POLITENICO DI TORINO

MSc in Energy and Nuclear Engineering – Renewable Energy Systems

ENERGY NETWORKS COURSE

DESIGN OF A DISTRICT HEATING SYSTEM

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SUMMARY

INTRODUCTION

The objective of this practice is the design and analysis of a district heating system (DHS). District heating has many advantages with respect to the traditional heating system that includes a boiler for each house; for example it allows the heat available from renewables, waste heat from industries and heat from cogeneration plats to satisfy the energy needs of the consumers.

These kind of networks are based on economies of scale, as the generation of heat in one large plant can often be more efficient than production in multiple smaller ones. A growing number of cities worldwide are adopting district energy solutions, as it is the best way to bring sustainable heating and cooling in dense urban environments.

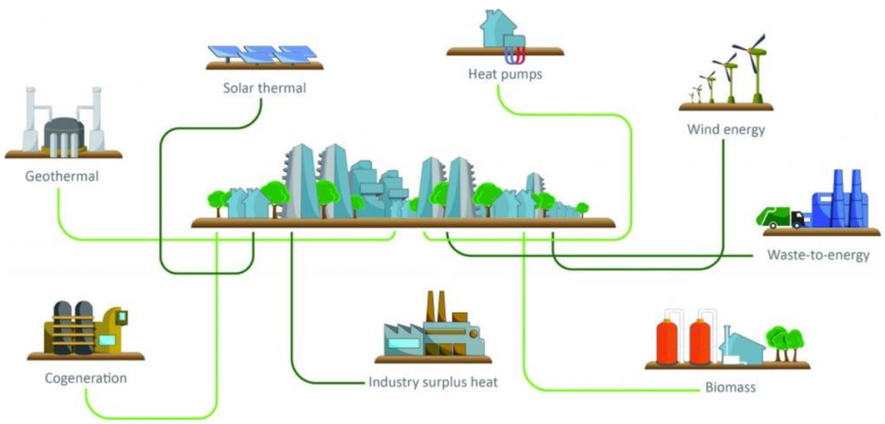

Figure 1 - DH network

The network is composed of pre-insulated stainless-steel pipes. The length of each pipe is limited so more pipes have to be joined in order to reach all the buildings, this is the trickiest operation because the only way to perform it is to manually join the two pipes. This also imposes some constrains on the velocity of water in the network, which is limited due to vibrations that could break the junctions.

The network is a twin pipe system: it has a supply pipeline and a return one. In the supply network, water (which is the energy carrier) collects heat from the various sources and brings it to the thermal substation of each building or group of buildings. In the return network, water comes back to the plant at a lower temperature.

This project is divided into three main parts: network design, simulation and retrofitting.

Regarding the first part, our network needs to have at least 16 buildings plus the thermal plant and we have some constraints about the building volume and the external temperature (therefore the location of the buildings). In this case we have chosen Turin as the location of the network, so the winter external temperature will be -8 °C. The network is a tree shaped network, this means that initially there are no loops, then we have considered three loops that are added for reliability, these additional branches are modelled following the neighboring ones.

The second part is the simulation, so thanks to the SIMPLE algorithm we have solved first the fluid dynamic problem and then the thermal problem for our network. The fluid dynamic problem consists in the application of the continuity equation and of the momentum equation to the network. The thermal problem uses as input the data calculated in the fluid dynamic one and, by applying the energy equation, finds the temperature at each node. To consider the movement of water in the pipelines we have used the upwind numerical scheme, since we know the flow direction (we are studying just the supply network, then the return network will have the same topology of the supply one). So at this point we know the temperature and pressure at each node and the mass flow rate in all the branches.

The last part consists in the retrofitting of the previous network: the old buildings that have an higher thermal demand because they are badly insulated, now have demands comparable to the old buildings, so the total demand that our network has to satisfy is lower. At this point we can reduce the operating temperatures of the primary side keeping constant the mass flow rate flowing in it.

NETWORK DESIGN

As already said, our district heating network is based in Turin. In order to have a shape of the network as faithful as possible with respect to the real networks and knowing that usually the pipelines of the network have to follow the shape of the streets (in fact they cannot be placed anywhere under the soil), we have decided to shape the network taking into account a real map of the center of Turin.

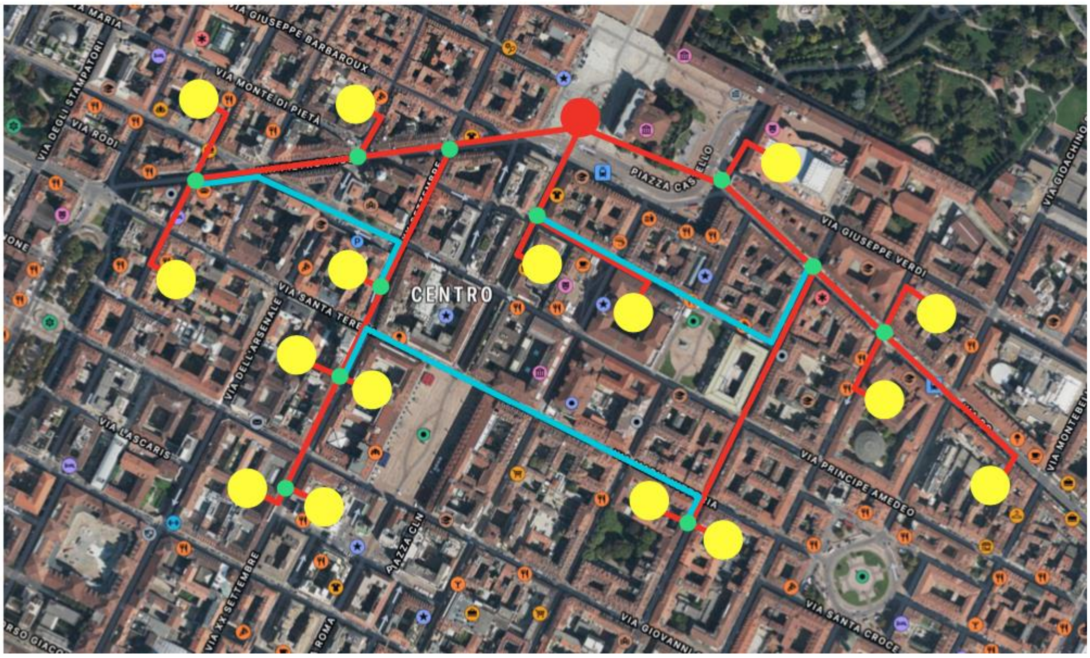

Figure 2 - Map of DH network

In this case we have hypotized to place the thermal plant at the center of “Piazza Castello”, from this point the network follows the topology of the city. Considering the tree-shaped network, there are three main branches starting from the plant, then we have added additional branches to create three loops. The loops are useful for reliability purposes, in fact if a pipeline fails, we can still reach the building connected to the failed pipeline by following another path.

