much colder temperature than usual. The steep ends of the curves on the left side of figure 2 provide information on the intensity of this phenomenon. If the district heating was to be designed for the coldest weather recorded, it would be run at a partial load most of the time. Since investment costs are proportional to the installed power, installing a district heating system for the coldest weather recorded would not be viable. One of the design premises for district heating is that the indoor temperature might drop to a certain extend below design temperature during the coldest weather conditions. Actually this assumption is quite safe in the case of such systems, as has been shown in various district heating system's behavior studies.

Another phenomena that must be kept in mind is the heat stored in building walls and interiors that tends to dampen out the influence of the cold waves. This dampening effect can often increase the outdoor design temperature by 5-10°C, related to location and building standards.

### 4.2 Space heating and Domestic Hot Water (DHW) power and energy requirements

The assessment of power and energy requirements is based among other things on data from the local construction standards. With such information, it is possible to assess power requirements for a given type of building. In some cases, it might be necessary to classify buildings in the area considered for district heating according to their type, for instance single house or multiple store buildings. This first step provides key power figures, W/m$^2$ of indoor building area for instance, for different types of buildings.

In most cases, production of DHW in conjunction with geothermal district heating is possible and recommended (Figure 10). Daily domestic hot water needs are the needs for bathing, washing etc. It is practical to assess the amount of hot water, for instance 60°C, required daily for each user. Domestic hot water is either provided directly by the system or produced indirectly by the district heating system by heating cold water with heat exchanger at the end-users.

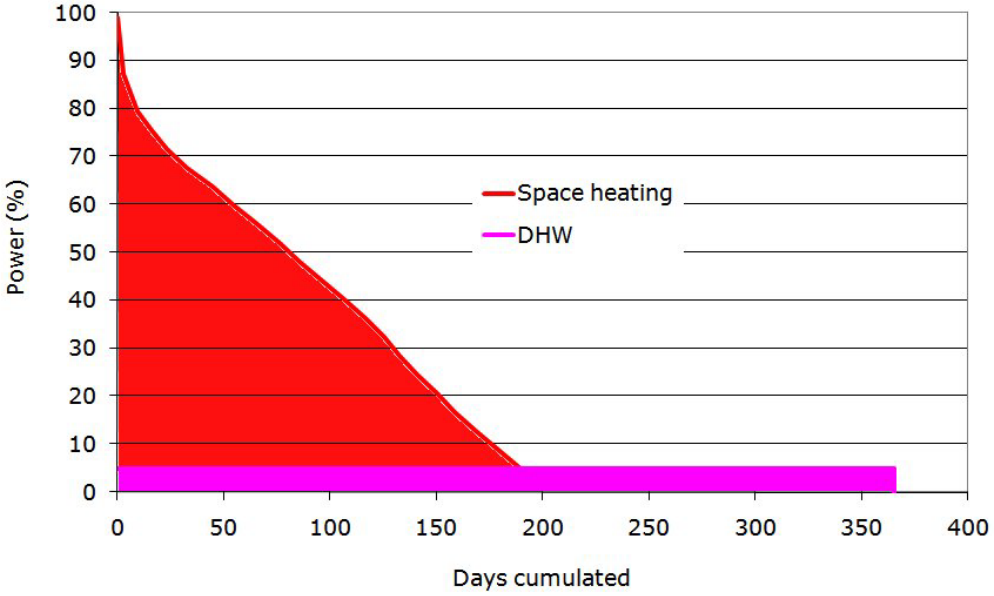

FIGURE 10: Typical load duration curve for space heating and domestic hot water

### 4.3 Power and energy requirements as seen from the heat central

When load duration curve and power requirements for given types of buildings are known, it is possible to assess the power and energy requirements as seen from the heat central.

### 4.4 Population and indoor floor area

Size and density of population are important criteria for the design phase. Because a district heating system is expected to be run over decades, one should not only look into the existing facilities to be connected to the system but also into the projected planning development, possibly for the coming 20-30 years.

