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Case Study: Exergy and Energy Analysis of Hot Water Loop and Branch Network Using Two CHP

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Abstract

In this paper the analysis of two municipal hot water supply network (loop and branch) based on the energy and exergy analysis is investigated. A Hot water network for a residential town in northern Iran with a mild climate and based on a 20 year period design and the calculation of per capital consumption of hot water is designed. The design was based on loop and branch network design. By the analysis of energy and exergy the amount of heat and exergy losses for these two deferent design was obtained and the results showed that with a suitable insulation, the effect of pipes material in heat losses can be minimized so that the lowest temperature decrease of branch and loop networks, by changing the type of pipe material from galvanized iron to PVC, is decreased by 0.08% and .039% respectively. That is while the pipe material and network design have major effect on exergy losses. For example by shifting from branch design to loop design with PVC pipes, the exergy loss is increased by 0.46 KW and by changing galvanized iron pipes to PVC pipes in branch network, the exergy loss is decreased by 0.2 KW with 98.39% of network exergy efficiency.

Keyword: branch network, loop network, exergy loss, energy, CHP.

Introduction

Karen N. Finney et al. tried to show some opportunities for expanding district energy network to modeling geographical information systems software for the in-depth analysis of heat demands in the city [1]. Thus, heat maps were produced to locate the existing and emerging heat sources and sinks, out of which six heat zones where an expansion to the existing network was possible were identified and the infrastructure was planned for each development. D. Dobersek and D. Goricanec optimized pipe network with hot water [2]. The mathematical model which consisted of the nonlinear objective function and system of nonlinear equations for the hydraulics limitations was developed. Accordingly, the computer program for determining optimal tree path by the simplex method was solved. For economic estimation, the capitalized value method that considers all costs of investment and operation was used. Results were presented for a real case study network with 24 nodes and 33 pipe sectors. H. I. Tol and S. Svendsen introduced a method for designing a low-energy district heating (DH) system and used studies of different pipe dimensioning methods, substation types, and network layouts for this purpose [3]. It was also demonstrated that appreciable considerable reduction in heat loss from the DH network could be obtained. Effects of the network type on the pipe dimensions were also investigated for different types of substations that contained buffer tanks and heat exchangers and for the booster pumps installed in the DH network. Two types of network layouts were compared in terms of satisfaction of customers with supply temperatures and heat loss within the DH network to prevent excessive drops at supply temperature during the summer months. H. Gül and E. KAkpinar investigated the effect on heat transfer rates, friction factor, and exergy loss of oscillating pipe [4]. For this case, bulk and local wall temperature distribution, pressure drop, inlet and outlet temperatures, and frequency were measured.

Variations of Nusselt number and exergy loss with these parameters were also determined and graphically presented. Their results revealed that exergy loss was decreased with the increase in Reynolds number. Ali Kecebas proposed that energy consumptions in buildings can be considerably reduced using insulation materials [5]. Even in well-insulated buildings, energy consumption may reduce further by insulating transmission pipes. In the present research, insulation thickness was optimized using exergy method. Consequently, combustion parameters such as excess air stack gas temperature and combustion chamber parameters were much more effective in optimum insulation thickness. V.L. Speight elaborated on the impact of pipe roughness on pumping energy in complex distribution systems [6]. Tetsuya Wakui et al. investigated the feasibility on a residential energy supply network using multiple cogeneration systems, known as combined heat and power optimization approach [7]. Target residential energy supply network was based on a microgrid of residential cogeneration systems without electric power export and hot water supply network, in which the produced hot water was supplied to multiple residence units via the networked pipes. Results showed that the energy-saving effect of the residential energy supply network was dominated by power interchange and decreased with the increasing number of residential units involved in the hot water supply network.

Nowadays CHP systems, with a suitable gas engines in the range of 83 to 93 ˚C of hot water, are well developed for municipal hot water networks. In this paper the analysis of hot water networks using CHP systems is discussed. The use of water-supply systems and network heat losses are of important factors when selecting water-supply networks.

These networks, considering network design parameters such as water velocity inside the pipe and the pressure drop compensation in the pipe and etc. are designed and performed using Water GEMS3 software. In this paper by integrating the energy and exergy approaches with these parameters, the analysis of different water-supply networks for a residential town is investigated so that the best design from the thermodynamic perspective, according to the design limits and the least heat and exergy losses, is obtained. The analysis of energy and exergy is performed using MATLAB.

The salient features of this work can be referred to the following cases:

- *Branch and loop hot water network design*
- *Exergy analysis of water-supply network*
- *Proper ware-supply selection with the lowest heat and exergy losses*
- *Sensitivity analysis of ambient temperature change on the best selected network in this paper, and the influence of temperature from the energy and exergy point of view*

Water –Supply Network Design

Hydraulic calculation of pipes methods

Darcy–Weisbach equation and Hazen–Williams equation are *usually used to calculate the pipes and pipes diameters.*

Darcy–Weisbach equation

Pressure drop in pipes can be obtained through Darcy–Weisbach equation as follow:

$$h_L = f\,\frac{L}{D}\,\frac{V^2}{2g} \qquad (1)$$

Which $h_{L\text{ is pressure}}$ *drop (m), f is Friction coefficient, L is pipe length (m), D is internal diameter (m), V is flow velocity (m/s), g is gravity acceleration (m/s*^{2}*).*

In this equation the f is an important variable depended on the pipe roughness coefficient and Reynolds number. Reynolds number depends on water temperature which will effect of f variable.