A more schematic representation of the network is shown below:

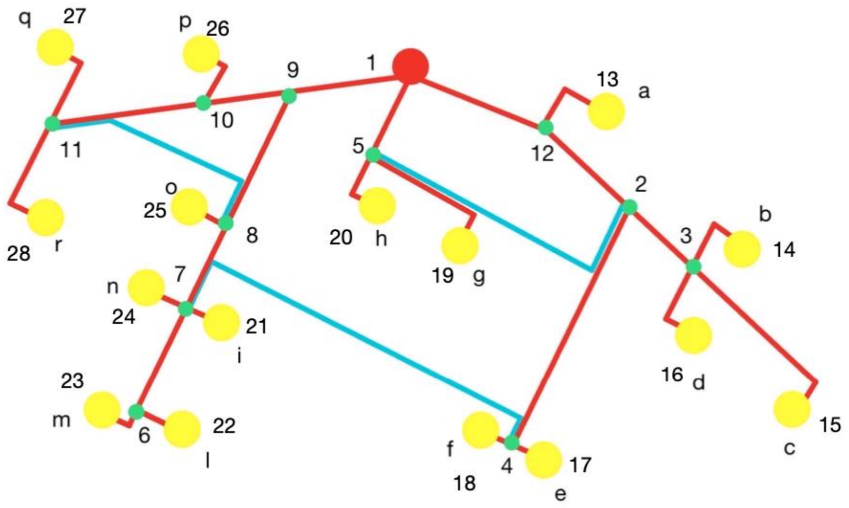

Figure 3 - Scheme of DH network

In figure 3 the red dot is the thermal plant, the yellow dots are the users and the green ones are the nodes of the network.

SIMULATION

The flow system is studied by means of continuity equation and momentum equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \boldsymbol{v} = 0$$

$$\rho \frac{D\boldsymbol{v}}{Dt} = -\nabla p - \nabla \cdot \boldsymbol{\tau} + \boldsymbol{F}$$

Where F is the general body force.

In case of one dimensional description of a system the partial derivatives with respect to the dimension of x_2 and x_3 are identically to zero.

$$\boldsymbol{v} = \boldsymbol{v}(x_1, t)$$

$$p = p(x_1, t)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_1)}{\partial x_1} = 0$$

$$\rho \frac{\partial v_1}{\partial t} + \rho v_1 \frac{\partial v_1}{\partial x_1} = -\frac{\partial p}{\partial x_1} - (\nabla \cdot \boldsymbol{\tau})_1 + F_1$$

Where in the viscous stress tensor factor the partial derivatives with respect to the directions orthogonal $x_1$are neglected. We can write for the 1-dimension formulation:

$$(\nabla \cdot \boldsymbol{\tau})_1 = F_{FRICT}$$

The final formulation of the momentum equation considering a duct of length L and diameter D with $L>>D$ in 1 D formulation with pump or fan is:

$$\frac{\partial v_1}{\partial t} + \rho v_1 \frac{\partial v_1}{\partial x_1} = -\frac{\partial p}{\partial x_1} - F_{FRICT} + \rho g_{x_1} - F_{LOCAL} + F_{PUMP}$$

By integrating this formula and introducing the total pressure:

$$P \doteq p + \rho \frac{v^2}{2} + \rho g z$$

The total momentum equation becomes:

$$\rho \frac{\partial v_1}{\partial t} L + (P_{out} - P_{in}) = -\Delta P_{FRICT} - \Delta P_{LOCAL} + \Delta P_{PUMP}$$

Where:

$$\Delta P_{FRICT} = \frac{1}{2} f \frac{L}{D_h} \rho v_1^2$$

$$\Delta P_{LOCAL} = \frac{1}{2} \sum_k \beta_k \rho v_1^2$$

$$\Delta P_{PUMP} = a v_1^2 + b v_1 + c$$

Where f and D_h are the friction factor and the hydraulic diameter of the duct, while β_k is the local loss coefficient and the summation refers to the different local losses of the duct.
By integrating the mass conservation, we obtain the equation:

$$\frac{d}{dt} M + \sum_j \rho_j {v_1}_j S_j + G_{ext} = 0$$

Where M indicates the mass fluid in the respective control volume (CV), S_j is the cross section of the generic duct j and G_{ext} refers to a possible extraction of fluid from the junction to the external ambient.
Assuming compressibility effects and viscous heating as negligible, constant properties and 1D model, we can write the energy equation:

$$\frac{\partial \rho c_p T}{\partial t} + \frac{\partial \rho c_p v_1 T}{\partial x_1} = k \frac{\partial^2 T}{\partial x_1^2} + \varphi_s$$

Where φ_s is the volumetric source taking into account the heat generated into the system and the non-adiabatic walls. By integrating the equation for the control volume, it is difficult to define temperatures for the junctions: we assume adiabatic and perfect mixing. All the flows exiting from the junctions are at the same temperature T by means of the energy equation.

In order to proceed with the solution by MATLAB, we assemble the continuity, momentum and energy equations so that it is numerically solvable.
The continuity equation presents the formulation:

$$A \cdot G + G_{ext} = 0$$

Where *A* is the incident matrix, *G* is the column vector of the flow rates in the branches, while G_{ext} refers to the mass flow rate extracted/injected at the node.
The momentum equation is:

$$G = Y \cdot A^T \cdot P + Y \cdot t$$

Where *G* is the vector of mass flowrate in the pipes, *Y* is the diagonal matrix of friction, A^T transposed incident matrix, *P* is the vector of pressure at the nodes and *T* is the pressure rise due to pumps.
These equations have been obtained by neglecting the effects due to transient: we are interest at the thermal effects, where the speed is lower than the speed of sound.
For the thermal problem, the equation is discretized by backward Euler method:

$$\frac{\left(\rho_i c_{p_i} T_i\right)^t - \left(\rho_i\, c_{p_i} T_i\right)^{t-\Delta t}}{\Delta t}\left(\sum_j \frac{S_j L_j}{2}\right) + \sum_j G_j^t T_j^t S_j = \Phi'_{v,j} - \sum_j \frac{L_j}{2} \Omega_j U_j (T_i^t - T_{\infty})$$

In matrix form:

$$(M^t + K^t) \cdot T^t = f^t + Q_v^t \cdot M^{t-\Delta t} \cdot T^{t-\Delta t}$$

MAIN HYPOTHESYS
The losses term for the local losses contains the coefficient β_k as shown in the formula:

$$P_{LOCAL} = \frac{1}{2} \sum_k \beta_k\ \rho\ v_1^2$$

The assumption that we make as explained in class is that the coefficients are:
$\beta_k = 0.8$ for each junction
$\beta_k = 0.9$ for each junction at 90°
$f_k = 0.014$ as friction coefficient for each pipe

Our network presents three loops, where the flow direction is supposed to be from right to left. The temperature distribution of supply is assumed at 90 °C while the nominal return corresponds to 60 °C. The pipes are insulated by 5 mm polyurethane (conductivity λ=0.03 $\frac{W}{mK}$) and ground temperature 5 °C. The temperature drop at building is equal to 30 °C for old ones and 45 °C for new ones.

RESULTS
The results of the simulation are the following. The heat demand for each building is reported in the table 1.