### 4.5 Dimensioning the heat central

Although outdoor temperature is one of the major factor for space heating load, all buildings do not require peak power at the same time. Among the elements impacting on the power demand at a given time for a given location are the characteristics of each building envelope of each facility (inertia among other things), internal load, facility orientation and sun load. Also, empty buildings might have been set on spare mode and will require less energy. Formulas have been developed to take these facts into account for the design of a district heating system and a so-called simultaneity factor is generally used.

On top of that, the heat central needs to be able to cover the heat losses in the distribution system depending on the local conditions.

By combining the temperature duration curve and the peak power demand as seen from the heat central we obtain the so-called load duration curve. This curve enables to assess the total energy requirements for the system which is also an important element for the financial analysis because it indicates the energy that can be sold to the end users.

### 4.6 Geothermal energy production system and peaking facilities

Energy provided by the geothermal reservoir and produced at a peaking facility is the most common combination for a geothermal district heating. These two energy production systems are connected to the heat central where energy is transferred to the distribution system

Provided the geothermal reservoir can provide a sufficient amount of energy, sizing the geothermal production system is in fact a matter of finding the optimal share of peak power to be covered by an additional source of energy as regards to the investment and running costs. Drilling geothermal boreholes is rather expensive but their running costs are rather low (mainly pumping and maintenance costs) and it is generally possible to use them for the basic load, i.e. all year long. On the other hand running costs for peak boiler depend mainly on the additional energy prices and can turn out to be rather high.

Depending on the type of additional energy and on the local conditions (drilling costs among other things), a geothermal district heating system will be optimal from the economical point of view with an installed geothermal power ranging from 40 to 80% of the total peak power. Nevertheless, since geothermal energy is always used for the base load, the share of energy provided by the geothermal system can turn out to be rather high, from 70 to 90%, depending on the shape of the load duration curve. Figure 11 shows how the various sources of energy can combine.

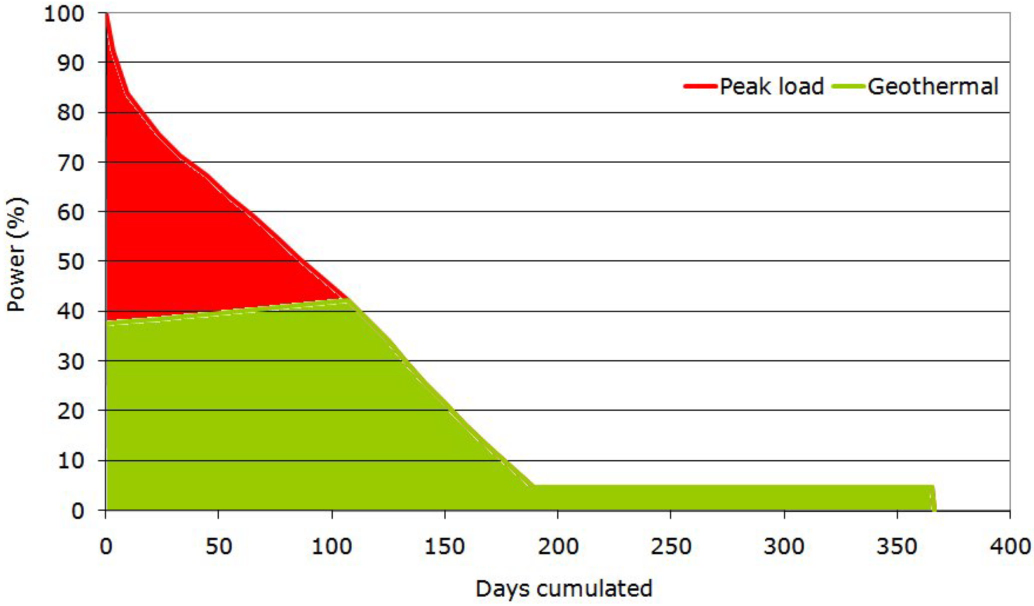

FIGURE 11: Load duration curve for a geothermal district heating system

Sometimes technical design considerations might not be sufficient in themselves to develop a viable geothermal district heating system. As a matter of fact, another important factor for the successful operation of a geothermal district heating system is the design of the metering and tariff systems.

