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Preliminary communication

POSSIBILITIES OF HEAT LOSS REDUCTION DURING HOT WATER PREPARATION IN RESIDENTIAL BUILDINGS

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The aim of the article is based on an analysis of heat losses arisen before the renovation of hot water distribution pipeline of a selected residential building and after the subsequent renovation is to design possibilities for more efficient insulation. Three alternatives of insulation thickness in terms of heat loss along with the condition of the existing isolation after the renovation of the distribution pipelines and with the condition before the renovation are compared in the article. By choosing a suitable insulation, energy efficiently operation will take place in the hot water supply which has a direct impact on operation economy, and finally it leads to reduction of environment pollution through fossil fuels saving.
Key words: hot water, hot water distribution pipeline, heat loss, thermal insulation.

Mogućnosti smanjenja gubitka topline u pripremi tople vode u stambenim zgradama. Temeljeći se na analizi toplinskih gubitaka nastalih prije i poslije obnove cjevovoda distribucije tople vode odabrane stambene zgrade, cilj rada je osmisliti mogućnosti realizacije učinkovitije izolacije. Tri alternative debljina izolacije su promatrane u smislu gubitka topline uspoređujući stanja postojeće izolacije prije i nakon obnove distribucijskih cjevovoda. Odabirom odgovarajuće izolacije, ostvarit će se energetski učinkovit rad sustava za pripremu tople vode što ima izravan utjecaj na ekonomičnost rada i u konačnici dovodi do smanjenja zagađenja okoliša kroz smanjenu potrošnju fosilnih goriva.
Ključne riječi: topla voda, distribucijski cjevovod pripreme tople vode, gubitak topline, toplinska izolacija.

INTRODUCTION

In the present, people think more and more about how to pay less for energy consumption in household due to the increasing prices. By reducing energy consumption they save, but they will also do something good for our environment. There are many ways to save energy, such as replacement of windows, insulation of the edifice, insulation of floor, roof etc.. Another measure, which significantly affects the reduction of energy cost, is renovation of old pipelines used for distribution of hot water (HW) to the final consumers, that is insulation of the feed and circulation pipeline. By choosing the right pipe insulation, savings of up to 70 % can be achieved. This means tens of euro per year as converted to financial means. Of course, it is necessary to use certain amount of input cost for the renovation of the old distribution pipelines, but this investment is profitable for the inhabitants in the long term.

This paper is dedicated to the issue of minimization of heat loss generation in the ascending and circulation pipelines of hot water in a residential building. For the purposes of this analysis, a selected residential building, in which an exchange of old pipelines for the new ones was carried out, was used.

THE CHARACTERISTICS OF THE DISTRIBUTION SYSTEM BEFORE RENOVATION

The original feed ascending HW pipeline was made from threaded galvanized steel pipes of DN32 diameter along the entire height of the pipe. Thermal conductivity coefficient of the steel pipe is $\lambda = 46.5$ ($W.m^{-1}.K^{-1}$) [5]. The length of the ascending distribution pipeline is 21.2 m.

The circulation HW pipeline was made from threaded galvanized steel pipes of the DN 20 diameter along the entire height of the pipe. The length of the ascending distribution pipeline is 21.2 m.

The feed and circulation HW pipeline were wrapped by felt belts before renovation. Thermal conductivity coefficient of the felt strip is $\lambda = 0.07$ ($W.m^{-1}.K^{-1}$) [5].

Test measurements at the uninterrupted operation of the hot water distribution system before renovation of the distribution pipelines

Test measurements were performed from April 1, 2011 to May 30, 2011 and took place at uninterrupted operation of the distribution system. The recording interval of the measured temperatures took 30 minutes. The progression of the measured hot water temperatures and hot water circulation during 1 week is displayed in figures 1 and 2.