Table 1 - Demand and mass flow rate requested by each building

Buildings	volume [m3]	R [W/m3K]	ΔT air [K]	Φ demand [W]	cp [J/kgK]	ΔT water [K]	Flow rate [kg/s]
a	5000	0,9	28	126000	4816	30	0,872
b	10000	0,9	28	252000	4816	30	1,744
c	15000	0,9	28	378000	4816	30	2,616
d	20000	0,4	28	224000	4816	30	1,550
e	25000	0,4	28	280000	4816	30	1,938
f	30000	0,9	28	756000	4816	30	5,233
g	7000	0,9	28	176400	4816	30	1,221
h	12000	0,9	28	302400	4816	30	2,093
i	17000	0,4	28	190400	4816	30	1,318
l	22000	0,9	28	554400	4816	30	3,837
m	27000	0,9	28	680400	4816	30	4,709
n	6000	0,9	28	151200	4816	30	1,047
o	14000	0,4	28	156800	4816	30	1,085
p	18000	0,9	28	453600	4816	30	3,140
q	21000	0,9	28	529200	4816	30	3,663
r	28000	0,4	28	313600	4816	30	2,171

The heat supply is evaluated by the formula:

$$\Phi = r * V * (T_{inD} - T_{outD})$$

Where the r is the volumetric heat transfer coefficient about 0.85-0.95 $\frac{W}{m^3K}$ for old buildings and 0.35-0.45 $\frac{W}{m^3K}$ for new buildings (last 10-15 years), V is the volume and the difference of temperature consider 20 °C inside the building and -8 °C outside in winter time.
The mass flow rate is evaluated by the formula:

$$G = \frac{\Phi}{cp * \Delta T_{water}}$$

Where the specific heat of the water is 4816 $\frac{kJ}{kgK}$ and the difference of temperature is 30 °C referred to the plant water.

In figure 4 the mass flow rates are shown for all the sections in the pipeline. As we expected the mass flow rate in the connections near the node 1, where there is the plant.

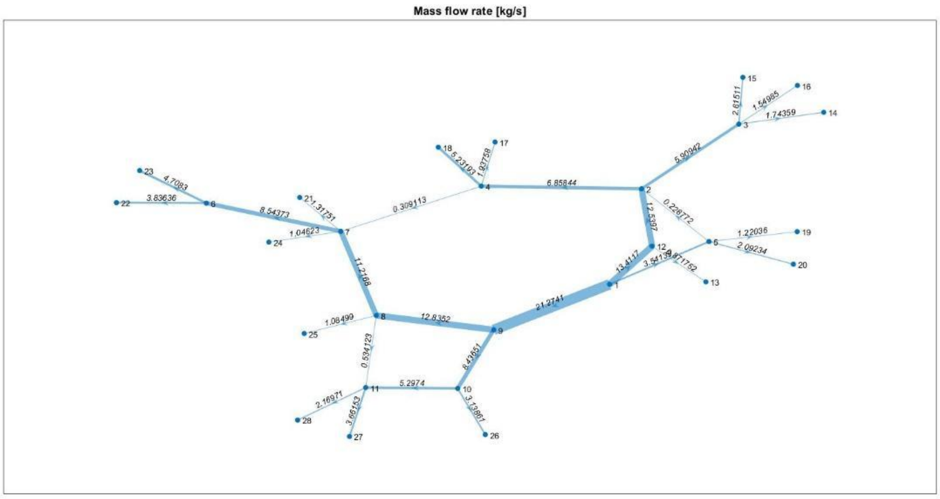

Figure 4 – Pipeline mass flow rate values

In figure 5 are shown the different values of diameters for each branch. The distribution of the network is of tree-shaped kind. As we expected, the more we get closer to the central plant the bigger are the diameters. The more we reach the user the lower the values are.

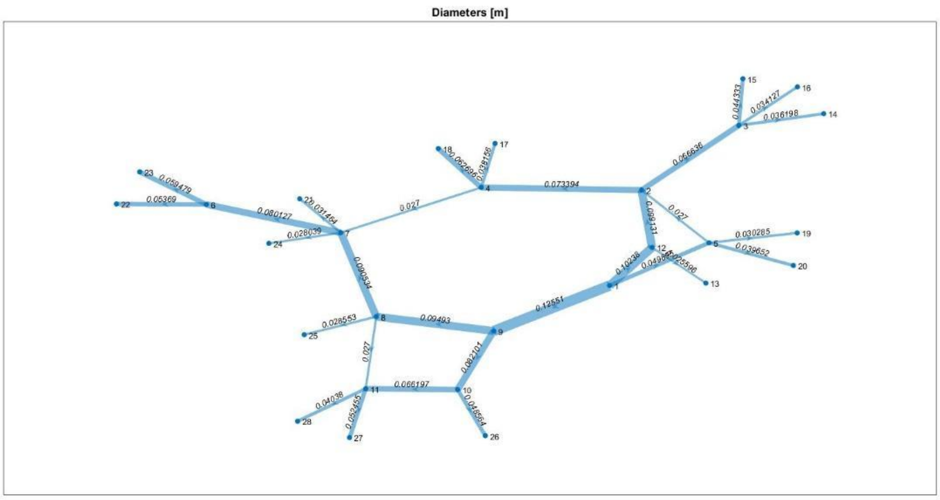

Figure 5 - Pipeline diameter values

The figure 6 represents the behavior of the temperature values at supply side. At the supply the temperatures are included between 90 °C and 86 °C. The more we get far from the plant station, the lower will be the temperatures at the external nodes: this is because by travelling in the pipes the flow has losses of energy.

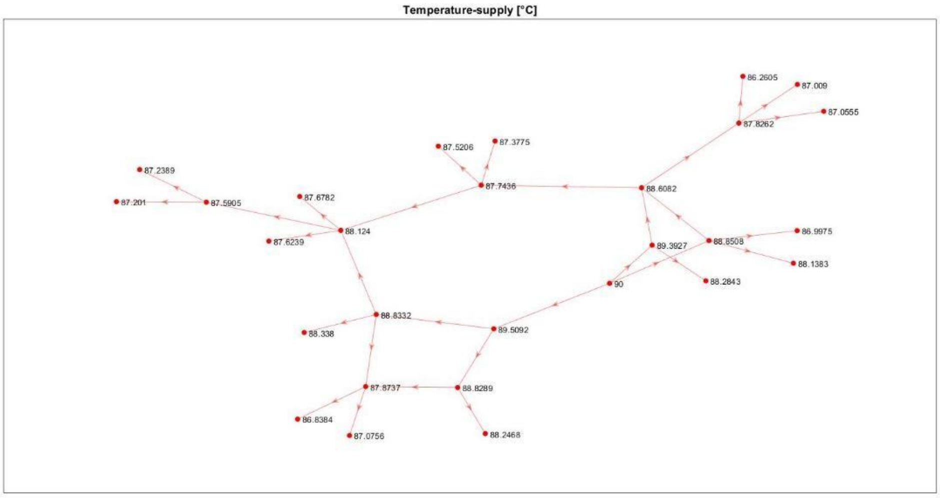

Figure 6 - Temperature values at supply

The figure 7 represents the behavior of the temperature values at the return side. At the return the temperature values are included between 41 °C and 44 °C. The temperature decreases by the external nodes to the plant station because by travelling from the nodes to the station the flow loses energy.

