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Comparison of the Heat Consumption of Icelandic and Chinese District Heating Systems

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ABSTRACT

Western district heating systems usually supply heat to clients with radiator building heating systems, which requires a supply temperature to the building above 60°C. They supply heat as well for production of tap water in the buildings. The tap water production requires heat at minimum least 60°C due to the danger of growth of the Legionella bacteria in the tap water system. During the summertime the only load on the systems is the heat needed for the tap water production, and the heat losses to the soil in the distribution system account for a large part of the heat supplied to the system.

The Chinese district heating systems do not supply heat for tap water production. It is most common to produce tap water by combustion of natural gas in small tap water heaters in each apartment. Most commonly of the district heating systems supply heat to buildings heated by floor heating. This results in that the Chinese systems can operate with as low building supply temperature as 45-50°C. In addition to that the systems are shut down during the summertime, so there is no distribution network heat loss at all during the non-heating season.

A simulation model is made to simulate the performance of these two systems for a typical year. Data for a typical year from the "International Weather for Energy Calculations (IWEC)" is used for a few locations in China and Western Europe.

The system consumption of geothermal water, heat and electricity gas is calculated.

1. INTRODUCTION

The purpose of a district heating system is to supply heat to heat a group of buildings from a central heat source in an economical and environmentally friendly way. Western district heating systems supply usually as well heat to the production of hot tap water for the inhabitants.

Macroscopic modes have traditionally been used for design and analysis of Icelandic district heating systems. The consuming buildings in the network are then all lumped together into a single reference building. The pipe network is modeled in the same way as a single model block, ignoring the spatial distribution and variability of the pipe network. The methodology is described in Karlsson (1982) and Valdimarsson (1993).

A macroscopic model is made to study the heat and water consumption of a Chinese and an Icelandic geothermal district heating system. The systems modelled are hypothetical, and normalization based on the floor area of the heated building is used as a basis for the normalization.

A fuel for a geothermal district heating system is water from the reservoir. The yearly water usage from the reservoir is used as a main performance indicator.

2. SYSTEM DESCRIPTION

A macroscopic model lumps all consumers into a single consumption model block. The pipe network for supply and return water from the consumers is as well lumped into blocks. The legend for the building blocks of the models is shown on Figure 1.

An "ideal control" and "steady state" is assumed for the buildings. This means that the flow to the radiators or the floor heating cells is exactly the flow which is needed to supply the heat lost from the building to the environment.

The building control system is not only composed of the control equipment, because the inhabitants are as well a part of this control system. The quality of the control may be low, so the inhabitant may open a window to reduce too high indoor temperature. This is of course wasteful control, and a model which describes this wasteful real-life control of the must be based on measurements within the building or buildings.

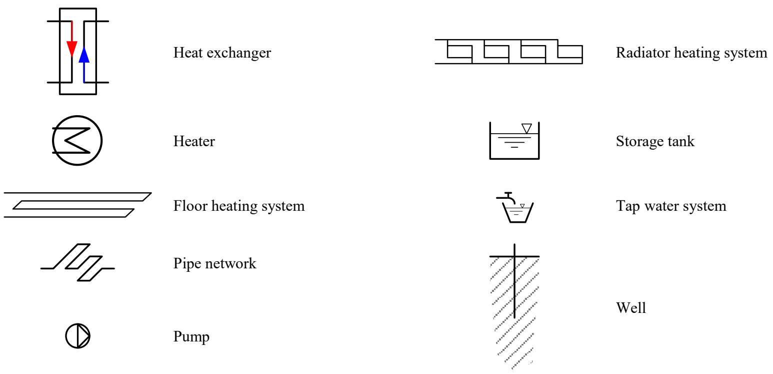

Figure 1: Model blocks – legend

2.1 Icelandic district heating systems

Most of the Icelandic district heating systems are single line systems, so there is only a supply network and the used district heating water is disposed of at the consumer building. The water is of high quality, so there are no environmental concerns by this disposal, and the supply has not been limited, so the investment in a return pipe network has not been justified.

