District Heating Pipelines in the Ground
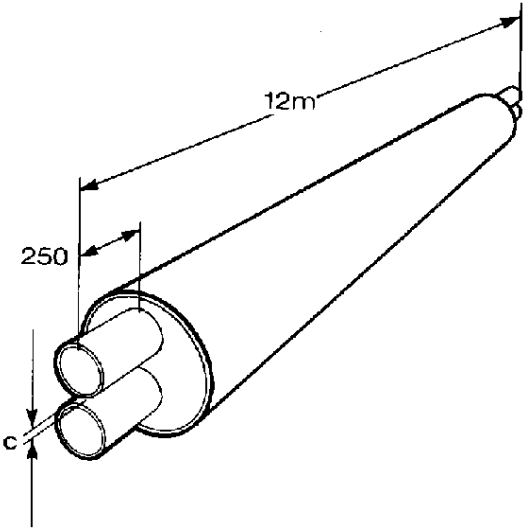# - Simulation Model -

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Version 1, 04. May 2001

District Heating Pipelines in the Ground
- Simulation Model -

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1. INTRODUCTION

TYPE 313

Table 1.1: Information Flow Diagram

PARAMETER No.			DESCRIPTION	
1	MODE	-	Operation mode:	m
2	L	-	Pipe length	m
3	D_i	-	Pipe inside diameter	m
4	D_o	-	Pipe outside diameter	m
5	X_p	-	Pipe depth in the ground	m
6	C_p	-	Specific heat capacity of the fluid	kJ/kg,K
7	ρ	-	Density of the fluid	kg/m^3
8	λ_{ISO}	-	Thermal conductivity of the pipe	W/m,K
9	λ_g	-	Thermal conductivity of the ground	W/m,K
10	T_0	-	Initial temperature of the fluid	°C
11	L_{rel}	-	Relative pipe length	m
12	F_{asy}	-	Heat transfer factor used for	-
13	Hx	-	Distance between pipe centres	m
14	$D_{i,t}$	-	Inside diameter of twin-/opposite pipe	m

INPUT				
1	T_i	-	Fluid inlet temperature	°C
2	m	-	Fluid inlet mass flow	kg/h
3	T_{env}	-	Surface temperature	°C
4	T_{twin}	-	Average temperature of the twin-/opposite pipe	°C

OUTPUT				
1	T_o	-	Fluid outlet temperature	°C
2	m	-	Fluid mass flow rate	kg/h
3	Q_{env}	-	Energy losses to environment	kJ/h
4	Q_{in}	-	Enthalpy difference inlet - outlet	kJ/h
5	ΔE	-	Change in internal energy	J
6	T_{av}	-	Average temperature of the fluid	°C
7	T_{env}	-	Surface temperature	°C

$$T_i \qquad \dot{m} \qquad T_{env} \qquad T_{twin}$$

Type 313
ground buried pipe
or duct

$$T_o \quad \dot{m} \quad \dot{Q}_{env} \quad \Delta E \quad \dot{Q}_{in} \quad T_{av} \quad T_{env}$$
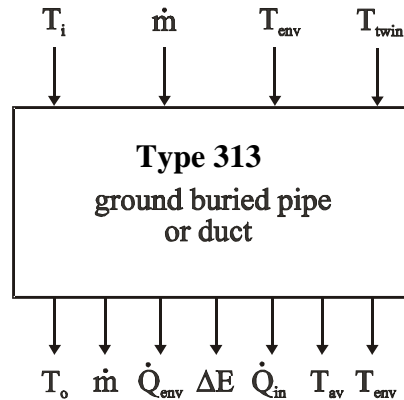
Figure 1.1: Information flow diagram of TYPE 313

Mode 1:

In Mode 1 two pipelines in one insulation (twin-pipes) in the ground are modeled. Required are physical parameters of the pipe and insulation as well as physical properties of the ground. Parameter 11, the relative length, is multiplied with the length given by parameter 2. Using this factor up- and downscaling of a network is possible. For parameter 12 refer to the description of the model. The parameter describes an additional heat transfer due to metal spacers between the pipes an inhomogeneous insulation material. The validation procedure described in the following derived a value of 3.3 for this parameter.

Mode 2:

In Mode 2 two pipelines (single-pipes) in the ground with separate insulation are modeled. Required are physical parameters of the pipe and insulation as well as physical properties of the ground.   Parameter 11, the relative length, is multiplied with the length given by parameter 2. Using this factor up- and downscaling of a network is possible. For parameter 12 refer to the description of the model. The parameter describes an additional heat transfer due to inhomogeneous insulation material. The recommendation for this parameter in mode 2 is 1.0.

2.   MODEL DESCRIPTION

The standard TRNSYS library offers a pipe model using a user defined UA-value to calculate heat losses dependent on fluid temperature and ambient temperature. This model is not sufficient for calculating ground buried district heating pipelines, since it is not possible to consider the heat exchange between supply and return pipeline. Especially for small district heating systems with smaller pipe diameters supply and return pipeline are sharing one common insulation. For those pipelines the heat exchange between the two pipelines can not be neglected. Different work has been done to describe the heat transfer to the ambient and the heat exchange between the two pipelines, mostly assuming stationary conditions [2].

For dynamic simulation it is not sufficient to consider stationary conditions only. The propagation speed of the fluid in the pipeline, $dx/d\tau$, must be taken into account. Using TRNSYS, the simulation is carried out in predefined time steps and thus, Sections ('plugs') of different length and volume will proceed inside the pipe. This model type is commonly called plug-flow model and is used by several different models.

In this work a ground buried plug-flow model was developed, combining the ground buried pipe model by Wallentén with a plug-flow pipe model. Regarding the modelling of plug-flow the model is based on the standard TRNSYS Type 31 component. The heat transfer equations for the ground buried pipe for stationary conditions are based on analytic equations presented by Wallentén [13].

Furthermore, Wallenténs equation set was modified by introducing a constant factor, to be multiplied with the U-value for the heat exchange between two pipes in the ground. This factor accounts for heat bridges and inhomogeneous insulation material over the length of the pipeline.

