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Methodology for the Assessment of Temperature Reduction Potentials in District Heating Networks by Demand Side Measures and Cascading Solutions

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Abstract

The reduction of system temperatures in district heating networks increases the potential for renewable energies and industrial waste heat, reduces heat losses, increases the capacity of the heating network as well as enables a higher efficiency of many conventional heat generators.

In this paper a methodology for assessing local temperature reduction potential in district heating networks by demand side measures (thermal retrofitting) and cascading solutions is described. For the case study of Klagenfurt the local return temperature reduction potentials have been evaluated, achieved by thermal retrofitting of the building envelope according to OIB RL 6 and in turn reduced temperature demand for space heating.

Exemplary, "business-as-usual" (BaU) and more ambitious retrofitting scenarios have been identified, modelled and simulation results allowed the evaluation of the impact on the return temperature reduction and heat distribution losses in every pipe at city scale. The simulation results of the BaU scenario showed only a very limited impact with about 0.3 K weighted average network return temperature reduction and a decrease of about 5 MWh heat distribution losses. The "very ambitious" retrofitting scenario results in a reduction of about 1.2 K and 21 MWh heat distribution losses decrease. However, it can be seen that, due to the distribution of the different building types and structures throughout the city, the return temperature reduction in the pipes varies significantly, represented in a standard deviation of 4.1 K for the BaU scenario and 4.6 K for the "very ambitious" scenario.

Keywords: district heating network return temperature reduction, building envelope retrofitting, network simulation, aggregation, district heating network data handling

1. Introduction

District heating networks are designed to supply heat to various customers, for covering space heating (SH), domestic hot water (DHW) demand and process heat (PH) for industries.

The reduction of the network temperatures, both supply and return, is one key measure for establishing the next generation of DH networks [1], having an improved performances by: 1) increasing the potential of integrating renewable energies (such as solar and geothermal heat as well as heat pumps) and industrial waste heat, 2) reducing heat distribution losses and 3) increasing the efficiency of conventional heat generators. As an example, a study for Swedish DH networks [2] shows an estimated operational costs reduction of 0.15 €/K.MWh (per degree of return temperature and energy generated).

DH network temperatures are determined basically by the customer structure. Especially the return temperature depends mainly on the cooling of the heat carrier at the customer side. For the most part of the year, the supply temperatures directly depend on the return temperatures: Except in summer times[1], an increasing heat demand is covered by an increasing ΔT between supply and return temperature to minimize pumping costs[2]. The return temperature in many Austrian DH networks is in the range of 60-65°C and this is resulting in 120-160°C supply temperature at very low outdoor temperatures. This high temperature levels represent a major barrier for the integration of alternative heat sources – especially in winter periods.

Evaluating return temperature reduction measures: [3] developed a method for reducing return temperature by detection of faults in substations. In [4] the authors developed a decentralized substation helping to reduce the heat distribution losses within the building and also lowering the return temperature to the district heating. In [5] [6] control algorithms have been investigating in order to reduce return temperature to the DH network.

One focus of the current study is the effect of retrofitting measures on the return temperature. However, currently, most studies evaluating retrofitting measures impact have the main focus on primary energy savings [7] or plants operational implications [8] without a detailed dynamic analysis of the impact on the network operation and network temperatures.

The *aim of the study* is to develop a methodology for assessing the local potentials for reducing the return temperature by different building side measures such as retrofitting and cascading, using as case study the city of Klagenfurt (Austria). Since the building structures vary, demand side measures will have different effects on the local return temperature, leading to a distribution of return temperatures throughout the network. Additionally, mixing effects by joining different branches of the network need to be

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[1] In summer times, a minimum supply temperature must be set for guaranteeing hygienic domestic hot water (DHW) production

[2] since the pumping cost are proportional to the mass flow to the power of 3, it would have an significant negative effect on the economic efficiency of the DH network if an increasing heat demand would be covered by an increasing mass flow.

considered, challenging especially in meshed networks where mass flows in each branch depend on the local pressure distribution.

The knowledge *of the local return temperature* reduction potential is important for the following reasons:

a) in large DH networks, often multiple generation sources with individual characteristics exist at different locations and it enables to evaluate its effect individually;
b) it enables to evaluate the long term feasibility of cascading solutions. In this context, cascading is related to taking the heat energy from the return line and supplying it to a customer (and therefore reducing the local return temperature even further). However, if the local return temperatures drop upstream of the point of receipt due to demand side measures of upstream located buildings, cascading might not be possible anymore;
c) finally, in regions with low return temperatures, the local supply of low temperature sources can be very efficient. By matching the (long term) return temperature pattern with potential locations for renewables and industrial waste heat, decisions for investing in local resources can be supported.