The return water has value in some cases, and there a double line system is installed. In this paper a double system is chosen as a reference for the Icelandic systems. The source is assumed to be a geothermal low temperature field.

The water is of high quality and is used directly as tap water. The buildings are heated by radiators, which require higher supply temperature than a floor heating system.

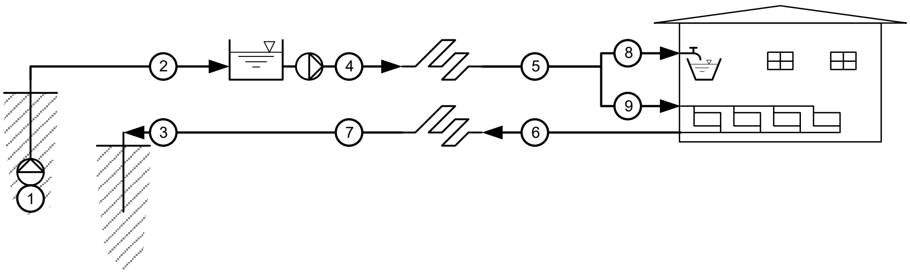

Figure 2: System diagram of a typical Icelandic district heating system.

The geothermal water is in the reservoir at station 1. It is then pumped towards a storage tank, which is used to even out diurnal load variations and in some cases act as a short-term peak load source. The distribution network main pumps pump the water into the supply network at station 4. The water enters the consumer building at station 5. A part of the water is used as tap water in station 8. Water enters the radiator heating system in station 9. The return water from the radiators enters the return pipe network in station 6. Finally, the water is reinjected or disposed of by other means in station 3. Station 7 is "dummy" to keep commonality with the station numbering of the Chinese system.

2.2 Chinese district heating systems

The water quality in most of the Chinese systems advisable to keep the handling of the water on the surface to a minimum, mainly because of scaling issues. The Chinese systems do not supply any heat for the tap water, so the systems are shut down outside of the heating season. Tap water is supplied by heating drinking water in the consumer building, usually by natural gas or electricity.

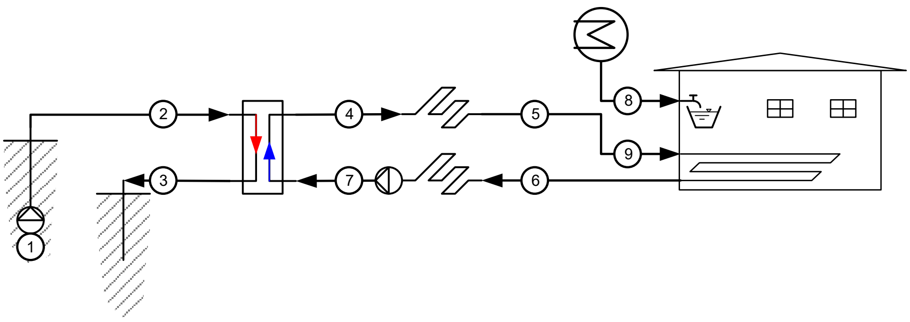

Figure 3: System diagram of a typical Chinese district heating system.

The geothermal water is in the reservoir at station 1. It is then pumped towards a heat exchanger in station 2, where heat is transferred to the secondary system loop. The cooled geothermal water is then re-injected in station 3. The heated secondary loop water enters the supply piping network in station 4. The secondary loop water enters the consumer building in station 5 and goes directly to the floor heating cells. Station 9 is a "dummy" station to keep commonality with the station numbering of the Icelandic system. The return water from the floor heating cells leaves the consumer building and enters the return pipe network in station 6. The secondary loop circulation pumps are at the outlet of the return pipe network at the heating central and pump the secondary loop water into the secondary side of the heat exchanger in station 7. Heated drinking water enters the building tap water system in station 8, but it is not connected to the district heating system. Note that there are no heat exchangers connecting the building to the district heating network.