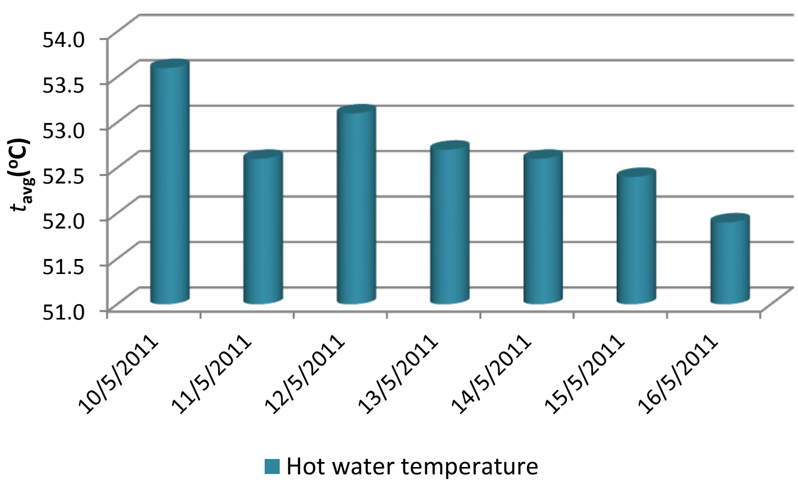

Figure 1. The average hot water temperatures of the feed pipeline measured in days - from May 10 to May 16, 2011
Slika 1. Prosječne temperature tople vode u dolaznom cjevovodu mjereno u danima - od 10. do 16. svibnja 2011.

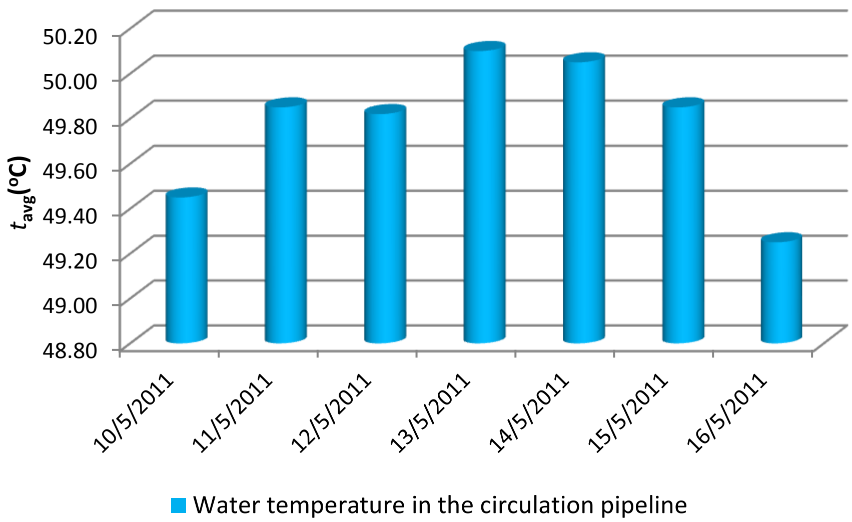

Figure 2. The average hot water temperatures of the circulation pipeline measured in days - from May 10 to May 16, 2011

Slika 2. Prosječna temperatura tople vode u cirkulacijskom cjevovodu mjereno u danima - od 10. do 16. svibnja 2011.

The progression of temperatures for pipes without thermal insulation is non-uniform during one day, as shown in the graphs in Fig. 1 and 2, the average measured temperatures in the HW pipeline are in the range of 51.9 °C to 53.7 °C. In the circulation HW pipeline, the average values are recorded from temperature of 49.3 °C to 50.1 °C

HW temperature non-uniformity is mainly affected by the daily progression of water consumption. The lowest HW temperature is from 8.00 p.m. to 11.00 p.m. where there are the largest water take-offs. The temperature is highest between 3.30 a.m. and 6.00 a.m. which is caused by the fact that water is not taken off from the system. Due to the fact that the water take-off mode is different for each day the average temperatures are also different.

When water is not taken off from the distribution system, when HW only circulates in the system, it is possible to achieve a constant temperature in the place of the installed temperature sensor. This situation is unrealistic in practice and also undesirable since the distribution pipeline serves for HW distribution to the take-off points.

From the above-mentioned, it can be concluded that the HW taken off from the system is replaced by an adequate amount of cold water added into the water heater and it is also the cause of the change in water temperature in the system. Given the amount of HW take-off from the system is uneven and depends on the human factor. As well as the HW output of the heater is designed for constant output, the outlet water temperature differs for each time period.