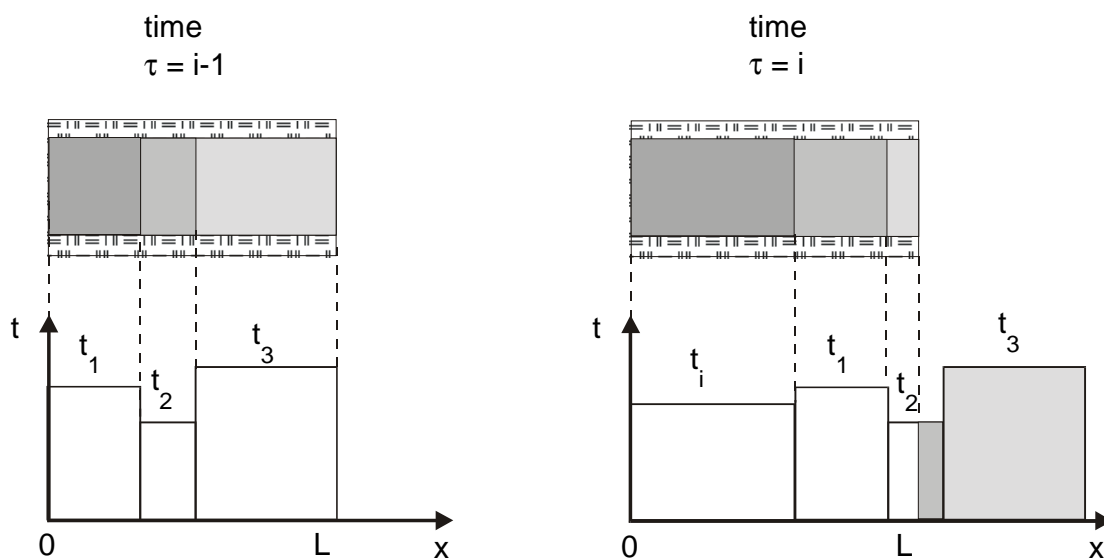The principle of the plug-flow pipe simulation model is shown in Figure 2.1.

Figure 2.1: Principle of the plug-flow simulation model. TRNSYS Type 31.

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In general, the outlet temperature is calculated:

Equation 2.1: $\qquad t_o = \dfrac{1}{\dot{m} \cdot \Delta\tau}\left(\displaystyle\sum_{j=1}^{k-1} M_j \cdot t_j + a \cdot M_k \cdot t_k \right)$

Where *a* and *k* must satisfy:

$$0 \leq a \leq 1$$

$$\sum_{j=1}^{k-1} M_j + a \cdot M_k = \dot{m} \cdot \Delta\tau$$

Energy losses are considered for each element by solution of the following equation:

$$M_j \cdot c_p \frac{dt_j}{d\tau} = -(UA_p)_j \cdot (t_j - t_{env})$$

For elements that enter or leave the pipe during a particular time step, only the duration time within the pipe is considered. The total energy loss rate to the environment is the summation of the individual losses from each element given as:

Equation 2.2: $\qquad \dot{Q}_{p-env,j} = (UA_p)_j \cdot (t_j - t_{env})$

c_p	=	specific heat capacity of fluid	[kJ/kg,K]
M	=	mass of fluid	[kg]
$\dot{m}$	=	mass flow rate of fluid	[kg/s]
$\dot{Q}_{p-env}$	=	energy loss rate from pipe	[W]
τ	=	time	[s]
t	=	fluid temperature	[°C]
t_o	=	pipe outlet temperature	[°C]
UA_p	=	heat loss coefficient	[kJ/K]
$\Delta\tau$	=	simulation time step	[s]
j,k	=	refer to segments of fluid in pipe	

In this model mixing or conduction between the elements inside the pipe is not considered. The pipe UA-value has to be calculated separately and is given as an input for the simulation.

Wallentén developed calculation models for ground buried pipes. One model describes two single pipes in the ground and another model describes two pipes in one insulation (twin-pipe). The models consider the heat exchange between the pipes and calculate the heat loss to the environment. The principle for both calculation models is shown in Figure 2.2. Difference between the two models are different calculation routines for the U-values.
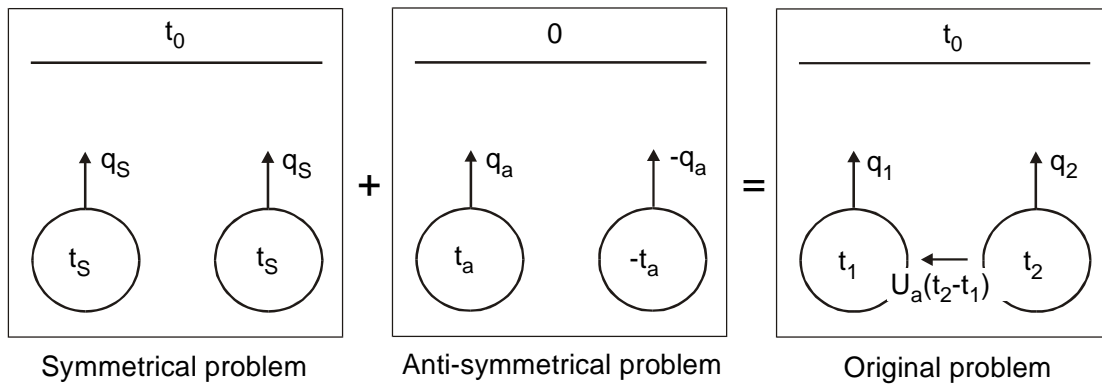
Symmetrical problem   Anti-symmetrical problem   Original problem

Figure 2.2: Heat loss calculation principle of two pipes in the ground, Wallentén.

The original problem is divided in two part problems. The first part problem is described as symmetrical problem. Here it is assumed that both pipes have the same temperature and thus, no heat exchange between the two pipes occurs. The second part problem is the anti-symmetrical problem. Here, the surface temperature is the average temperature between the two pipelines and thus, no heat exchange between the two pipes and the environment occurs. It can be written:

$$q_1 = q_s + q_a$$
$$q_2 = q_s - q_a$$

where :

Equation 2.3:
$$q_S = U_S \cdot (t_S - t_0) = U_S \cdot \left(\frac{t_1 + t_2}{2} - t_0 \right)$$

$$q_a = U_a \cdot t_a = U_a \cdot \frac{t_1 - t_2}{2}$$

with :

$$t_s = \frac{t_1 + t_2}{2}; \quad t_a = \frac{t_1 - t_2}{2}$$

t_1	= temperature of pipe 1	[°C]
t_2	= temperature of pipe 2	[°C]
t_0	= temperature of the ground surface	[°C]
q_1	= heat loss from pipe 1 per meter	[W/m]
q_2	= heat loss from pipe 2 per meter	[W/m]
q_a	= heat loss anti-symmetrical problem	[W/m]
q_s	= heat loss symmetrical problem	[W/m]
U_a	= heat loss coefficient anti-symmetrical problem	[W/m,K]
U_s	= heat loss coefficient symmetrical problem	[W/m,K]

First order approximations are proposed for the exact solution for calculating the U-values of both part problems. The error introduced by the approximation compared to the exact solution is in within 5%.

