QUALITY INDICATORS FOR DISTRICT HEATING NETWORKS

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ABSTRACT

District heating networks are very common energy systems all over the world but only few studies have been carried out to assess their performances through quality indicators. These indicators express district heating performances through different points of view. Four ones are developed in this study: energy sources, efficiencies, heat delivering equipments characteristics and environmental efficiency as a sum up.

First, the only energy indicator generally used is the primary energy factor (PEF), which quantifies the primary energy use of a device. However it does not give a complete insight of the whole energy use of district heating networks. Two other parameters have to be stated for this purpose: primary energy efficiency and the energy share.

Second, district heating efficiencies are generally not been taken into account unless sometimes the only amount of heat losses. A first indicator is defined to quantify networks heat losses relatively to the amount of heat delivered to customers. To take heat plant efficiencies into account, a more global indicator is defined. Its definition is close to a seasonal efficiency and it permits comparisons with other heating systems.

Third, indicators have been defined for heat plants equipments. Their aim is to permit stakeholders to check networks management of district heating companies. Two indicators are defined: one measures subscripted power relatively to network length and the other one represents the fictitious number of plants working hours while maximum plants power was delivered all the year.

Finally, environmental efficiency is stated. This analysis can include different aspects: green house gas emissions, water use and other pollutants emissions. For both design and management of district heating networks, an indicator representing CO2 emissions appears to be the most suitable one. Expressed relatively to delivered energy, it can be seen as a sum up of previous indicators because result of bad performances increases these emissions.

In this paper, these eight indicators are defined and their use is highlighted by a comparison of four different Finnish district heating networks.

INTRODUCTION

Although the district heating networks have been used as dwellings heating systems for millions of people in the world for many years, there is no method to optimize their design. However, they induce consequent investments and are not common at all in some European countries, like Belgium. Moreover, this energy medium is once again in the focus of European engineers and stakeholders. This upsurge in Europe is partly due to the objectives of the 3x20 [1] because District heating networks represent a great opportunity to carry out these objectives for large building stocks because they allow a wide range of energy sources for buildings heating including various renewable energy sources. These sources can be geothermal energy [2], Combined Heat and Power Plants [3], industrial waste heat [4], biomass [5], etc.

Only few studies have been carried out to assess heating district networks performances through quality indicators. First, a project lead by Euroheat&Power and finished in 2006 proposed a performance assessment of a district heating network based on only one parameter that was the primary energy factor (PEF) [6]. In 2007, the European norm CEN [7] proposed to use this parameter to manage a district heating or its design. But this indicator does not give a complete insight of the whole energy use of district heating networks.

Other quality parameters have been proposed to assess the performances of a district heating network by the French associations IGD and AMF [8]. They proposed 23 parameters that are important issues for existing networks but a lot of them cannot be stated at the design stage. Moreover, the only energy indicator used in this method is also the primary energy factor. van Lier [9] has developed a methodology related to a specific district heating, based on six indicators: heat loss, water replenishment, avoided CO_2 emissions, unplanned repairs, networks degradation and off-time replacement. These indicators have been developed to improve the management of old district heating networks and not to help investment decisions in new or old networks. Moreover, they neglect the energy point of view.

This paper will define eight key performance indicators for the environmental and technical design optimization of heating district networks. Then, the use of these energy indicators will be highlighted by a comparison between four Finnish cities.

DEFINITION OF QUALITY INDICATORS

The purpose of the indicators developed in this paper is to give a very complete overview of a district heating network for decision makers, project engineers, etc...

The primary energy factor, PEF

The first indicator, which is widely used, is the **primary energy factor** [6, 7]. It quantifies the primary energy use of a district heating network. Its definition is given by equation (1).

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{p,j} + E_{aux} \cdot f_{p,el} - E_{CHP} \cdot f_{p,el}}{E_{del}} \tag{1}$$

where E_j is the amount of the jth primary energy consumed by the network, E_{aux} is the sum of auxiliary and pumping electric consumption, E_{CHP} is the amount of electricity provided by the combined heat and power plant (CHP) if any is installed, $f_{p,j}$ is the primary energy factor related to an energy source, $f_{p,el}$ is the primary energy factor for the power plants and E_{del} is the amount of energy delivered to the consumers.

This is a major factor allowing people to compare in an efficient manner two heating technologies e.g. district heating network and conventional boiler.

