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SIMULATION MODELS AND PERFORMANCE ASSESSMENT OF DISTRICT HEATING SUBSTATIONS

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ABSTRACT

Development of new technologies and methodologies regarding district heating substation operational control strategies are increasingly found nowadays. At the same time a great number of modern buildings are provided with energy monitoring and control systems which supervise and collect operating data from different energy components. Accordingly, an exemplary district heating systems is being implemented in the city of Kortrijk in Belgium, as part of a demonstration zero-carbon neighborhood. This study deals with the energy performance assessment of one of the systems component -the consumer substation- installed in this low-temperature district heating system. A comparative analysis of the energy performance with several existing district heating substations was carried out. Three different district heating substation models are set up (using TRNsys) for investigation of the gross energy use, energy-efficiency and comfort issues. In order to evaluate the performance of the analyzed substations two scenarios concerning the space heating system (radiator or floor heating system) were considered. The study aims to investigate the impact of different operational circumstances on the performance of district heating substations. The study generate understandings for energy saving operational strategies to be developed. Results indicate that the design concept together with a suitable selection of the substation has an important impact on the energy performance of the entire system.

KEY WORDS: Low energy building, district heating substations, dynamic simulations

MODELACION, SIMULACION Y EVALUACIÓN ENERGETICA DE SUBESTACIONES DE SISTEMAS CENTRALIZADOS DE CALEFACCIÓN COMUNITARIA

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RESUMEN

En la actualidad, se encuentran cada vez más el desarrollo de nuevas tecnologías y metodologías en las estrategias de control operacional de subestaciones de sistemas centralizados de calefacción urbana. En consecuencia, un sistema centralizado de calefacción comunitaria se está implementando en la ciudad de Kortrijk, en Bélgica, como parte de un caso de estudio demostrativo de comunidad con balance cero de emisiones de carbono. Este estudio se ocupa de la evaluación de la eficiencia energética de uno de los componentes del sistema – la subestación a nivel del consumidor - instalada en este sistema centralizado de calefacción urbana de baja temperatura. En el trabajo se realiza un análisis comparativo de la eficiencia energética con varias subestaciones existentes. Tres modelos diferentes de subestaciones de calefacción urbana se configuran (usando TRNSYS) para la investigación de la utilización de energía, la eficiencia energética y las cuestiones de comodidad. Con el fin de evaluar el rendimiento de las subestaciones analizadas se consideraron dos escenarios en relación con la instalación de calefacción de los apartamentos (radiador o sistema de calefacción integrado en el piso). El estudio tiene como objetivo investigar el impacto de las diferentes circunstancias operacionales sobre el desempeño de las subestaciones de calefacción urbana. Los resultados indican que el concepto de diseño, junto con una selección adecuada de la subestación tiene un impacto importante en la eficiencia energética de todo el sistema.

PALABRAS CLAVES: Edificio bajo consumo energético, subestaciones de calefacción, simulaciones dinámicas

1. INTRODUCTION

Examples of district heating systems are scarcely found in the Belgian housing sector, as they were rarely implemented in the past. However in the current evolution towards renewable energy supply, district heating networks are seen as a promising solution. In the city of Kortrijk in Belgium a low temperature district heating systems is being implemented as part of a demonstration zero-carbon neighborhood with about 200 dwellings that is under construction in the context of the ECO-Life project within the CONCERTO initiative. It is well known that the energy sector is central in sustainable development and it affects all aspects of development – social, economic and environmental. Precisely, environmental concerns and fuel supply security are the main driving factors behind the growth of district heating in most countries. District heating (DH) networks gain in importance, since they facilitate large scale renewable energy integration and a better matching between supply and demand [1]. A district heating system is composed of many elements, building a chain from the heat source to the heated buildings. During the last years it has been demonstrated that low-temperature district heating (supply temperatures lower than 65°C) is the next evolution in district heating systems. Recently, the performance of two consumer units for a low temperature district heating net was investigated using TRNsys [2]. A numerical modeling and experimental measurements for a low-temperature district heating substation for instantaneous preparation of domestic hot water was presented by Marek Brand [3]. While Rämä and Sipilä [4] studied the problem on low heat density district heating network design in a representative case of a low heat density area. In this context, simulation tools play an important role for design, operational optimization, and performance evaluation of those complex systems.

This study deals with the energy performance assessment of one of the systems component (consumer substation) installed in this low-temperature district heating system. In this study a comparative analysis of the energy performance with several existing district heating substation was carried out. This paper describes the simulation model and the performance evaluation of several configuration of district heating substation. Three different district heating substation models are set up (using TRNsys) for investigation of the gross energy use, energy-efficiency and comfort issues. The building energy simulation model is used to investigate three types of dwelling substations: a direct substation type DSH – without heat exchanger in the space heating circuit and instantaneous hot water preparation-, a direct substation type DSHST -with local storage tank and without heat exchanger in the space heating circuit- and an indirect substation type ISH (without a local storage tank but with heat exchanger in the space heating circuit. For each type of substation two scenarios regarding space heating system were analyzed: a) Radiator system; b) floor heating system. The study generate understandings for energy saving operational strategies to be developed. Results indicate that the design concept together with a suitable selection of the substation has an important impact on the energy performance of the entire system.

2. DISTRICT HEATING DESCRIPTION

The case-study collective heating systems are designed for a multi-family building with 25 dwellings on 5 floors. The collective heat distribution system distributes heat for space heating and domestic hot water production from a central plant in the basement to the individual apartments, which are equipped with the customer substation. For this general building and system geometry, two variants were designed with a similar energy performance of the building but different space heating system. The analysis was carried for a low-energy building with a heat supply temperature of 60°C to the substations and highly insulated collective heat distribution pipes. One case is the one where the space heating system is based on radiator with supply temperature of 60°C and return temperature of 40°C.

