The Impact of Thermal Insulation on Heat Losses in The Hot Water Distribution Pipeline at Central Heating System of an Apartment Building

Salah Elayeb[1 (*)], **Khalid Alrbaey**[2]

1- College of Engineering Technology – Surman

College of Engineering Technology – Surman

Abstract

This paper presents the results of the experimental research in the area of heat losses in the hot water distribution system in a block of flats and the conclusions which were drawn from the measurements. The analysis of the impact of modernising the old hot water pipeline system using the synthetic rubber (EPDM) without additives and without PVC Freon is provided. Outwardly trivial detail like a thermal insulation is a very significant element in diminishing the heat losses. It is a common

(*) Email: salah_hr2000@yahoo.com

fact that a layer of thermal insulation contributes to a drop in the heat transferred to the ambience and helps to maintain the optimal temperature of the medium.

By doing so, hot water in the feed pipeline does not lose part of its temperature on the way to the consumer. This way it is possible to reduce the need for extra energy to substitute the loss and maintain the temperature. Thus, reducing the energy demand of the block of flats which results in cutting down the energy costs, especially at the current energy crisis. Moreover, it is also crucial to maintain the standard temperatures to avoid fluctuations of temperature in the system. That is important to prevent the temperatures to fall to the values near 40°C which are the optimal temperatures for breeding and multiplication of the dangerous bacteria such as Legionella. After the results of the hot water distribution pipeline before and after renovation were compared, it was possible to verify our hypothesis that there is a significant difference in the heat losses in the pipes with a layer of thermal insulation.

Keywords*, *hot-water pipeline, heat losses, thermal distribution, thermal insulation.

الملخص

يتناول هذا البحث نتائج الفقد الحراري في نظام توزيع الماء الساخن لمجموعة من الشقق السكنية. حيث كانت خطوات البحث بتوفير تحليل تأثير تحديث نظام أنابيب الماء الساخن القديم باستخدام المطاط الصناعي (EPDM) حيث انه عنصر مهم جدًا في تقليل فقد الحرارة. ولعله من الشائع أن طبقة من العزل الحراري تساهم في انخفاض الحرارة المنقولة من النظام إلى المحيط الخارجي وتساعد في الحفاظ على درجة الحرارة المثلى للوسط.

حيث اظهرت النتائج ان الماء الساخن لايفقد جزءاً كبير من درجة حرارتة خلال خط الانابيب الموجهة إلى المستهلك. بهذه الطريقة يمكن تقليل الحاجة إلى طاقة إضافية لتعويض الفقد والحفاظ على درجات الحرارة. وبالتالي، فإن تقليل الطلب على الطاقة في مجمع الشقق

يؤدي إلى خفض تكاليفها، خاصة في أزمة الطاقة الحالية . هذا وبالاضافة الى الحفاظ علي درجات الحرارة القياسية وتجنب تقلبات درجات الحرارة في النظام مهم جداً لمنع الحرارة من الانخفاض إلى القيم القريبة من 40 درجة مئوية وهي درجات حرارة مثلى لتكاثر البكتيريا الخطرة.

بعد مقارنة نتائج خط أنابيب توزيع الماء الساخن قبل التجديد وبعده ، كان من الممكن التحقق من فرضيتنا أن هناك فرقًا كبيرًا في الفقد لحرارة للانابيب المعزولة عن سابقتها غير المعزولة وتحسن كبير في كفاءة النظام .

A table of symbols

D_1 - Inner diameter of the pipe (mm)

D_2 - Outer diameter of the pipe (mm)

α_1 - Thermal diffusivity on the inside of the pipeline ($m^2 s^{-1}$)

α_2 - The thermal diffusivity on the outside of the pipeline ($m^2 s^{-1}$)

q - Heat Loss ($W.m^{-1}$)

t_1 - Temperature on the inside of the pipe (°C)

t_2 - Temperature on the outside of the pipe (°C)

1. Introduction

With the energy prices currently skyrocketing and the countries struggling with finding the solutions to the imminent energy crisis, the households and industry are searching for any options of saving the extra energy costs arising from the happenings. As a matter of fact, there are plenty one could think of at a moment's notice. However, the construction material crisis and the constantly growing prices reduced them to the simplest and cheapest alternatives. One of the easiest and most effective customer-friendly options of dealing with this phenomenon is to renovate the old hot-water pipelines by fitting it with a thermal insulation. Besides being very effective, such a solution can bring as much as up to 70-percent energy savings ensuing from the process of modernisation of the old pipeline system when using the right insulation materials. [1,3].