In 1930 Karmen and Prandtel published the turbulence theory which later in 1939 Colebrook used the theory to estimate the pressure drop in existed pipe in the market.

Nowadays, *Colebrook* and White equation is the most precise equation used for performing hydraulic calculation which the accuracy is approved by numerous experiments for different sate of water flow.

Prandtel, based on the mixing theory and logarithmic distribution of velocity on the cross sectional area of the pipe, proposed equation (2):

$$\frac{1}{\sqrt{f}} = A\,Log\,\frac{D}{K} + B \qquad (2)$$

Which K represents all the geometric properties of the internal pipe wall, A and B are constant coefficients.

Hazen-Williams (The criteria used in WaterGEMS3 software)

The Hazen-Williams equation can be shown as below in metric system:

$$V = 0.849CR^{0.63}S^{0.54} \qquad (3)$$

Which v is velocity, C is Hazen-Williams coefficient, R is hydraulic radius and S is energy line slope

This equation is still widely used in English countries especially in USA.

The following equation is used to obtain pressure drop in pipe (according to Hazen-Williams equation):

$$h_L = 10.700\left(\frac{Q}{C}\right)^{1.85} D^{-4.87} \tag{4}$$

Which h_L is pressure *drop (m)*, C is Hazen-Williams coefficient, D is diameter and Q is flow (m^3/s).

Hazen-Williams equation disadvantage is that the effect of viscosity and Reynolds number, followed by the temperature effect is ignored, whereas in low flows in relatively smooth and polished pipes the effect of these factors should be considered.

The relation between f (*Darcy*–Weisbach equation) and C (*Hazen-Williams equation) can be obtained by putting mentioned equation equal.*

$$f = \left(\frac{1}{C^{1.83}}\right)\left(\frac{134}{V^{0.15} D^{0.167}}\right) \tag{5}$$

Which V is velocity and D is diameter.

Branch network design steps

The process of branch network design and also the design flowchart of *loop* networks are discussed (Fig1).

1. Pipes cumulative flow supply
2. energy slope calculation for the critical path (critical path refers to a path in which water have a maximum loss and If the water pressure drop is observed and considered on this path, others will be supplied automatically.)
3. Pipe diameter calculation using *Darcy*–Weisbach equation
4. Pressure and velocity control at all grid points according to regulations and agenda

In order to obtain H and Q, the equations can be solved using following methods:

- Newton Raphson
- Hardy Cross
- Linear theory

In this paper the linear method is used to solve the equation.

According to the zoning map of the region, study was conducted using ground adjacent to each node, and a height for each node is determined. Assuming a constant population density of the city, using the specified area, the consumption rate of each node is determined. The software will perform the design using inlet data analysis. It should be noted that Hazen equation is selected as the basis for the software calculations. The velocity and head should be checked in each analysis and if they did not fit the criteria and regulations, it would be corrected by changing the diameter of the tubes.

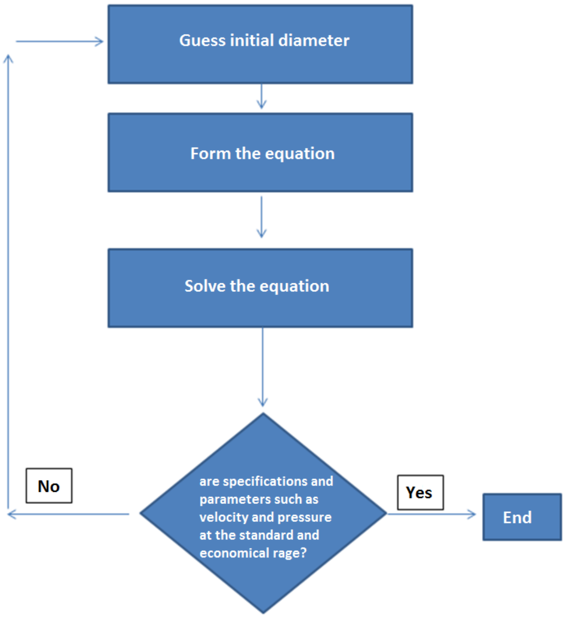

Fig1. Branch network design steps flowchart

Heat Transfer Calculations

Conduction heat transfer from a pipe with the surface temperature of T_1 at the underground depth of Z and ground surface temperature of T_2 (Fig1) can be calculated as follow [8]:

$$q = Sk\left(T_1 - T_2\right) \tag{6}$$

Which k is earth conduction coefficient and S is geometric coefficient which can be calculated trough bellow relation [8]:

$$S = \begin{cases} \dfrac{2\pi L}{\cosh^{-1}\left(\dfrac{2z}{D}\right)} & L \gg D \\[2ex] \dfrac{2\pi L}{\ln\left(\dfrac{4z}{D}\right)} & L \gg D, z > \dfrac{3D}{2} \end{cases}$$