THE CHARACTERISTICS OF THE DISTRIBUTION SYSTEM AFTER RENOVATION

The new ascending feed HW pipeline was made from threaded galvanized steel pipes of DN 32 and DN 25 diameters. The ascending distribution pipeline of DN 32 diameter is 12.7 m long and the one of DN 25 diameter is 8.5 m long. Thermal conductivity coefficient of the steel pipe is $\lambda = 46.5$ ($W.m^{-1}.K^{-1}$) [5].

The new HW circulation pipeline was made from multi-layer PE-Al-PE plastic pipes of the outer diameter of D 26 mm and of the pipe wall thickness of 3 mm along the entire height of the building. Nominal pipe size is DN 20 after conversion. Thermal conductivity coefficient of the plastic pipe is $\lambda = 0.43$ ($W.m^{-1}.K^{-1}$) [5]. All pipes are fitted with PE thermal insulation of 10 mm; $\lambda = 0.04$ ($W.m^{-1}.K^{-1}$) [5].

Test measurements at the uninterrupted operation of the hot water distribution system after renovation of pipelines

Test measurements were performed from June 1, 2011 to October 30, 2011 and they took place at uninterrupted operation of the distribution system. The recording interval of the measured temperatures took 30 minutes. The average measured temperature of hot water and of hot water circulation during 1 week is displayed in figures 3 and 4.

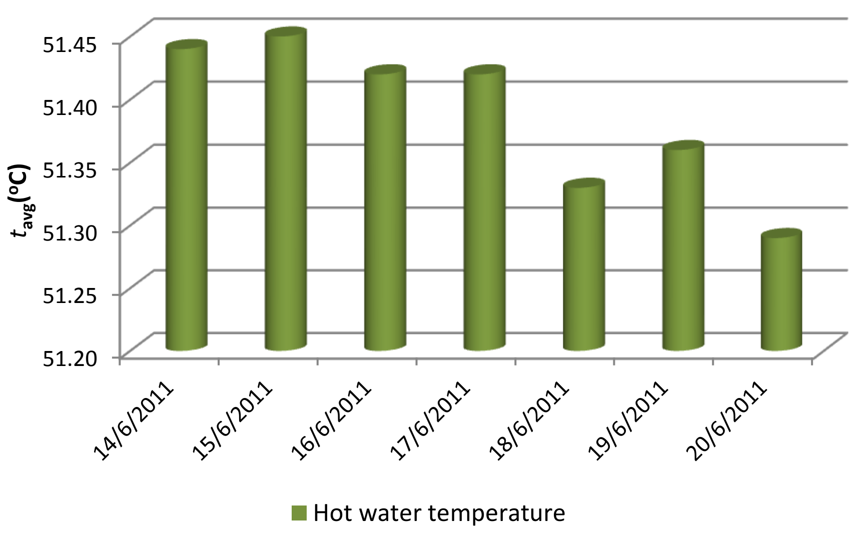

Figure 3. The average hot water temperatures of the feed pipeline measured in days - from June 14 to June 20, 2011

Slika 3. Prosječna temperatura tople vode u dolaznom cjevovodu mjereno u danima - od 14. lipnja do 20. lipnja 2011.