2. Theoretical Heat Loss Calculations

Before we can provide any experimental data relevant for the issue discussed in this paper, we primarily must provide the fundamental theoretical basis necessary to define the crucial numerical data in the department of the heat loss assessment.

The reason is a very prosaic one. The heat transfer through the pipeline's surface is a very significant determinant of determining the heat losses and the impact of the thermal insulation on the renovated system. The default equation for calculation of the heat losses of the uninsulated pipeline system is as follows[1]::

$$q = \frac{\pi\ (t_1 - t_2)}{\frac{1}{\alpha_1\ D_1} + \frac{1}{2\ \lambda}\ln\frac{D_2}{D_1} + \frac{1}{\alpha_2\ D_2}} \quad (1)$$

The individual variables from Equation 1 are calculated by means of the following equations:

- The thermal diffusivity $\alpha_1$on the inside of the pipeline is calculated through the Nusselt an Reynolds numbers[2.9]:

$$Nu = \frac{\alpha_1 d}{\lambda} => \alpha_1 = \frac{Nu\ \ \lambda}{d} \quad (2)$$

$$Nu = \frac{\frac{f}{8}RePr}{1.07+12.7\sqrt{\frac{f}{8}}\left(Pr^{\frac{2}{3}}-1\right)} \quad (3)$$

$$Re = \frac{vd}{v} \quad (4)$$

$$f = [1.82\log(Re) - 1.64]^{-2} \quad (5)$$

- the thermal diffusivity α_2 on the outside of the pipeline is calculated through the Rayleigh, Nusselt, Grashof an Reynolds numbers[**2**]:

$$Ra = \mathrm{P_r} G_r \quad (6)$$

$$Nu_{con} = \left(0.825 + 0.387[R_a f_1(P_r)]^{\frac{1}{6}}\right)^2 \quad (7)$$

$$\mathrm{N_u} = N_{ucon} + 0.435\frac{h}{d} \quad (8)$$

$$\mathrm{G}r = \beta\frac{gl^2}{v^2}(t_{outside} - t_z) \quad (9)$$

$$t_{inside} = t_t - \frac{q}{\alpha_1 \pi D_{vn}} \quad (10)$$

$$t_{outside} = \frac{q}{\alpha_2 \pi D_{vo}} + t_z \quad (11)$$

$$\alpha_{convectionoutside} = \frac{N_u \lambda_z}{l} \quad (12)$$

$$\alpha_{radiationoutside} = \varepsilon\sigma(T_{conoutside} + T_z)\left(T_{conoutside}{}^2 + T_z^2\right) \quad (13)$$

$$\alpha_2 = \alpha_{convectionoutside} + \alpha_{radiationoutside} \quad (14)$$

-The default equation for calculation of the heat losses of the insulated pipeline system is as follows [2,5,8]:

$$q = \frac{\pi(t_{inside} - t_{outside})}{\frac{1}{\alpha_{in} D_{in}} + \frac{1}{2\lambda_{in}}\ln\frac{D_{out}}{D_{in}} + \frac{1}{2\lambda_{out}}\ln\frac{D_{insu}}{D_{out}} + \frac{1}{\alpha_{out} D_{insul}}} \quad (15)$$

3. Experimental Analysis

a) Thermal Properties of the Uninsulated Hot-Water Pipeline System

The examined hot-water distribution pipeline system was not fitted with any sort of the modern thermal insulation and was found in the original condition with the wear-and-tear signs adequate to the extent and length of operation of the system from the time it was installed.

Therefore, it was necessary to examine the thermal properties of the old pipeline prior to the renovation. The experimental research of the uninsulated system had to be carried out in order to effectively and accurately assess the contribution of the insulation to the heat loss reduction[4.5]:.

The original feed pipeline of the hot-water system was found in an apartment building and consisted of the steel pipes fitted with the threads along its length of 21.6 metres. Its diameter was determined in the metric equivalent called the Diameter Nominal system (DN). The size corresponded to DN 32 that is 42.16 mm of the outer diameter of the pipe in the metric system. The thermal conductivity coefficient λ of the pipeline used equaled 46.9 $W.m^{-1}.K^{-1}$.

The circulation pipeline of the hot-water distribution system corresponded to DN 20 in the Diameter Nominal system that is 26.67 mm of the outer diameter of the pipe in the metric system. It consisted of the steel pipes fitted with the threads along its length of 21.6 metres. The previous felt wrapping used to protect the pipeline from the time of its installation was threadbare and worn-down. Hence, we decided to neglect its thermal conductivity coefficient due to the bare parts of the pipeline.