The other case is the option with space heating system based on floor heating with supply temperature of 35°C and return temperature of 25°C. Both cases work with variable supply temperature in function of the outdoor condition as control strategies for space heating.

First the apartments are designed and their heat demand for space heating and domestic hot water is calculated with the Flemish building energy performance (EPB) software. Three types of apartments were designed, with different floor areas (90 to 150 m²), and different thermal performance. The resulting net energy demand for space heating of the apartments is between 15 and 30 kWh/m²/year, so the dwellings are low-energy or passive dwellings [5]. The domestic hot water demand is equal for dwellings in both cases, since those are only dependent on the dimensions of the dwellings. Table 1 summarizes the information regarding the selected dwellings.

Chart 1: Energy use for the low, normal and high profile

Type of House in the building	Number of house	Area (m²)	Volume. (m³)	Space heating (kWh/m²/year)	Hot tap water (kWh/day)
1	10	90	312	15	2.7
2	5	119	427	22	3.5
3	10	148	490	27	3.9

In the EPB calculations the monthly heating demand of the energy sectors is calculated and the monthly energy demand for domestic hot water is estimated. For the purpose of dynamic simulations with smaller time steps (30 seconds), energy demand profiles for space heating and domestic hot water were developed such that they equalise the energy demands in EPB when accumulated to monthly values. Although a multi-family buildings is a representative case, it contains all components of a district heating system: a central plant, a distribution network and a number of dwelling substations. The distribution networks of the buildings are connected to a central heat generation plant through simple pipes. The one-way network length is *125 m*. The diameters of the pipes in the network were calculated for network layouts with 25 connected dwellings with supply pipe temperatures of *60°C*. Fluid velocities were restricted to *1 m/s* inside dwellings, *1.5 m/s* in trunks, *2 m/s* in the basement and *2,5m/s* outside [6], [7] and [8]. In order to reduce the heat losses in the distribution system, the pipes are insulated with PUR-foam that has linear heat conductivity (*λ-value*) of *0,022 W/mK* at *60°C*. The pipes themselves are assumed to be made of copper (λ = *401 W/mK*) and the outer casing around the insulation layer is made of polyethylene. An important function of the outer casing is to protect the pipes from direct contact with the surrounding, thus avoiding moisture damage of the pipes insulation material.

3. MODELLING AND SIMULATION

The network and building energy simulation model was carried out by using TRNsys software. Following, the main components in the TRNsys model are described, based on the mathematical reference user guide of TRNsys [9]. A flow mixer component (TRNsys Type11) guarantees the addition of two inlet liquid streams to one outlet stream according to an internally calculated control function. The heat exchangers (TRNSYS Type 91 and Type 5) are respectively used for space heating and domestic hot water circuits. Type 91 is a constant effectiveness heat exchanger, so the effectiveness and the inlet conditions are inputs to the type. Type 5 relies on an effectiveness minimum capacitance approach to modelling a heat exchanger. Under this assumption, it is necessary to provide the heat exchanger's *UA* and inlet conditions. Thermal stratification in the insulated storage tank (TRNsys Type 4) is modeled by assuming that the tank consists of a number of fully-mixed equal volume segments. In the mathematical user guide of TRNsys a detailed description of the model can be found [9].

The pipe model (TESS Type 709) models the thermal behavior of the pipe by splitting the pipe in a number of fluid segments at different temperatures. The calculation of the temperature in each segment takes into account the heat losses to the environment by solving the following differential equation at every time step:

$$M_j C_p \frac{dT_j}{dt} = (UA)_j (T_j - T_{environment}) \quad (1)$$

With *UA* the overall energy loss rate from the pipe (*kJ/h*), C_p the specific heat of the fluid in (*kJ/kgK*) and $T_{environment}$ the temperature of the surroundings of the pipe (*°C*).

Direct substation type DSH

As was mentioned before, in this study three substation unit has been used. In a directly connected substation the heat is transferred to the house space heating system by the primary water flow through the internal house circuit. The direct substation type DSH is equipped with a heat exchanger for transferring heat from the network to the tap water, while the individual SH systems are supplied with hot water from the collective network (figure 1). The return pipe of the space heating has a bypass which allow regulate the flow rate in function of the heat demand and supply temperature required.

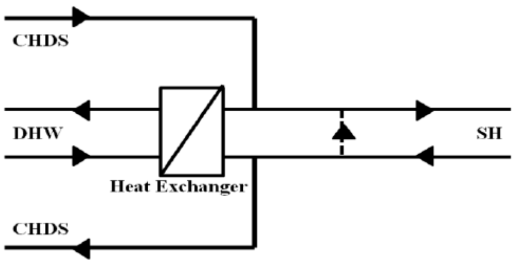

Fig. 1 Scheme of the direct system.

In addition to the geometrical properties of the network, the impact on the working mode of the distribution system by the control strategies of the local unit at customer side have to be considered. In the analyzed substation, a self-sensing temperature regulator indexed in the plate heat exchanger controls the hot water temperature. This measures the temperature of the hot water in the heat exchanger and automatically adjusts the outgoing flow. Besides, the control activate a minimum flow rate when the temperature drop below 50°C degrees after a long period without demand [10]. The substation models were implemented in TRNSYS and tested with actual measured values in order to exclude mistakes and check the correct behaviour of the substation. Figure 2 displays the final model of the substation. We can see the different components used to model the substation. The main components are a heat exchanger named *DHW HX* and a pump used for space heating.

