EVALUATION OF INTERACTIONS BETWEEN BUILDINGS AND DISTRICT HEATING NETWORKS

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ABSTRACT

In the context of district energy systems, changes in a building’s heat demand also affect the energy efficiency of the whole district heating network. We present an integral dynamic model of a district heating network branch with three buildings. By comparing simulations of a reference case and a retrofit scenario we show that reducing the buildings’ heat demands also reduces the mass flow rate in the network branch. We discuss the effects of this mass flow reduction on the energy efficiency of the district heating network and deduce that a district-level system perspective can lead to more comprehensive evaluations of retrofit efforts.

INTRODUCTION

The buildings, district heating networks, and heat generation units in city districts with central heat distribution can be seen as one connected large-scale energy system. A common approach to increase energy efficiency within this system is to evaluate and improve the performance of subsystems, for example by retrofitting individual buildings. A complementary approach is to investigate such energy systems at a city district level. Focusing on the higher-level relations and interactions between the subsystems offers potential for improving individual subsystems with regard to positive effects on the system as a whole. Therefore, such evaluations at city district level can help to identify the most efficient strategies to increase energy efficiency under constraints of limited time and budget.

To model a district-wide energy system, it is helpful to use a modular, acausal approach with interconnected models of individual subsystems. This way, it is possible to combine and modify subsystems often without the need to make changes in other parts of the whole district energy system model (Fritzson, 2011). For an analysis of the interactions between subsystems like buildings and heating networks, their coupling is an essential part of the system model. Only if these interactions are part of a holistic system model is it possible to evaluate energy systems on a city district scale.

In this paper we show our approach towards an integral dynamic model of buildings and district heating networks. To this end, we modelled a district heating substation and compared its results to measurement data. As a test case of limited complexity, we used the substation model to simulate a branch of a district heating network with three connected buildings. We present the results of this simulation in order to illustrate the advantages of a district-level evaluation over an isolated view on subsystems like individual buildings.

As Keirstead et al. (2012) show in their recent review, there is growing interest in modeling energy systems on a city district and urban scale. One of the key challenges they identify in this process is the systems’ complexity. In order to arrive at an urban energy model which delivers significant results without excessive computing effort, it is necessary to use simplified submodels and assumptions. The simplification approaches used usually depend on the intended task and the specific type of submodel. A central part of urban energy models is the submodel representing individual buildings. Buildings’ energy performance has been modelled in various levels of detail (see Hensen et al. 2011). In the context of city districts and urban scales, it is common to use more simplified building models based on thermal resistances and capacities like the one described in ISO 13790 or e.g. (Robinson et al. 2009). We use a similar model based on the guideline VDI 6007 (see Lauster 2012, Fuchs et al. 2012).

Another complex part of urban energy systems are district heating networks. One important approach for simplifying district heating network models is aggregation. The two methods proposed by Loewen (2001) and Larsen et al. (2002) aggregate consumers and pipes to simpler model networks. They show similar results as detailed models with regard to energy flows at the supply unit while reducing computation times significantly. Concerning the interaction of consumers with the grid, the models use different approaches. In a model comparison, Larsen et al. (2004) summarize that Loewen uses a prescribed return temperature while Larsen et al. use a combined model of a building’s substation and heating system. The simulation uses a step-wise calculation process, alternating calculation steps for flows and temperature distributions based on Pálsson et al. (1999).

Within the networks, buildings act as heat consumers and influence the network by means of extracting heat from the circulating fluid. District heating substations connect buildings to the network. This connection can be made directly or indirectly. Different types of substations and detailed connection schemes are described e.g. in (Wollerstrand 1997) and (Johansson 2011). With indirectly connected substations, a heat exchanger transfers heat from the district heating network to the building's heating system. A control valve determines the amount of heat extracted from the district heating network by controlling the flow of fluid through the substation depending on the building's heat demand.

Thus, the building's heat demand has a direct effect on the dynamic behavior of the whole district heating network. Given that there are several substations operating in a district heating network, their cumulative dynamic influence on the network further complicates efforts to model and investigate the complex systems of district heating networks. As described by Wernsted (2002), a major problem lies in the fact that the substations react only to the building's heat demand without taking into account the state of supply or the total demand in the network. As this can lead to a non-optimal operation of the energy system as a whole, understanding the effects of the interaction between individual buildings and the heating network can help improving its overall energy efficiency. This applies for investigations of individual substations connecting buildings and network, but only a district-wide evaluation can truly incorporate the joint effects of all subsystems involved in shaping the behavior of an interconnected district energy system.