3. SYSTEM MODEL

3.1 Weather data

International Weather for Energy Calculations (IWEC) is used for the calculations, see ASHRAE (2001). The IWEC are the result of ASHRAE Research Project 1015 by Numerical Logics and Bodycote Materials Testing Canada for ASHRAE Technical Committee 4.2 Weather Information. The IWEC data files are 'typical' weather files suitable for use with building energy simulation programs for 227 locations outside the USA and Canada. The files are derived from up to 18 years (1982-1999 for most stations) of DATSAV3 hourly weather data originally archived at the U. S. National Climatic Data Center.

The dry bulb air temperature is the only weather parameter used in the calculations. The influence of sunshine, wind and rain is stochastic and is secondary to the dry bulb air temperature. The steady state approach used here will even this stochastic influence out, so that the error caused by this simplification is not believed to be large.

The IWEC dry bulb air temperatures for Beijing, China and Reykjavik, Iceland are shown on Figure 4.

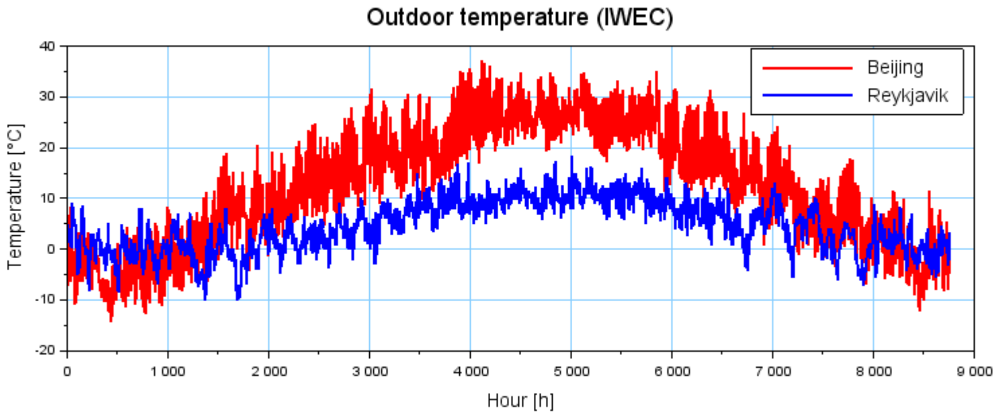

Figure 4: Outdoor dry bulb temperature (IWEC) for Beijing and Reykjavik.

3.2 Duration curves

The duration curve is commonly used in electric power generation for load analysis and in hydrology for flow analysis. A point *x,y* on a load/flow duration curve states that the load/flow will be equal or greater than the load/flow *y* for *x* hours per year.

The duration curve has the good property that having the *y*-axis as load in kW and the *x*-axis in hours, then the integral will have the dimension of energy in kWh.

The heating load is inversely proportional with the outdoor temperature. Therefore a point *x,y* on a duration curve for the outdoor temperature will state that the outdoor temperature is less than or equal to *y* for *x* hours per year.

A duration curve for the outdoor air temperature is shown on Figure 5.

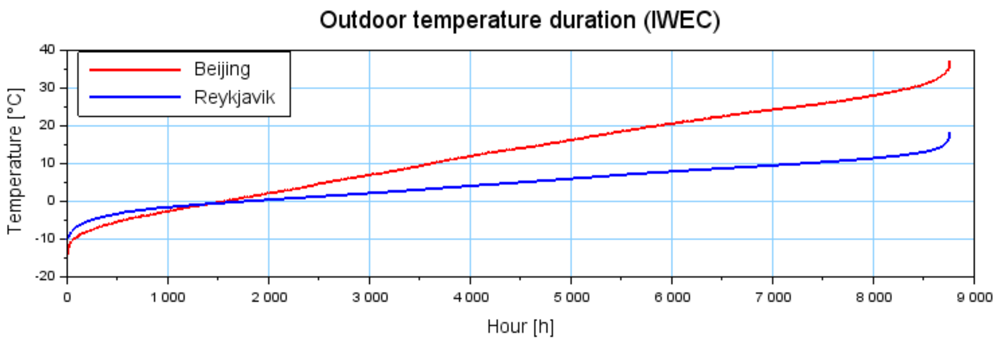

Figure 5: Outdoor dry bulb temperature duration (IWEC) for Beijing and Reykjavik.