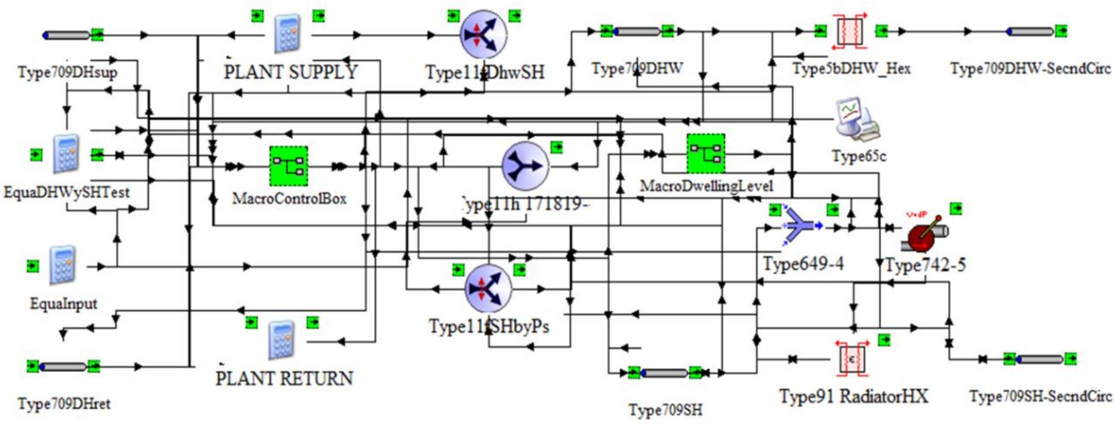

Figure 2: TRNSYS model of the DSH substation

The green box, named *Macro Control Box,* contains the control scheme of the different components of the substation. Two PI control (*Valve DHW* and *Pump SH*) are used to guarantee the hysteresis behaviour of the control strategy. To handle the appropriate temperature and flow rate for domestic hot water and space heating, both mixing and diverter hydraulic components have been used. Finally the domestic hot water profile, the temperature set points, as well as the solar gains have been modelled by use of components which allow to define a schedule for a given input. Figure 3 presents a comparison of the simulation results and the calibration of the model with information available from the manufacturer. The graph clearly shows that the model is able to describe the actual performance of the substation adequately. Both heating demand and domestic hot water behaviour present similar results.

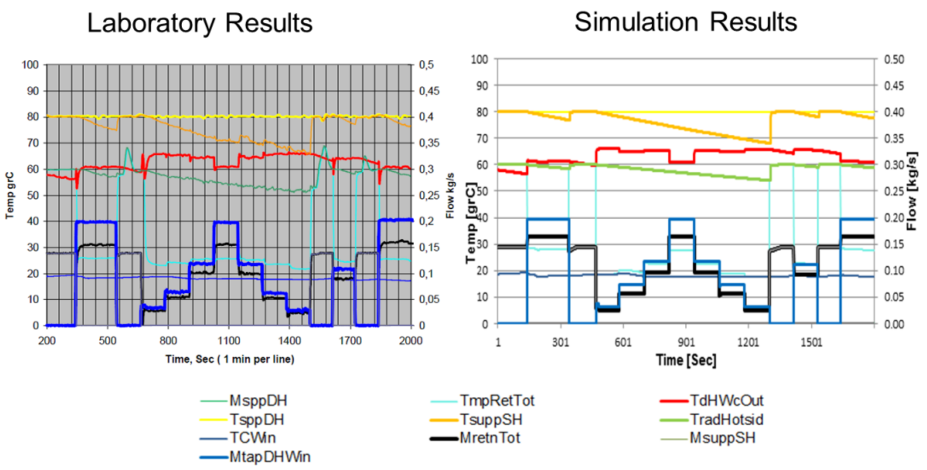

Figure 3: Calibration of the TRNSYS model of the DSH substation

Indirect substation type ISH

In an indirect connection the secondary system is hydraulically separated from the primary side with a heat exchanger. The indirect substation type ISH have two heat exchangers for transferring heat from the primary water flow of the network to both the tap water and the SH systems. This substation presents a self-sensing temperature regulator indexed in the plate heat exchanger to controls the hot water temperature as well. Thus, regarding recirculation control, performance in a similar way of the DSH substation.

Direct substation type DSHST

The substation type DSHST is a more complex type of substation (figure 4). Its main components are a tank for storing water from the collective part of the district heating system , a plate heat exchanger for heating tap water, a connection from the collective network to the dwelling space heating system and a bypass between the storage tank outlet and the space heating system which can be used to further reduce the temperature of the water returning to the DH network. The entire system is provided with a rather complex control system [11].

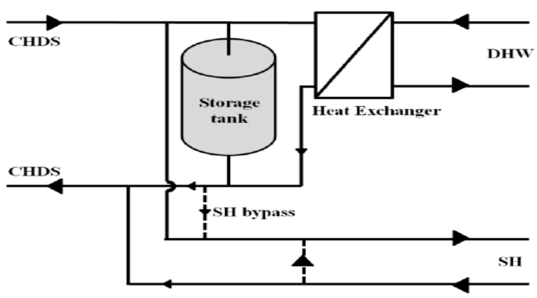

Figure 4: Scheme of the direct system with storage tank.

The storage tank is filled with heating water coming from the district heating supply. On the moment that domestic hot water is wanted, heating water is extracted at the top of the storage tank and sent through the heat exchanger. The cold water returning from the heat exchanger is pushed into the tank at the bottom. When the tank is getting too cold, heating water is immediately supplied from the district heating network and return water goes immediately back to the district heating (DH bypass). In order to guarantee a proper operation of the substation, a control strategy is imposed. Synchronous and successive actions and commands are summarised in the decision making tree in figure 5. In addition to the components used to simulate the direct substation, a storage tank component is included, as can be seen in figure 6.