After this introduction we explain our efforts to model the subsystems of a district energy system. This includes models for buildings, networks as well as the district heating substation, which we will explain in more detail. Afterwards we give the results for verification of the substation model with measurement data from a reference substation. On this basis, we present an example of a simple district heating network branch with three buildings each connected by our substation model. We simulate a reference case in which we model buildings with properties of typical office buildings. We compare this reference case with a retrofit case in which the properties of the building envelope with regard to heat transfer have been improved to current standards. In the concluding discussion, we show the advantages that a district-level evaluation of the retrofit case has over an isolated view on the subsystems alone.

MODELLING OF SUBSYSTEMS

In order to investigate energy systems at city district level by means of dynamic simulations, the models used must be suited to cope with the system's scale and complexity. Two of the main restrictions are the level of detail in modeling and parameterization, and the resulting computation times. For this reason, we use a simplified building model based on thermal resistances and capacities. As shown in Figure 1, the model based on the guideline VDI 6007 represents the outer walls with 1 thermal capacity and 2 resistances while the inner walls use only 1 resistance because they are assumed to be adiabiatic. Between the walls, there are thermal resistances representing radiative and convective heat transfer.

The building model is coupled with a thermo-hydraulic model for the district heating network. This is done by modelling the building's substation for heat transfer. We use the object-oriented programming language Modelica and the simulation program Dymola to model and simulate the energy system.

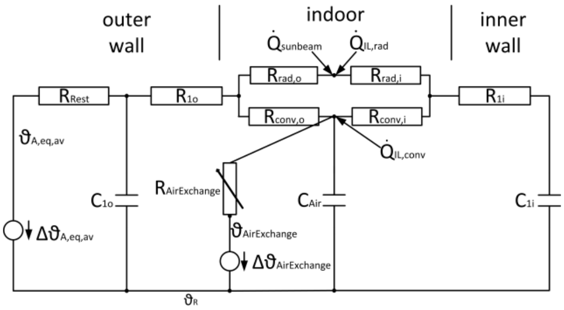

Figure 1: Thermal Resistances and Capacities of Building Model based on VDI 6007

In the context of district energy system models, individual buildings act as heat sinks and thus as consumers of heat from the district heating network. Therefore, the building model calculates a building's heat demand depending on conditions like outside air temperature, solar radiation, as well as user occupancy, and use of machines and lights. The temporal resolution of the model's output depends on the coarsest resolution of these boundary condition inputs. For our dynamic simulations, we use hourly input data for simulating the building's hourly heat demand. To arrive at the building's heat demand, the model calculates the amount of heat input necessary to keep the temperature at an air node representing the air volume of a thermal zone above a given temperature set-point. Each thermal zone is modelled by thermal resistances and capacities representing the outer and the inner walls of the specific building. The total heat demand of a building is calculated by summing up the heat demand of all its thermal zones.

The building's calculated heat demand is satisfied by the heat supply from the district heating network's fluid. For the district heating branch presented in this paper, we modelled the heating network using the pipe model from the Modelica Standard Library. One crucial parameter of this model is the number of nodes used for discretization in order to calculate the heating fluid's properties. With a low number of nodes, it is not possible to simulate the temporal behavior of temperature wave propagations in the heating fluid over the length of the pipe. Yet, too many nodes result in high computation times. We use 1 node per 10 m of pipe length (with a minimum of 2 nodes per pipe), which we consider to be an adequate compromise between computation effort and the resulting dynamic behavior. As our focus is on the interaction between network and buildings, we used an ideal source and an ideal sink with constant pressure as supply and return for the network. For the district heating supply temperature we defined a simple dependence on the outside air temperature in the range of $-15°C < T_{air} < 15°C$:

$$T_S = 110°C - T_{air} \cdot (40°C/30°C) \qquad (1)$$

As shown in Equation 1, the district heating grid has a higher supply temperature at lower outside air temperatures and vice versa. At outside air temperatures below -15°C we use a fixed supply temperature at the maximum of Equation 1, i.e. at 130°C. At outside air temperatures above 15°C, when the building model calculates only minor heat demand, we set the district heating supply temperature to the minimum of Equation 1, i.e. 90°C.