## 5. METERING AND TARIFF DESIGN

Metering and tariff methods might have a significant impact of the users' energy usage and consumption pattern. It is the author's opinion that special emphasis should be put on the metering methods and design of the tariff system in a geothermal energy heating perspective, as these are a matter of concern for sustainable use of the geothermal resources and the success of the district heating projects.

A good metering method constitutes an incentive that encourages users to reduce energy squandering and energy use, preferably with low cost metering equipment. Poorer metering methods do not form these incentives at all, or with a significantly poorer focus.

Although the metering equipment used for measuring and charging purposes have to function with appropriate accuracy, the main concern when designing a metering and tariff system is to provide an appropriate incentive to use the geothermal resources in a sustainable manner.

Seen from the perspective of a geothermal district heating, good metering and charging methods are important to insure the success of such project. A good metering system provides an incentive to use the energy as sparingly as possible and to use the geothermal resources in a sustainable way. In the context of a geothermal district heating system, metering should:

1) Encourage energy saving behavior;
2) Encourage optimum energy extraction from the district heating water; and
3) Be put up to sell as much as possible, depending on the availability of the heating media.

Issues 1 and 2 are the main sought aims in cases where geothermal energy is extracted from a reservoir with limited potential and is used mainly for heating purposes. In district heating networks, users not only have to pay for their energy consumption, they also have to pay for salaries of staff, peak load energy, and the installation cost of the network. The cost of the heating utility is carried out to the users in form of billing. One has to keep in mind that competition with the heating utility exists, with or without another heating network in the ground. To minimize their energy bill, users could for instance improve the energy efficiency of their building or choose to purchase energy from another cheaper source.

Different metering methods should be used to suit each and one of the conditions above mentioned.

### 5.1 Structure of a typical charging method

A metering method is a combination of three types of fees:

- One time connection fee: It is a fee that an owner pays for connecting the house to the district heating grid. This fee is used to pay for parts of the installation cost of the heating utility. The remaining installation cost is paid by users with usage fees.
- Fixed annual fee: A fixed annual fee is nearly always used. This can be the only fee, or part of the fee depending on the charging method used. The fixed annual fee often pays for fixed maintenance costs of the heating network.
- Variable fee: A variable fee is used in many types of charging methods. This fee is often related to each users usage, for instance as a proportion of incoming flow or used energy.

The financial fundamental of a heating utility is to get fees to cover for its expenses. Finding a feasible ratio between the one time connection fee and the two types of annual fees is the first decision. When that has been done, a ratio of incomes between fixed and variable annual fees should be chosen carefully.

The metering methods mentioned in the following chapters do not consider the connection fee, but in all of them a ratio between a fixed and a variable annual fee is due consideration.

### 5.2 Using square meters ($m^2$) as a metering basis – an insufficient method

When using square meters, the heating area is the main basis for heating. This metering method does not take into account any of the variables of importance with respect to energy savings, i.e. $T_{in}$ ,$T_{out}$, mass flow or used heat (Q). The results when applying this method could be as follows:

Advantage:

- A simple way of metering which does not require any flow measuring or flow restriction equipment.

Inconvenient:

- Supervision and monitoring is poor as no measures are performed. The system even encourage users to announce incorrect heating area. Furthermore, no information is provided on the performance of the space heating systems.
- The method does not penalize excessive use of heat.
- The method does not support energy savings.
- When heating utility is providing heat to a network of houses, the user with the poorest heating system will complain until his apartment/facility is given enough heat. Other users might have an oversupply of heat and open windows for cooling at these times.

Any mitigation method to compensate for the negative impact of this metering method is rather unrealistic, as the parameter used is heated area. This method is seldom recommended as its impacts on using patterns are unclear.