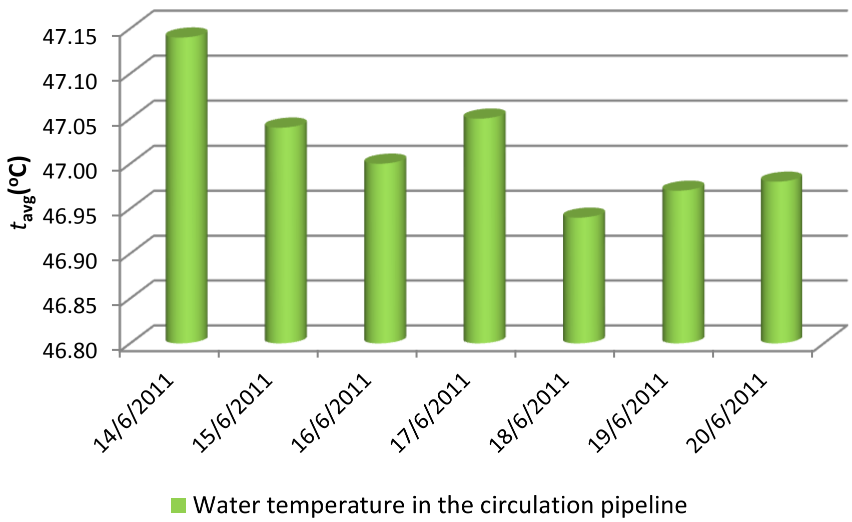

Figure 4. The average hot water temperatures in the circulation pipeline measured in days - from June 14 to June 20, 2011

Slika 4. Prosječna temperatura tople vode u cirkulacijskom cjevovodu mjereno u danima - od 14. lipnja do 20. lipnja 2011.

It follows from the measured temperatures that the progression of temperatures during the day is less uneven for the pipes with insulation than for the non-insulated pipes. The average values of the temperatures from 51.3 °C to 51.47 °C are recorded in the HW pipeline. The average values of temperatures from 45.9 °C to 47.15 °C are recorded in the HW circulation pipeline.

In the blocks of flats, hot water constantly circulates in the circulation pipelines as so it would be available at the desired temperature in all outlet places of the building. Hot water is constantly getting cold in the distribution pipelines. From the economic and the technical points of view, it is therefore important that the distributed hot water maintains its temperature. It is therefore necessary to provide thermal insulation that eliminates heat loss.

Thus, thermal insulation significantly contributes to the reduction of heat loss and thereby to the reduction of hot water cost due to its properties.

Calculation of heat loss of the feed pipeline without insulation

As it was mentioned above, energy efficiency is significantly affected by thermal insulation of heat and hot water distribution pipelines in the buildings. The efficiency of HW distribution is a function of heat loss in the HW distribution pipelines. Heat loss per 1 meter of pipeline length without any insulation according to the particular nominal pipe sizes are listed in Tab. 1.

Steel, which thermal conductivity coefficient is λ = 46.5 (W.m^{-1}. K^{-1}), was considered at calculation.

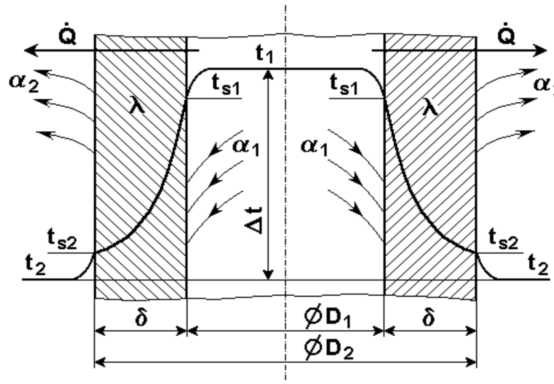

Figure 5. Heat transfer through the pipe without insulation
Slika 5. Prijenos topline kroz stijenku cijevi bez izolacije

To calculate heat loss of the pipeline without insulation, the following relationships were used [1], [7]:

1 . $$q = \frac{\pi \cdot (t_1 - t_2)}{\frac{1}{\alpha_1 \cdot D_1} + \frac{1}{2 \cdot \lambda} \ln \frac{D_2}{D_1} + \frac{1}{\alpha_2 \cdot D_2}} \qquad (\mathrm{W.m^{-1}}) \qquad (1)$$

Relationships for calculation of α_2 on the outer surface of the pipe:

2. The Rayleigh criterion:

$$Ra = \mathrm{Pr} \cdot Gr \qquad (-) \qquad (2)$$

3. The Nusselt criterion for free convection:

$$Nu_{plane} = \left(0.825 + 0.387 \cdot \left[Ra \cdot f_1(Pr) \right]^{\frac{1}{6}} \right)^2 \qquad (-) \qquad (3)$$

4. $$Nu = Nu_{plane} + 0.435 \cdot \frac{h}{d} \qquad (-) \qquad (4)$$

5. The Grashof criterion:

$$Gr = \beta \cdot \frac{g \cdot l^3}{\nu^2} \cdot (t_{s2} - t_2) \qquad (-) \qquad (5)$$