For coupling the building model to the district heating network, we model a district heating substation consisting of a mass flow control valve, a heat exchanger and a differential pressure control valve. We chose a simple substation setup, in which only one heat exchanger supplies energy to satisfy the building's heat demand for space heating. This setup corresponds with the real setup of our monitored reference station. It is located in a building where the domestic hot water is heated by local electric heaters. Therefore, we do not consider domestic hot water heating as part of the substation.

Figure 2 shows the valves and the connections to the district heating network on the primary side and to the building's heating system on the secondary side of the heat exchanger. In this setup, the mass flow control valve extracts a certain mass flow from the district heating system so that the heat exchanger transfers enough heat to the secondary side for the heating system's supply temperature to reach its given set-point temperature. The difference between the resulting secondary return temperature and the set secondary supply temperature at a given mass flow rate determines the amount of heat needed from the primary side.

As the mass flow control valve reacts to the heat demand from the secondary side and adjusts the primary side's mass flow accordingly, the pressure drop in the primary side changes. In order to ensure a fixed pressure drop over the mass flow control valve and the heat exchanger, the differential pressure control valve adjusts its opening accordingly. This way, the mass flow control valve and the heat exchanger can operate under stable, predefined conditions.

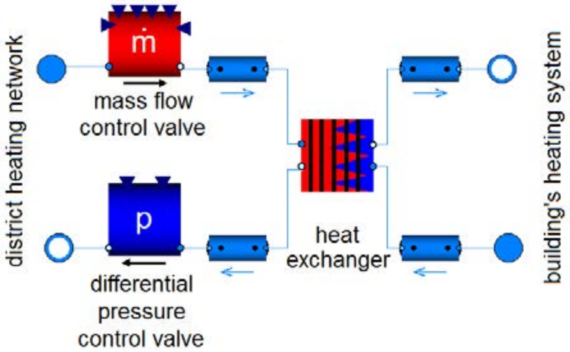

Figure 2: Substation Model

In order to fulfill these tasks, both valve model blocks contain an actual valve model from the Modelica Standard Library as well as a control block. We designed the mass flow control valve's control block so that it adjusts the valve opening according to the heat demand from the building's heating system, its temperature levels, the supply and resulting return temperature of the district heating network as well as the valve characteristics. The differential pressure control valve is controlled depending on the dynamic pressure drops of the substation's upstream elements.

For the heat exchanger, we use equations based on the number of transfer units (NTU) method in (VDI 2006). This method uses dimensionless quantities to describe the heat exchanger. From the temperature differences at both sides of the heat exchanger (here denoted 1 for primary and 2 for secondary) follows the logarithmic temperature difference over the heat exchanger

$$\Delta T_{ln} = (\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2) \ . \qquad (2)$$

This leads to the basic relation for the transferred heat flow depending on the logarithmic temperature difference and the basic heat exchanger properties

$$\dot{Q} = k \cdot A \cdot \Delta T_{ln} \ . \qquad (3)$$

To arrive at dimensionless quantities, this equation can be set into relation to the maximum transferable heat flow of an ideal counter flow heat exchanger. Equation 4 shows this maximum heat flow for the mass flows on both sides of the heat exchanger (with $i = [1;2]$).

$$\dot{Q}_{max} = \dot{m}_i c_p (T_{1,in} - T_{2,in}) = \dot{m}_i c_p (\Delta T_{max}) \ . \qquad (4)$$

Dividing Equation 3 by Equation 4 results in

$$\frac{\dot{Q}}{\dot{m}_i c_p (\Delta T_{max})} = \frac{kA}{\dot{m}_i c_p} \frac{\Delta T_{ln}}{\Delta T_{max}} \qquad (5)$$

which can be interpreted as a thermal efficiency of the heat exchanger. Each of the fractions in Equation 5 can be interpreted as a dimensionless quantity, so that the equation can be written as

$$P_i = NTU_i \cdot \theta \ , \qquad (6)$$

where the performance factor P is given by the product of the number of transfer units NTU and the relative temperature difference θ. For a given mass flow in the building's heating system (i.e. $i = 2$ for the secondary side of the heat exchanger) and known properties of the heat exchanger, it is possible to use the definition of NTU_2 to calculate its value.