### 5.3 Using flow meters as a metering basis – a rather good method

When using flow meters as a metering basis, the consumer is charged for his use of water according to the amount of water used (cubic meters or tons). This metering method is commonly used in Iceland and is presented in Figure 12. A sealed regulating valve might be used to limit the maximum flow into the system. The role of the sealed regulating valve is to prevent unbounded flow into the system. It can be regarded as a safety equipment, for instance, in case of accidental leaks.

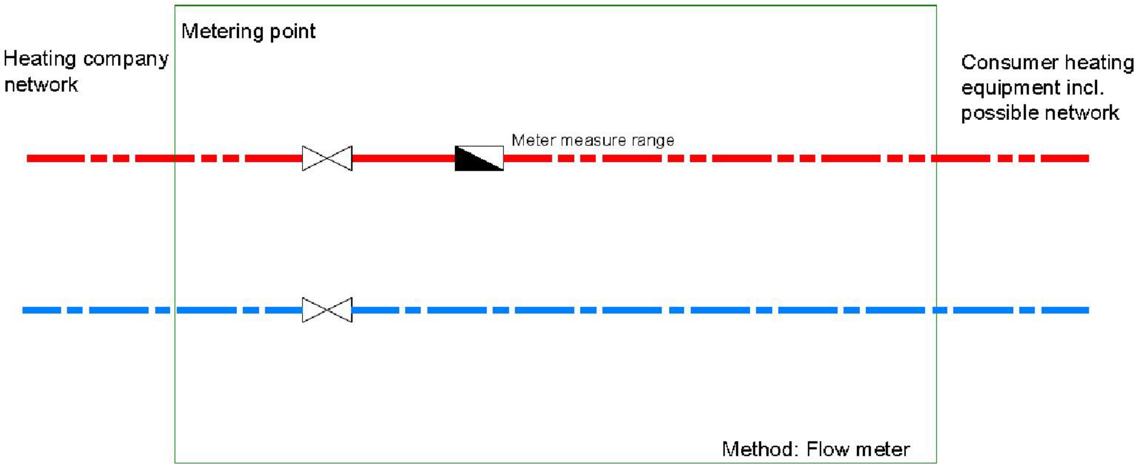

FIGURE 12: Measurement environment of flow meter charging

The method itself does not require a measure on $T_{in}$ or $T_{out}$ although such measurements are often performed on behalf of the user. The results of this metering method on the user could be the following:

Advantage:

- A rather simple and cheap way of metering that requires only flow measuring equipment.
- The method encourages high temperature drop and low flow and hence a good energy utilization of the geothermal resource.

Inconvenient:

- The method does not take into account the temperature of supply water, which can affect the behavior of the radiator system. This can be an issue as colder incoming water makes heating more difficult.

Mitigation:

- A potential mitigation of colder incoming water is to have some kind of compensation for lower incoming temperature. This could be applied to users farthest away from the heat central.
- If the user measures the temperature on his purchasing point, he will effectively check when the temperature goes down and complain to the heating utility.

Metering by flow meters is recommended when the heating utility is using a limited heat source. This method encourages energy savings and is rather applicable to serve as a basis for heat selling when utilizing limited low enthalpy heat sources. In practice, the use of heat will vary with outdoor temperature.

### 5.4 Using maximum flow as a metering basis – a limited method

Metering house heating by restricting the maximum allowable maximum flow is simple. Each owner negotiates the maximum quantity he can buy and is allowed to use up to that amount anytime. The sought amount is made available by the set up by a flow restrictor (often with a built in orifice), at the users' connection point as shown in Figure 13. This method can be useful when heating needs do not change a lot between seasons, as the maximum flow will stay nearly constant.