4. THE CALCULATION MODEL

A reference condition is selected for the system. The system state for any condition is then calculated relative to the reference condition. The necessary physical parameters for the system are then estimated at the reference condition. An index *0* is used to denote the reference condition. The buildings are modeled by lumping all the buildings into a single equivalent building.

The building heat loss is calculated by:

$$\dot{Q}_{loss} = \dot{Q}_{loss,0} \frac{T_i - T_o}{T_{i,0} - T_{o,0}} \tag{1}$$

where $\dot{Q}_{loss}$ is the building heat loss, T_i is the indoor temperature T_o is the outdoor air temperature. Index *0* refers to the reference condition.

Valdimarsson (1993) defines a pipe transmission effectiveness for a buried pipe as:

$$\tau = \frac{T_{outlet} - T_{soil}}{T_{inlet} - T_{soil}} \tag{2}$$

where τ is the transmission effectiveness, T_{inlet} is the temperature of the inflow liquid, T_{outlet} is the temperature of the outflow liquid and T_{soil} is the temperature of the undisturbed soil. The pipe network is modeled by lumping the whole network into a single equivalent distribution pipe.

Bøhm (1988) states that the pipe network losses are calculated by assuming that all the heat loss from the network is to the "undisturbed" soil at the same depth as the pipe The heat is flowing from the pipes through the soil to the ground surface and from there to the ambient air, but the heat capacity of the soil on this heat flow path is very large, evening out the air temperature variations. The heat flow resistance from the pipe to the surface is also mostly in the pipe insulation. This method is used here.

The heat transfer from the pipes to the undisturbed constant temperature ground is then the same as in a boiler, where the heat is transferred from a finite heat capacity stream to a heat sink with constant temperature and thus infinite heat capacity. The transmission effectiveness can now be calculated using these assumptions for a known refence condition and a known mass flow as:

$$\tau = \tau_0^{\frac{\dot{m}_0}{\dot{m}}} \tag{3}$$

where $\dot{m}$ is the mass flow in the pipe. Index *0* refers to the reference condition.

Karlsson (1982) and Valdimarsson (1993) have used a logarithmic mean temperature method to calculate the heat transfer from the radiators to the building, as presented in the presently valid standard DIN4703-3 (2000). This method is used in this work.

Present standard for radiator heat duty test methods and rating, DIN EN 442-2 (2015) uses an arithmetic overtemperature instead of the logarithmic temperature difference method, which will overestimate the heat duty at low water flow and overtemperature. The reason for this is that when the water flow through the radiator is small, then the temperature of the water falls abruptly close to the inflow and most of the radiator surface is at temperature very close to the indoor air temperature. The overtemperature method assumes on the other hand that the temperature falls linearly from the inflow towards the outflow of the radiator. This was studied and verified numerically by Gretarsson et al (1991).

The logarithmic temperature difference between a radiator or floor heating cell and the indoor air is defined as:

$$\Delta T_{m,radiator} = \Delta T_{m,floor} = \frac{T_s - T_r}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} \tag{4}$$

where $\Delta T_{m,radiator}$ is the logarithmic temperature difference, T_s is the water supply temperature to the radiator, T_r is the water return temperature from the radiator and T_i is the indoor air temperature. The radiator heat duty is now calculated as:

$$\dot{Q}_{radiator} = \dot{Q}_{radiator,0} \left(\frac{\Delta T_m}{\Delta T_{m,0}}\right)^n \tag{5}$$

where $\dot{Q}_{radiator}$ is the radiator heat duty and n is the radiator exponent, usually taken as 4/3. Index 0 refers to the reference condition.

The heat duty of floor heating can be assumed to be proportional to the logarithmic temperature difference between the water in the floor heating call and the indoor air. The floor heating cell heat duty is now calculated as:

$$\dot{Q}_{floor} \quad \dot{Q}_{floor,0} \quad m \qquad (6)$$

where $\dot{Q}_{floor}$ is the floor heating cell heat duty. Index 0 refers to the reference condition.