Anyhow, Wallenténs equation set to calculate the U -value for the symmetrical and anti-symmetrical problem is valid for homogeneous insulation and ground materials. Pipelines on the market usually include metal spacers between the pipelines inside the insulation to keep the prescribed distance between the pipelines during production. Spacers between the pipelines are heat bridges which increase the pipeline overall value of the anti-symmetrical U_a-value. As well, pipe connections and welding seams can increase the pipe overall U_a-value. Therefore a heat transfer factor F_{asy} was introduced to account for inhomogeneous pipe insulation material and heat bridges. Thus, q_a in Equation 2.3 can be written as:

Equation 2.4:
$$q_a = F_{asy} \cdot U_a \cdot t_a = F_{asy} \cdot U_a \cdot \frac{t_1 - t_2}{2}$$

However, calculating the heat exchange between the pipes for each segment inside the pipe the temperature of the other pipe at the same location has to be known. Here, using the plug flow model introduces difficulties, since usually supply and return pipeline in counter flow have to be considered. Calculating the heat exchange between the pipes was simplified by using the average temperature of the counter pipe instead of the exact temperature at the same location of the counter section. The heat exchange for each section of each pipe is thus:

Equation 2.5:
$$q_{2-1,j} = F_{asy} \cdot U_a \cdot \frac{t_{1,j} - t_{2,average}}{2}$$
$$q_{1-2,j} = F_{asy} \cdot U_a \cdot \frac{t_{1,average} - t_{2,j}}{2}$$

$t_{1,average}$	= average temperature of pipe 1	[°C]
$t_{2,average}$	= average temperature of pipe 2	[°C]
$t_{1,j}$	= temperature of segment j in pipe 1	[°C]
$t_{2,j}$	= temperature of segment j in pipe 2	[°C]
$q_{2-1,j}$	= heat transfer from pipe 2 to segment j of pipe 1	[W/m]
$q_{1-2,j}$	= heat transfer from pipe 1 to segment j of pipe 2	[W/m]

With this simplification the heat transfer from e.g. the hot supply pipe to the cold return pipe will be higher in the beginning of the pipe and lower in the end.

By using Wallenténs model as described Equation 2.2 can be written as:

Equation 2.6: $Q_{p-env,j} = (U_S - F_{asy} \cdot U_a)_j \cdot (t_j - t_{env}) + (F_{asy} \cdot U_a)_j \cdot (t_j - t_{counter,average})$

where $t_{counter,average}$ is the average temperature of the counter pipeline.

3. MODEL CALIBRATION

In this chapter the previous described pipeline model is calibrated using measurements. The measurements were carried out for a small district heating network in Tölö, about 30 km south of Göteborg, Sweden. In this residential area a small district heating network is connected to a larger network via heat exchanger. The small district heating network itself is divided into three subnets while one is taken out for measurement purposes. In more detail the measurements are presented in [3].

In this chapter the measurement set-up, the measurements and the calibration of the model are presented.

3.1. Measurement Set-up

Initially the measurement set-up was designed to obtain the coincidence factor of the network and separate sections. Anyhow, this set-up also enables a measurement of network heat losses. In Figure 3.1 the more detailed measured part, net 1, of the larger network is shown. To obtain the coincidence factor one house station, the net 1 and the supply line to the Kungsbacka DH network have to be measured. To measure the distribution heat loss of net 1 all substations of that route have to be measured.

Many measurement stations and a short sampling interval of 1 minute lead to a large amount of data. Therefore some important measurement points were chosen and only one route, net 1, was measured in more detail. One data logger was installed in each of the five house substations. Additionally one measurement station was used to record the heat supply to net 1 (five houses plus distribution heat losses) and to record the total heat supply for the residential area Tölö (20 houses plus two under construction). Figure 3.1 shows the location of the measurement stations in the network.
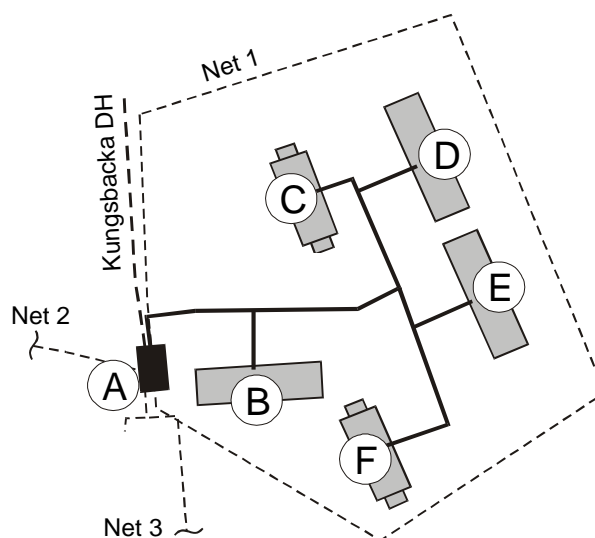

Figure 3.1: Location of data logger stations in the DH network Tölö. A = main substation, B-F = house substations.

The main substation is named A while the house stations are numbered from B to F. Each data logger station is connected to one computer which operates as measurement computer including software and data storage. The measurement computers are not interconnected and data was transferred frequently from each station separately in periods of about 10 days.