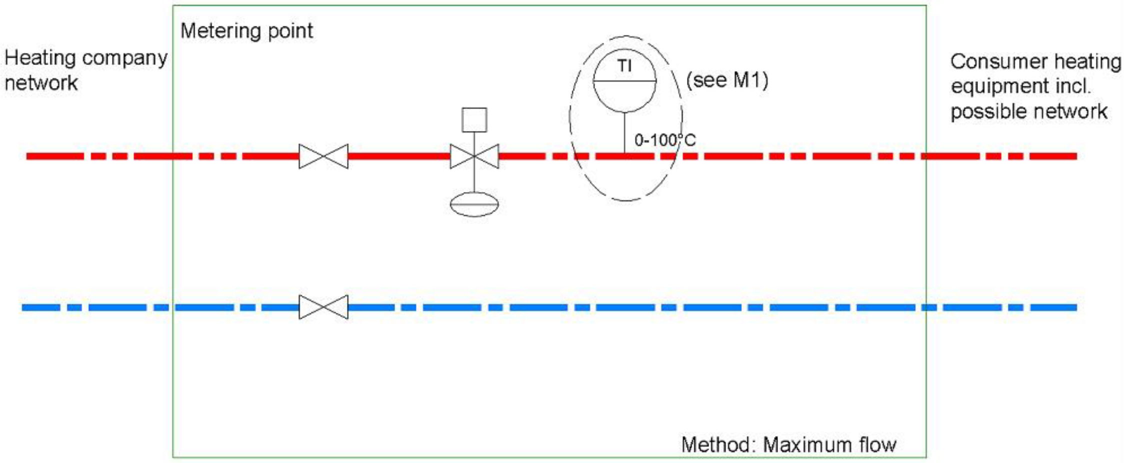

FIGURE 13: Measurement environment of maximum flow charging

Please note that the thermometer M1 is not necessary, but encouraged and mentioned as a possible mitigation method.

Advantage:

- Maximum flow is a simple metering method.
- The method may increase the users' awareness of their heat usage and potentially reduces the peak use as the maximum use is the decisive parameter for the charging amount.
- The heating utility does not have to concentrate as much on delivered temperature and cooling in district networks during summer is a less problem.
- The method tends to make the heat usage more uniform throughout the year.

Inconvenient:

- When the heating usage differs a lot during seasons, the maximum use is in line with the heating need at the coldest day. This means that after the coldest period there is no reason to use hot water sparingly. Thus, where heating loads are periodic, this charging method performs poorly, unless the heating media is in excess.
- This method tends to make the heat usage more uniform throughout the year.
- The method does not encourage energy savings.
- During winter time, but not at peak load, radiators or other heating equipment may be at full load, and temperature control during day is done by opening windows.
- The method does not take into account the temperature of incoming water, which can affect the behavior of the radiator system.
-

Mitigation:

- If the user measures the temperature on his purchasing point, he will effectively check if the incoming temperature goes down and has the possibility to complain to the heating utility.
- The tendency of making the heat usage more uniform throughout the year can either be positive or negative, depending on the heat source. A more uniform use is positive in a few cases: If the heat source is waste heat from a factory, or heat from a producer that has heat in excess, a uniform use might be positive. The same applies when using artesian flow from a natural spring from a natural constant energy source. However, the uniform use of heat over the year often has a negative impact when the source does not provide excessive heat.

Experience of this metering basis is that total annual energy usage is at least 30-40% more compared to situations where flow metering is being used. This method is therefore not recommended for low enthalpy heating utilities with limited water supply as its application will result in more use of water than necessary. On the other hand, when flow from a source is constant and in excess, as might occur with heat from a geothermal power plant, this method may be preferred.

### 5.5 Using energy meters as a basis for charging consumers – an unsatisfactory method

As shown in Figure 14, the use of energy meters is based on measurements of the flow and the supply and return temperatures ($T_{in}$ and $T_{out}$). In addition to this, the energy usage is calculated and accumulated in a computer or advanced meter.