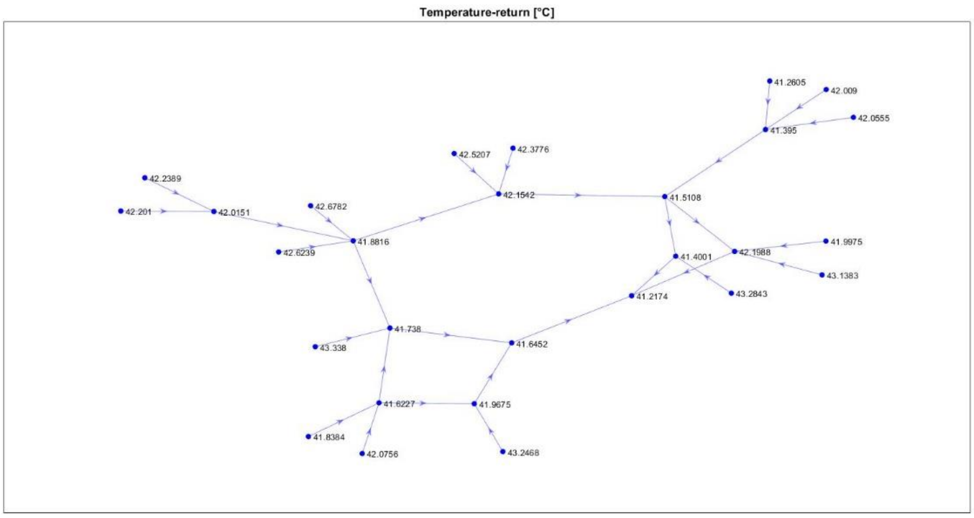

Figure 7 - Temperature values at return

The figure 8 represents the comparison of the temperature values at supply and return. We can notice that the range of temperature are not so wide. It is important to highlight that the values of the return temperatures depend on those of the supply temperature, on the energy performance of the building and on the mass flow rate required by the building.

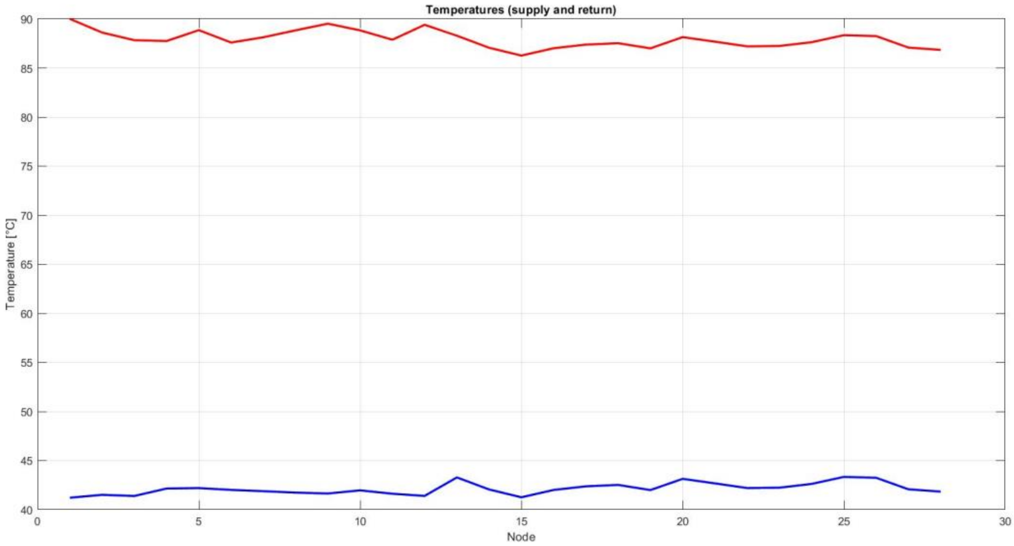

Figure 8 - Comparison between temperature values at supply and return

The figure 9 shows the values of the pressure at the supply side. At the supply side the highest pressure is at the node 1 corresponding to the plant station. The more we travel the network, the lower will be the pressure due to pressure losses.

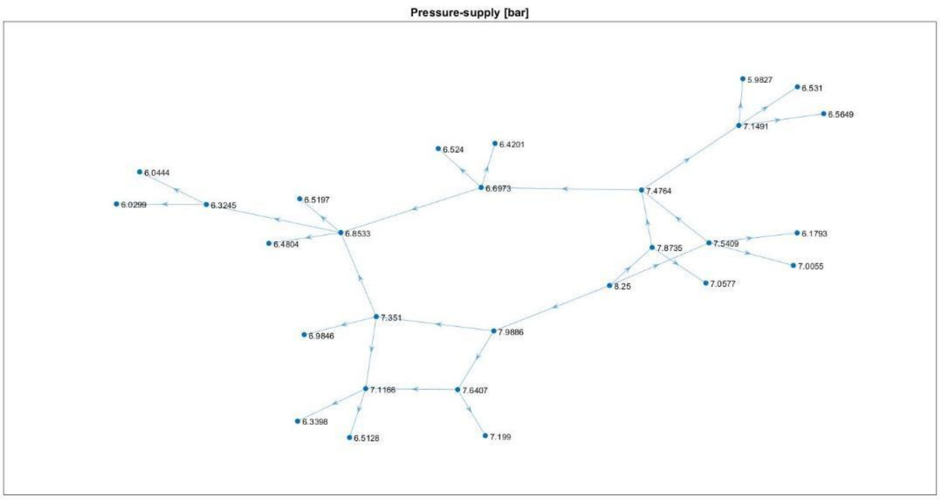

Figure 9 – Pressure values at supply

The figure 10 shows the values of the pressure at the return side. We can observe that for the return side some values are near to the minimum requested of 1.5 bar. In this case, the highest values at return side are at the node which are more distant to the node 1, while the lowest are corresponding to the nodes directly connected at node 1. This phenomenon is due to the pressure losses: from the external node to the node 1 the flow will reduce its pressure.