The relative importance of losses, RiL

Other important information is the amount of heat loss consumed by the network. These energies are compared to heat delivered to the consumers as shown in equation (2). Electricity from CHP plants is not considered.

$$RiL = \frac{E_{loss} + E_{aux}}{E_{del}} \tag{2}$$

Where E_{loss} is the amount of energy lost in the district heating e.g. thermal loss through pipes, water replenishment, etc ... It can be stated by measuring energy leaving the heat plant and subtracting the sum of the energy at the customers’ substations.

The primary energy efficiency

As *Ril* does not take into account electricity delivered to the power grid by CHP plants, a third parameter is set. It compares all the net delivered energy (e.g. thermal to the district heating network and electric to the power grid) to the primary energy use and is given in equation (3). Delivered energies are thus no more weighted and electric production does not reduce primary energy consumption (as it does in *PEF*).

$$\varepsilon_{DH} = \frac{E_{del} + E_{CHP} - E_{aux}}{\sum_j E_j \cdot f_{p,j}} \tag{3}$$

The district heating global efficiency

Another parameter is defined closely to a seasonal efficiency: the ratio between all provided energies and all the necessary energies (see equation (4)). This global efficiency is defined to compare networks from a technical point of view because it will be affected by efficiencies of the network and the power plants. It also allows the comparisons of different heating systems for buildings e.g. the networks and a heat pump.

$$\eta_{DH} = \frac{E_{del} + E_{CHP}}{\sum_j E_j + E_{aux}} \tag{4}$$

Energy share

The last energy indicator expresses the energy share of the different district heating networks. It represents the relative importance of all the energy sources providing heat to the network and can be stated through the yearly energy consumption of these sources. It gives some keys to state the energy independency of networks.

Then an energetic analysis can be conducted thanks to these 5 first parameters. Some more parameters are needed to make sure district heating companies are able to fulfil customers' heat demands. For this purpose, IGD defined 7 parameters [8]. Four of them are related to network extension and heat delivery quality (outage) and cannot been stated in district heating design. Then the last three indicators, of which two are combined, will be highlighted.

Subscripted Heat Power by km (SHP)

This parameter was proposed by IGD [8]. It is expressed as the sum of all the maximum callable heat power divided by the length of the network. Its value gives an insight of the commercial profitability of a district heating network. The more this parameter, the more energy will be sold for a similar investment in piping equipments.

Equivalent to nominal power duration (Heq)

This indicator consists in the multiplication of two IGD defined indicators: rate of called power and equivalent to **full** power duration. As a result this new indicator is influenced by three parameters: weather, heat demand characteristics (e.g. dwellings or industrial customers) and networks heat losses. Its equation is given by (7).

$$H_{eq} = \frac{E_{del}}{P_{HP,tot}} \tag{7}$$

Where $P_{HP,tot}$ is the maximum heat plants power.

CO2 emissions

CO2 emissions can be seen as a summary indicator because it is a result of all the previous parameters: kind of energy sources, heat losses, efficiencies, etc. van Lier proposed to state avoided CO2 emissions. As this calculation asks assumption on conventional boilers use, CO2 emissions are expressed relatively to delivered energy (thermal and electric).

APPLICATION OF THESE INDICATORS AND DISCUSSION

These eight key performance indicators are able to give a complete view of the district heating and support decision making. This will be shown through the cases of four Finnish cities: Inari (Lapland), Helsinki (main city), Lahti and Juva (South Savo). They are derived from [10] which presents 175 district heating companies in Finland. In cases of Helsinki and Lahti, several companies are connected to the same network and data have been aggregated to allow criterion calculation at the city scale. The defined indicators are stated and results are shown in Table 1. Their analysis is conducted through four levels: Energy sources (through PEF, energetic efficiency and energy share), thermodynamics efficiency (through Global efficiency and RiL), heat plants and heat delivery characteristics (SHP and Heq) and environmental efficiency (CO2 emissions).