(7)

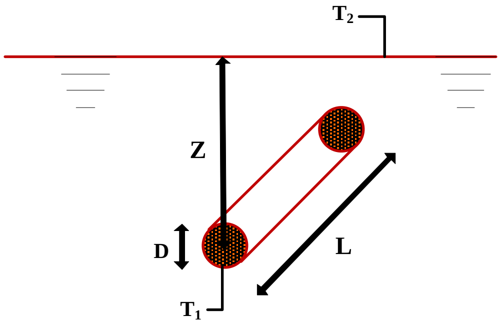

Fig2. Effective parameter in geometric coefficient for conduction heat transfer

Given the assumption that the surface temperature is equal to ambient temperature equations are solved.

In both cases, polystyrene insulation type with conductivity of 0.027 and 1 cm in thickness is considered.

Exergy Analysis

The exergy analysis can help to develop strategies and regulations in order to effective application of energy in various systems.

Exergy can be classified into four groups. Among them physical and chemical exergy are important.

In this study, two other components of the kinetic exergy and potential exergy are assumed to be negligible [9].

Physical exergy equals to the maximum work obtainable from the material flow and can be calculated when a process exchanges heat from initial state with the ambient environment.

Chemical exergy is a part of exergy in combustion process and along with the outgo of chemical compounds of a chemical equilibrium.

Using first and second law of thermodynamic exergy equilibrium can be obtained:

$$\frac{dE_{cv}}{dt}=\sum_{j}\left(1-\frac{T_0}{T_i}\right)\dot{Q}_i-\left(\dot{W}-p_0\frac{dV_{cv}}{dt}\right)+\sum_i \dot{m}_i e_i-\sum_e \dot{m}_e e_e-\dot{E}x_D$$

(8)

If the rate of change is zero the following equation can be obtained:

$$\dot{E}x_Q+\sum_i \dot{m}_i ex_i=\sum_e \dot{m}_e ex_e+\dot{E}x_W+\dot{E}x_D \qquad (9)$$

Which ex is the amount of specific exergy and $\dot{E}x_D$ is exergy loss.

$$\dot{E}x_D=T_0\dot{S}_{gen} \qquad (10)$$

$$\dot{E}x_Q=\int_i^e\left(1-\frac{T_0}{T_b}\right)q'\,dL \qquad (11)$$

$$\dot{E}x_W=\dot{W}-p_0\frac{dV_{CV}}{dt} \qquad (12)$$

$$ex_{ph}=\left(h-h_0\right)-T_0\left(S-S_0\right) \qquad (13)$$

Which S is entropy, h is enthalpy, $\dot{E}x_w$ the rate of the exergy of the work, and the index I, e, ph, 0 are inlet, outlet, physical exergy and reference atmosphere and T_0 reference temperature (293 K). In equation 11, q' is the heat exchange rate per unit length L, T_b is boundary temperature from which the heat exchange happens. As a result the exact amount of exergy loss for pipe can be obtained as follow [9]:

$$\dot{E}x_i=\dot{E}x_e+\dot{E}x_D+\dot{E}x_L \qquad (14)$$

Case Study

The case study is a residential town in northern Iran with a mild climate and yearly mean ambient temperature of 17 °C which is reduced to -1 °C in cold days. This town is newly constructed with initial population of 8000 people and Electricity and hot water can be supplied using two CHP systems.

Evaluated scenarios in case study

In this study analysis of municipal water-supply cycle is based on exergy analysis. The water-supply network is studied based on two prevalent piping networks.

The networks are designed in both *loop* and branch network and in both cases PVC and galvanized iron is applied.

In this study, by calculating the minimum temperature that is reached to consumers and minimum exergy loss in water-supply network with high exergy efficiency, the best water-supply network is selected.

Case study estimated population

Several graphical and mathematical methods can be used to estimate the short term population. This estimation can be classified into geometrical growth, arithmetic growth, and reduced growth rate. Each class has an independent relation and in order to find a proper mathematical relation, the previous data of the area must be plotted on population-time graph. A proper relation to estimate the population can be obtained using the plotted curve. A short-term method for estimating population between two population censuses and also population estimates since the last census is used.

To calculate the population growth rate according to the following relations the population of the town for a one-year construction period and 20-year projection period is calculated as follows:

$$r = \frac{Ln\, P_2 - Ln\, P_1}{t_2 - t_1} \qquad (15)$$

$$\frac{dP}{dt} = r \times t \qquad (16)$$

$$Ln\, P_2 = Ln\, P_1 + r \times \Delta t \qquad (17)$$

$$P_n = P_\circ \times (1 + r)^n \qquad (18)$$

Which P_0 population at the beginning of the project, P_n population n years after project initiation.

Assuming a geometric growth rate of 2 percent, the population in the first year of the project and upcoming years is estimated according to the following table1.