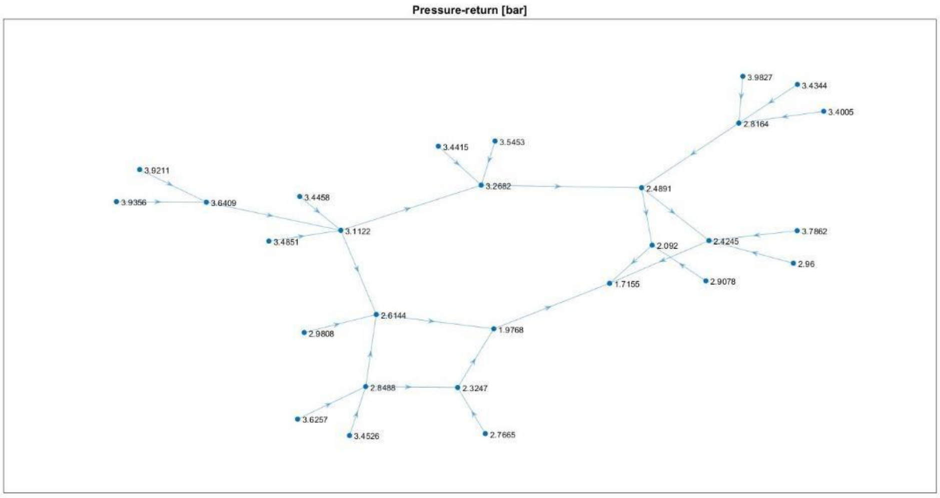

Figure 10 - Pressure values at return

The figure 11 shows the comparison between the values of the pressure at the supply and return. We can observe that for the range of pressure at the supply are included between 8.2 bar and 6 bar; at the return side values are included between 1.7 bar and 4 bar.

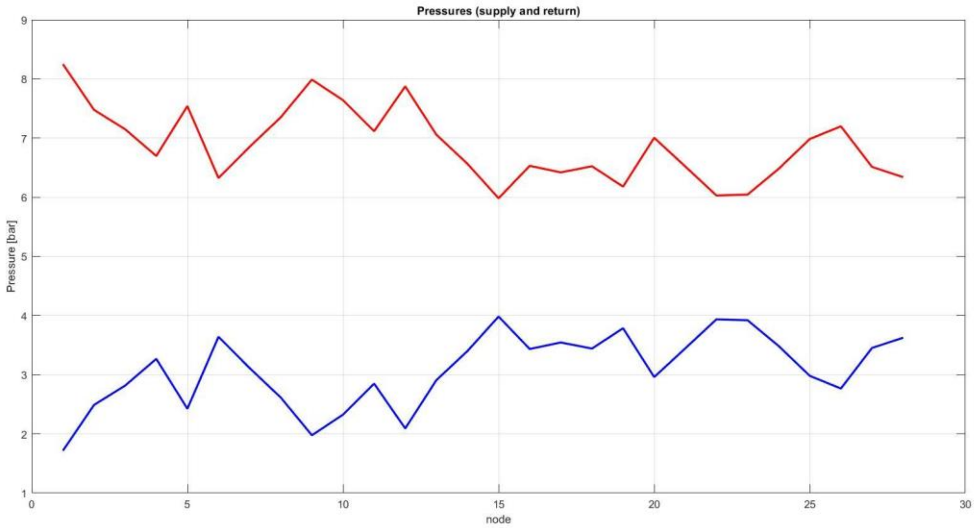

Figure 11 - Comparison between pressure values at supply and return

RETROFITTING

In this part we want to determine the size of the heat exchangers in the substations, so we assume the temperatures on the secondary side as 65°C-55°C for the old buildings. These are the temperatures called *T3* and *T4* and from MATLAB we know the temperatures *T1* and *T2*, so we calculated the logarithmic mean temperature for the heat exchangers with this formula:

$$\Delta T_{mlog} = \frac{(T1 - T2) - (T3 - T4)}{\ln\left(\frac{T1 - T2}{T3 - T4}\right)}$$

Then we calculate the thermal flux (from the first part of the project) we calculated the product UA from this formula:

$$\Phi = U \cdot A \cdot \Delta T_{mlog}$$

In table 2 there are all the buildings that were considered old in part 1 and we calculate the area, supposing a typical value for the global heat transfer coefficient U considering a flat plate heat exchanger**.**

Table 2 - Heat exchangers at the primary side for the old buildings

Old buildings		ϕ [W]	ΔTmlog [°C]	U · A [kW/°C]	U [kW/m2 · °C]	A [m2]
a	13	126000	23,3	5,414678628	4	1,35
b	14	252000	23,3	10,82935726	4	2,71
c	15	378000	23,3	16,24403589	4	4,06
f	18	756000	23,3	32,48807177	4	8,12
g	19	176400	23,3	7,58055008	4	1,90
h	20	302400	23,3	12,99522871	4	3,25
l	22	554400	23,3	23,82458596	4	5,96
m	23	680400	23,3	29,23926459	4	7,31
n	24	151200	23,3	6,497614354	4	1,62
p	26	453600	23,3	19,49284306	4	4,87
q	27	529200	23,3	22,74165024	4	5,69

The second step was to consider the implementation of retrofitting on the old buildings so that the global heat transfer coefficient is reduced to values comparable with new buildings.
In table 3 we changed the volumetric heat transfer coefficient "r" for these old buildings from 0,9 $[W/m3{\cdot}K]$ to 0,4 $[W/m3{\cdot}K]$ a value comparable to the one of the new buildings.

Table 3 - New thermal demand of old buildings after the retrofitting

Old buildings		φ [W]	φ new [W]
a	13	126000	56000
b	14	252000	112000
c	15	378000	168000
f	18	756000	336000
g	19	176400	78400

h	20	302400	134400
l	22	554400	246400
m	23	680400	302400
n	24	151200	67200
p	26	453600	201600
q	27	529200	235200

Then, in order to cover the new thermal demand, we find the new operating temperatures *T3'* and *T4'* on the secondary side, with the same mass flow rates as before the retrofitting.
We consider this formula:

$$\Phi_{new} = G_{sec} \cdot cp_w \cdot (T3' - T4')$$

The mass flow rate G_{sec} on the secondary side is calculated with this formula, with *T3=65°C* and *T4=55°C*.

$$\Phi = G_{sec} \cdot cp_w \cdot (T3 - T4)$$

The second formula use to find the two unknown temperatures *T3'* and *T4'* is this one:

$$\Delta T'_{mlog} = \frac{(T3' - T4')}{\ln\left(\frac{T3' - Ta}{T4' - Ta}\right)}$$

Where Ta is the indoor temperature at 20 °C.
We know the value of the ΔT_{mlog} for the old configuration at the secondary side and we know the value of the old heat flux. Keeping constant the value of UA we can calculate the new $\Delta T'_{mlog}$ knowing the new heat flux.
In table 4 we consider constant the value of U and we calculate the new value of area, that are smaller than the previous one.

Table 4 – Area of heat exchangers at the secondary side for the old building

Old buildings		ϕ [W]	ΔTmlog indoor [°C]	ϕ new [W]	ΔTmlog indoor new [°C]	U · A' [kW/°C]	U [kW/m2 · °C]	A' [m2]
a	13	126000	39,79	56000	17,68	3,167	4	0,79
b	14	252000	39,79	112000	17,68	6,333	4	1,58
c	15	378000	39,79	168000	17,68	9,500	4	2,37
f	18	756000	39,79	336000	17,68	18,999	4	4,75
g	19	176400	39,79	78400	17,68	4,433	4	1,11
h	20	302400	39,79	134400	17,68	7,600	4	1,90
l	22	554400	39,79	246400	17,68	13,933	4	3,48
m	23	680400	39,79	302400	17,68	17,099	4	4,27
n	24	151200	39,79	67200	17,68	3,800	4	0,95
p	26	453600	39,79	201600	17,68	11,400	4	2,85
q	27	529200	39,79	235200	17,68	13,300	4	3,32

We solve the system of the two equations, and we obtain the two temperatures *T3'=40°C* and *T4'=35,56°C*.

