HEAT LOSSES IN COLLECTIVE HEAT DISTRIBUTION SYSTEMS: COMPARING SIMPLIFIED CALCULATION METHODS WITH DYNAMIC SIMULATIONS

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ABSTRACT

Heat losses in collective heat distribution systems can be reduced significantly in well-insulated and well-controlled low-temperature networks. However, this reduction is not always rewarded for in legislative energy performance of building standards in Europe. In this paper, simplified heat loss calculation methods (SCM) are compared to dynamic simulations for networks that distribute heat for both space heating and domestic hot water to low-energy houses. Results show that SCMs overestimate the distribution heat losses in these systems and that the variation in heat losses due to seasonal behaviour and control strategies is little addressed. An investigation of the influential parameters showed that they can be significantly improved by a more accurate estimation of the working time of the system and average temperature of the heat conducting medium.

INTRODUCTION

In the evolution towards renewable energy supply in buildings, collective heat distribution systems (CHDS) are seen as a promising solution for the distribution of heat for both space heating (SH) and domestic hot water (DHW) from a central generation plant to low-energy dwellings. The more so as distribution heat losses can be reduced significantly in well-controlled and well-insulated low-temperature networks. However, this reduction is not always rewarded in the simplified calculation methods (SCM) of the energy performance of building directive (EPBD) implementations in Europe. Most of them are tailored to distribution systems for space heating or domestic hot water loops, but they do not provide an adequate calculation method for combined SH and DHW distribution systems. Especially in CHDS for low-energy houses, where the heat demand is no longer dominated by SH, existing methods are not satisfactory. Therefore the goal of this study is to identify influential parameters and values for an improved simplified heat loss calculation method for combined DHW and SH networks. First, a small-scale case-study CHDS for combined SH and DHW is designed and modelled. For this system, three scenarios were designed, with two types of dwelling substations and different control strategies. Next, existing simplified calculation formulas from the Flemish, Dutch and European EPBD-standards are explained. Finally, the dynamic simulation (DSM) and SCM results are discussed and compared. Two influential parameters of the SCM are observed in detail: the average temperature $\theta_{net,m}$ of the heat conducting medium in the distribution network and the monthly working time $t_{net,m}$ of the distribution system. Improvements to the SCMs are investigated.

SIMULATIONS

The subject of this study is a small-scale collective heating system, providing heat for both space heating and domestic hot water in a multi-family building with 25 apartments (Figure 1). This system contains the essential parts of a district heating system: a central plant, a collective heat distribution network, 25 dwelling substations and energy demand functions for SH and DHW. The transient system simulation tool TRNSYS is used to make a dynamic simulation model (DSM) of this system.

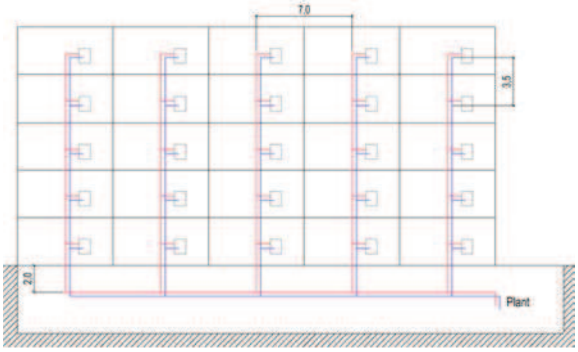

Figure 1: Building and distribution network scheme

Energy demand

The building consists of low-energy apartments with on average 3 inhabitants and 1,9 kW design heat losses at the winter design temperature θ_{amb} of -8°C. As the heat demand of the building is determined by DHW rather than SH, it was decided to use a simple model for the SH demand and to provide detailed DHW demand profiles. Regarding DHW, three energy demand profiles were developed for a household with on average 3 inhabitants: a 'low', 'normal' and 'high' day profile (Table 1). The resulting average energy use is about 5,3kWh/day, which is similar to 132l/day at 45°C. The allowed minimum tapwater temperature is 42°C.

Time	Low	Normal	High
7:00		small	small
7:05			**shower**
7:15		**shower**	**bath**
7:30	small	small	small
8:01		small	small
8:30	small		
9:30	small		
11:30	small		
11:45	small	small	small
12:45	small dish washing	small dish washing	small dish washing
18:00	small		
18:15	clean	clean	clean
18:30		clean	clean
20:30	medium dish washing	medium dish washing	large dish washing
21:00		small	**bath**
21:30	**large**	**shower**	small
Energy (kWh/day)	**2,0**	**5,4**	**11,6**
Water (l/day @45°C)	49	134	288
Occurrence ratio	40%	40%	20%

Table 1: Daily DHW demand profiles

Regarding SH, each apartment has a floor heating system 35/25°C. The space heating control is designed according to a general expression for the space heating demand Q_{SH} [in W]:

$$Q_{SH} = U \times A \times (\theta_{int} - \theta_{ext}) - I - S \quad (1)$$

The constant $U \times A$ is 72W/K and the internal gains I are 485W. During daytime solar gains S are considered through the use of average monthly values. The set point temperature is 21°C by day and 16°C during the night. Hourly ambient temperatures are selected for the Belgian climate.