5. PARAMETERS ASSUMED FOR THE SYSTEM

The parameters which have been assumed for the calculation are shown in Table 1.

Table 1: Parameters assumed for the calculation model

	Iceland	China	
Temperature of undisturbed soil	4	10	[°C]
Reference outdoor temperature	-15	-10	[°C]
Building reference supply temperature	75	45	[°C]
Building reference return temperature	35	35	[°C]
Assumed tap water temperature	60	60	[°C]
Reference transmission effectiveness	95%	95%	[%]
Reference heat load per square meter floor area	40	40	[W/m^2]
Floor area per capita	100	50	[m^2/capita]
Tap water consumption per day and capita	70	50	[kg/capita/day]
Number of inhabitants	100 000	100 000	[capita]
Geothermal source temperature	80	80	[°C]
Network supply temperature	80	50	[°C]
Indoor temperature	20	20	[°C]
Heat exchanger reference pinch	N/A	3	

It is assumed that the geothermal source temperature and the network supply temperature is constant throughout the year. The tap water temperature is assumed to be constant, and the value is selected as 60 °C due to the danger of growth of the bacteria "Legionella" in the tap water system. Most countries will demand some mechanism to ensure this minimum tap water temperature, see WHO (2007).

The Icelandic systems do not have any control of the tap water temperature. The network water has sufficient quality to be used directly as tap water. If the network cooling is large and the network water temperature is low, then the consumer will let the water flow until the tap water temperature has risen to an acceptable level. The common Icelander will feel the temperature simply by letting the tap water flow on her/his hands until sufficiently hot. The flow is called "Bypass flow" here. It is likely that the consumer will be satisfied with somewhat lower temperature than 60°C, keeping in mind that water with temperature 45 °C or higher will cause pain on the hands.

The indoor temperature is taken as a "zero" temperature for all heat flow calculations. It is also assumed that the cold drinking water is at the indoor temperature.

6. RESULTS

6.1 Icelandic district heating system

The temperature duration curves for the Icelandic system are shown on Figure 6. A reference is made to the numbered stations in Figure 2.

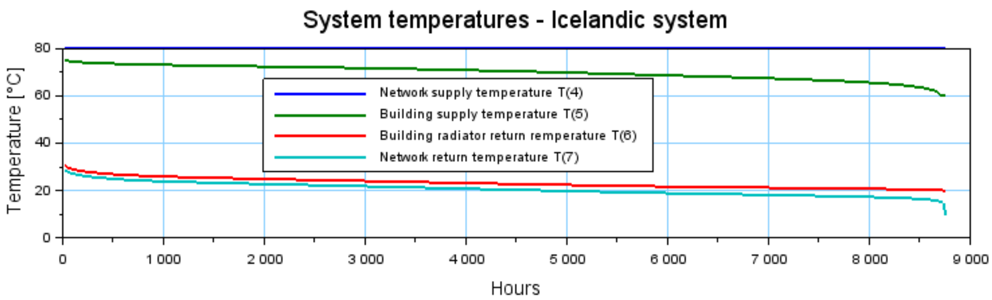

Figure 6: Temperature duration curves for the Icelandic system

The abrupt fall in the network return temperature as the heat load approaches zero shows that the steady state network loss model is not correct for the return network at low network flow. The model used is not considering the heat flow from the network losses of the supply pipes, as well as the dynamics of the heated soil around the pipes is ignored.

The mass flow duration curves are shown on Figure 7.