With these two new temperatures we can calculate in the primary side *T1'* and *T2'*. We keep constant the mass flow rate at primary side and the product UA also for the heat exchangers at the primary side. Knowing the new heat flux, with this formula, the new mean logarithmic temperature becomes: $\Delta T'_{mlog}$= 10,34 [°C] for all the old building.

$$\Phi_{new} = U \cdot A \cdot \Delta T'_{mlog}$$

So, in order to calculate *T1'* and *T2'* we need two equations:

$$\Phi_{new} = G \cdot cp_w \cdot (T1' - T2')$$

$$\Delta T'_{mlog} = \frac{(T1' - T3') - (T2' - T4')}{\ln\left(\frac{T1' - T3'}{T2' - T4'}\right)}$$

In the end we obtain *T1'=52,21°C* and *T2'=36,86°C.*
Now we calculate the new areas for the heater exchangers for the new buildings, we already have 5 new buildings and also for them we set the new temperatures, after the retrofitting. We want to guarantee the same heat flux, so we keep it constant, but decreasing the temperatures we expect the new areas will increase.
In table 5 we calculate the areas with the old temperatures and compare them with the new one. We use this formula for the old temperatures, keeping constant the value of the global heat exchanger coefficient U.

$$\Phi = U \cdot A \cdot \Delta T_{mlog}$$

Then we use this formula to calculate the areas with the new temperatures.

$$\Phi = U \cdot A' \cdot \Delta T'_{mlog}$$

Table 5 - Re-sizing the heat exchangers at the primary side for the new buildings

New Buildings		ϕ [W]	ΔTmlog [°C]	ΔT'mlog [°C]	UA [kW/°C]	UA' [kW/°C]	U [kW/m2 · °C]	A [m^2]	A' [m^2]
d	17	224000	23,3	8,799	9,614	25,459	4	2,403	6,365
e	18	280000	23,3	8,799	12,017	31,823	4	3,004	7,956
i	22	190400	23,3	8,799	8,172	21,640	4	2,043	5,410
o	26	156800	23,3	8,799	6,730	17,821	4	1,682	4,455
r	29	313600	23,3	8,799	13,459	35,642	4	3,365	8,910

The areas of the heat exchangers increase of about *165%.*

Then we run the code with the new four temperatures. In figure 12-13-14 we can notice that the temperature values are drastically reduced at supply and return. The supply temperatures are included between 52 °C and 50 °C. The return temperatures are included between 34 °C and 36 °C.

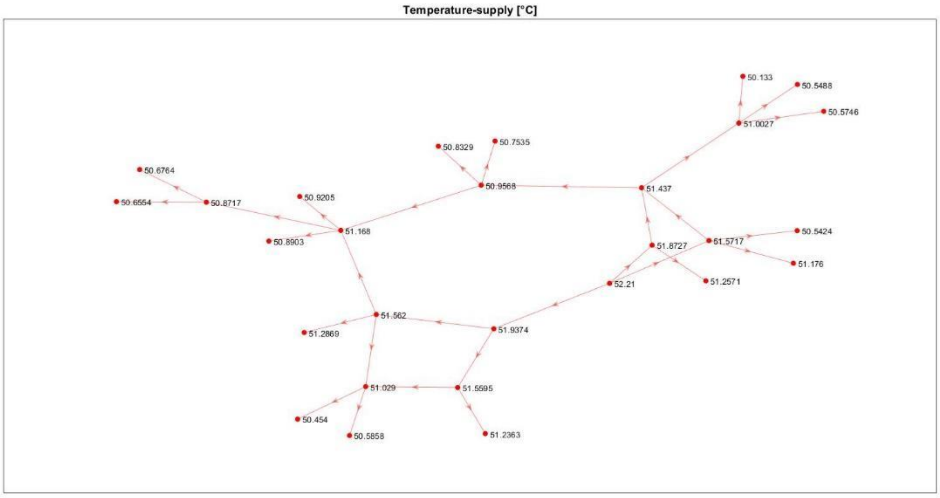

Figure 12 – Temperature supply after retrofitting

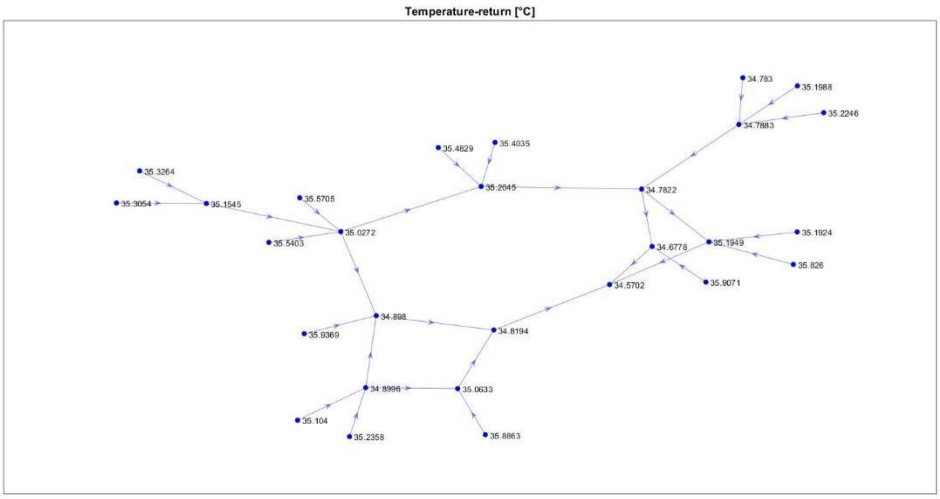

Figure 13 – Temperature return after retrofitting

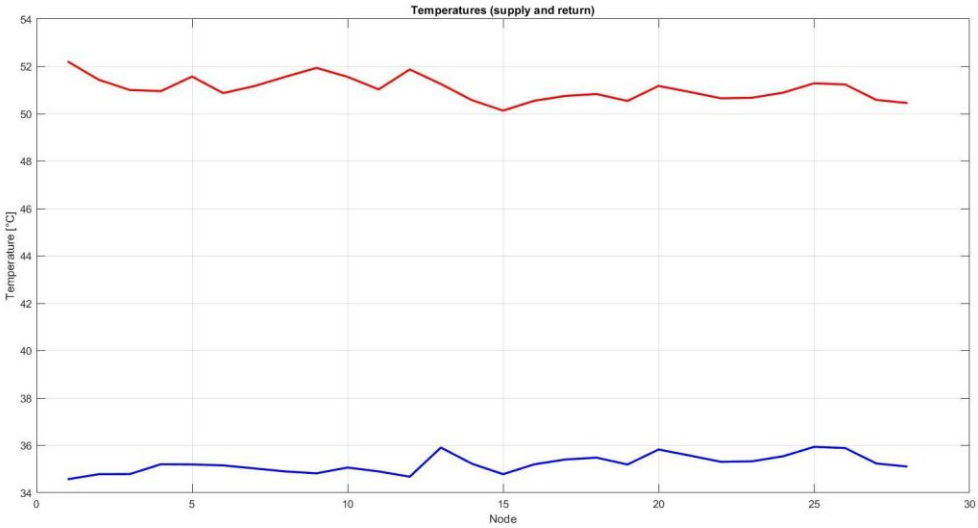

Figure 14 – Comparison between temperature supply and return after retrofitting

In figure 15 - 16 – 17 we can notice that, after retrofitting, the pressure values are similar at supply and return side compared with the design simulation.