6. The wall temperature inside the pipe:

$$t_{s1} = t_t - \frac{q}{\alpha_1 \cdot \pi \cdot D_1} \qquad (^{o}\mathrm{C}) \qquad (6)$$

7. The wall temperature on the pipe surface:

$$t_{s2} = \frac{q}{\alpha_2 \cdot \pi \cdot D_2} + t_2 \qquad (^{o}\mathrm{C}) \qquad (7)$$

8. Convective heat transfer coefficient:

$$\alpha_{2conv} = \frac{Nu \cdot \lambda_{air}}{l} \qquad (\mathrm{W.m^{-2}.K^{-1}}) \qquad (8)$$

9. Radiative heat transfer coefficient:

$$\alpha_{2rad} = \varepsilon \cdot \sigma \cdot (T_{s2} + T_2) \cdot (T_{s2}^2 + T_2^2) \qquad (\mathrm{W.m^{-2}.K^{-1}}) \qquad (9)$$

10. Heat transfer coefficient:

$$\alpha_2 = \alpha_{2conv} + \alpha_{2rad} \qquad (\mathrm{W.m^{-2}.K^{-1}}) \qquad (10)$$

Relationships for calculation of α_1 inside the pipe:

11. $$Nu = \frac{\alpha_1 \cdot d}{\lambda} \Rightarrow \alpha_1 = \frac{Nu \cdot \lambda}{d} \qquad (11)$$

12. The Reynolds criterion:

$$\mathrm{Re} = \frac{v \cdot d}{\nu} \qquad (-) \qquad (12)$$

13. $$Nu = \frac{\frac{f}{8} \cdot \mathrm{Re} \cdot \mathrm{Pr}}{1.07 + 12.7 \cdot \sqrt{\frac{f}{8}} \left(\mathrm{Pr}^{\frac{2}{3}} - 1 \right)} \qquad (-) \qquad (13)$$

where: $$f = \left[1.82 \cdot \log(\mathrm{Re}) - 1.64 \right]^{-2} \qquad (-) \qquad (14)$$

After substitution into the relationship (1), the heat loss can be calculated as follows:

Table 1. The calculated heat loss of the feed pipe for particular nominal pipe sizes without insulation

Tablica 1. Izračunati gubitak topline dovodne cijevi za pojedine nominalne promjere cijevi bez izolacije

Material	DN	q (W.m^{-1})	S (m^2)	t_{s1} (°C)	t_{s2} (°C)
steel	15	**19.051**	0.066	54.954	54.932
	20	**23.589**	0.082	54.955	54.934
	25	**28.126**	0.097	54.955	54.935
	32	**34.478**	0.119	54.956	54.935

where S - surface area of the pipe

Calculation of heat loss of the feed pipe using insulation of various thicknesses

PE insulation of various thicknesses was considered at calculation. Thermal conductivity coefficient of the PE insulation is [5]:

- λ_{iz} = 0.04 (W.m^{-1}. K^{-1})

PE insulations are made of physical foaming polyethylene whose temperature range of usage is from -40 to +90 °C.

To calculate heat loss of insulated distribution pipelines, the following thicknesses of thermal insulation were considered:

- 10 mm, 15 mm and an insulation of thickness at which heat loss will not exceed 10 W.m^{-1}.K^{-1}.

To calculate pipe heat loss in the insulated distribution pipelines, the relationship was used [1]:

$$q = \frac{\pi \cdot (t_1 - t_2)}{\frac{1}{\alpha_1 \cdot D_1} + \frac{1}{2 \cdot \lambda_1} \ln \frac{D_2}{D_1} + \frac{1}{2 \cdot \lambda_2} \ln \frac{D_3}{D_2} + \frac{1}{\alpha_2 \cdot D_3}} \quad (\mathrm{W.m^{-1}}) \qquad (15)$$

- where D_3 - outer surface of the insulation.