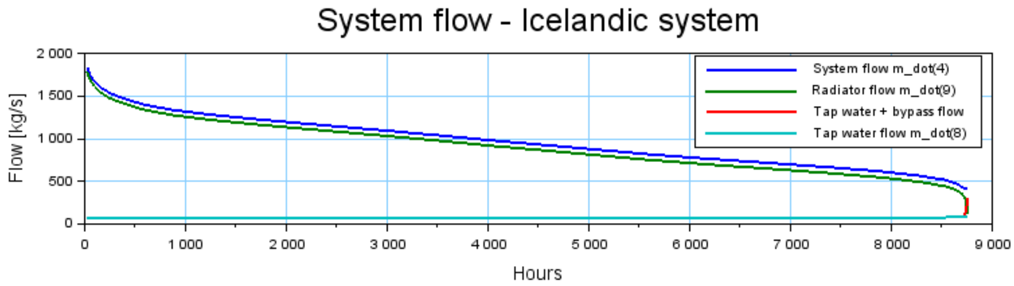

Figure 7: Mass flow duration curves for the Icelandic system

The tap water bypass flow is only present on two of the hottest days. The bypass flow approaches 225 kg/s for outdoor temperature at or above 20°C (no heating load). This is to compare with tap water flow of 58 kg/s on the coldest days, when the building inlet temperature is highest and therefore the consumed network water is at the lowest value. Running the Icelandic system for only tap water production will cause waste bypass flow which is two to three times larger that the consumed tap water flow!

The heat flow duration curves are shown on Figure 8.

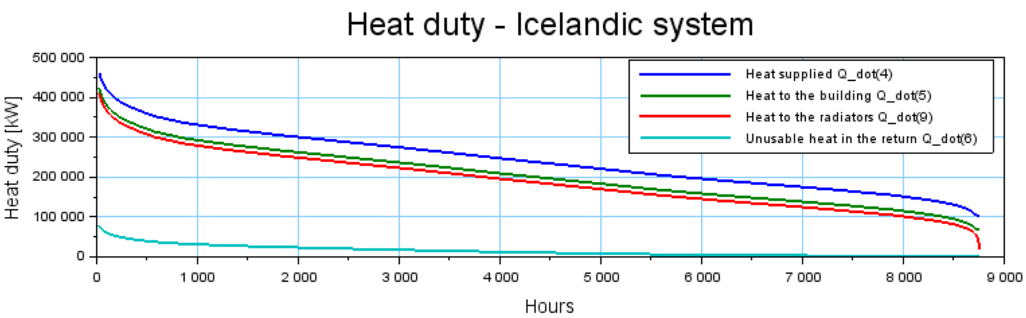

Figure 8: Heat flow duration curves for the Icelandic system

6.2 Chinese district heating system

Presently the Chinese district heating systems are not operated for outdoor temperature higher than 5 °C. This is an operational time of around 2 500 hours, as can be seen on Figure 5.

A flow control is assumed here. Some of the systems are only controlled by the supply temperature from the heating central, which is wasteful control. It was more realistic to use an "ideal control concept in the same way as has been done when modelling the Icelandic system.

The temperature duration curves for the Chinese system are shown on Figure 9. A reference is made to the numbered stations in Figure 3. Note that the temperatures are lower than 60 °C, which is possible because there is no connection between the tap water and the district heating water.

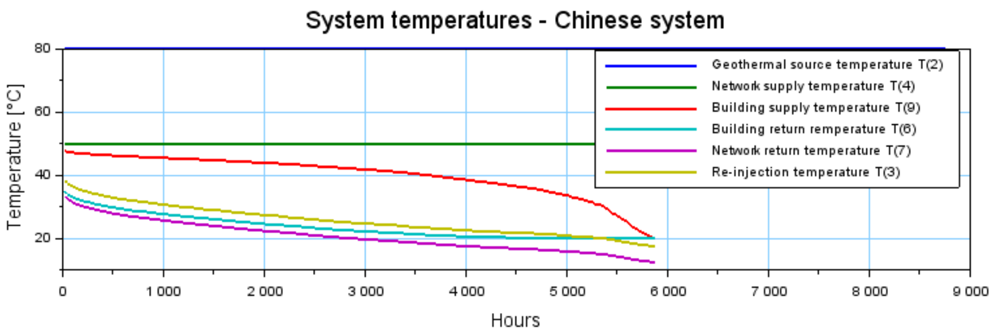

Figure 9: Temperature duration curves for the Chinese system

The mass flow duration curves are shown on Figure 10.