3.1.1. Applied pipelines

The district heating network in Tölö consists of PE mantled steel twin-pipes in three different sizes from DN50 and DN40 for the main distribution lines and DN25 for the house connection pipes. The idea by using twin-pipes (two pipes in one insulation mantle) is a lower specific heat loss (W/m) of the distribution line and lower ground costs by decreasing the width of the route.
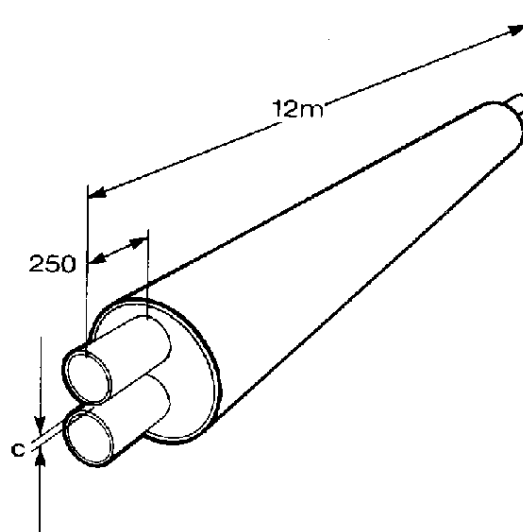

Figure 3.2: PE- mantled steel twin-pipe. (picture: PowerPipe)

The route length of net 1 is 170m (DN50: 32m, DN40: 60m, DN25: 78m) taken from architect drawings.

3.2. Measured distribution heat loss

This chapter deals with the heat loss of the distribution network in Tölö. Especially for residential areas with a low heat density the heat loss of the heat distribution system is of greater interest and the distribution heat loss for those areas can be up to 20% of the yearly heat demand. The Tölö district heating network is, as described, a two pipe network with supply and return pipe in one common insulation. The largest diameter is DN50 and the smallest diameter DN25. A two pipe steel network in one common insulation was chosen in order to minimise the heat loss. The network is equipped with a pipe leakage detection, which is a copper circuit additionally inserted in the insulation in some distance from the steel mantle of the pipe. Using high voltage and measuring the resistance between steel pipe and copper circuit shows weather the insulation material is moistened or not. The leakage check

was performed for all three circuits, net 1 - 3, of the Tölö district heating network and no leakage was detected. Thus, the network heat losses presented here are representing the heat losses of an undamaged heat distribution system.

With the actual measurement set-up it was possible to determine the distribution system heat loss of net 1. Measuring the flow and return temperature as well as the volume flow of net 1 and of each house substation B-F the heat loss can be calculated as an average value from the energy balance of net 1. The route length of net 1 is 170m in total (DN50: 32m, DN40: 60m, DN25: 78m) whereof about 15% (26m) are bends or T-pieces. As well, about 1 m not insulated pipes (3.5% of the total) are included in each substation.

In Figure 3.3 the measured specific network heat loss is shown for the average diameter of net 1 (DN32) versus the producers data. The measured values are representing average daily values and the applied uncertainty corresponds to the average uncertainty described in chapter 3.3. The grey area represents the error introduced by the uncertainty of the total route length, here assumed to be ±10m (170m total route length).
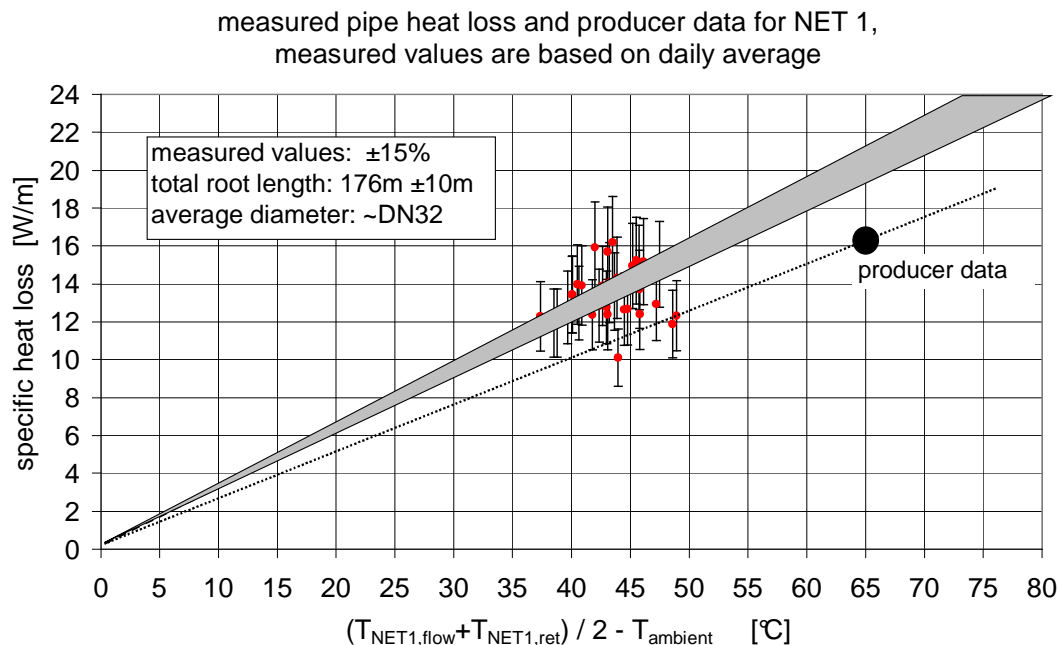

Figure 3.3: Heat loss net 1:
big black dot = producer data;
dots with error bars = measured values based on daily average values;
dashed line = measured values assuming constant heat loss coefficient,
grey area represents upper and lower limit for the pipeline length of 176m ±10m;
black line = producer data assuming constant heat loss coefficient.

The first observation is that all measured values are located in a narrow temperature interval. This is due to the constant flow and as well constant return temperature of the network. Furthermore it can be observed that with given uncertainties of ±15% the network heat loss is about 20% higher than the producers data for new pipelines. Regarding Jarfelt [8] ageing of the insulation material leads to an increase of the thermal conductivity of about 20% over a period of 15 to 20 years. This effect is stronger for a CO_2 blown pipe insulation as used in Tölö compared to CFC blown pipelines. From Fröling [6] it can be learned that small pipes are ageing faster than larger diameters. Fröling shows that for a pipe dimension DN20 an increase of 10-20% of the thermal conductivity is accomplished after three years. The

residential area Tölö and the heat distribution system were built 1996 and were at the time of the measurement at an age of three years. Furthermore, it has to be considered that the measured heat loss also includes insulated pipe connections, not insulated pipes inside the substations, T-pieces and wall ducts. The measured distribution heat loss is reasonable regarding these considerations.