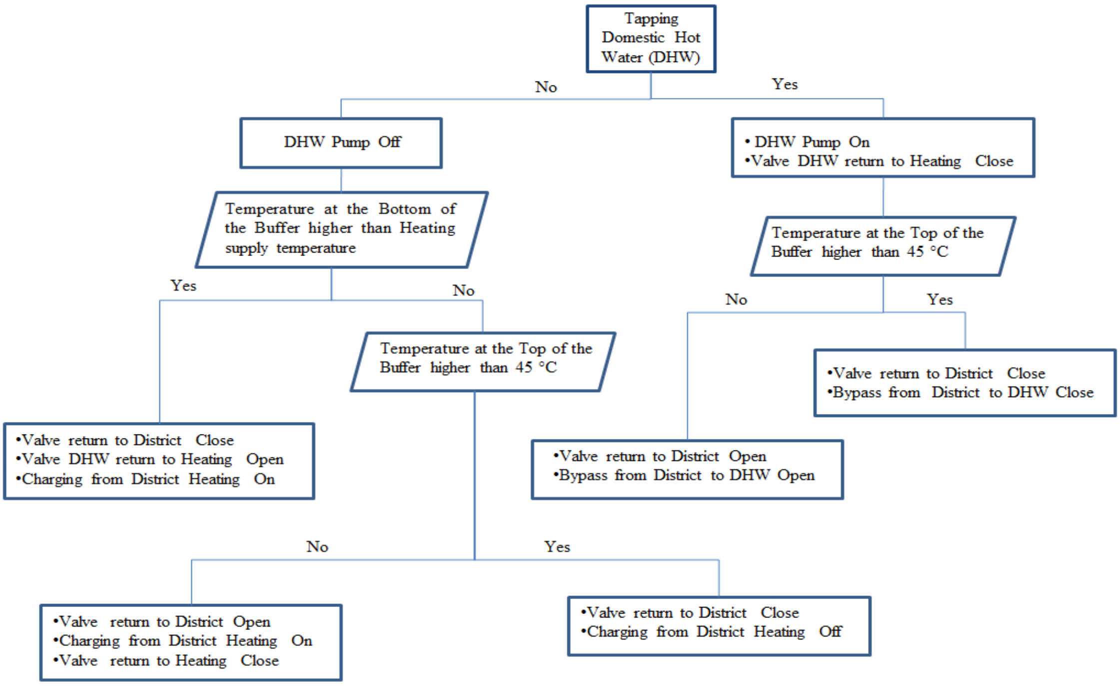

Figure 5: Decision making tree for the Indirect substation control strategy

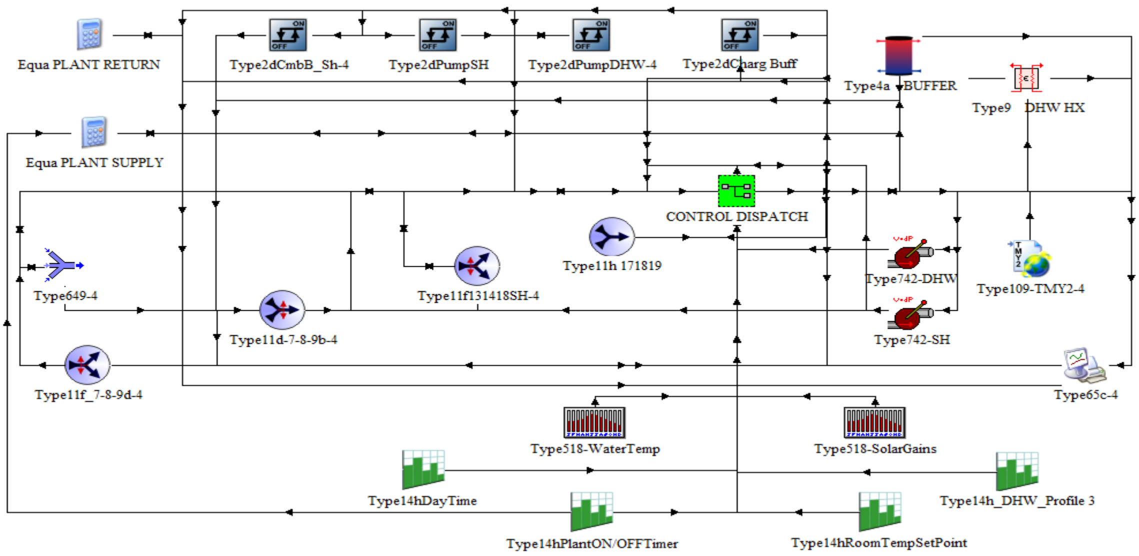

Figure 6: TRNSYS model of the DSHST substation

When space heating is required, heating water is immediately commanded at the district heating supply so heating water from the storage tank is not used for space heating. In the space heating circuit, heating water from the district heating supply is mixed with colder heating water at the floor heating outlet, in order to provide the desired temperature in the space heating circuit. When the temperature in the storage tank is too low (because there has been a domestic hot water tap or because of the heat losses of the tank during long waiting periods), heating water from the district heating supply is led into the tank and the colder water at the bottom of the tank is led out the tank. If the temperature of the water going out of the tank is lower than the temperature in the space heating circuit, than it is immediately sent to the district heating return network. If the temperature of the outgoing water is higher than the temperature of the space heating circuit, the water is sent through the bypass and mixed into the space heating circuit. Thus, the colder heating water is further cooled down before it is sent to the district heating return.

In a next step, the dwelling substations, the distribution network, the simplified model of the central plant and output data are assembled in an overall file. Figure 7 shows this configuration. The *Macro Plant* shows the central plant and *Macro Building Network* includes the building network and the integrated substation models.