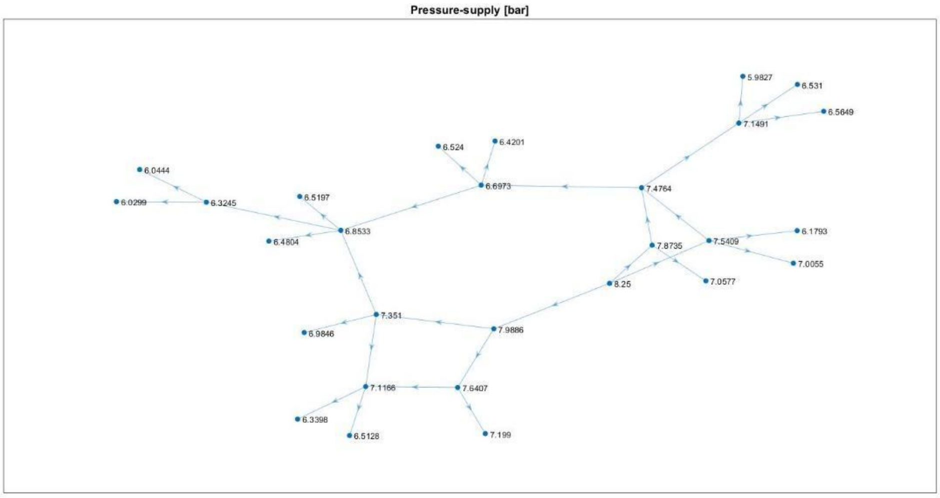

Figure 15 – Pressure Supply after retrofitting

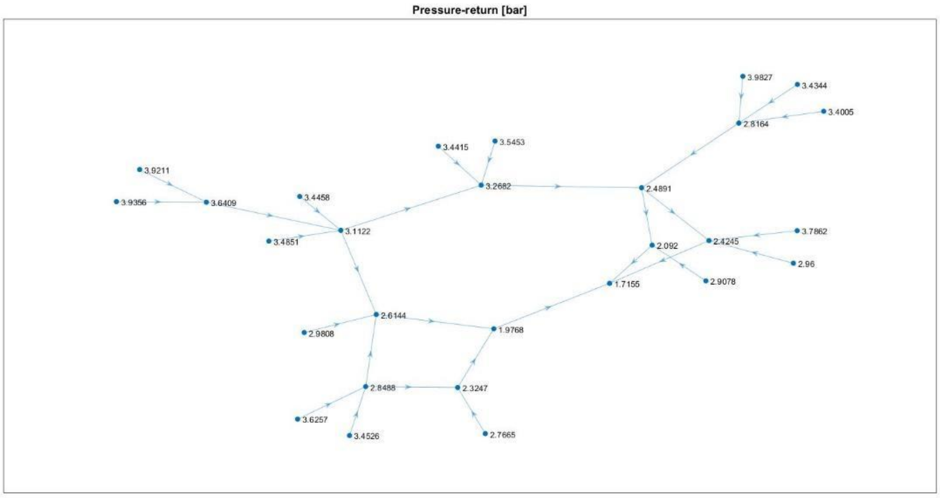

Figure 16 – Pressure return after retrofitting

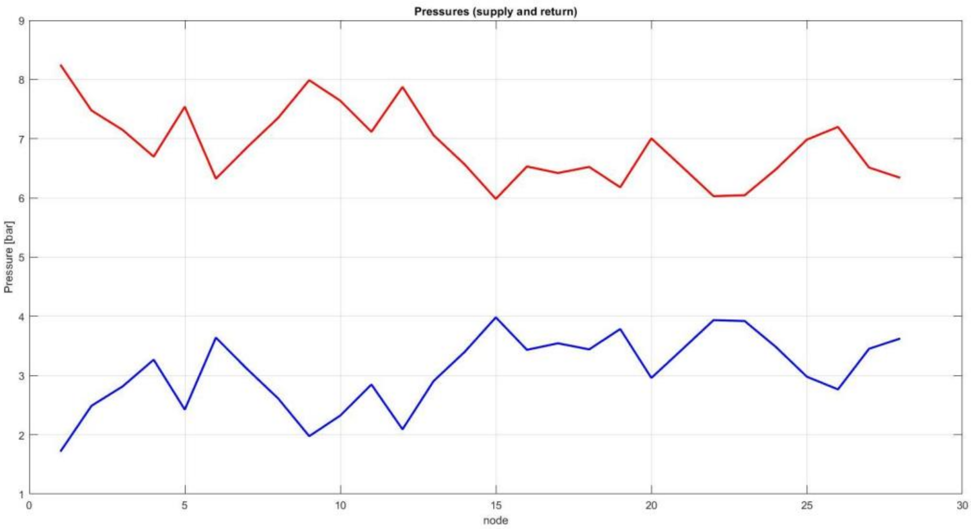

Figure 17 – Comparison between pressure values at supply and return after retrofitting

THERMAL LOSSES

In the end we consider the thermal losses. We took for each branch the two temperatures at the terminals, for both the supply and return network, the mass flow rate and we calculated the thermal losses with this formula:

$$\Phi = G \cdot cp_w \cdot |\Delta T|$$

Table 6- Thermal losses for the Design network

Branches	T1sup [°C]	T2sup [°C]	G [kg/s]	Power delivered [kW]	Power losses supply [kW]	T1ret [°C]	T2ret [°C]	Power losses return [kW]
11-10	88,829	87,874	5,297	0,000	21,176	41,623	41,967	7,644
6-7	88,124	87,590	8,544	0,000	19,076	42,015	41,882	4,774