$$NTU_2 = \frac{kA}{\dot{m}_2 c_p} \qquad (7)$$

Having calculated NTU_2, we can transform Equation 6 to

$$\theta = P_2 / NTU_2 \, . \qquad (8)$$

We can solve Equation 8 by using the equations for calculating the performance factor P_2 given in (VDI 2006). These equations are different for various types of heat exchangers. Therefore, the model can be easily adapted to represent different types of heat exchangers by adapting this one equation. For the simulations presented in this paper we used the configuration of a plate heat exchanger. By solving Equation 8, we can derive the district heating return temperature from θ. Furthermore, Equation 9 leads us to NTU_1, from which we can derive the needed mass flow on the heat exchanger's primary side.

$$P_2 / NTU_2 = P_1 / NTU_1 = \theta \qquad (9)$$

With this input, the mass flow control valve's control block is able to calculate the necessary valve opening.

VERIFICATION OF SUBSTATION MODEL

We calibrated our substation model with measurement data from a reference substation shown in Figure 3. On the left side, the figure shows the connection to the district heating network, while the heat exchanger (in dark blue) transfers heat to the building's heating system, shown on the right. This substation supplies a laboratory building with a nominal heat load of 480 kW.

Figure 3: Reference substation

The reference substation is equipped with an ultrasonic flow meter on the primary district heating side as well as measurement points for temperature and pressure in both supply and return flows. From the temperature difference between primary supply and return flow and the flow metering, an energy meter calculates the amount of energy transferred to the building's heating system. These measurements are sent to the central building control system, where they are displayed and stored. With this data we can evaluate the district heating side return temperature depending on the heat transferred to the building and the temperatures in the heating system.

Given the measurement data from the reference substation, we aim at verifying the substation model so that it is able to simulate the dynamic behavior realistically. Therefore, we set up a simulation of the substation in which the supply and return of both primary and secondary side (see Figure 2) are directly connected to ideal fluid sources and sinks.

As the reference substation shows stable pressure levels, the pressures of these sources and sinks are set to fixed values. On the primary side, the district heating supply flows into the substation while the in-flow on the secondary side is the building's heating system return flow. For both we define the temperature at the sources to be equal to an input time series of temperature measurements in intervalls of 5 minutes. The properties of the heat exchanger are described by the values for the heat exchanging area and thermal transmittance which were taken from the manufacturer's data sheet. The mass flow rate on the primary side of the heat exchanger is calculated by the mass flow control valve block dynamically.

For the building's heating system we calculated an hourly mass flow rate using Equation 10.

$$\dot{m} = \dot{Q} \, / (c_p \Delta T_2) \qquad (10)$$

For the heat flow we used the hourly measurement data from the primary side's energy meter. We assumed a constant specific heat capacity and calculated hourly means of the secondary side's temperature differences also from measurement data. This leads to a dataset of hourly values for the mass flow rate. For the application of the model in a district heating network, the actual mass flow of the heating system is unknown. For this case, we fitted a profile of hourly values for one day to the calculated dataset. With this profile integrated into the model, we were able to achieve better results compared to assuming a constant mass flow rate.

Figure 4 shows a comparison of the simulated district heating side return temperature and the corresponding measurement data. For better readability we show a time of 10 hours from a simulation with an output intervall of one minute. The simulation results show a slightly lower return temperature than the measurement data. This might be explained by the fact that the measurement data for the heat flow had to be taken from the heat exchanger's primary side for lack of a measurement point on the secondary side. Still, the simulation result is in good accordance with the measurement data. A comparison of the two datasets yields a coefficient of determination of 0.78 and a root mean square error of 1.2°C. More importantly, we consider the model to display a dynamic behavior similar to the real system.

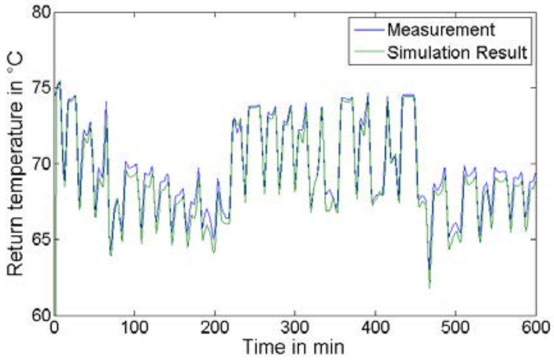

Figure 4: Comparison of simulated and measured primary return temperatures of the substation

COUPLED NETWORK SIMULATION

In order to show the interaction between buildings and the district heating network, we simulated a district heating branch with three office buildings, each connected to the network by the presented substation model. We modelled these buildings according to standard values for German office buildings depending on their year of construction. As a reference case, we modelled three older buildings and calculated the amount of energy needed to supply their heat demand via a simple district heating network. For a comparison, we simulated the same network with buildings retrofitted to current standards. On this basis, we investigate the predicted energy savings between the two test cases.