2. Methods

▪ *Description of the Methodology*

In this paper the following methodology has been used and the steps are presented in Figure 1 (from right to left): 3) (supply modelling) heat plant characteristic lines are identified based on monitoring data provided by the grid operator and simplified operational strategies (priorities settings) are implemented; 2) (customer modelling) customers are modelled with heat load demand and return temperature to the distribution grid; the heat load demand is modelled as combination of space heating and domestic hot water demand, where: a) space heating is based on the “BuildingOneNode” model parametrised with physical properties of the buildings from the database of the project Tabula [9] according to their size, usage, construction age and renovation status and b) domestic hot water demand is calibrated with monitoring data; return temperature functions for space heating and domestic hot water are calibrated based on monitoring data. 1) (grid modelling) grid topology provided by the grid operator is aggregated and translated/modelled into the Modelica language. Return temperature reduction is achieved by thermal retrofitting (renovation scenarios) of the building envelope according to OIB RL 6 [10] and in turn reduced temperature demand for space heating. In order to facilitate both the process of modelling and the post-processing of simulation results, the geographic information system (GIS) tool QGIS [11] has been used. The detailed description of the single components is reported in the following sections.

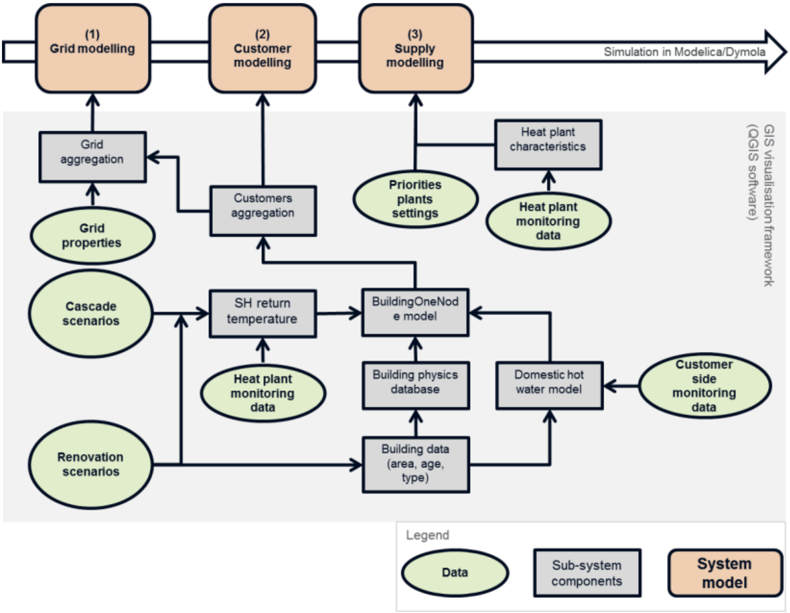

Figure 1: Methodology flow diagram

- ***Data acquisition***

Thanks to the constant advances in all fields tied to Geomatics, an increasing number of cities are in the process of creating 3D virtual city models as a means for data integration, harmonisation and storage, which go far beyond the somehow “standard” visualisation purposes both in 2D and 3D. A unique and spatio-semantically coherent urban model [12] can provide a multiplicity of beneficial effects, as it can represent an information hub for further advanced applications ranging from urban planning, noise mapping, augmented reality, up to energetic simulation tools [13] [14]. To these extents, CityGML [15] is an international standard conceived specifically as information and data model for semantic city models at urban and territorial scale. It models, both geometrically and semantically, all principal urban features, including buildings, land use, terrain, vegetation, etc.

For the City of Klagenfurt a structured database has been developed in order to guarantee a reusable common data structure which in short contains: 1) district heating grid specifications (topology and heat plants data) and 2) building attributes such as: building id, building address, building type (e.g. single family house), building use (e.g. office), year of construction, year of refurbishment and total heated floor area. A number of relevant parameters were extracted from the city model and aggregated to be fed as input to the heat demand model.

- ***Network modelling***

The dynamic thermo-hydraulic behaviour of the grid models is carried out with numerical models of the partially simplified and/or aggregated DH system of the case study developed in Modelica/Dymola [16] [17] based on models of the Modelica Fluid library [18] and on the DisHeatLib library [19]. Grid models include the implementation of the grid topology with pipe models which properties (U-value, overall heat losses coefficient) are retrieved from manufacturer data (Conti series 1 [20]). In order to meet the yearly energy heat distribution losses as given from the grid operator monitoring data, the U-values have been calibrated accordingly. Due to the complexity of the case study grid, aggregation [21] has been performed ensuring small deviations [21] in terms of simulation results compared to the original network topology.