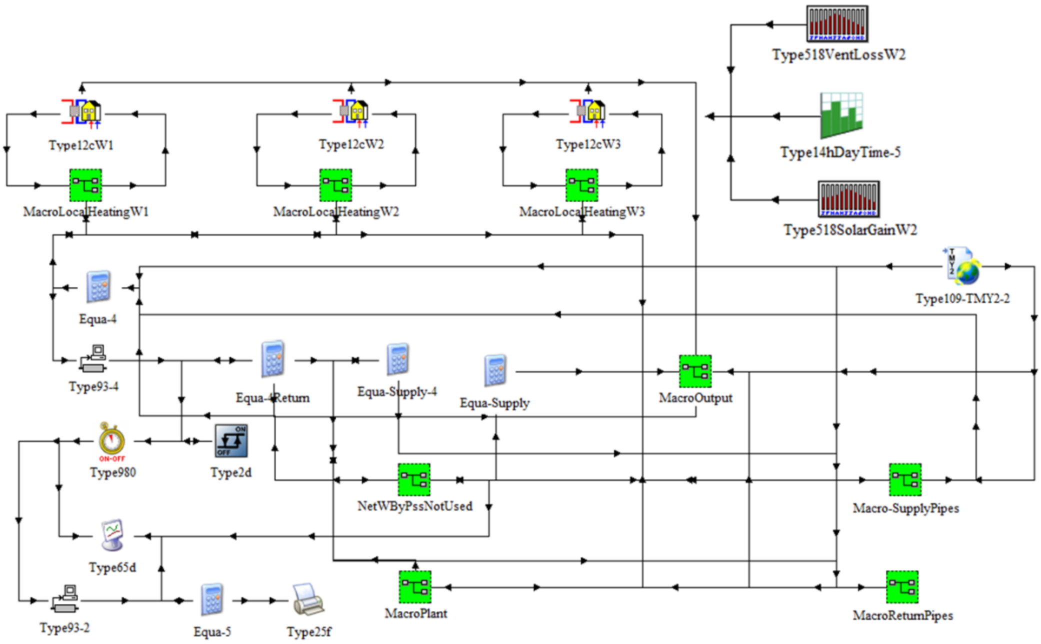

Figure 7: TRNSYS model of the System

4. SYSTEM SIMULATION RESULTS

Simulations were made on the different levels of the district heating system, starting from the individual substation up to the distribution system. In this section, some results on the characteristics and behaviour of the substations and network are reported. The behaviour of the individual dwelling substations is investigated with regard to the flow rate as well as to the supply and return temperature, so the district heating distribution network is not considered here. Figure 8 presents the results of the simulations for a DHS substation of the low-energy building where design temperatures for the substations are 60°C /22°C for DHW production and 60°C/40°C for space heating. The simulation period is one day and the energy demand profile corresponds to dwelling type 2

Results reflect the behavior of the supply temperature, red line with a trend to reach 50°C when there is not domestic hot water demand. The value increases up to 60°C when there is a heat demand, this can be seen between 6.00 and 8.00h. After this hours of demands, the gradient of temperature drop as a result of the heat losses in the substation can be observed. The orange lines represent the flow rate of space heating. It can be noticed that the system is only active during a certain period of the day. The return temperature of the total substation to the collective heating network is showed with a blue line.

Results denote the temperature behaviour in function of the heat demands with higher value when there is space heating demand and lower value during domestic hot water demand. When there is no domestic hot water demand for a long period the return temperature tends to rise, converging to about 40°C during recirculation.

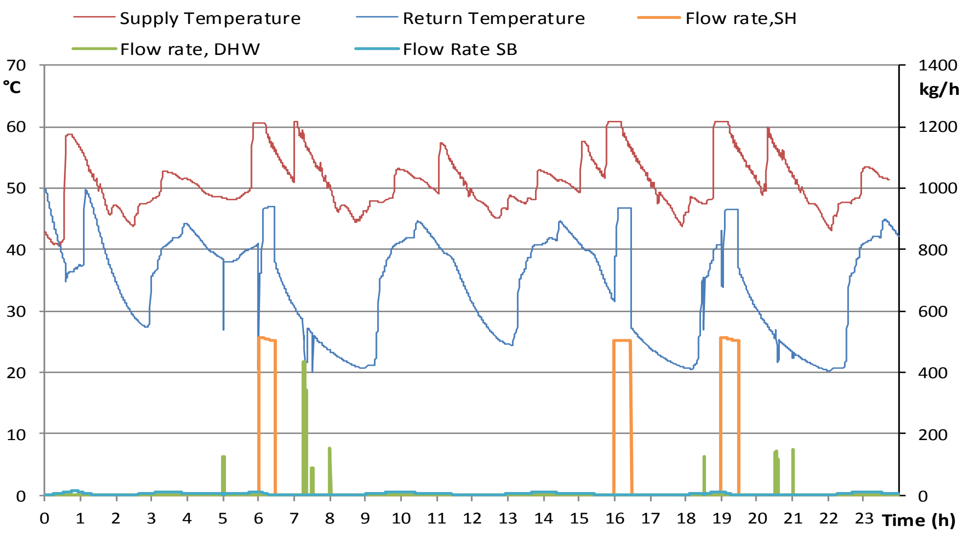

Figure 8: Supply and Return temperature at the substation of one dwellings with DHS substation

Return temperatures from the substation to the network

In the next sections, the temperatures appearing in the distribution network are discussed. In the distribution system the temperature produced at the plant is 61°C and the design temperature at the substation is 60°C. The return temperatures from the substations of the three different dwelling types were analysed in detail, based on simulation results with a time-step of 30 s. during winter and summer conditions. In figure 9 the return temperatures from the substations are summarised per operation mode for one week simulation in January