Table1. Rate of increase in population during the design period

Details	**Population**	**year**
	8000	2014
beginning of the plan	8160	2015
End of the plan	12125	2035

In order to find the hot water flow, per capita consumption of 80.27 liters per person per day and also the final population of 12125 is considered in calculations.

In order to make the entire network more efficient and responsive during peak hours (heating system in winter), a coefficient is considered in calculation process.

The necessary hot water for the entire town is 3379 liter per second which must be produced daily by two CHP each 1459.728 liter per second.

Result

Branch network analysis using two hot water sources

Two 8 Kw. pumps with variable rotation is chosen to compensate for pressure drop for both iron galvanized and PVC pipes. The results for both types of pipe material are presented in table2.

Also CHP systems from the selected hot water production point of view are characterized and modeled based on the following table3.

Table2. Pumps specifications for branch network (Galvanized Iron and PVC pipes)

Label	Elevation (m)	Control Status	Intake Pump Grade (m)	Discharge Pump Grade (m)	Discharge (l/s)	Pump Head (m)	Calculated Water Power (kW)
PMP-1	111.00	On	111.73	164.99	15.32	53.25	8.00
PMP-2	111.00	On	110.86	155.00	18.48	44.14	8.00

Table3. CHP specification from the selected hot water production point of view for branch network and PVC and galvanized iron pipes

Label	Elevation (m)	Zone	Inflow (l/s)	Calculated Hydraulic Grade (m)
R-2	112.00	Zone	-15.32	112.00
R-3	111.00	Zone	-18.48	111.00

Network design and piping are performed using WaterGEMS software. In branch network, the hot water enters each pipe and is transferred to another node until it is reached to the last node. In this system the beginning and the end of the branch can't reach together to form a loop (Fig3).

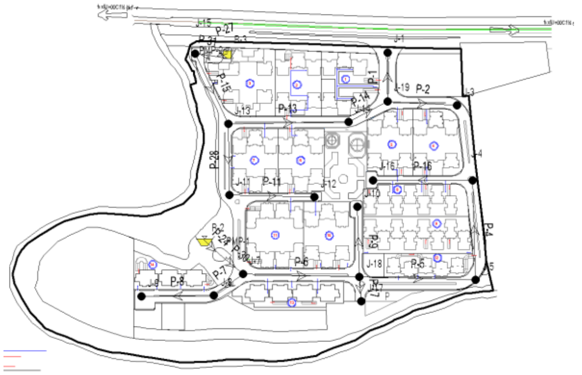

Fig3. Case A. Branch network design using two hot water sources (PVC and galvanized pipe) (indicated with yellow color).

The results for both galvanized and PVC pipes are presented in two tables4 and table5.

Also the effect of changing pipe material on pressure drop (indicating the effect of pipe roughness) is shown.

Table4. Results for pipes with galvanized iron material

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Headloss (m)	Headloss Gradient (m/km)	Velocity (m/s)
P-16	134.11	50.0	Galvanized iron	120.0	1.42	2.34	17.41	0.72
P-17	33.53	50.0	Galvanized iron	120.0	1.44	0.60	17.86	0.73
P-7	48.77	80.0	Galvanized iron	120.0	3.94	0.57	11.69	0.78
P-30	85.30	150.0	Galvanized iron	120.0	15.32	0.58	6.75	0.87
P-24	39.60	150.0	Galvanized iron	120.0	15.32	0.27	6.75	0.87
P-9	94.49	40.0	Galvanized iron	120.0	1.21	3.60	38.12	0.96
P-11	112.78	50.0	Galvanized iron	120.0	1.90	3.35	29.74	0.97
P-5	155.45	80.0	Galvanized iron	120.0	5.02	2.84	18.28	1.00
P-13	161.54	100.0	Galvanized iron	120.0	7.93	2.32	14.37	1.01
P-31	45.70	150.0	Galvanized iron	120.0	18.48	0.44	9.56	1.05
P-27	15.00	150.0	Galvanized iron	120.0	18.48	0.14	9.56	1.05
P-1	67.06	50.0	Galvanized iron	120.0	2.11	2.44	36.37	1.08
P-14	57.91	80.0	Galvanized iron	120.0	5.65	1.32	22.77	1.12
P-6	155.45	100.0	Galvanized iron	120.0	9.33	3.02	19.45	1.19
P-2	94.49	50.0	Galvanized iron	120.0	2.34	4.15	43.91	1.19
P-28	94.50	70.0	Galvanized iron	120.0	4.90	3.16	33.46	1.27
P-8	97.54	50.0	Galvanized iron	120.0	2.59	5.17	53.00	1.32
P-15	103.63	120.0	Galvanized iron	120.0	15.91	2.23	21.49	1.41
P-4	131.06	50.0	Galvanized iron	120.0	2.94	8.79	67.09	1.50