- ***Customer modelling***

Customer heat demand is modelled as combination of DHW (from monitoring data) and SH demand (building model). Process heat demand (for industrial usage and/or for absorption machines) is neglected. Customer models are characterised by the heat load profile and the return temperature to the distribution grid.

The building model "BuildingOneNode" is a derivation of the Austrian standards [22] [23] which define the calculation procedures to obtain the energy performance of (residential) buildings. The dynamic behaviour of the building model is described by three thermal capacities: an air node (including the overall thermal capacity of the air volume), a concrete wall node (including the thermal capacity of the outside walls) and a concrete floor/ceiling node (including the thermal capacity of the floor and ceiling). The thermal resistance, which characterises the heat losses towards the outside, is modelled as a combination of four resistances: 1) one resistance which corresponds to the losses through the floor and the ceiling is splitted into three components, allowing the model to integrate properly the different heating set-ups, such as floor heating and radiator heating circuits; 2) one resistance which specifies the losses through the walls and the windows, including the effect of thermal bridges. The parametrisation of the buildings´ physical properties (e.g. properties of walls, ceiling, etc.) is based on the Austrian residential building stock developed within the project Tabula [9]. Additionally the model includes the following phenomena:

- Effect of the solar radiation (window model), for which the resulting heat load is connected to the air node and input is calculated as: $Q_{Solar} = I_{Global} \cdot A_{Window} \cdot g_{Value}$ with:

I_{Global} (W/m^2) solar radiation on the vertical surface for each direction (north, south, east, west) (monitoring data)

A_{Window} (m^2) available surface of the window (values from the Tabula database scaled with the floor heated area)

g_{Value} (-) solar energy transmittance of the window (values from the Tabula database)

- Effect of the infiltration losses, which are leakages through walls, windows, etc. (values retrieved from the Tabula database)
- Effects of the air exchange, which is the ventilation for hygienic reasons, and the internal gains due to occupants as well as appliances inside the building (standard profiles from [24]). Heat recovery can be included in the model as well (e.g. for passive houses).

▪ ***Heat plant modelling***

Considering the requirements of the project, an ideal model for the heat plants has been used, which assumes as input the heat load to be produced and the supply temperature to the grid. Therefore the required mass flow for each heat plant is determined on the basis of the so call "plant priorities", for which depending on the actual demand the plant with the higher priority is assumed to run.

3. Results

Four different scenarios have been simulated for 1 week in winter, assuming increasing building renovation rates as defined by the grid operator of Klagenfurt based on experience and city planning directions. Those scenarios refer to:

- **Baseline** (very low renovation rate, range from 0% to 15% of the total heated area)
- Business as usual (**BaU**) scenario (good renovation rate, range from 0% to 30% of the total heated area)
- **+100% BaU** renovation rates (ambition scenario, range from 0% to 80% of the total heated area)
- **+200% BaU** renovation rates (very ambitious scenario, range from 0% to 100% of the total heated area)

Energetic results based on the network simulations are presented in Figure 2 and Figure 3. They show the total heat energy demand, the network weighted return temperature (calculated as weighted value with the heat flow from each return pipeline) and the total heat distribution losses for the 4 scenarios in Klagenfurt. Heat demand is reduced compared to the reference scenario up to 1.5 GWh for the representative week in winter if renovation measures are applied with a very ambitious renovation rate, see Figure 2.

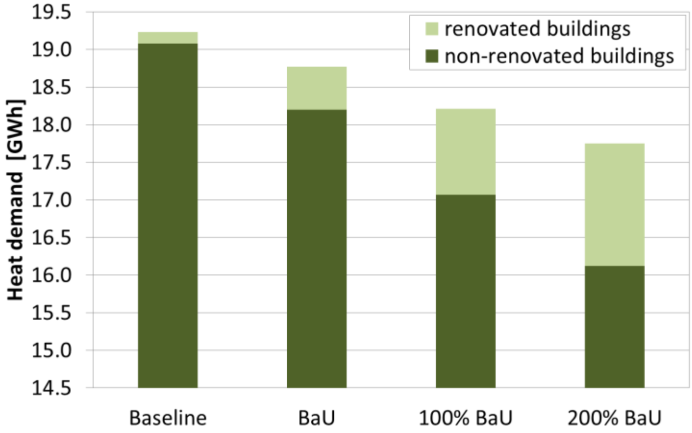

Figure 2: Overall heat demand (1 week in winter)

In the scenario +200% BaU, where the maximum return temperature reduction can be achieved, weighted return temperature is reduced of about 1.2 K and heat distribution losses can be reduced to a maximum of 21 MWh for the representative week in winter, see Figure 2..