7-8	88,833	88,124	11,217	0,000	33,293	41,882	41,738	6,739
8-9	89,509	88,833	12,835	0,000	36,310	41,738	41,645	4,984
10-9	89,509	88,829	8,436	0,000	24,021	41,967	41,645	11,378
9-1	90,000	88,851	21,274	0,000	102,312	41,645	41,217	38,090
5-1	90,000	88,851	3,541	0,000	17,032	42,199	41,217	14,545
4-2	88,608	87,744	6,859	0,000	24,816	42,154	41,511	18,468
3-2	88,608	87,826	5,909	0,000	19,339	41,395	41,511	2,863
2-12	89,393	88,608	12,540	0,000	41,173	41,511	41,400	5,808
12-1	90,000	89,393	13,412	0,000	34,084	41,400	41,217	10,255
q-11	87,874	87,076	3,662	459,705	12,229	41,623	42,076	6,940
r-11	87,874	86,838	2,170	408,610	9,401	41,623	41,838	1,959
p-10	88,829	88,247	3,139	394,053	7,645	42,076	41,967	1,420
m-6	87,590	87,239	4,708	591,127	6,928	42,239	42,015	4,409
l-6	87,590	87,201	3,836	481,655	6,253	42,201	42,015	2,985
i-7	88,124	87,678	1,318	248,119	2,458	42,678	41,882	4,393
n-7	88,124	87,624	1,046	131,355	2,189	42,624	41,882	3,250
o-8	88,833	88,338	1,085	204,330	2,249	43,338	41,738	7,265
h-5	88,851	88,138	2,092	262,693	6,239	43,138	42,199	8,227
g-5	88,851	86,997	1,220	153,216	9,465	41,997	42,199	1,028
f-4	87,744	87,521	5,232	656,869	4,882	42,521	42,154	8,024
e-4	87,744	87,378	1,938	364,894	2,968	42,378	42,154	1,811
d-3	87,826	87,009	1,550	291,875	5,301	42,009	41,395	3,983
b-3	87,826	87,056	1,744	218,908	5,624	42,056	41,395	4,820
c-3	87,826	86,260	2,615	328,327	17,136	41,260	41,395	1,472
a-12	89,393	88,284	0,872	109,448	4,044	43,284	41,400	6,874
11-8	87,874	88,833	0,534	67,060	2,145	41,623	41,738	0,258
5-2	88,608	88,851	0,229	28,724	0,232	42,199	41,511	0,659
7-4	87,744	88,124	0,309	38,820	0,492	41,882	42,154	0,353
SUM				**5439,789**	**480,512**			**195,677**
Supply losses	**7,86**	**%**						
Return losses	**3,20**	**%**						
Total losses	**15,71**	%						

In table 6 we calculate the thermal losses for the supply and for the return networks with this formula:

$$Thermal\ losses\ supply = \frac{P\ losses\ supply}{P\ demand\ design + P\ losses\ supply + P\ losses\ return} = 7{,}86\%$$

$$Thermal\ losses\ return = \frac{P\ losses\ return}{P\ demand\ design + P\ losses\ supply + P\ losses\ return} = 3{,}20\%$$

The total thermal losses for the design network are equal to 15,71%.
For the case of the retrofitting, we make the same calculations in table 7

Table 7 - Thermal losses for the retrofitted network

Branches	T1sup [°C]	T2sup [°C]	G [kg/s]	Power delivered [kW]	Power losses supply [kW]	T1ret [°C]	T2ret [°C]	Power losses return [kW]
11-10	51,560	51,029	5,297	0,000	11,761	34,900	35,063	3,628
6-7	51,168	50,872	8,544	0,000	10,595	35,155	35,027	4,553
7-8	51,562	51,168	11,217	0,000	18,491	35,027	34,898	6,063
8-9	51,937	51,562	12,835	0,000	20,167	34,898	34,819	4,223
10-9	51,937	51,560	8,436	0,000	13,342	35,063	34,819	8,610
9-1	52,210	51,937	21,274	0,000	24,269	34,819	34,5702	22,188
5-1	52,210	51,572	3,541	0,000	9,460	35,195	34,5702	9,259
4-2	51,437	50,957	6,859	0,000	13,783	35,205	34,782	12,122
3-2	51,437	51,003	5,909	0,000	10,741	34,788	34,782	0,151
2-12	51,873	51,437	12,540	0,000	22,868	34,782	34,678	5,482
12-1	52,210	51,873	13,412	0,000	18,931	34,678	34,5702	6,037
q-11	51,029	50,586	3,662	235,216	6,792	35,236	34,900	5,151
r-11	51,029	50,454	2,170	139,381	5,221	35,104	34,900	1,856
p-10	51,560	51,236	3,139	201,624	4,246	35,886	35,063	10,810
m-6	50,872	50,676	4,708	302,460	3,848	35,326	35,155	3,387
l-6	50,872	50,655	3,836	246,447	3,473	35,305	35,155	2,423
i-7	51,168	50,920	1,318	84,636	1,365	35,570	35,027	2,995
n-7	51,168	50,890	1,046	67,210	1,216	35,540	35,027	2,247
o-8	51,562	51,287	1,085	69,699	1,249	35,937	34,898	4,717
h-5	51,572	51,176	2,092	134,411	3,465	35,826	35,195	5,526
g-5	51,572	50,542	1,220	78,396	5,257	35,195	35,192	0,013
f-4	50,957	50,833	5,232	336,098	2,711	35,483	35,205	6,096
e-4	50,957	50,753	1,938	124,469	1,649	35,403	35,205	1,613
d-3	51,003	50,549	1,550	99,562	2,944	35,199	34,788	2,662
b-3	51,003	50,575	1,744	112,008	3,123	35,225	34,788	3,184
c-3	51,003	50,133	2,615	167,994	9,517	34,783	34,788	0,058
a-12	51,873	51,257	0,872	56,001	2,246	35,907	34,678	4,485
11-8	51,029	51,562	0,534	34,312	1,191	34,900	34,898	0,004
5-2	51,572	51,437	0,229	14,697	0,129	35,195	34,782	0,395
7-4	50,957	51,168	0,309	19,863	0,273	35,027	35,205	0,229
SUM				**2524,485**	**234,325**			**140,166**
Supply losses	**8,08**	**%**						

Return losses	**4,84**	**%**						
Total losses	**16,17**	%						

We calculate the thermal losses for the supply and for the return networks with the same formulas and we obtain:

$$Therml\ losses\ supply = 8{,}08\%$$

$$Therml\ losses\ return = 4{,}84\%$$

The total thermal losses for the retrofitted network are equal to 16,17%.

CONCLUSION

As a conclusion we can say that district heating is a solution with a lot of potential for the integration of renewables and the use of waste heat. It also allows a CO_2 emission reduction with respect to conventional house heating.

Thanks to the SIMPLE algorithm we have been able to find the pressure at each node and the mass flow rate in each branch, it is fundamental to know these parameters for the network design and operation. We can say that this algorithm is indeed a powerful tool even if it is formulated by making some hypothesis, for example it is assumed that the non-linearity in the momentum equation is weak and this is a strong assumption, so it is important to know that we are simplifying the problem with this hypothesis.

The temperature distribution in the network is then found by solving the thermal problem using the upwind scheme, so in this case the flow direction is assumed from right to left.

The last part is the retrofitting of the old buildings, we have assumed that the old buildings have been modernized (for example with a better insulation), as a consequence now their thermal demand is lower and comparable with the one of the new buildings. Now it is possible to lower the temperatures at the secondary side by keeping the same mass flow rate as before the retrofitting. It is also possible to lower the operating temperatures at the primary side (always with the same mass flow rate), this allows us to fully exploit low temperature heat from other industries that had been excluded before, because we needed an higher supply temperature.

WEB REFERENCES

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