Table 2. The calculated heat loss of the feed pipe for the particular pipe diameters with insulation
Tablica 2. Izračunati gubitak topline dovodne cijevi za pojedine promjere cijevi s izolacijom

		***q* (W.m^{-1})**			***t_{s1}* (°C)**			***t_{s3}* (°C)**		
		Insulation thickness			Insulation thickness			Insulation thickness		
Material	**DN**	10 mm	15 mm	$q_{max.}$ 10 W.m-1	10 mm	15 mm	$q_{max.}$ 10 W.m-1	10 mm	15 mm	$q_{max.}$ 10 W.m-1.
steel	15	8.122	6.880	8.122	54.981	54.984	54.981	33.351	30.687	33.351
	20	9.406	7.877	9.406	54.982	54.985	54.982	33.621	30.930	33.621
	25	10.67	8.858	8.858	54.983	54.986	54.986	33.826	31.122	31.122
	32	12.44	10.21	8.814	54.984	54.987	54.989	34.044	31.332	29.764

- N.B.: q_{max} 10 W.m^{-1} – maximum allowed heat loss of pipeline according to the decree of the Ministry of Construction and Regional Development of the Slovak Republic no. 311/2009

The calculated values from Tab. 1 and Tab. 2 are shown in a graph in Fig. 6.

As it is shown in Fig. 6, heat loss of steel pipes without insulation is incomparably higher than the heat loss arising if the steel pipe is wrapped by any kind of insulation. The biggest heat loss arises in the pipes of DN 32 diameter without insulation. For instance, using insulation of thickness of 15 mm for this type of pipe heat loss is reduced by 70 %.

THE EFFECTIVENESS OF INSULATION OF THE HW DISTRIBUTION SYSTEM - THE CIRCULATION PIPELINE

The circulation system is a device that maintains hot water temperature at the same level in all parts of the distribution system. The circulation system is designed to drain cooling water from the feed pipe for heating up to the HW source and to prevent excessive cooling down by water circulation in the distribution pipelines. The circulation system does not fulfil its function if the same temperature in all parts of the distribution system is not maintained at the time of HW delivery while sufficient temperature is maintained in the outlet of the source.

HW circulation dysfunction causes non-objective accounting as well as other negative phenomena, both in terms of energy and sanitation.

To calculate the heat loss arisen in the circulation pipes, the same relationships as the ones for the feed pipe were used.

Calculation of heat loss of the circulation pipe without insulation

The calculated values of heat loss of the circulation pipe without any insulation are illustrated in the following table, Tab. 3:

Table 3. The calculated heat loss of the circulation pipe according to the particular pipe diameters without insulation
Tablica 3. Izračunati gubitak topline cirkulacijske cijevi za pojedine promjere cijevi s izolacijom

Material	DN	q (W.m^{-1})	t_{s1} (°C)	t_{s2} (°C)
steel	15	**17.517**	52.957	52.937
	20	**21.689**	52.958	52.939
	25	**25.861**	52.958	52.939
	32	**31.702**	52.958	52.940

Heat loss of the circulation pipe is comparable to heat loss of the feed pipe. The highest heat loss arises in case of using steel pipe of DN 32 nominal pipe size. From the above-mentioned table, we see that there is a slight difference between the pipe surface temperature (t_{s2}) and the temperature inside the pipe (t_{s1}). The two temperatures are even equal in some cases.

Calculation of heat loss of the circulation pipe using insulation of various thicknesses

The calculated heat loss arising in the circulation pipe without insulation and after insulation of the distribution pipelines are compared in Tab. 4:

Table 4. The comparison of heat loss of the circulation pipe without insulation and with insulation of various thicknesses
Tablica 4. Usporedba gubitka topline cirkulacije cijevi bez izolacije i s izolacijom različitih debljina

		Without insulation	**With insulation of 10 mm thickness**	**With insulation of 15 mm thickness**	**With insulation for $q_{max} \leq 10$ W.m^{-1}**
Material	**DN**	**q (W.m^{-1})**			
steel	15	17.517	7.508	6.380	9.460
	20	21.689	8.693	7.303	8.693
	25	25.861	9.866	8.210	9.866
	32	31.702	11.493	9.464	9.464

The fact that it is appropriate to insulate the feed pipe and also the circulation pipe is shown in Tab. 4. Heat loss of the circulation pipe without insulation is several times higher than that of the pipe with insulation of various thicknesses.