Substations

A substation is a component which connects and separates the CHDS with the individual SH system and DHW pipes. In this project two types of substations are simulated, that is one *direct* system without storage and an *indirect* system with a local storage tank. The direct substation (Figure 2) is equipped with a heat exchanger for transferring heat from the network to the tapwater, while the individual SH systems are supplied with hot water from the collective network.

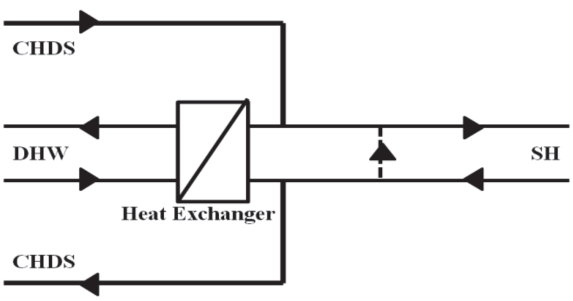

Figure 2: Direct substation scheme (AlfaLaval, 2012)

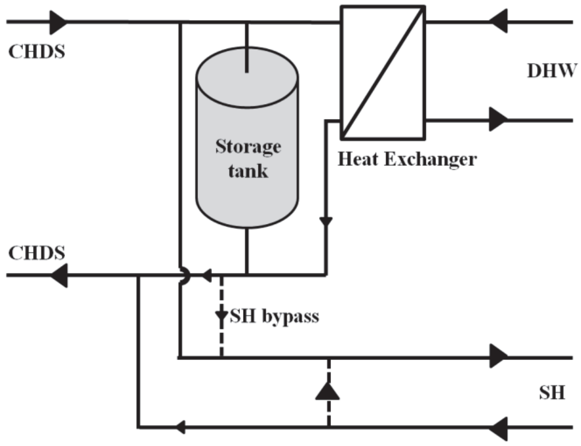

Figure 3: Indirect substation scheme (Danfoss, 2011)

The indirect system (Figure 3) has a storage tank on the collective heating side and a heat exchanger to the DHW side of the system. The outlet of the storage tank has a bypass to the floor heating system, which can be used to further reduce the temperature of the water returning to the CHDS.

Distribution network

The collective heat distribution network consists of supply and return pipes, measuring 125m each. The basic element of the network sub-models is a vertical pipe in the technical trunk of the building to which the substations of 5 apartments are connected (Figure 1). This vertical element is repeated for each of the five trunks and at the top of each trunk, a bypass between supply and return pipes enables recirculation through the network. Horizontal pipes on the basement level connect the vertical pipes with the central plant. The fluid velocities in the pipes were restricted to 1 m/s in dwellings, 1,5m/s in trunks, 2m/s in the basement and 2,5m/s outside (Kreps et al. 2007; Olsen et al., 2008; Recknagel et al., 1996). The pipe diameters depend also on the peak flow rates in the network, which are in turn dependent on the substation type. For the direct substation the peak flow rate is 0,37l/s, calculated according to Recknagel et al. (1996, p. 1117). For the indirect substation, the peak flow rate of 0,043 l/s was derived from the simulations. The copper pipes are insulated with PUR-foam with a thermal conductivity of 0,022W/mK at 50°C. The insulation thickness is between 25 and 35 mm, depending on the pipe diameter. As a result, the heat loss coefficient of the pipes is between 0,07 and 0,14 W/mK. Heat losses through special and irregular elements (bearing structures, flanges, fittings, pipe suspensions…) are not regarded in this study.

Through variations in the control strategies, different working modes for the distribution networks were designed. The continuous working mode *"24/24"*, with continuous heat circulation through the collective network, is designed for both scenarios equipped with direct or indirect substations. During periods with no heat demand, the circulation flow rate drops down in order to reduce velocities below 0,5m/s. For the scenario in which the collective heat system is equipped with direct substations, also an intermittent "*on/off*" operation mode is designed, in which the distribution system is able to work at every moment, but it actually works only at the moment there is a heat demand (no demand = no flow).