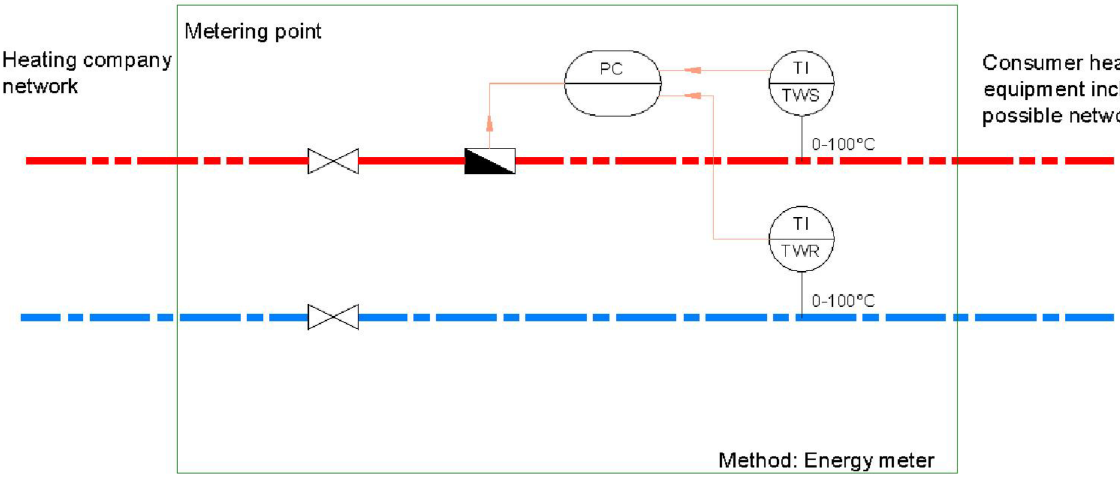

FIGURE 14: Measurement environment of energy meters

Advantage:

- This method measures the energy use exactly. The consequence of that is however not necessarily positive, as heat does not have the same properties as electricity (see chapter on energy availability hereafter).

Inconvenient:

- This kind of metering does not pay any attention to the return temperature or the consumers' temperature usage.
- A small temperature drop in users' heating equipment goes un-penalized. When used wrongly, users may put up extremely small house heating equipment which require large pipes and pumps which are expensive for the heating utility.
- A high return temperature is negative in geothermal heating and will result in wasting energy.

Energy metering is an improvement when the heating utility is based on coal or natural gas burning only, as these methods are less dependent on a low return temperature. The method gives some idea of various buildings' energy usage, and can increase awareness of excessive use in this manner.

### 5.6 Future meter, energy meter with calculated return temperature

An energy meter with calculated (or fixed) return temperature is a theoretically correct meter, where cooling in district networks may be a problem (Figure 15). This meter charges users equally for the energy that they are provided with from the supply water. The meter uses mass flow and supply temperature as necessary incoming parameters. Outside temperature can be used to calculate the expected return temperature.

This meter does not exist on commercial markets yet, but it would be a quite good meter, especially in geothermal heating networks and would contribute to an equal treatment of customers in rural areas. The meter would typically calculate the energy according to the following formulas:

$$P = F + \dot{m} \cdot (T_s - T_{out*}) \tag{13}$$

where

$$T_{out*} = \begin{cases} f(T_s, T_{outdoors}) \text{ or} \\ \text{constant} \end{cases} \tag{14}$$

and $P$ = Fee for heat;
$F$ = Fixed annual rate;
$T_s$ = Supply temperature;
$T_{out*}$ = Acceptable return heat, depending on heating systems;
$f(T_s, T_{outdoor})$ = Return heat according to radiator formulas; and
$constant$ = Constant of acceptable return temperature.