3.3. Uncertainty of measured quantities

Using the measurements as presented and in chronological order ([3]) it has to be considered, that the heat losses of a district heating system are small compared to the transferred energy as well as the volume flow in the pipe is relatively high. In turn, the temperature drop of the flow pipeline is at its most about 2grC from main station to the substation. Therefore it is necessary, to evaluate measurement uncertainties more accurate.

Here, the measurement uncertainty is evaluated according to the recommendations given by the International Organisation for Standardisation, [7], [10], [12]. Here the general statement is made that 'In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement that is, the measurand, and thus the result is complete only when accompanied by a quantitative statement of its uncertainty'. Two terms are used to describe two types of uncertainty. 'Type A' uncertainty is used for uncertainties due to random effects. Evaluation of this type of uncertainty can be treated by statistical methods. 'Type B' uncertainty includes all uncertainties which are not of 'Type A', commonly so called systematic errors. Type B uncertainties can only be evaluated by experience and knowledge about the experimental set-up.

The measured data from Tölö includes Type A and Type B uncertainties. The instrument uncertainty is presented as combined Type A and Type B uncertainty. Here, the instrument uncertainty is due to random effects, including the Type A and B uncertainties for calibration, meter reading and operating conditions. To evaluate Type B uncertainties, i.e. for installation, knowledge about the measurement set-up and physical conditions is necessary. Therefore, this type of uncertainty is evaluated in more detail and corrections to compensate these effects are proposed. Finally, combined uncertainties for calculated quantities such as power and energy are calculated and presented.

In general uncertainties can be combined in three ways: 1. uncertainties are added, 2. uncertainties are taking out each other or 3. combined using a statistical compromise. Method 1. produces usually too high and method 2. too low uncertainties. A statistical compromise results to uncertainties somewhere in between method one and two. In this study, the so called "law of propagation of uncertainty" or as well called "root-sum-of-squares" is used to describe combined uncertainties. It is presumed that the measured parameters are not correlated. Thus, all uncertainties have been combined as:

Equation 3.1

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$$

where:

$u_c(y)$ = *combined uncertainty*

N = *number of specific standard uncertainties*

$u(x_i)$ = *standard uncertainty associated with input estimate x_i*

In the following all combined uncertainties are given for a confidence level of 68%, which corresponds to a coverage factor of k=1.

3.4. Parameter Identification

The district heating circuit model consists of twin-pipe models as described in 3.1.1. To calibrate the model for the heat distribution two requirements have to be met: the calculated distribution heat losses and distribution temperatures have to be in agreement with the measured values.

For calibration the net 1 flow temperature and volume flow and the house substation volume flow and power were provided as an input for the simulation. The measured ambient temperature was taken as an input to calculate the pipe heat losses. The simulation was carried out using a time step of one minute.

Using these inputs for simulation the model calculates the flow temperature for each house substation taking heat losses and heat transfer between the supply and return pipeline into account. Together with the house substation power as an input the house substation return temperature can be calculated. Again calculating distribution heat losses and heat transfer between the pipelines the net 1 return temperature is calculated. The model is taken as being calibrated when the calculated distribution heat loss is in best agreement with the measurement and the difference between measured and calculated return temperature is smallest. The principle of the heat distribution model for Tölö is shown in Figure 3.4.
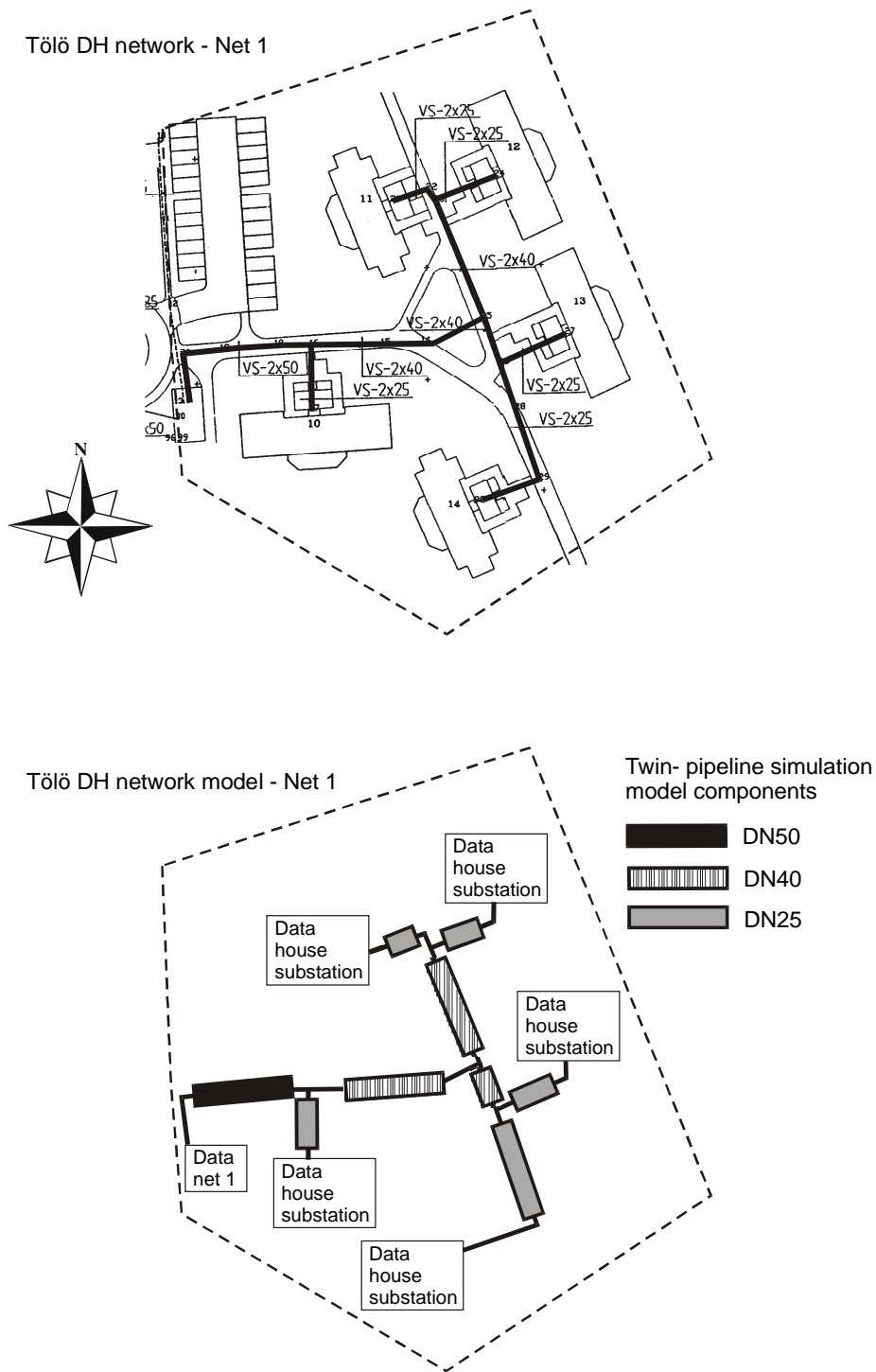
Tölö DH network - Net 1