The plant

The supply temperature of the collective heating system is fixed at 55°C, as renewable heat generation systems often provide heat at a lower temperature. The heat generation plant is simplified to a generic element that turns the return temperature to the plant into the fixed supply temperature.

SIMPLIFIED CALCULATION METHODS

In this section, SCM for the heat losses in CHDS are described. They are part of the legislative building energy performance calculation methods in the EU. The Flemish EPBD-implementation is taken as a starting point (Energiebesluit 2010, Inrekening combilus 2011), and alternative approaches are found in the Dutch and European standards NEN7120+C2:2012, EN15316-2-3:2007 and EN15316-3-2:2007.

General

In the Flemish EPBD-implementation, calculation of the monthly heat losses $Q_{loss,m}$ in the distribution network [in MJ/month] is based on the general physical formula:

$$Q_{loss,m} = t_{net,m} \times \sum_j \left(\theta_{net,m} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) \qquad (2)$$

in which $t_{net,m}$ is the monthly operation time of the distribution network, $\theta_{net,m}$ is the monthly average temperature of the heat conducting medium in the network, l_j is the length of a pipe element *j*, $R_{l,j}$ is the linear thermal resistance of this pipe element and $\theta_{amb,m}$ is the average temperature of the pipe environment: the conditioned space ($\theta_{amb,m,j} = \theta_{interior}$ = 18°C), the technical stairs and corridors ($\theta_{amb,m,j}$ = 11 + 0,4 $\theta_{exterior,m}$) or the outdoor space ($\theta_{amb,m,j} = \theta_{exterior,m}$). The calculation time step is one month, so all parameters are monthly averages. Calculation of the thermal heat resistance $R_{l,j}$ of a pipe element is based on the NBN EN ISO 12241:2008 standard. For example this equation is used for unburied circular pipes [in mK/W]:

$$R_{l,j} = \frac{1}{2\pi} \times \sum_{j=1}^{n} \frac{1}{\lambda_j} ln\left(\frac{D_{e,j}}{D_{i,j}}\right) + \frac{1}{h_{se,j}\pi \times D_{e,j}} \qquad (3)$$

The Flemish EPBD implementation prescribes fixed values for the surface coefficient of heat transfer: $h_{se,j}$ = 8 W/m²K (for pipes situated within the heated space of the building), 10 W/m²K (for pipes situated in an unheated indoor environment), 25 W/m²K (for exterior unburied pipes).

Three types of collective heat distribution systems are recognised in the implementation of EQUATION 2. The types are dependent on the function to which the heat serves: for SH, for DHW or for combined SH and DHW heat distribution. The definition of $\theta_{amb,m}$, l_j and $R_{l,j}$ is the same in the three cases, whereas rules for $t_{net,m}$ and $\theta_{net,m}$ are different:

Space heating

In case the CHDS is meant for SH only, the monthly time $t_{net,m}$ during which the network is operational, is specified as the maximum of the conventional operation times of the heat emission systems in the different conditioned areas (dwellings). In a similar way, the monthly average temperature of the heat conducting medium in the network, $\theta_{net,m}$, is the maximum of the monthly average temperatures in the heat emission systems in the different conditioned areas. Both operation times and average temperatures can be calculated for systems with variable and with constant supply temperatures (Energiebesluit 2010). In the European and Dutch standards, the general equation is similar to EQUATION 2, and variations exist in the calculation of R, $t_{net,m}$ and $\theta_{net,m}$. In the Dutch standard it is an option to use a continuous operation time (full month), while European EN15316-2-3:2007 standards use their own methods to calculate the monthly operation time of the heating system. In both standards, the average heating medium temperatures are calculated or prescribed per month.

Domestic hot water

In case of a collective distribution system for DHW only, the monthly operation time $t_{net,m}$ and average temperature in the network $\theta_{net,m}$ are fixed in the Flemish standard: $t_{net,m}$ is the length of an entire month and $\theta_{net,m}$ is 60°C. These assumptions are very similar to the operation mode of traditional DHW loops in which DHW is produced centrally and circulates in a collective distribution ring at temperatures around 60°C for legionellae safety measures.