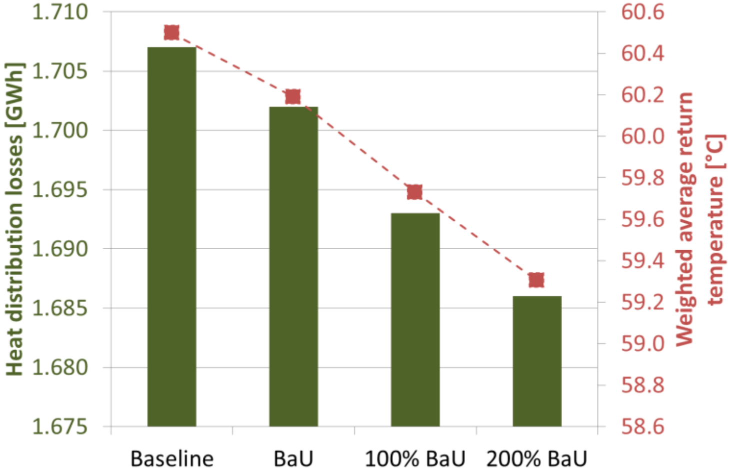

Figure 3: Heat distribution losses and weighted average return temperature (1 week in winter)

Figure 4 displays the average return temperature reduction over the 1 week period for all pipeline in the +200% BaU scenario compared to the baseline. It can be noticed for the largest share of pipes a variation less than

1.5 K with only few sections of pipelines having a larger return temperature reduction higher than 4 K.

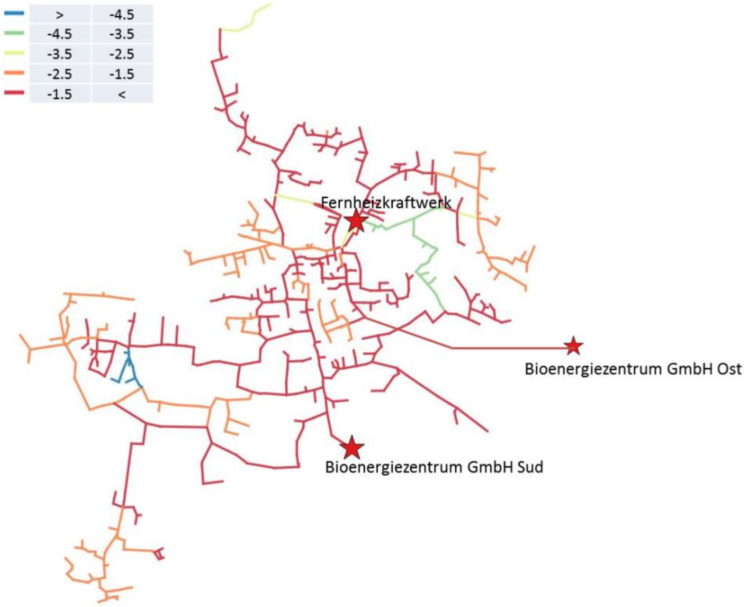

Figure 4: Average temperature reduction between +200% BaU scenario and baseline

4. Discussions, Conclusions and Future Work

In this study a methodology for assessing the local return temperature reduction for district heating networks and its application on a case study is presented. From the analysis of the results it can be noticed that temperature reduction has a perceivable impact on the district heating system only if substantial retrofitting measures are taking place. Indeed in the case of the +200% BaU scenario a weighted return temperature reduction of 1.2 K is achieved resulting in a heat distribution losses decrease of 21 MWh.

The heterogeneous distribution of the return temperature reductions in the different pipes opens possibilities for efficient supply of local heat sources, such as introduction of heat pumps or solar thermal systems.

In the investigated case study, lower network temperatures have only a small effect on the performance of the overall system, especially due to the characteristics of the current high temperature heating plants. As a consequence, the motivation for reducing the network temperatures is rather low. Correspondingly, concrete incentives for demand side measures are missing. This behaviour is stabilising the dominance of high temperature sources. If one cannot break out of this vicious circle, severe lock-in effects can result – both on supply side (in general long life time of fossil based heating plants, especially for CHP) and customer side (if a building is once equipped with a high temperature heating system, it will be very cost intense to change it)

Since building retrofitting is quite a cost intensive measure and very often affects the comfort of the inhabitants, retrofitting rates are typically very low. As a consequence, other return temperature reduction measures will be investigated in the future, e.g. hydraulic balancing. Hydraulic balancing represents a very cost efficient measure with a higher impact [25]. However considering the limited information of the hydraulic balancing effect on the return temperature from different building types, further investigations are needed in order to consider it in the presented methodology. As part of the future work, CityGML model is considered to be investigated to further exploit the integration between the different components of the methodology presented in this paper.

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