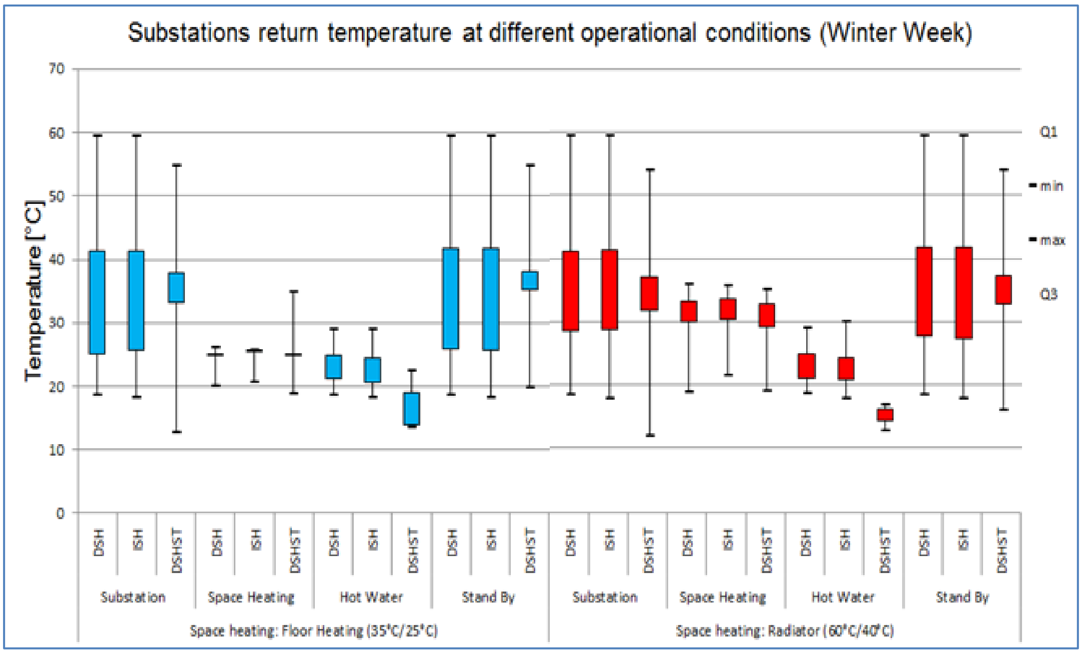

Figure 9: Return temperatures at different operational conditions radiator and floor heating for space

The results for the 3 different dwelling types were integrated, taking into account the proportions in which they appear in the multi-family building. A variable space heating supply temperature dependent on the outdoor temperature as a control strategy was considered. Two operational range of temperature 60°C/40°C (radiator) and 35°C /25°C (floor heating) for each substation were simulated.

The three variants of substation type differ with regard to the interactions between space heating control and domestic hot water circuit. In two of the analysed substations direct heating supply , DHS and indirect heating supply IHS, there are no interaction between domestic hot water and space heating circuit, so the return temperatures during hot water generation and stand-by are similar independently of the space heating system (ie., radiator or floor heating). The return temperatures during domestic hot water generation are on average 23°C and vary between 18 and 29°C. During stand-by the minimal temperature equals the minimal temperature during domestic hot water demand and the maximal temperature comes close to the district heating supply temperature at the substation. The average return temperature during stand-by is 35°C for the DHS substation and 34,5°C for the IHS system in both situation with radiator and floor heating system.

On the other hand in the substation type DHSST there is interaction between the control of both type of energy demand. As was aforementioned an important components of this substation is the storage tank for storing water from the collective part of the district heating system. Since the cold water returning from the heat exchanger is pushed into the tank at the bottom and there is a bypass between the storage tank outlet and the space heating system, the influence of the entire control system is rather complex. Results denotes that the hot water return temperature is lower when using radiator as space heating system with an average value of 15 °C. In both cases with radiator and floor heating system this substation type presents lower values of hot water return temperature in comparison with other two substation types

The primary return temperature during space heating demand is on average 32°C, with a maximum return of only 36°C for the three substation when using radiator as space system. For the case of floor heating system the substation presents an average around 25°C. While the difference in return temperature during space heating is significant for both system, the overall return temperature of the substation is on average 36,5°C for the substations DHS and IHS as well as 34,5°C for the substation with storage tank DHSST in both cases with radiator and floor heating .

Temperatures in the distribution network

Figure 10, displays the monthly average temperatures in the supply (blue) and return (green) pipes of the heat distribution system, from the pipes near the central plant (darkest colours) to the substation connection pipes (lightest colours) for the case of substation type DHS. The heat generation plant provides a temperature of 61°C to the distribution network. The yearly average temperature of the first supply pipe of the network (TSPO) is almost 61°C, and the hourly temperatures in this pipe are always between 59 and 61°C. Due to heat losses to the pipe environment, the monthly average temperature in the next supply pipes will decrease.

Figure 10 clearly shows that the more distant a supply pipe is from the plant, the lower its monthly average temperature. In the substation supply connection pipes (TS1F1 to TS1F5), the monthly average temperature is between maximum 55°C in winter and minimum 50°C in summer. The lower averages during summer appear as a result of the cooling down of the network pipes when the substations are in stand-by mode. The hourly average temperatures of these pipes are between 45°C and 60°C, and thus despite of their low monthly average temperatures, the space heating design supply temperature of 60°C can also be obtained in the most distant substation connections when needed.

The return temperatures from the substations (TRF1 to TRF5) are dependent on the space heating and domestic hot water demand profiles. As a result, the hourly average return temperatures vary between 19°C and 49°C, leading to monthly average return temperatures of minimum 34°C in winter and maximum 39°C during summer (averaged over the three profiles). Cooling-down of the network finally leads to return temperatures at the central plant of around 33°C in winter and 35°C in summer.