In contrast, the European standard EN15316-3-2:2007 distinguishes between the time $t_{net,on}$ that a DHW circulation loop is actually in operation and the period the system is not operating. During the on-period of the system, EQUATION 2 is used and $\theta_{net,m}$ is 60°C in the circulation loops and 32°C in individual pipes (as to regard the cooling of the water in these pipes when there is no demand). The heat losses during the off-period are added in a separate term, with $n_{norm,day}$ is the number of operating cycles of the system. Thus the resulting equation is [in MJ/day]:

$$Q_{loss,DHW} = \left[\sum_j L_j \times U_j \times (\theta_{net} - \theta_{amb}) \times \left(\frac{3600}{10^6}\right) \times t_{net,on,day}\right] + \left[\sum_j \frac{(C_w \times \rho_w)}{1000} \times V_w \times (\theta_{net} - \theta_{amb}) \times n_{norm,day}\right] \qquad (4)$$

The European standard has also inspired the Dutch standard NEN 7120+C2:2012, for the specific case the system is turned off once a day [in MJ/year]:

$$Q_{loss,DHW} = \left[\sum_j L_j \times U_j \times (\theta_{net} - \theta_{amb})\right] \times f_{on} \times t_{on} + \left[\sum_j (c_w \times \rho_w \times V_w + c_m \times \rho_m \times V_m) \times (\theta_{net} - \theta_{amb})\right] \times \frac{365}{10^6} \quad (5)$$

With t_{on} is the length of one year and f_{on} is the relative operation time of the system. In EQUATIONS 4 and 5, c is the specific heat capacity, ρ is the specific mass and V is the volume of the medium. The subscript *w* indicates the heat conducting medium in the pipes (water) and *m* is the pipe material.

Finally, the European standard EN15316-3-2:2007 also proposes a method for detailed calculation of the heat losses due to the temperature decrease of the water in pipes without recirculation. This method takes into account the influence of pipe insulation [in MJ/consumption]:

$$Q_{loss,DHW,max} = \frac{(c_w \times \rho_w \times V_w + c_p \times m_p)}{1000} \times (\theta_{net} - \theta_w) \quad (6)$$

With θ_w the final hot water temperature in pipe section j before the next tapping [in °C]:

$$\vartheta_w = \vartheta_{amb} + e^{\frac{-(q_j \times L_j \times t_{tap})}{(c_w \times \rho_w \times V_w + c_p \times m_p) \times (\theta_{net} - \theta_{amb}) \times 1000}} \times (\theta_{net} - \theta_{amb}) \quad (7)$$

And the density of the heat flow rate [in W/m]:

$$q_j = U_R \times (\theta_{net} - \vartheta_{amb}) \quad (8)$$

Space heating and domestic hot water

Simplified calculation methods for distribution systems serving heat for both SH and DHW consist of minor adaptations to the existing methods for SH or DHW supply. In the Flemish method, the monthly working time $t_{net,m}$ of the system is the length of an entire month, and $\theta_{net,m}$ is the maximum of the monthly average temperatures in the space heating emission systems ànd is at least 60°C. These assumptions reflect the operation mode of a typical DHW circulation system with continuous circulation of DHW at temperatures around 60°C. However, the composition and operation of a combined DHW and SH system are intrinsically different to that of a DHW circulation system. The heat conducting water in the collective distribution system remains in the system and DHW is produced at the dwelling substation by use of a heat exchanger, which is likely to improve legionellae safety. Consequently, intermittent operation modes and lower temperatures become viable. Unlike the considered European standards, the Dutch standard does also provide a SCM for combined systems. Here, the distribution heat losses during the heating season are dealt with in the space heating distribution heat losses, where a fixed temperature of the heating medium is now being used (50 or 65°C). The heat losses outside the heating season are allocated to the DHW system distribution losses. In this case the t_{on} in EQUATION 5 is not the length of a year but the full length of the summer season.

In conclusion, while in the SCMs for SH or for DHW the calculation parameters and their values are more or less in line with the theoretical standard operation modes of these systems, the few available SCMs for combined SH and DHW systems merely reflect a basic combination of the existing methods for SH or DHW rather than an adaptation of the calculation parameters to the specificities and the design of these systems. For example, most existing methods have difficulties to deal with the influence of different operation modes (e.g. intermittent operation).

RESULT ANALYSIS

Dynamic simulations are used to observe two parameters of the SCMs in detail: the average temperature $\theta_{net,m}$ of the heat conducting medium in the distribution network and the monthly working time $t_{net,m}$ of the distribution system. The focus is on the interaction of the SH and DHW heat demand and the influence of operation modes in combined space heating and domestic hot water collective heat distribution systems. The average temperature and working time of a heat distribution network will be influenced by the availability of a local heat storage near the substation, the flow rate control strategy (continuous or intermittent flow, seasonal control), the return temperatures from the substation etc. Therefore, the simulated scenarios include systems with direct and indirect substations and continuous and intermittent operation modes. In order to enable the comparison, assumptions in the SCM and DSM have to be more or less consistent. Thus equal values for environmental properties such as the temperature of the pipe environment and the surface coefficient of heat transfer were used (based on the SCM values). The comparison was made with monthly values, consistent with the SCM. Thus, in the dynamic simulations, results for time steps of 30 seconds were added to monthly values.