Table5. Results for pipes with PVC material

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Headloss (m)	Headloss Gradient (m/km)	Velocity (m/s)
P-16	134.11	50.0	PVC	150.0	1.42	1.54	11.52	0.72
P-17	33.53	50.0	PVC	150.0	1.44	0.40	11.81	0.73
P-7	48.77	80.0	PVC	150.0	3.94	0.38	7.73	0.78
P-30	85.30	150.0	PVC	150.0	15.32	0.38	4.47	0.87
P-24	39.60	150.0	PVC	150.0	15.32	0.18	4.47	0.87
P-9	94.49	40.0	PVC	150.0	1.21	2.38	25.22	0.96
P-11	112.78	50.0	PVC	150.0	1.90	2.22	19.67	0.97
P-5	155.45	80.0	PVC	150.0	5.02	1.88	12.09	1.00
P-13	161.54	100.0	PVC	150.0	7.93	1.54	9.51	1.01
P-27	15.00	150.0	PVC	150.0	18.48	0.09	6.32	1.05
P-31	45.70	150.0	PVC	150.0	18.48	0.29	6.32	1.05
P-1	67.06	50.0	PVC	150.0	2.11	1.61	24.06	1.08
P-14	57.91	80.0	PVC	150.0	5.65	0.87	15.06	1.12
P-6	155.45	100.0	PVC	150.0	9.33	2.00	12.87	1.19
P-2	94.49	50.0	PVC	150.0	2.34	2.74	29.04	1.19
P-8	97.54	50.0	PVC	150.0	2.59	3.42	35.06	1.32
P-15	103.63	120.0	PVC	150.0	15.91	1.47	14.22	1.41
P-4	131.06	50.0	PVC	150.0	2.94	5.82	44.38	1.50
P-28	94.50	60.0	PVC	150.0	4.90	4.43	46.90	1.73

Loop Network analysis using two hot water sources Table 6, Table 7 and Table 8 shows the result from _loop_ network design for Fig4.

Table6. Selected pumps specifications for _loop_ network (Galvanized Iron and PVC pipes)

Label	Elevation (m)	Control Status	Intake Pump Grade (m)	Discharge Pump Grade (m)	Discharge (l/s)	Pump Head (m)	Calculated Water Power (kW)
PMP-1	111.00	On	111.78	159.47	17.10	47.69	8.00
PMP-2	111.00	On	110.98	159.84	16.69	48.87	8.00

Table7. CHP specification from the selected hot water production point of view for _loop_ network and PVC and galvanized iron pipes

Label	Elevation (m)	Zone	Inflow (l/s)	Calculated Hydraulic Grade (m)
R-2	112.00	Zone	-17.10	112.00
R-3	111.00	Zone	-16.69	111.00

Table8. Results for pipes with galvanized iron material

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Headloss (m)	Headloss Gradient (m/km)	Velocity (m/s)
P-29	100.60	20.0	Galvanized iron	120.0	0.19	3.73	37.09	0.61
P-9	94.49	50.0	Galvanized iron	120.0	1.21	1.21	12.86	0.61
P-16	134.11	50.0	Galvanized iron	120.0	1.42	2.34	17.41	0.72
P-17	33.53	50.0	Galvanized iron	120.0	1.44	0.60	17.86	0.73
P-7	48.77	80.0	Galvanized iron	120.0	3.94	0.57	11.69	0.78
P-27	15.00	150.0	Galvanized iron	120.0	16.67	0.12	7.90	0.94
P-31	45.70	150.0	Galvanized iron	120.0	16.67	0.36	7.90	0.94
P-5	155.45	80.0	Galvanized iron	120.0	4.83	2.64	17.01	0.96
P-11	112.78	50.0	Galvanized iron	120.0	1.90	3.35	29.74	0.97
P-30	85.30	150.0	Galvanized iron	120.0	17.12	0.71	8.30	0.97
P-24	39.60	150.0	Galvanized iron	120.0	17.12	0.33	8.30	0.97
P-10	106.68	50.0	Galvanized iron	120.0	2.00	3.49	32.72	1.02
P-28	94.50	60.0	Galvanized iron	120.0	2.90	2.54	26.87	1.03
P-13	161.54	100.0	Galvanized iron	120.0	8.12	2.43	15.02	1.03
P-1	67.06	50.0	Galvanized iron	120.0	2.11	2.44	36.37	1.08
P-14	57.91	80.0	Galvanized iron	120.0	5.84	1.40	24.23	1.16
P-6	155.45	100.0	Galvanized iron	120.0	9.14	2.91	18.71	1.16
P-15	103.63	120.0	Galvanized iron	120.0	14.11	1.78	17.20	1.25
P-2	94.49	50.0	Galvanized iron	120.0	2.53	4.80	50.81	1.29
P-8	97.54	50.0	Galvanized iron	120.0	2.59	5.17	53.00	1.32
P-4	131.06	50.0	Galvanized iron	120.0	2.75	7.76	59.21	1.40

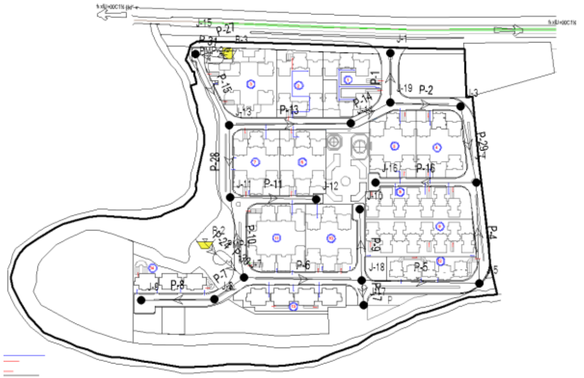

Fig4. Case B. _loop_ network design using two hot water sources (PVC and galvanized pipe) (indicated with yellow color).