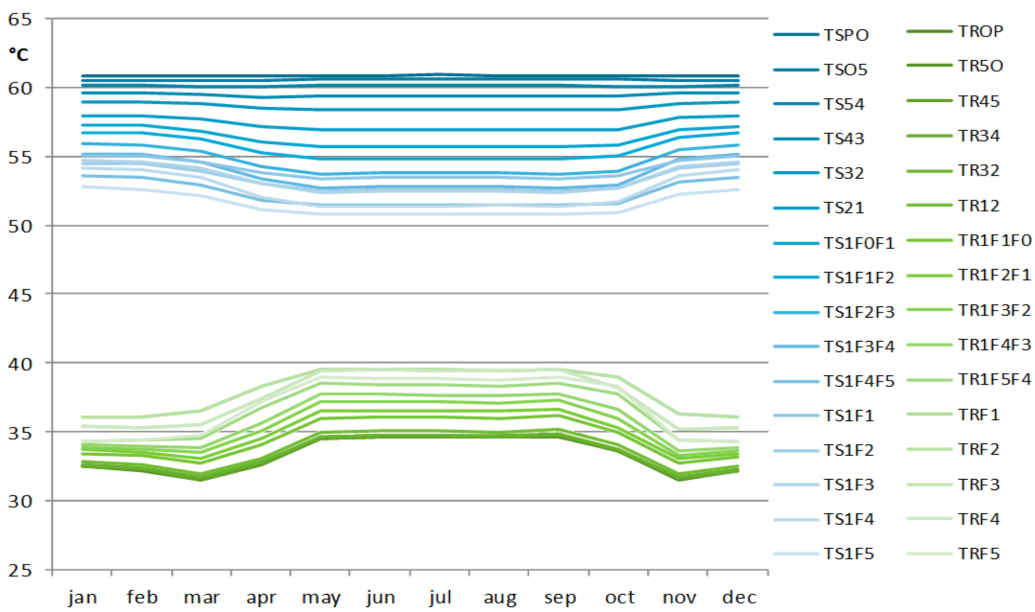

Figure 10: Temperatures in Supply and Return pipes from main pipes (in dark) to substation (light)

Heat losses in the distribution network

Figure 11 illustrates the distribution heat losses for the different variants analysed. The heat losses are higher in winter than in summer, as a result of the higher temperature of the heating medium and the lower temperature of the pipe environment. However since the seasonal temperature variation both inside and around the pipes is not that big (the pipes are located in an unheated part of the building, not outside), the differences between summer and winter season are smaller than 15%. The differences between the system with the substations without storage tank, thus instantaneous preparation of domestic hot water and the one with storage tank remind somewhat about 12% and it is related to the reduction of the pipe diameter in the distribution network and the decrease of flow rate requirement during operation when a storage tank is used.

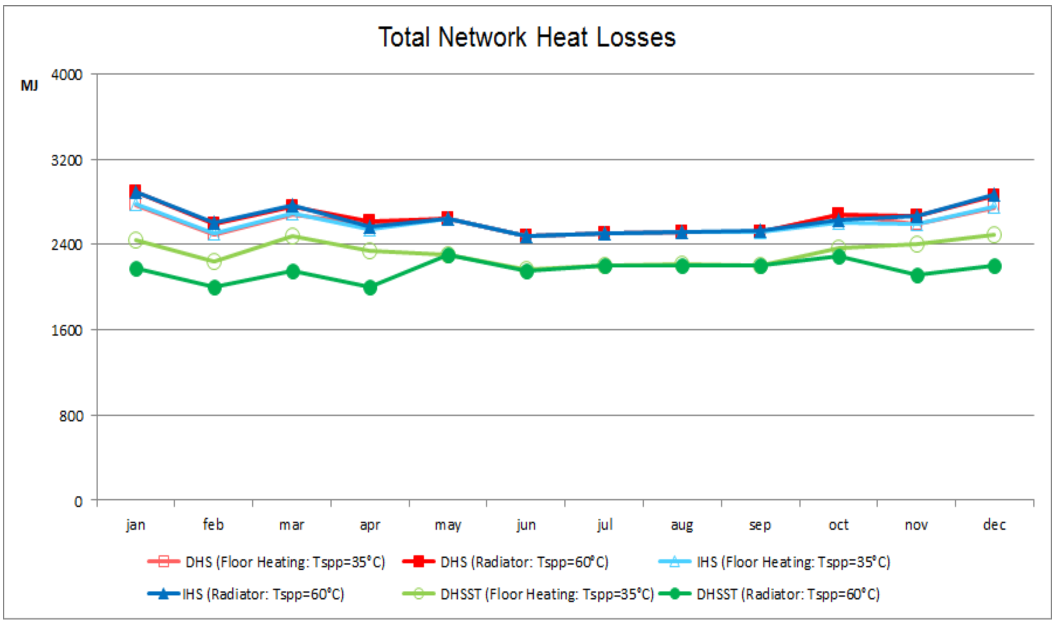

Figure11: Heat losses in the distribution network

It can be clearly seen that for the two substations with instantaneous hot water production, DHS and HIS, during the summer there is not difference of the heat losses when a different space heating system is used. Similarly occur with the substation DHSST during summer, where the losses are equal independently that if radiator or floor heating is used. An interesting behaviour can be identified during winter in the case of the substation with storage tank. Two elements of the heat losses during winter for the case of DHSST are remarkable.

Firstly a reduction of the heat losses somewhat about 15% when a radiator is used with respect to the heat losses when floor heating is installed. An explanation of this behaviour can be on the combination of the effect of increased operational temperature difference between supply and return of the space heating for the two analysed system. Noted that when radiator is used the difference is twice that those for the floor heating. Similar explanation can be used to understand the difference between winter and summer in the case DHSST with radiator. In addition to the significant reduction of the flow rate as a result of a larger temperature difference during winter, the increase of the recirculation during summer due to larger period of stand by without demand contribute to rice the heat losses in the summer. As a result of more recirculation the average temperature in the return pipe network increases causing an increase of the heat losses, as well.