Continuous 24/24 DS with direct substations

Figure 4 shows the monthly heat losses in the continuous CHDS with direct substations, according to the dynamic simulation (DSM) and simple calculation (SCM) methods. For the supply part of the network (DSM-SUP), the variation in heat losses is in the same order of magnitude during the entire year, because the supply temperature is constant and the high insulation level softens the influence of the ambient temperature. In the return part of the network (DSM-RET), the heat losses in summer are higher than those in winter, as a result of the higher return temperatures due to recirculation of hot water during summer.

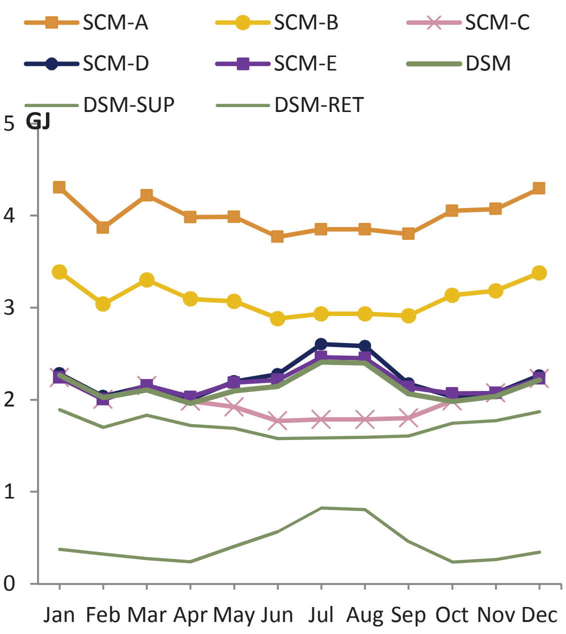

Figure 4: Heat losses in the 24/24 direct CHDS

The Flemish method for CHDS for combined SH and DHW (SCM-A) does overestimate the distribution losses with 60% in July and up to 100% during the heating season, when comparing to the DSM results. These large differences are mainly caused by the difference in yearly average temperature of the heat conducting medium in the entire network, which is lower than 40°C in the results of the DSM. In the Flemish SCM, a continuous working time is assumed and average temperatures $\theta_{net,m}$ are fixed at 60°C. A first improvement to the SCM is found in the application of the Dutch standard (SCM-B), which uses the same equation and $t_{net,m}$ for this type of CHDS, but also offers the possibility to use fixed average temperatures of 50°C for a low-temperature system. However, in both methods the actual temperatures in the return network are disregarded, and thus the average temperatures are overestimated. Therefore, in SCM-C the $\theta_{net,m}$ is changed into the average of design supply and return temperatures at the substation (50/25°C). Here, a much better correlation is achieved with the results of the DSM during the winter months, when there is a continuous heating demand in the system. In fact, the SCM-B represents the expected upper limit for the heat losses in this specific CHDS, in a situation in which there would be no heat demand and continuous recirculation. The SCM-C symbolises the expected lower limit, in a situation with a continuous heat demand in the system. Nevertheless, by use of these yearly average temperatures, it is not possible to take into account the seasonal variations in the behaviour of the system. Therefore, the next step is to introduce monthly average supply and return temperatures at the central plant (SCM-D), that are derived from the simulation results. This method is also used in the Dutch standard for space heating CHDS, though with prescribed values and not for combined space heating and DHW systems. A final approach (SCM-E) is inspired by the European and Dutch standards for DHW-systems (EQUATION 4 and 5), in which a difference is made between periods in which the system is working, and periods it is not working. Now in this case, the system is obviously continuously working, but it works in two different modes, dependent on whether there is a heat demand or there is recirculation. The monthly period during which there is a heat demand is $t_{net,on,m}$ and then $\theta_{net,m}$ is approached by the average of supply and return temperatures at the substation. During the rest of the time $t_{net,recirc,m}$ there is recirculation and $\theta_{net,m}$ equals the supply temperature at the substation:

$$Q_{loss,m} = t_{net,on,m} \times \sum_j \left(\frac{\theta_{sub,sup,d}+\vartheta_{sub,ret,d}}{2} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) + t_{net,recirc,m} \times \sum_j \left(\theta_{sub,sup,d} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) \; [MJ] \qquad (9)$$

In SCM-E, $t_{net,on,m}$ and $t_{net,recirc,m}$ are derived from the simulation results. Both SCM-D and SCM-E come very close to the results of the DSM. Of course it is noticed that in this case, this is not only caused by a physically more correct approach, but also because of the use of simulation results for $\theta_{net,m}$ in SCM-D and for $t_{net,m}$ in SCM-E. If these SCM's are to be used in practice, it is important to find methods to estimate these monthly values without DSM (see Discussion).