Tölö DH network model - Net 1

Twin- pipeline simulation
model components

DN50
DN40
DN25

Data
house
substation

Data
house
substation

Data
house
substation

Data
net 1

Data
house
substation

Data
house
substation

Figure 3.4: Heat distribution simulation model of the Tölö DH network.

The pipe model component represents steel twin-pipes where supply and return pipeline are combined inside the same insulation. For each pipe section the geometrical properties of the actual laid pipe (PowerPipe) are applied as well as the length, taken from the principle drawing of the residential area. Measured data for two periods were taken to identify parameter values of the pipe model. The first period was taken to identify the parameter values while the second period was taken to validate the identified set of parameter values and vice versa. The general procedure to identify the pipe model parameters is shown in Figure 3.5.
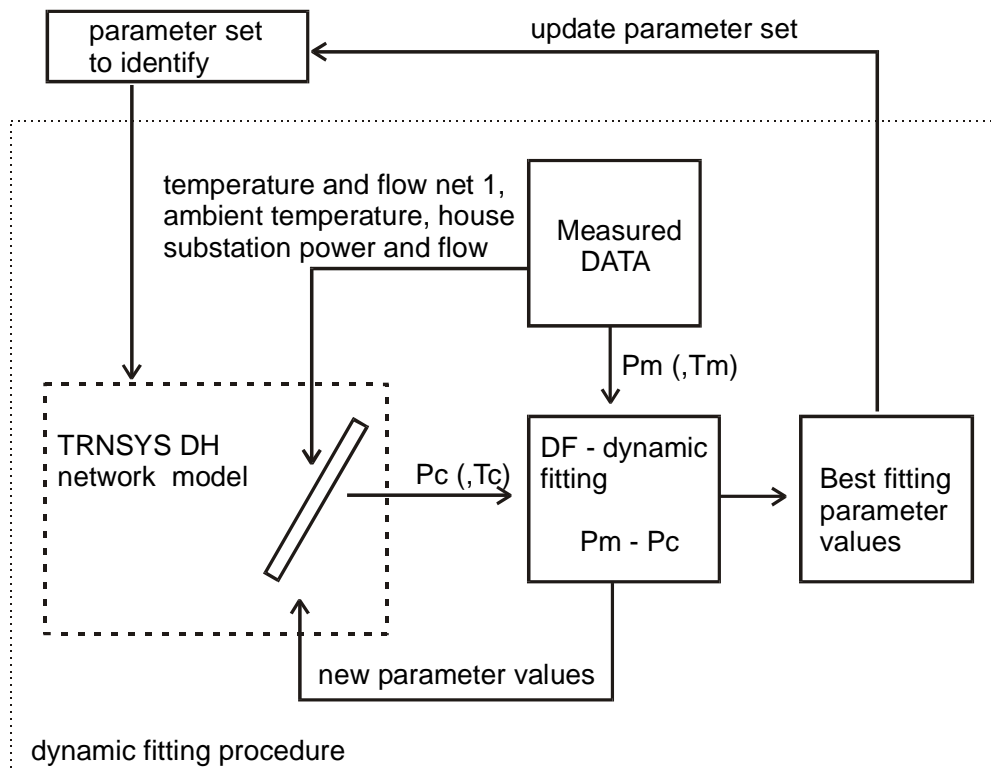
Figure 3.5: Heat distribution pipe parameter identification using TRNSYS and DF.

Fixed inputs for each pipe component are the geometrical properties of the pipe dimension, the heat conductivity of the ground and the fluid properties of the water in the pipe. Parameters free for identification were the pipe insulation heat conductivity and heat transfer factor for the heat exchange between the supply and return pipeline. As an example the pipe parameters are shown in

Table 3.1 for the first pipe section of net 1, using a DN50 twin-pipe.

Table 3.1: Important parameters for first pipe section of net 1, DN50 twin-pipe.

No.	Description	Value	Unit
1	Operation mode: 1 = calculating ground temperature 2 = Type 31 original mode 3 = twin-pipe in the ground 4 = single pipe in the ground after Wallentén	3	-
2	Pipe length	*31.6*	m
3	Pipe inside diameter	*0.0603*	m
4	Pipe outside diameter	*0.2*	m
5	Pipe depth in the ground (surface - pipe centre)	*0.6*	m
6	Specific heat capacity of the fluid	4.18	kJ/kg,K
7	Density of the fluid	988	kg/m^3
8	Thermal conductivity of the pipe insulation, λ_{iso}	**to be identified**	W/m,K
9	Thermal conductivity of the ground	1.5	W/m,K
10	Initial temperature of the fluid	60	°C
11	Relative pipe length	1	-
12	Heat transfer factor used for asymmetrical heat transfer coefficient, F_{asy}	**to be identified**	-
13	Distance between pipe centres	*0.0803*	m

Italic letters are set values specific for each pipe dimension and are taken from the producers data sheet. Bold letters are values to be identified. Normal letters are general parameter values set and used for all pipe dimensions.

The parameter identification procedure was carried out in two steps: First the parameter value for the pipe insulation heat conductivity was identified by comparing measured and calculated pipe heat loss. The transfer factor was set to a value of 1 which represents Wallenténs equation set in its original version. Second, using the best fitting pipe insulation heat conductivity from step one as an input the heat transfer factor was identified by comparing the sum of measured and calculated net 1 and house return temperatures.

In Table 3.2 the result of the parameter identification of step one is presented for the first and the second measured data period. The objective represents the average difference between the measured and calculated heat loss of the distribution system of net 1. The shaded cell for the first data period represents the objective using the identified thermal conductivity from data period two. Vice versa for the second data period.