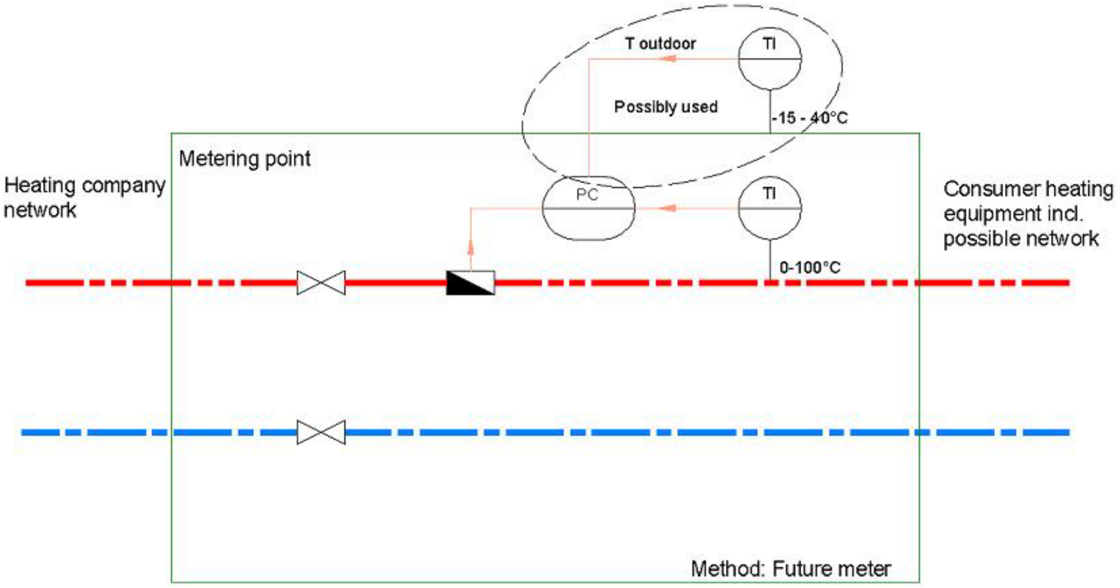

FIGURE 15: Measurement environment of future energy meters

Advantage:

- This method measures use of incoming water temperature with respect to energy availability.
- The meter encourages a good utilization of the geothermal resource.

Inconvenient

- This kind of meter is not a commercial product yet. Ideas of this kind of metering have however been set forth in the recent years.
- Such meters could be difficult for users to understand for the end-users.

This meter would serve well in rural areas, but in dense areas direct flow metering would suit better, as cooling in district networks is not large.

### 5.7 Comparison

Several energy metering methods exist as shown in Table 3. For instance, another possibility is to have a flow meter and an energy meter, and combine the cost in quite complicated ways. Other methods could be to combine square meters and other methods and so forth.

It is strongly emphasized that simplicity is important in this manner, especially at first stages of exploitation.

TABLE 3: Metering methods

| **Metering method** | **Statement** | **Mitigation possibilities** | **Rank when used in geothermal heating networks** |
|---|---|---|---|
| **Area, m$^2$** | Insufficient method | None | 5 |
| **Flow meter** | Rather good method | Many | 2 |
| **Maximum flow** | Limited method | A few | 3 |
| **Energy meter** | Unsatisfactory method | Very few | 4 |
| **Future energy meter** | Future method | Works best in rural heating areas. | 1 |

Choosing an applicable metering method is extremely important to reach the goal of gaining an economical and practical geothermal district heating utility.

## 6. CONCLUSION

The papers shows that various data are required for a preliminary assessment of a geothermal district heating system. Also the conception of geothermal district heating systems slightly differs that that of conventional district heating systems.

To conclude this paper, the authors would like to emphasize two important elements for the achievement of a successful project:

- Metering and tariff methods; and
- Design criteria for space-heating at end-users.

A metering method of good quality is expected to serve as an active boundary for the conditions in situ with pricing at competitive levels so that all can afford to purchase heat, and do their best to adjust to preferable heating conditions.

In this perspective, space heating at the end-users should be designed for return temperature as low as possible, with 35°C being an ideal and reasonably feasible temperature. In the case of existing buildings, the connection to a geothermal district heating often requires upgrading of the space-heating system to optimize extraction of energy from the district heating water. This element has to be considered from the beginning when developing such project.

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