Table9. Results for pipes with PVC material

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (l/s)	Pressure Pipe Headloss (m)	Headloss Gradient (m/km)	Velocity (m/s)
P-9	94.49	50.0	PVC	150.0	1.21	0.80	8.50	0.61
P-29	100.60	20.0	PVC	150.0	0.19	2.51	24.91	0.62
P-16	134.11	50.0	PVC	150.0	1.42	1.54	11.52	0.72
P-17	33.53	50.0	PVC	150.0	1.44	0.40	11.81	0.73
P-7	48.77	80.0	PVC	150.0	3.94	0.38	7.73	0.78
P-27	15.00	150.0	PVC	150.0	16.69	0.08	5.24	0.94
P-31	45.70	150.0	PVC	150.0	16.69	0.24	5.24	0.94
P-5	155.45	80.0	PVC	150.0	4.83	1.75	11.24	0.96
P-11	112.78	50.0	PVC	150.0	1.90	2.22	19.67	0.97
P-30	85.30	150.0	PVC	150.0	17.10	0.47	5.48	0.97
P-24	39.60	150.0	PVC	150.0	17.10	0.22	5.48	0.97
P-10	106.68	50.0	PVC	150.0	1.98	2.28	21.34	1.01
P-28	94.50	60.0	PVC	150.0	2.91	1.70	17.95	1.03
P-13	161.54	100.0	PVC	150.0	8.12	1.61	9.94	1.03
P-1	67.06	50.0	PVC	150.0	2.11	1.61	24.06	1.08
P-14	57.91	80.0	PVC	150.0	5.84	0.93	16.03	1.16
P-6	155.45	100.0	PVC	150.0	9.14	1.92	12.38	1.16
P-15	103.63	120.0	PVC	150.0	14.12	1.18	11.40	1.25
P-2	94.49	50.0	PVC	150.0	2.53	3.18	33.65	1.29
P-8	97.54	50.0	PVC	150.0	2.59	3.42	35.06	1.32
P-4	131.06	50.0	PVC	150.0	2.75	5.13	39.13	1.40

In branch design, by using two reservoirs, and by dividing the town into two similar area, the head and velocity in pipes is easily attainable.

In *loop* design two reservoirs at two distinct points were in charge of providing network flow.
Because of the connection between reservoirs in *loop* systems, the design process will be much complicated than branch systems.

Proving the velocity in pipes is much harder than providing head for nodes. It is easier to supply head in nodes by pump after each source, whereas the velocity is hard to be provided because of low per capital consumption.

Low per capital consumption leads to a lower pipe diameter than standards for municipal water-supply pipes.
Usually, the minimum required diameter in common grids is 100 mm, but sometimes in order to supply an appropriate speed in the pipes, the diameters were smaller than the standard size for cold water.
The results from exergy analysis of galvanized iron pipe for branch network are presented in table 10.

Results of Exergy analyses

Table10. Exergy analysis for branch network with galvanized pipes

	Ex_{in} (KW)	Ex_{out} (KW)	Ex_{Lpipe} (KW)	Ex_{D} (KW)	T_{out} (°C)
P_15	381.4639	380.001	0.7089	0.7539	89.86706
P_30	231.3651	230.1699	0.5773	0.6179	89.82087
P_28	122.5276	121.5401	0.3746	0.6129	89.58802
P_13	198.8637	196.7869	0.9403	1.1365	89.50526
P_6	234.3047	232.3107	0.9025	1.0916	89.57235
P_7	98.2898	97.7413	0.2229	0.3256	89.67394
P_14	139.6953	139.0511	0.2613	0.3829	89.34663
P_11	47.3714	46.4186	0.2985	0.6543	88.89282
P_8	64.6213	63.7924	0.2594	0.5695	89.23067
P_5	124.9658	123.2296	0.7058	1.0303	89.09294
P_9	29.9918	29.2955	0.1894	0.5069	88.76957
P_17	35.6348	35.3504	0.0888	0.1955	89.29735
P_1	52.3827	51.8177	0.1764	0.3886	88.97606
P_2	57.718	56.9258	0.2474	0.5447	88.87478
P_4	72.2288	71.1327	0.342	0.7542	88.57315
P_16	34.1559	33.0544	0.3438	0.7577	87.47362

The results from exergy analysis of PVC pipe for branch network are presented in table11.