For the building model, we defined a reference building with a net area of about 1000 m . From the works of Lichtmeß (2010) and BMVBS (2010) we derived standard values for the usage patterns, distribution of thermal zones, and properties of the building envelope of typical German office buildings. In the mentioned works, the values for properties of the building envelope are categorized depending on the building's year of construction. This accounts for the development of building properties over time, with newer buildings needing less energy for space heating.

On this basis, we modelled the same reference building with properties of different years of construction. For each of these building variations, we used the same hourly profiles for user occupancy, machine and light use as well as weather conditions. Also, each building variation consists of the same 6 thermal zones with the same ground areas in order to show only the effect of varying building envelope properties on the calculated heat demand. Table 1 shows the calculated heat demand of such a building for one year depending on the year of construction.

Table 1
Simulated yearly heat demand of a building depending on its year of construction

YEAR OF CONSTRUCTION	HEAT DEMAND	SAVINGS POTENTIAL*
1960	333.4 MWh/a	50%
1970	240.6 MWh/a	31%
1980	223.8 MWh/a	26%
1990	202.4 MWh/a	18%
2010	166.6 MWh/a	0%

** Potential energy savings by retrofitting to 2010 standard*

From these results it is possible to derive a simple evaluation of retrofit strategies for the building's envelope. This isolated view on the building suggests that improving the building's envelope from the standard of a building constructed in 1960 to the standard of 2010 would yield yearly energy savings of 50%. In a realistic scenario, it is likely that a retrofit to today's standard would not only concentrate on the building envelope's thermal properties but also cause changes in the heating system, air exchange rates and even in the building's usage patterns. Yet, for the scope of this paper, the retrofit of the building envelope is a good simplified example to illustrate the effect of lowering a building's heat demand, even if the absolute values do not fully describe a real retrofit case.

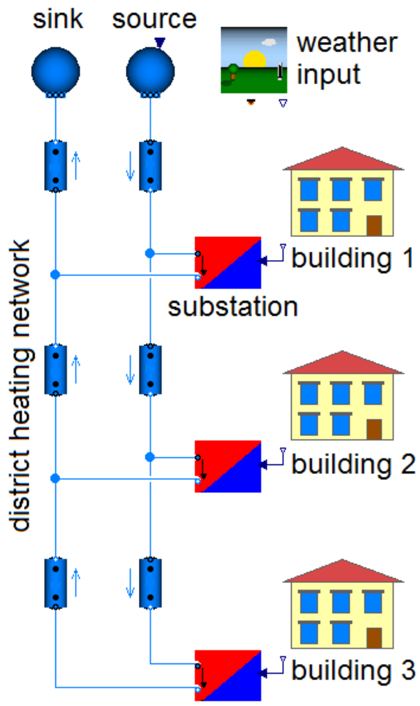

Figure 5: Model of a district heating branch with three buildings

In the context of a district heating network, a similar evaluation of the effects from retrofit measures can include the interactions of the buildings and the heating network. Figure 5 shows the model setup of a network branch with three buildings connected to a part of a district heating network. As the supply to the network is an ideal source, the network is always able to satisfy the buildings' heat demand up to the limitations imposed by the maximum opening of the substations' mass flow control valves. We assume the network branch to be part of a larger district heating network, in which the pressure is controlled to satisfy the demand of a point of lowest pressure outside the modelled branch. Therefore, the source and sink are set to constant pressures for the reference case as well as the retrofit case. The supply pressure for the simulations is set to 16.5 bar while the pressure at the sink is set to 14 bar.

In the reference case for an evaluation of building retrofit effects on the network, we simulate the buildings with the values of building 1 being constructed in 1960, building 2 in 1970, and building 3 in 1980. Because of the differences in heat demand, each building's substation takes a different amount of mass flow from the network. This determines the total mass flow in the branch from source to sink. The combined return flows from the substations also determine the overall return flow temperature at the network's sink boundary.