Intermittent on/off CHDS with direct substation

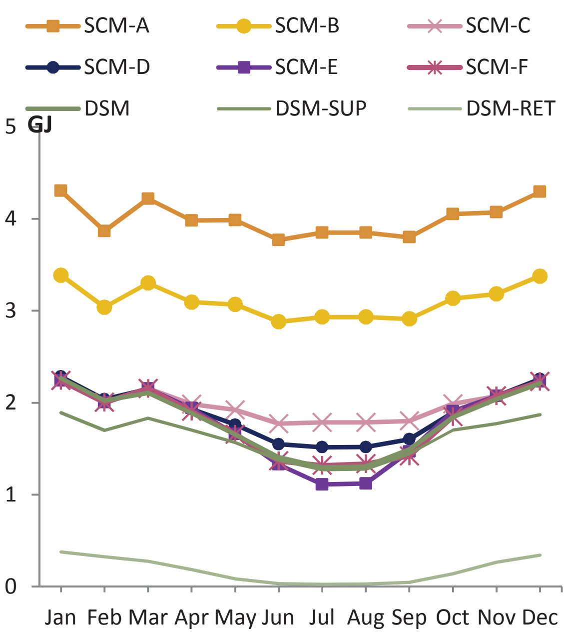

Figure 5: Heat losses in the on/off direct CHDS

The direct ON/OFF system is identical to the direct 24/24 system, except for the control strategy in which the system is turned off when there is no heat demand. The absence of heat recirculation in the network is especially recognised in the DSM results for the summer season in Figure 5. The heat losses decrease as a result of the decreasing average temperatures in the network. As was the case with the continuous system, the results of the Flemish method (SCM-A) largely overestimate the heat losses, up to 190% in summer months. Again improvements are made by making use of the actual design supply temperature of 50°C at the substation (in SCM-B) and even more by using the average of actual design supply and return temperatures at the substation (in SCM-C). The SCM-C now acts as an upper limit for the heat losses in the distribution network, representing the case that there is a continuous heat demand. The evolution of the heat losses due to seasonal behaviour was better approached by the use of monthly values, such as the monthly average of supply and return temperatures at the plant in SCM-D, or the inclusion of the actual monthly working time of the system in SCM-E:

$$Q_{loss,m} = t_{net,on,m} \times \sum_j \left(\frac{\theta_{sub,sup,d}+\vartheta_{sub,ret,d}}{2} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) + t_{net,off,m} \times \sum_j \left(\theta_{sub,ret,d} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) \quad (10)$$

During the time $t_{net,on,m}$ there is a heat demand and the average temperature $\theta_{net,m}$ is the average of design supply and return temperatures at the substation. During the rest of the time $t_{net,off,m}$, the average temperature in the network was by estimation equal to the 25°C design return temperature at the substation. However, this assumption is not physically explicable and in this case it causes an underestimation of the heat losses during off-periods. So while the SCM-E method is able to describe the evolution of the heat losses in the continuous system with direct substations, it is not sufficient for the intermittent working mode. It would actually be more correct to estimate the heat losses during off-periods through calculation of the cooling of the heating medium, as is proposed in the EN15316-3-2:2007 and NEN 7120+C2:2012 standards (see EQUATIONS 4 to 8). Therefore in Figure 5, SCM-F represents a variation of SCM-E in which the cooling of water in the network is taken into account:

$$Q_{loss,m} = t_{net,on,m} \times \sum_j \left(\frac{\theta_{sub,sup,d}+\vartheta_{sub,ret,d}}{2} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) + n_{off,m} \times \sum_j (c_w \times \rho_w \times V_w) \times \left(\frac{\theta_{sub,sup,d}+\theta_{sub,ret,d}}{2} - \theta_{amb,m,j}\right) \quad (11)$$

With $n_{off,\ m}$ is the number of times the water in the network is entirely cooling down (per month). In this case, it was assumed that the network is cooling down 2 times per day when $t_{net,off,m}$ is in the interval [50%,70%], once a day in [30%,50%], 0,5 times a day in [10%,30%] and not when $t_{net,off,m}$ < 10%. Nonetheless it is seen that when the $n_{off,m}$ is properly estimated, a satisfactory estimation of the heat losses in the intermittent system is reached by taking into account the heat losses during on-periods and the cooling of the heating medium during off-periods.