Table 3.2: Identification of thermal conductivity of pipe insulation material using first and second measured data period. Objective = average difference between measured and calculated heat loss of net 1.

	λ_{iso} [W/m,K]	objective [kW]	objective [kW]
1st data period	0.033 ± 0.001	2.51	2.53
2nd data period	0.038 ± 0.001	2.10	2.12

The outcome of the identification is a similar result for both runs. Anyhow, it can be seen that the thermal conductivity is somewhat higher for the second period with a lower objective. The objective of 2.1 or 2.5 kW can not be related to the average yearly heat loss of net 1 but to the average difference between supplied energy to net 1 and the actual total demand of the house substations of 8.3 kW on a minute basis. Due to the large amount of data the absolute error by identifying the thermal conductivity is little.

To provide a value for the thermal conductivity of the pipe insulation of net 1 the identified values were weighted related to the length of the measured data period. The value of 0.036 W/m,K was used as an input to identify the heat transfer factor for the heat exchange between the supply and return pipeline. The objective here represents the average difference between the sum of measured and calculated return temperatures of net 1 and all house substations.

Table 3.3: Identification of heat transfer factor using first and second measured data period. Objective = average difference between the sum of measured and calculated return temperatures.

	F_{asy} [-]	objective [°C]	objective [°C]
1st data period	3.7 ± 0.5	5.6	5.7
2nd data period	2.9 ± 0.4	6.9	7.1

The result is similar for the two data periods, especially with regard to the absolute error by determining the heat transfer factor. The heat transfer factor for the two periods is weighted by the length of the periods and the value of $F_{asy} = 3.3$ is taken for further investigations. It can be noted that the objective for the first period using a heat transfer factor of 1.0, i.e. using the equation set as originally proposed by Wallentén, is 8.1°C. This shows the necessity of the heat transfer factor, which can be explained by steel spacers welded between supply and return pipeline, which is not considered in the original equation set. Regarding a 12 m distribution pipeline a heat transfer factor of 3.3 would correspond to about 25cm steel spacers between supply and return pipeline (λ_{iso}=0.036 W/m,K; λ_{steel}=45 W/m,K).

In Table 3.4 the measured and calculated net 1 distribution heat loss is presented using a heat conductivity of the insulation material of 0.036 W/m,K and a heat transfer factor of 3.3.

Table 3.4: Measured and calculated net 1 heat loss for period 1, 2 and all measurements used for net 1 simulation model calibration.

	measured heat loss [kWh]	calculated heat loss [kWh]	difference [%]
Period 1	-379	-398	4.9
Period 2	-627	-599	-4.8
Total	-1 878	-1 822	-3.1

The difference is less than 5% for all presented periods. In Figure 3.6 the measured and calculated heat loss and the difference are shown on a daily basis. The maximum recorded difference is about 30%. It can be seen that the difference is higher than for the periods in total.
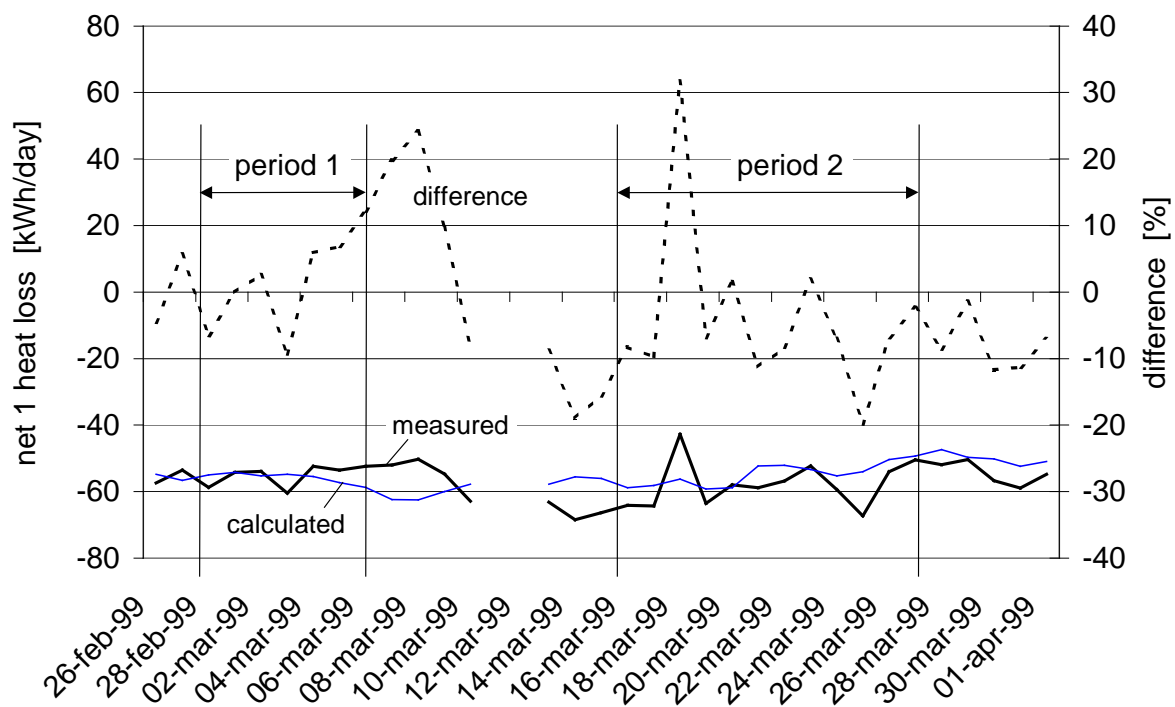

Figure 3.6: Measured an calculated net 1 distribution heat loss and difference on a daily basis.

Anyhow, it could be shown that by comparing longer periods the difference between measured and calculated heat loss decreases and the influence of the ground and pipe capacitance is less important. To evaluate the distribution heat loss on a yearly basis the model is taken as being calibrated regarding heat losses.