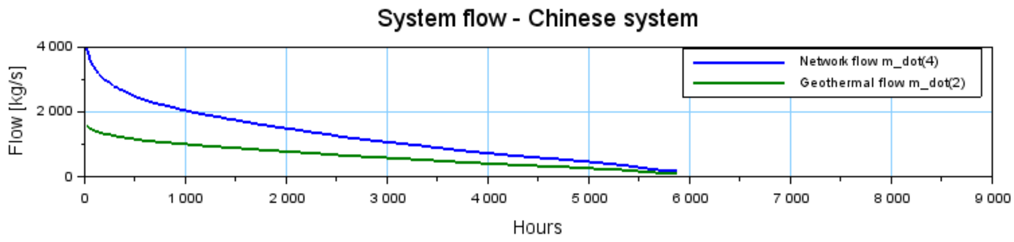

Figure 10: Mass flow duration curves for the Chinese system

The tap water is taken from the cold drinking water and heated by electricity up to the required 60 °C. The calculated tap water flow is 58 kg/s and the heater power is 9.7 MW, constant for all the year.

The heat flow duration curves are shown on Figure 11.

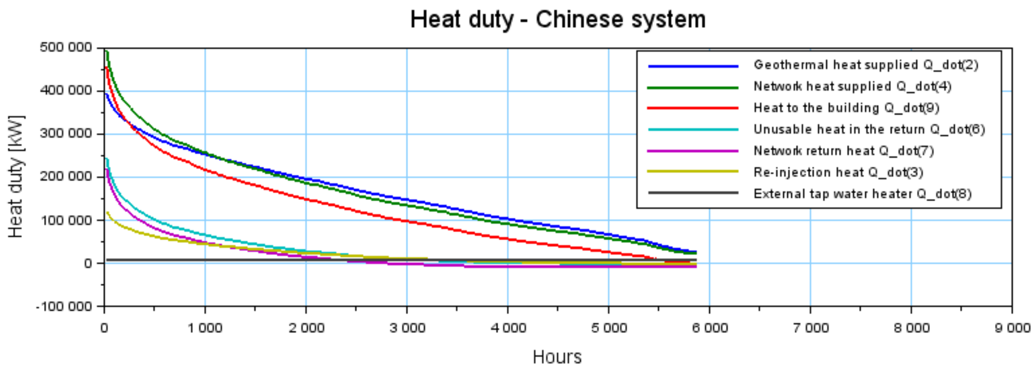

Figure 11: Heat flow duration curves for the Chinese system

7. PERFORMANCE

The main operating figures for the reference year are shown in Table 2.

Table 2: Yearly operating figures

	Iceland	China	
Total volume of geothermal water used	30 418 238	13 513 005	[m^3]
Thereof for tap water	2 056 563		[m^3]
Cold water used for tap water	0	1 825 000	[m^3]
Electric heating power for tap water	0	9 689	[kW]
Electric heating energy from tap water		84 882	[MWh]
Reference outdoor temperature	-15	-10	[°C]
Degree days based on 17 °C	4 539	2 650	[DD]

The water consumption excluding tap water is around 28 million cubic meters. in the Icelandic system.

The building area is double in the Chinese system as compared to the Icelandic system, and the reference outdoor temperature is -10 °C compared to -15 °C in the Icelandic system. Taking that into account the Chinese water consumption compared to the Icelandic system is 13.5 * 2 * 35/30 = 31 million cubic meters. It is obvious taking the large difference in degree days that the specific consumption in the Chinese system is considerably higher.

One explanation is that the return network loss does not matter in the Icelandic system, because the return water is simply disposed of, usually in the building. In the Chinese system on the other hand geothermal water is used to re-heat the return water to the heating central supply temperature.

8. CONCLUSION

The Icelandic systems seem to have lower consumption of geothermal water for heating. One of the explanations is that the Chinese system must heat the network return water, whereas this is not the case in the Icelandic systems. The Chinese systems are shut down for a large part of the year when no heating is needed. An operation only in order to supply tap water during this period would lead to heavy heat losses to the ground as well as high bypass flow to keep the building supply temperature above the “Legionella” limit.

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