Continuous 24/24 CHDS with indirect substation

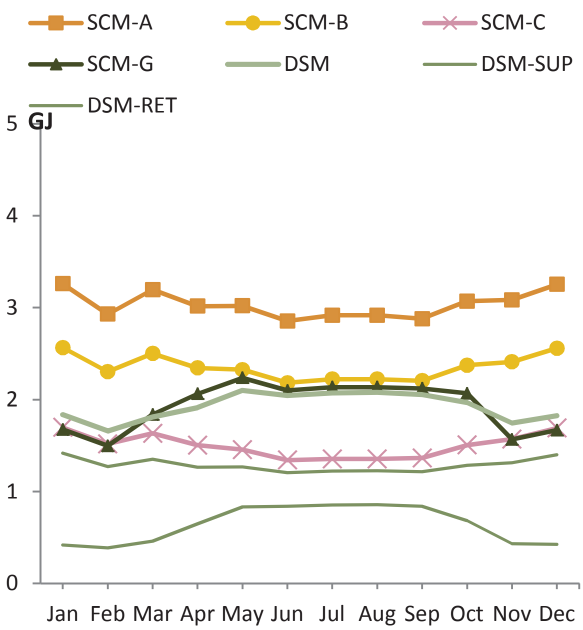

Figure 6: Heat losses in the 24/24 indirect CHDS

The distribution heat losses in the CHDS of the system with indirect substations (Figure 6) are lower than those in the continuous system with direct substations (Figure 4). A simple explanation is that when heat is stored in a local storage tank, flow rates in the network can be reduced. As a consequence the dimensions of the network pipes can be reduced, and the heat losses decrease. Another effect of the storage tank is the difference in seasonal behaviour of the heat losses.

The SCM-A again overestimates the heat losses up to 80% in winter and 40% during summer. As was the case with the continuous systems with direct substations, SCM-B and SCM-C are respectively the expected upper and lower limit of the heat losses in this CHDS, representing the situation in which there is a continuous recirculation of heat in the network, and the situation in which there is a continuous heat demand. As with the previous systems, the seasonal variations in heat losses are only approached when monthly values are entered in the simple calculation methods. So the logic from the SCM-E and SCM-F methods is now extended for systems with a local storage tank. In SCM-G the 24/24 hours working time of the system is divided in three parts, that is the time $t_{net,DHW,m}$ during which the storage tank (serving heat for DHW) is charging, the time $t_{net,heat,m}$ during which there is a space heating demand, and the recirculation time $t_{net,recirc,m}$ when there is no heat demand:

$$Q_{loss,m} = t_{net,DHW,m} \times \sum_j \left(\frac{\theta_{sub,sup,d}+\vartheta_{sub,ret,DHW,d}}{2} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) + t_{net,heat,m} \times \sum_j \left(\frac{\theta_{sub,sup,d}+\theta_{sub,ret,SH,d}}{2} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) + t_{net,recirc,m} \times \sum_j \left(\theta_{sub,sup,d} - \theta_{amb,m,j}\right) \times \left(\frac{l_j}{R_{l,j}}\right) \quad (12)$$

With $t_{net,heat,m}$ is derived from the DSM results, $t_{net,DHW,m}$ depends on the heat demand for DHW Q_{DHW} and the characteristics of the storage tank (Q_{stor} is the designed amount of heat stored in the tank, q_{charge} is the flow rate for charging the tank and V_{stor} is the volume of the storage tank):

$$t_{net,DHW,m} = \frac{Q_{DHW}}{Q_{stor}} \times \frac{t_m}{0{,}0864} \times \frac{q_{charge}}{V_{stor}} \quad (13)$$

$t_{net,recirc,m}$ is then the remaining time. Figure 6 shows that this method is able to follow the DSM results roughly, but there are considerable deviations. In a closer observation of the DSM results, it was seen that the actual supply temperature in the network is slightly higher than 50°C, so the heat losses in the supply network are underestimated. On the other hand, the heat losses in the return network are overestimated from March to October. This may be caused by an overestimation of the $t_{net,recirc,m}$ because the heat demand for compensation of the heat losses of the storage tank is not taken into account, or by an overestimation of the return temperatures from the substation.