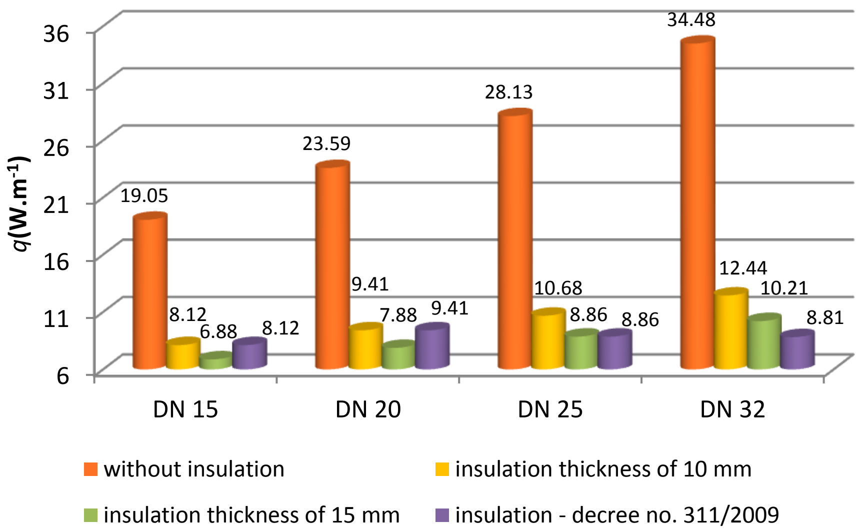

Figure 6. The calculated heat loss for steel pipes with and without insulation of various thicknesses in dependence on the pipe diameters
Slika 6. Izračunate vrijednosti gubitka topline za čelične cijevi bez i s izolacijom različitih debljina u ovisnosti o promjerima cijevi

The comparison of the calculated heat price to heat loss per year before the renovation and after the renovation is shown in Fig. 7.

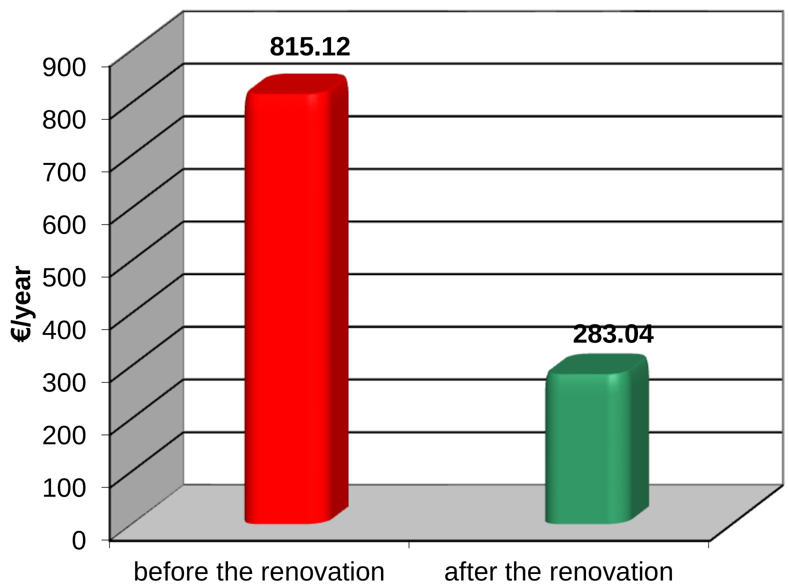

Figure 7. The comparison of the calculated heat price to heat loss per year before the renovation and after the renovation
Slika 7. Usporedba izračunatih troškova u pripremi tople vode po godini s obzirom na gubitke topline prije i poslije obnove

CONCLUSION

Hot water is part of our everyday life for which we pay more and more. Till hot water reaches our taps, it is constantly getting cold and heat loss arises. However, we often do not realize that our money escapes altogether with the heat escaping from the HW distribution pipelines into the environment.

Insulation is one of the solutions to save on the loss. Thermal insulation prevents heat loss from escaping to the environment and maintains temperature of the heat carrier in the pipeline. From the economic point of view, the right choice of insulation material, accurate thermal and technical calculation, and efficiently made insulation are crucial.

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