Table11. Exergy analysis for branch network with PVC pipes

	Ex_{in} (KW)	Ex_{out} (KW)	Ex_{Lpipe} (KW)	Ex_{D} (KW)	T_{out} (°C)
P_15	398.9053	397.5027	0.648	0.7546	89.87812
P_30	231.3651	230.2136	0.5322	0.6193	89.82742
P_28	122.6643	121.8049	0.2809	0.5786	89.63552
P_13	198.9258	196.9288	0.8619	1.1351	89.53031
P_6	234.0425	232.1277	0.8259	1.0889	89.54431
P_7	98.1799	97.655	97.655	0.3229	89.64256
P_14	139.7947	139.1772	0.2372	0.3803	89.37831
P_11	47.2938	46.3897	0.2636	0.6405	88.87029
P_8	64.5639	63.7768	0.2293	0.5578	89.22155
P_5	124.8663	123.2045	0.6397	1.0221	89.08531
P_9	29.9679	29.3093	0.165	0.4936	88.78493
P_17	35.6064	35.425	0.0527	0.1287	89.36888
P_1	52.43	51.8926	0.1562	0.3812	89.02605
P_2	57.7701	57.0166	0.2191	0.5343	88.92977
P_4	72.2131	71.1716	0.3024	0.7391	88.59147
P_16	34.174	33.1265	0.3042	0.7433	87.54645

In following section the analysis of exergy for *loop* network is discussed in Table12 and Table13.

Table12. Exergy analysis for *loop* network with galvanized pipes

	Ex_{in}	Ex_{out}	Ex_{Lpipe}	Ex_{D}	T_{out}
P_15	332.4211	330.9655	0.7029	0.7526	89.84819
P_10	50.3968	49.4845	0.2864	0.6259	89.37048
P_29	4.6745	4.1924	0.0793	0.4028	85.31001
P_28	72.9697	72.0698	0.3138	0.5861	89.42089
P_13	202.6935	200.6176	0.9398	1.1361	89.49351
P_6	229.2559	227.255	0.9061	1.0949	89.6971
P_7	38.5387	38.1226	0.1304	0.2857	89.62512
P_14	144.6361	143.9921	0.2612	0.3828	89.34037
P_11	47.1132	46.1653	0.2966	0.6513	88.70239
P_8	64.532	63.7041	0.259	0.5689	89.18215
P_5	120.3921	118.6504	0.7086	1.0331	89.19683
P_9	29.8825	29.0852	0.2503	0.5469	88.77195
P_17	35.761	35.4757	0.0892	0.1961	89.42161
P_1	56.2529	55.6879	0.1763	0.3886	88.9954
P_2	62.5571	61.7649	0.2474	0.5448	88.90514
P_4	50.2275	49.13	0.3431	0.7544	88.44599
P_16	32.5021	31.4505	0.3246	0.727	85.80533

Comparing the two tables of the hot water network (in both *loop* and branch design) in can be concluded that the amount of heat loss in *loop* network is more than branch network. The reason is not because of the drastic change in length, but due to the change in the diameters of the network, increasing the number of pipes and changes in the water inside the pipes which eventually leads to a higher heat loss.

Table13. Exergy analysis for *loop* network with PVC

	Ex_{in} (KW)	Ex_{out} (KW)	Ex_{Lpipe} (KW)	Ex_{D} (KW)	T_{out} (°C)
P_15	332.4211	331.0187	0.648	0.7543	89.85374
P_10	49.9027	49.0357	0.2535	0.6135	89.39592
P_29	4.7575	4.3064	0.0647	0.3864	85.65121
P_28	72.9811	72.1231	0.2807	0.5774	89.44641
P_13	202.7253	200.7295	0.8612	1.1346	89.5128
P_6	229.2559	227.3324	0.8302	1.0932	89.70885
P_7	98.6591	98.1319	0.203	0.3242	89.81468
P_14	144.7154	144.0982	0.2371	0.3801	89.36609
P_11	47.1473	46.2458	0.2626	0.6389	88.76217
P_8	64.8792	64.0885	0.2306	0.5601	89.39265
P_5	120.4322	118.7633	0.643	1.0259	89.22961
P_9	29.8924	29.1344	0.2216	0.5364	88.82965
P_17	35.7729	35.5017	0.079	0.1922	89.44704
P_1	52.4117	51.8746	0.1561	0.381	89.01388
P_2	62.6029	61.8496	0.219	0.5343	88.95239
P_4	67.6773	66.632	0.3039	0.7414	88.6994
P_16	32.7897	31.7819	0.2898	0.718	86.15542

In branch networks the minimum temperature occurs at the end of the branch while in *loop* network the lowest temperature needs to be determined by calculation and would not occur in the end of the path. Given the marked points and nodes and by integrating two joining paths from two existed CHP, the temperature of the end of the pipe is determined and It certainly cannot be said that the minimum temperature happens at the end of the path (Table13). For instance, in PVC pipes the minimum temperature happens at J_16 node and in *loop* network in J_3 node (Fig4). Also by comparing two networks it can be concluded that the heat loss reduction at the lowest temperature is 0.08% in branch networks and 0.39% in *loop* networks.