The results show that by the use of monthly values for $\theta_{net,m}$ and $t_{net,m,}$ it is possible to estimate the heat losses in CHDS quite properly and to take into account the influence of the operation mode, seasonal behaviour and substation type. Therefore, this study confirms that simplified heat loss calculation methods can be significantly improved by a more accurate estimation of these two influential parameters. Regarding possible improvements to the SCMs, it is found useful to split up the operation time of the system into values for the distinct working modes, and to provide the most suitable physical expression for each working mode (this is done in SCM-E, SCM-F and SCM-G). Especially when more complex systems are considered, this provides a better fit than when average values for θ_{net} are estimated for the entire operation time of the system (as in SCM-D). Another clear advantage of this approach is that only design values for θ_{net} are needed, and those are usually easy to provide.

DISCUSSION AND PERSPECTIVES

In this study, dynamic simulation results were used to calculate the monthly $\theta_{net,m}$ in SCM-D or $t_{net,m}$ in SCM-E, SCM-F and SCM-G. Of course our goal is to create better SCM for the energy performance of building standards in order to avoid the need for (direct inputs from) DSM or measurements. Therefore the Flemish, Dutch and European standards are screened for parameters that might be useful for the determination of monthly values in SCM. Regarding SCM-D, the monthly average supply and return temperatures in the network can be offered through standardised values, as is also done in the Dutch SCM for space heating distribution systems NEN 7120+C2:2012. The European standard EN15316-2-3:2007 proposes a method to calculate the mean temperature of a space heating distribution system, based on calculations of the mean part load of the individual systems, but the influence of DHW heat demands is not taken into account. Regarding the methods SCM-E, SCM-F and SCM-G, only design temperatures are needed, but the working period $t_{net,m}$ should be specified for the different working modes of the system. Regarding the working period for space heating $t_{net,heat,m}$, the European and Flemish standards contain methods to estimate the time that a heating system is working EN15316-2-3:2007. Estimation of the $t_{net,DHW,m}$ could be based on the heat demand for DHW and a standard average heat flow rate for DHW consumption, or various other approximation methods. In order to come to accurate SCMs, these suggestions should of course be investigated and optimised. But the availability of these parameters in existing standards reveals that it might be possible to compose more accurate EPBD based SCM while avoiding the need for input data from simulations or measurements.

The future perspectives to this research include the extension of the DSM with more detailed dwelling and different heating system models. Taking into account that in low-energy houses the heat demand is no longer dominated by SH, the general expression used in this study was found sufficient to represent the behaviour of a floor-heating system, but this will probably not be the case for other types of heating systems. Another perspective is the configuration of collective or district heating systems. Then the impact of these individual and collective elements on the SCM is to be investigated and it is planned to compare simulation results with measurements in a real case-study CHDS.

CONCLUSIONS

In this study, collective heat distribution networks for combined space heating and domestic hot water supply are designed with various types of substations and control strategies. The distribution heat losses are calculated by use of dynamic simulations and simplified calculation methods and the results are compared. It was found that especially in this low-temperature CHDS, the SCMs largely overestimate the heat losses. This is mainly caused by an incorrect estimation of the average temperature of the heat conducting medium in the distribution network. Secondly, the seasonal variation in heat losses was poorly approached by the SCMs, because of the estimation of the average temperature of the heat conducting medium in the network and the working time of the system. These parameters are influenced by the working modes (control strategies) and substation properties. It was found that by dividing the operation time of the system into values for the distinct working modes, and to provide the most suitable physical expression for each working mode, it was possible to make a proper estimation of the heat losses in CHDS with simple and more complex substations and control strategies. As a conclusion, it was found that simplified heat loss calculation methods can be significantly improved when the estimation of two influential parameters, that is the average temperature of the heat conducting medium and the working time of the system, reflects the actual design and operation of the systems.

NOMENCLATURE

CHDS = Collective Heat Distribution System
c = specific heat capacity
$D_{e,j}$ / $D_{i,j}$ = external and internal pipe diameter
DHW = Domestic Hot Water
DSM = Dynamic Simulation Method
l_j = length of the pipe
Q = heat
RET = Return
$R_{l,j}$ = thermal heat resistance of a pipe element j
SCM = Simplified Calculation Method
SH = Space Heating
SUP = Supply
t_{net} = working time of the CHDS
θ_{amb} = ambient temperature
θ_{net} = average temperature of the heat conducting medium in the CHDS
U_j = U-value of a pipe element j
V = volume
ρ = specific mass

ACKNOWLEDGEMENT

Part of this work was done in preparation for the MIP3-Haalbaarheidsstudie 2011 "*Onderzoek naar de economische haalbaarheid van een business model voor valorisering van restwarmte uit rioolwater*" of the Flemish Environmental & Energy Technology Innovation Platform (MIP Flanders).

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