	Inari	**Helsinki**	**Lahti**	**Juva**
PEF, [-]	0.58	0.53	1.00	1.75
Energetic efficiency, [-]	1.71	0.75	0.69	0.57
RiL, [%]	11.90	7.96	11.59	19.37
Global efficiency, [%]	87.24	84.90	78.60	71.86
SHP, [kW/km]	766	2546	1146	1174
Heq, [h]	2695	1983	1756	1776
CO2 emissions, [TCO2/GWh]	119	171	251	437

Table 1: Key performance indicators for the four Finnish cities, results from data available in Finnish Energy Industries report: District heating in Finland 2009 [10]

Energy sources

Inari district heating network is characterised by a low PEF and a high energetic efficiency because more than 60% of its energy share come from renewable energies (biomass). Helsinki overall network presents a low PEF but also a low energetic efficiency. This is explained by its high use of Combined Heat and Power plants (CHP): 7389 GWh of electricity and 9839.3 Gwh of thermal energy. Lahti and Juva district heating show high PEF and low energetic efficiency. A look at their energy share highlights that more than 70% of Lathi's energy comes from coal and 80% of Juva's energy comes from peat. As the renewability of peat is not clear [11], this source has been considered as non-renewable.

Thermodynamics efficiency

First, RiL shows that Inari, Helsinki and Lahti cities have low heat losses through district heating networks. Helsinki network seems to have the lowest energy losses of the compared cities. Besides this network is the longest one (more than 2000km long). Big district heating can be managed in an efficient way and lead to high efficiency heat delivering. Finally, Table 1 shows that Juva networks have high heat losses through its networks. This appears to be a first important investment to enhance this network. Analysis of global efficiency shows that Lahti and Juva networks have low efficiency. For Lahti, an enhancement of the heat plant appears to be a very high efficiency measure because its network shows low relative losses.

Heat plant and heat delivering characteristics

Helsinki has the highest SHP. This statement can be explained by successive developments of district heating networks. Inari presents here very low value of SHP which might be a consequence of city rural characters. Lahti and Juva are bigger town than Inari but are not as big as Helsinki. They present similar value of SHP. Finally, high value of Heq for Inari might be due to the share of delivered energy and weather. Indeed colder weather involves higher heat demand and Figure 1 shows that more than 70% of total energy is delivered to non-residential customers. However Figure 2 also shows that Juva has a higher non-residential heat demand than Lathi and Helsinki but Heq is almost the same for these three cities. So, we cannot identify a clear link between buildings functions and Heq but it might be a key point.

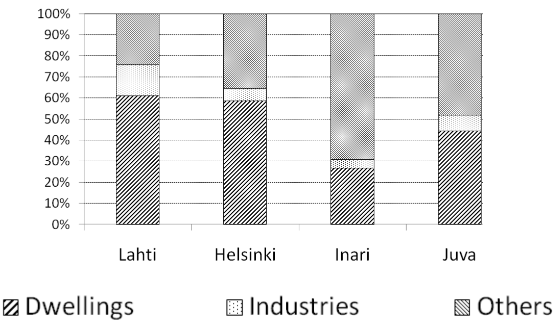

Figure 1: Delivered heat of district heating networks for different kind of customers expressed as a percentage of the whole delivered heat, source [10]

Environmental efficiency

This last step can be seen as a sum up of previous observations. Inari presents the lowest value as shown in Table 1. That means that 119T of CO_2 are rejected to deliver 1 GWh of heat to customers. By comparison, if one GWh was produced by a sum of oil boiler which mean efficiency was about 85%, they will generate 331T of CO_2. Helsinki and Lahti presents CO_2 emissions by delivered energy lower than this value but it is not the case of Juva.

CONCLUSIONS

District heating networks are quite common systems in Europe and they are intended to have a great play in future energetic world. However few key performance indicators are defined. Especially, only one energy indicator is often used to assess their energy performances. In order to help engineers and decisions makers to assess the quality of district heating networks projects, new key energy indicators have been defined. They can be used either for new district heating networks either for investments in old district heating networks. They also allow a good energy management of existing district heating networks.

Literature generally considers only the primary energy factor but it has been shown that this parameter alone is not sufficient to help decision making even if it gives a good overview of the energy performances of a district heating network. Based on the same variables three parameters have been added to enhance this insight: relative importance of energy losses, primary energy efficiency and district heating global efficiency. Coupled with the primary energy factor and the energy share, they give a more detailed picture about network quality related to energy use.

Indicators related to heat plants and heat delivering characteristics underline weather and customers influences. Beyond these influences building stock influence is underlying: buildings age, mixing of customers’ functions (dwellings, industrial, services, ...), built density. The whole indicators are able to provide interesting details over district heating performances and can help decision making and energetic management for both new and old networks. Further developments are needed in order to establish clearly impacts of urban stock characteristics on these indicators.

ACKNOWLEDGEMENTS

We gratefully acknowledge the economic support of the University of Liège. This paper had be written for the UNO projects (Urban Network Optimisation)

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