In the second case, we simulate the same network branch with each building model replaced by the one having 2010 as year of construction. In this case, the changes in the buildings' properties do not only result in a reduced heat demand, but consequently also in less mass flow through the individual substations. This leads to a lower overall mass flow in the network branch.

The results from the simulations of both cases are shown in Figures 6 and 7. Both simulations were set to a simulation time of one year with output intervalls of one hour. Figure 6 displays the simulated supply and return temperatures. For reasons of better readability, we extracted the results of 1 month (January) from the one-year-simulation. As the supply temperature is determined by the outside air temperature and Equation 1, it is identical for both cases. For this same supply temperature, the retrofitted case with a lower heat demand reaches a slightly lower return temperature. But as the temperature differences in the building's heating system do not change significantly under our assumptions, the effect on the district heating return temperature is limited. Thus, the reduction in heat demand under the assumption of constant supply and return pressures mainly results in a reduction of mass flow in the system.

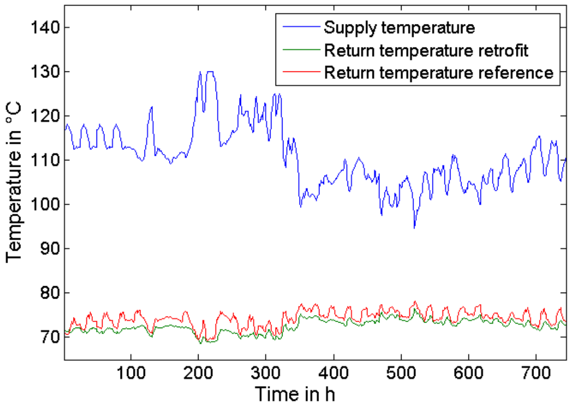

Figure 6: Results for the supply and return temperatures of reference and retrofit case

Figure 7 shows the corresponding mass flow rates for one year. The retrofit case does not only result in a reduced overall mass flow in the heating network, but also reduces the absolute variations of mass flow in the system. The variations seen in Figure 7 are in part due to changing heat demand, but also the result of variations in set temperature as the buildings are simulated with a night set-back. During night times, the set temperature is reduced from 22°C to 18°C. This results in a morning peak of heat demand, which accounts for the high local peaks in Figure 7. The peaks during summer (especially between hours 4500 and 5500) are in part also caused by the night temperature set-back. The model satisfies any heat demand to keep the indoor air temperature above the set temperature. Therefore, even in summer a relatively cold night and the set point change in the morning together can cause a simulated heat load, where in reality the heating system would likely be shut down.

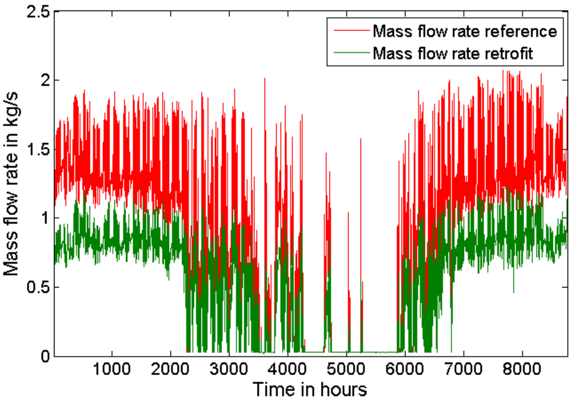

Figure 7: Results for the mass flow rates of reference and retrofit case

From the mass flow rates and temperature differences between supply and return flows, it is possible to calculate the overall energy input to the district energy system. For the reference case, this simulated energy input is 810 MWh. For the retrofit case, it is 516 MWh. That is 2-3% more than the heat demand of the buildings alone. This additional energy demand is caused by pressure and transmission losses in the district heating network.

DISCUSSION AND RESULT ANALYSIS

The simulation results show that the retrofitting of buildings to reduce their heat demand also has an effect on the supplying district heating network. A key factor determining this interaction is the behavior of the district heating substation. Especially the mass flow control valve affects the total mass flow in the district heating network depending on the heat demand of the connected building and the size of the district heating network. The results of a coupled simulation of buildings and a part of a district heating network can illustrate how a district-level view can help making evaluations more comprehensive.