Hot water comfort

Finally, beside to the gross energy use and energy-efficiency of the different studied substation, comfort issues were also investigated. Takes into account the customer satisfaction becomes an important element when evaluating district heating substation performance. The domestic hot water comfort is calculated as the mass flow rate that is withdrawn at temperatures above 40 °C divided by the total hot water consumption. The three studied substations presents a high level of hot water comfort reaching values around to the 98% of comfort in all the different alternative analyzed. In addition to the temperature conditions, customer comfort satisfaction is influenced by time required for DHW to reach a fixed temperature level after tapping was started, the so called waiting time. This parameter is also known as recovery time or tap delay. Based on the same European standard the waiting time t_m *(s)* is defined as the time taken to reach, at appliance outlet, a domestic hot water temperature higher than 44°C. Figure 12 presents an evaluation of this indicator for the three different dwelling studied. The graphic show the temperature of tap water deliveries at each substation after a long period without hot water demand.

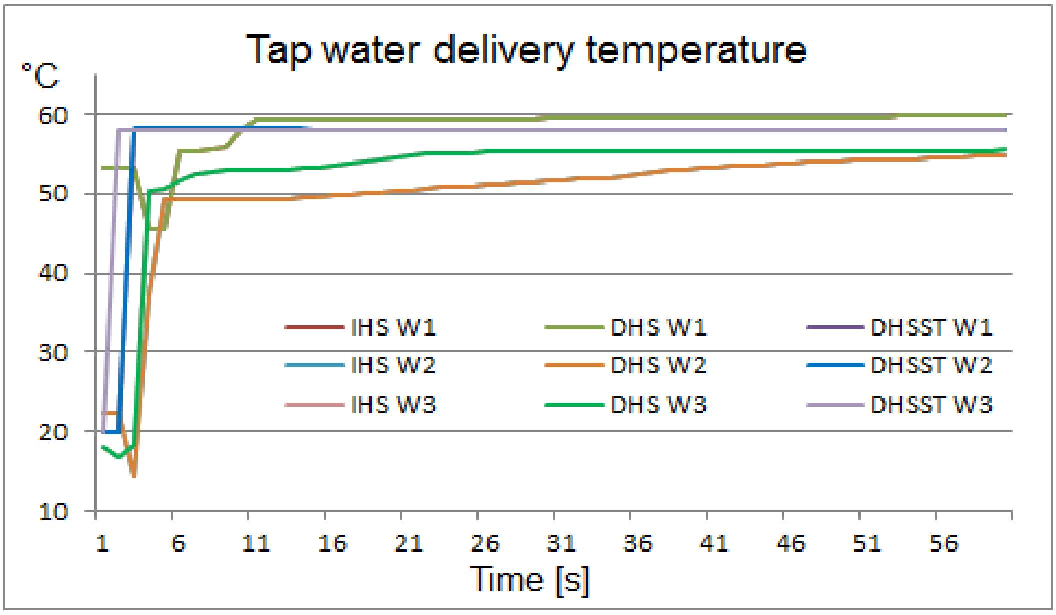

Figure 12: Substations Tap water deliveries temperature

It can be clearly see that the three substation guarantee temperature higher than 50 °C between the first five second. The substation DHSST presents a lower value of waiting time and the stability delivery temperature is more rapidly reached. The substation with instantaneous hot water production, DHS and IHS presents a quite good performance, as well.

5. CONCLUSION

The study aims to investigate the impact of different operational circumstances on the performance of district heating substations. The study generate understandings for energy saving operational strategies to be developed. Results indicate that the design concept together with a suitable selection of the substation has an important impact on the energy performance of the entire system. Regarding heat losses in distribution network the substation with storage tank performance better that those without storage tank. However, for a whole view of the efficiency aspect the losses in the storage tank should be taken into account. In addition economical consideration should also be studied in order to evaluate if the heat losses reduction as well as the reduction on pipe cost presented when installing a substation with storage tank compensate the increases of the investment cost regarding the substation cost. From the comfort point of view the three substation performance in a satisfactorily way.

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REFERENCES

[1] BEN HASSINE I., EICKER U. “Simulation and optimization of the district heating network in Scharnhauser Park”, *2nd Polygeneration Conference*, Tarragona, 2011.
[2] FAN Jianhua, FURBO Simon, SVENDSEN Svend “TRNSYS Simulation of the Consumer Unit for Low Energy District Heating Net”. *Project report Department of Civil Engineering, Technical University of Denmark*, Denmark, 2006.
[3] BRAND M, THORSEN JE and SVENDSEN S, “Numerical modelling and experimental measurements for a low-temperature district heating substation for instantaneous preparation of DHW with respect to service pipes” *Energy*, vol 41, no. 1, pp. 392-400.
[4] RÄMÄ, M., SIPILÄ, K. 2010 “Challenges on low heat density district heating network design”. *Proceedings of the 12th International Symposium on District Heating and Cooling*. 2010 Tallinn, Estonia.
[5] HIMPE E. , VAILLANT REBOLLAR J.E. and JANSSENS A., " Heat losses in collective heat distribution systems: an improved method for EPBD calculations ", The 14th International Symposium on District Heating and Cooling, Stockholm, Sweden, 2014.
[6] VAN DEN BOSSCHE, P., “Warm water”, *Cursus energietechniek in gebouwen: WTCB*, 2007
[7] KREPS S., DE CUYPER K., VANASSCHE S., and VRANCKEN K., “Best Beschikbare Technieken (BBT) voor Legionella-beheersing in Nieuwe Sanitaire”, 2008
[8] OLSEN P.K., H. LAMBERTSEN, HUMMELSHOJ R., BOHM B., CHRISTIANSEN C.H., SVENDSEN S., LARSEN C.T., and WORM J., 2008. “A new low-temperature district heating system for low-energy buildings” *The 11th International Symposium on District Heating and cooling*, Reykjavik, Iceland, 2008.
[9] TRANSSOLAR, CSTB, TESS TRNsys 17, “A Transient System Simulation Program”, 2010.
[10] Laval, A., Alfa Laval - Mini City Direct STC Lund, 2012.
[11] Danfoss 2012, “Danfoss - Comfort series for low-temperature district heating is available in two variants LGS and LGM”, Denmark, 2012.