With a proper insulation the effect of pipe material in heat losses can be to minimize and the cost for the selected pipe can be assessed. But the effect of pipe material in exergy analysis and exergy loss is very impressive so that in exergy analysis (based on the related Fig5) it can be concluded that the least exergy loss is associated with branch network with PVC pipe which shows 0.2 Kw. reduction of exergy loss.

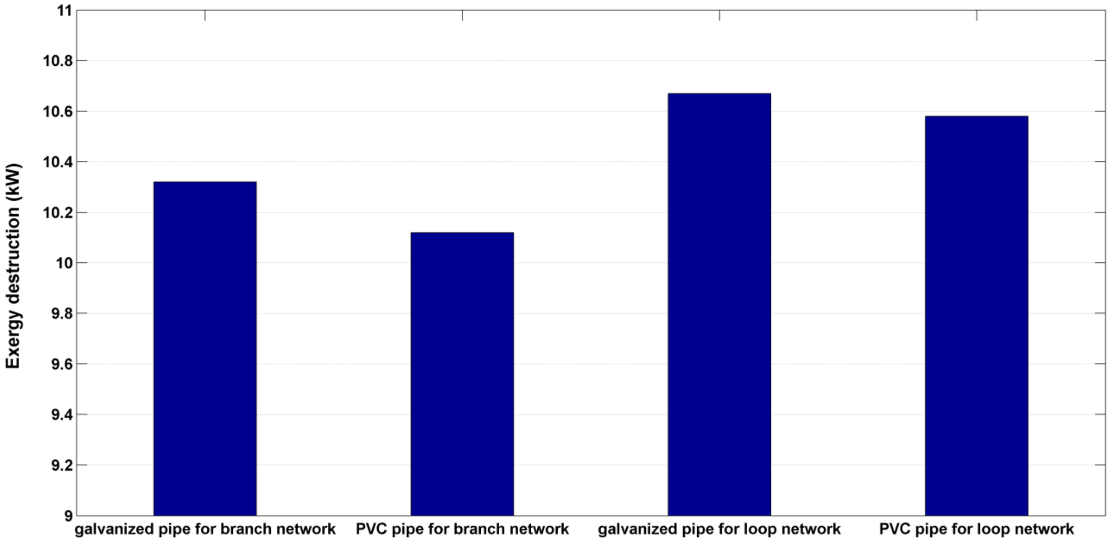

Fig5. The amount of Exergy destruction in various designs

As a result, according to exergy and energy analysis of networks, branch network with the least exergy and energy loss is a suitable network for piping of hot water system.

The exergy efficiency (second law) of the two cycles is shown in table14. As it can be seen branch network with PVC piping has higher efficiency in comparison with other water-supply networks containing different materials.

Table14. Exergy efficiency of water-supply network for hot water

	Galvanized pipe for beach network	PVC pipe for beach network	Galvanized pipe for loop network	PVC pipe for loop network
Exergy Efficiency (%)	97.23	98.39	96.97	97.08

Sensitivity analysis on the ambient temperature according to the performed analysis, branch network with PVC is selected as water-supply network for hot water pipes.
As a result, by changing the ambient temperature to the temperature of - 1° C, the minimum temperature of the branch network and the rate of exergy loss are presented in tables15. It can be seen that the exergy loss is greatly increased by decreasing of the ambient temperature.

Table15. Exergy analysis for *loop* network with PVC pipes at the temperature of -1° C

	Ex_{in} (KW)	Ex_{out} (KW)	Ex_{Lpipe} (KW)	Ex_D (KW)	T_{out} (°C)
P_15	401.2769	399.4942	0.5678	1.215	89.84597
P_30	247.5964	246.1328	0.4663	0.9973	89.8498
P_28	340.425	338.9671	0.3902	1.0676	89.69786
P_13	122.553	121.4825	0.1375	0.933	89.54356
P_6	235.185	232.7881	0.644	1.7528	89.64621
P_7	98.6591	98.0021	0.136	0.5211	89.76899
P_14	139.8473	139.0765	0.1579	0.6129	89.35382
P_11	47.3116	46.1839	0.0897	1.038	88.7196
P_8	64.7954	63.811	0.0793	0.9052	89.24289

P_5	125.2278	123.15	0.4276	1.6501	89.07265
P_9	30.0547	29.2317	0.02	0.8029	88.69727
P_17	35.7095	35.3718	0.027	0.3107	89.31982
P_1	52.3934	51.7232	0.0525	0.6177	88.91406
P_2	72.7686	71.8284	0.0737	0.8666	88.9096
P_4	72.1869	70.8868	0.1001	1.2	88.45557
P_16	34.0401	32.7358	0.0967	1.2077	87.14982
Total	-	-	-	15.6986	-

Conclusion

In this paper, *loop* and branch networks for a case study are designed. Results showed that the branch network reduces heat loss and minimizes the amount of exergy loss. The use of PVC pipes, in comparison with galvanized pipes, will reduce 200 watt of the exergy loss for branch network and 90 watt for *loop* network. *Loop* network with PVC piping at the minimum ambient temperature shows only 0.5 C decreases, that is while the exergy loss over the yearly mean temperature shows a 5.57 kW increases.

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