The second criteria to calibrate the calculation model of net 1 are the measured and calculated house substation flow temperatures and the net 1 return temperature. In addition to calibrate the model for heat losses the model was calibrated for temperatures. In Figure 3.7 the measured and calculated house flow and return temperatures for the building closest (house B) and the building furthest (house F) from the main substation are shown for 12 hours, based on minute values.
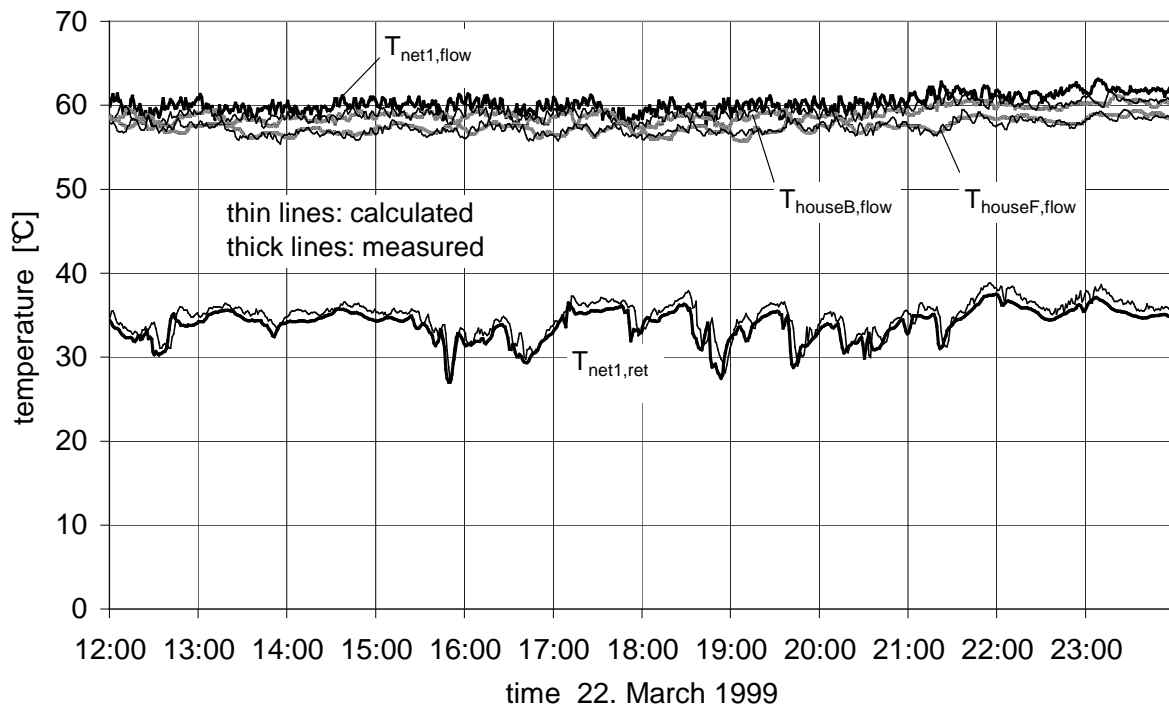

Figure 3.7: Measured and calculated house substation flow temperatures and net 1 flow and return temperature for the second half of the 22. March 1999, based on minute values.

It can be seen that the calculated temperatures are in the same range as the measured values. The measured temperature curve is slightly smoother than the calculated curve which can be explained by capacitance effects of the pipeline and ground which are not taken into account by the simulation model. Figure 3.8 shows the measured and calculated return temperature of net 1 for one hour based on minute values.
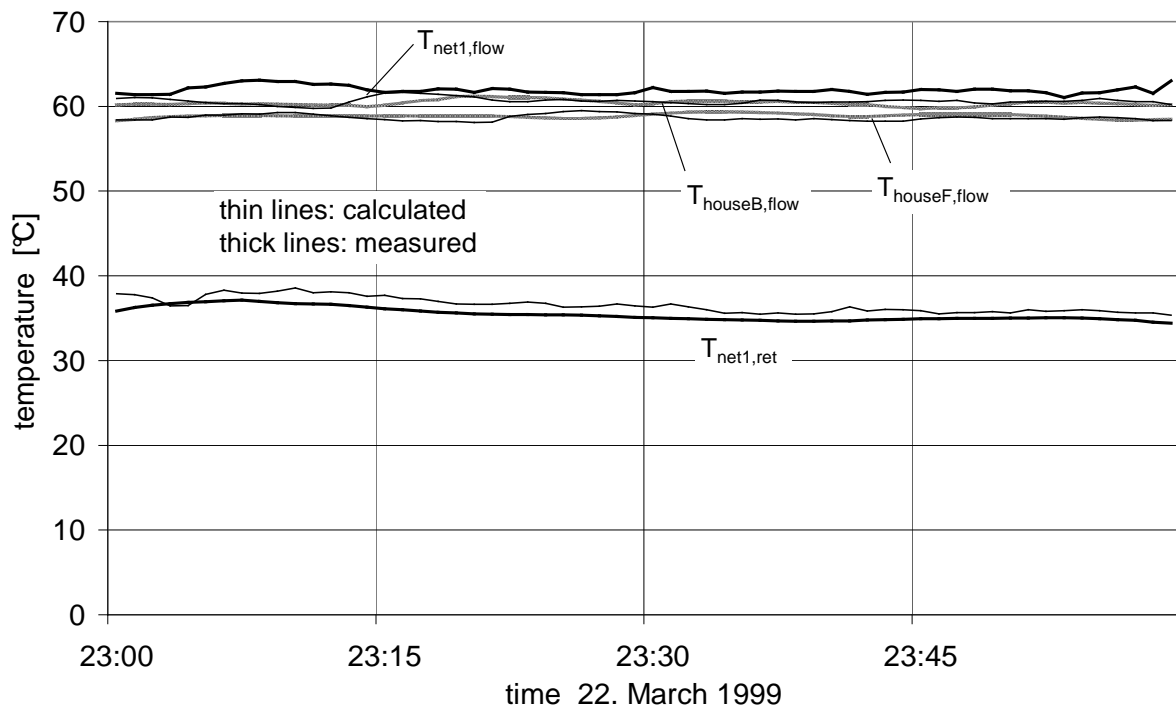
Figure 3.8: Measured and calculated house substation flow temperatures and net 1 flow and return temperature for one hour, based on minute values.

It can be seen that the calculated return temperature is higher than the measured return temperature most of the time. This indicates a slightly higher heat transfer from the supply to the return pipeline. A better fit of measured and calculated return temperature of net 1 could have been obtained by another choice of objective. Here, the sum of temperature differences between all measured and calculated house substation flow temperatures and the measured and calculated net 1 return temperature was taken to identify the heat transfer factor. Using this objective all temperature differences were valued equally and thus, more weight is put on fitting the house substation flow temperatures.

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