In our simulations, the predicted energy savings by retrofitting the example building depend on the assumed year of construction (see Table 1). For the reference case, three separate simulations of the building's heat demands result in a total heat demand of 798 MWh. With three buildings according to the 2010 standard, the total simulated heat demand is reduced to 500 MWh. This suggests that retrofitting the building's envelopes to today's standard has the potential to save almost 300 MWh/year or 37% of the reference case's heat demand. Given the costs for the retrofit, it would be possible to evaluate whether the retrofitting is economically feasible under the predicted energy savings potential.

Yet, from a system perspective, it would be useful to also take into account the effects on the district heating network. Especially the changing total mass flow rate in the simulated district heating branch is a factor worth considering. During the heating season, our simulation of the retrofit case calculates an average mass flow rate in the branch of 0.8 kg/s compared to an average of 1.3 kg/s for the reference case. Over the course of one year, the mass flow rate necessary to supply the three buildings with heat is subsequently reduced by 39%. Except for minor changes in the district heating return temperature, this reduction is almost a direct result of the heat demand lowered by 37%. Of course, both these values are in part the result of the underlying assumptions and would differ from those of a more detailed model. Still, this simplified example can illustrate basic relationships and interactions, even if it cannot give absolute numbers for real-world decision making.

Under the assumption that the retrofit measures in the simulated network branch have a negligible influence on the supply and return pressure, the mass flow in the branch is reduced significantly. As a consequence, the overall mass flow in the district heating network can be reduced. This also means that there is less need for pumping energy as less heating fluid has to be moved through the system. Equation 11 gives a simple relation for the pumping power of a heating system.

$$P = \dot{V}\,\Delta p \qquad (11)$$

With a constant pressure difference between return and supply, the pumping power scales directly with the volume flow rate. Neglecting temperature effects on the fluid's density, the pumping power is thus reduced by the same factor by which the retrofit reduces the overall mass flow in the system.

In reality, it is likely that the change in heat demand of the branch also has influence on the system pressures. In addition, the changing mass flow rates also affect the pressure and heat losses in the network as the fluid velocity decreases. This means that the overall effect of changing the heat demand of a single building in the context of a district heating network consists not only of the direct demand reduction but also of the changes in the networks pumping energy and heat supply.

It is justified to take all these effects into account when evaluating efforts to improve energy efficiency like retrofit measures for their energy savings and economic feasibility. As building retrofits often require huge investments with long amortisation times, the additional benefits caused in the district heating network could be a crucial factor, were they taken into account. For a case in which retrofitting from a building perspective does not seem economically feasible by a small margin, the district level perspective may decisively influence the decision making process.

Therefore, an integral dynamic model of the total energy system on a district level could be a valuable tool. The substation, building, and district heating branch model we presented in this paper are a step towards such a system model.

CONCLUSION

In this paper we presented an integral model for the dynamic simulation of a district heating network branch with three buildings. After introducing the model parts for the subsystems buildings, substations, and the heating network, we evaluated the effects of a reduced heat demand in the network branch on its supply and return flows. The heat demand was reduced by simulating the buildings with different standard values for the properties of their building envelopes. Depending on the year of construction, the theoretical reduction of heat demand by updating the building to today's standard ranged between 18% and 50%.

We showed that the local reduction of heat demand also significantly reduced the mass flow necessary to supply the group of buildings. This has a subsequent effect on the energy needed for the network's overall heat supply, namely for pumping energy and for balancing changes in the system's heat losses. From an ideal system perspective on a district or urban scale, it would be possible to quantify these effects and take them into account when evaluating whether a retrofit effort to reduce heat demand is economically feasible.

If costs for retrofitting buildings make it hard to achieve economic feasibility in the scope of a building level evaluation, the extended view on a district energy system presented in this paper can be a valuable help to evaluate the true benefit of the planned retrofit. Therefore we suggest evaluating efforts to improve energy efficiency in an urban energy system context with integral system models for dynamic simulations.

NOMENCLATURE

A = area of heat exchanging surface
k = thermal transmittance
$\dot{m}$ = mass flow rate in kg/s
NTU = number of transfer units
T_{air} = outside air temperature in °C
T_S = district heating supply temperature in °C
p = pressure
P = performance factor
$\dot{Q}$ = heat flow in kW
ΔT_1 = primary side temperature difference
ΔT_2 = secondary side temperature difference
ΔT_{ln} = logarithmic temperature difference in K
θ = relative temperature difference

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