The measurements were conducted during the early stage of winter in 2020 when the central heating system in the apartment building was set to the mode of the continuous operation during that time of the year. The experiments were performed in the regular intervals of 30 minutes in the period of time from September 5th to October 25th, 2020. A one-week excerpt from the overall measurements of hot water temperatures in the feed pipeline was provided and is illustrated in Figure 1.

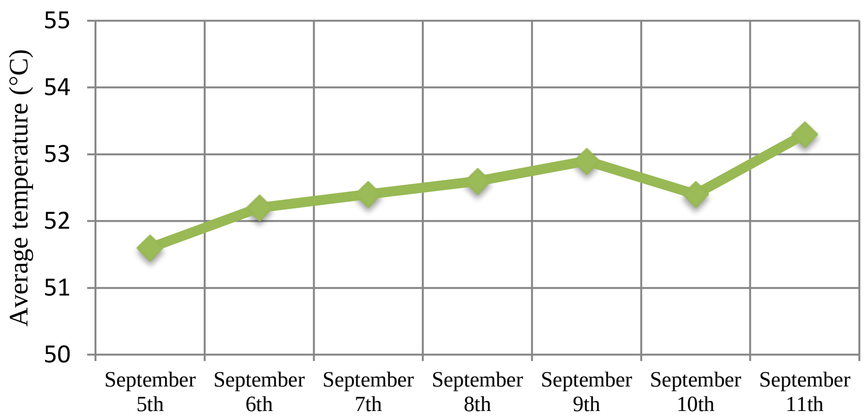

Figure 1.The course of the average hot water temperatures measured in the uninsulated feed pipeline in the week from September 5th to September 11th, 2020

The temperatures of hot water in the uninsulated feed pipeline had a very irregular course during the day-time operation which was mostly caused by the irregular need for hot water by the tenants. Therefore, the average temperatures were moving in the range of 51.6 °C to 53.3 °C during that time of the day. And they changed with the different period of the day depending on the consumption of hot water.

However, the measurements also proved that the lowest temperatures were recorded in the periods of the day when the tenants of the apartment building were preparing for leaving for work and returning back to their homes and used hot water more than in other periods of the day. The temperatures of hot water in the uninsulated feed pipeline achieved their bottom in the morning, between 6 a.m. and 9 p.m., and in the evening, between 8 p.m. and 11p.m.

On the contrary to this, the highest temperatures in the uninsulated feed pipeline were recorded between 3 a.m. and 6 a.m. And the peak in the temperature of hot water in the uninsulated feed pipeline was mainly caused by the fact that most tenants did not use hot water at this time of the night and that led to the phenomenon.

The hot water temperatures were measured in the circulation pipeline at the same period of time and the results are illustrated in Figure 2.

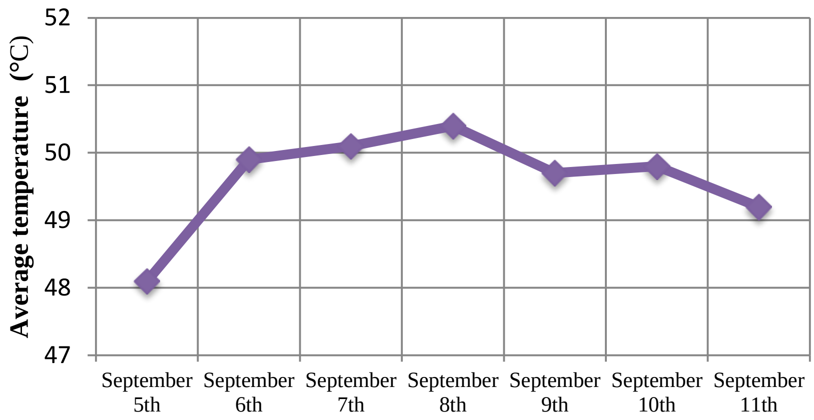

Figure 2. The course of the average temperatures of hot water measured in the uninsulated circulation pipeline in the week from September 5th to September 11th, 2020

The temperatures of hot water in the uninsulated circulation pipeline also had a very irregular course during the day-time operation just like the temperatures in the uninsulated feed pipeline which was predominantly caused by the irregular need for hot water by the tenants. The average temperatures of hot water in the uninsulated circulation pipeline were found in the range of 48.1 °C to 50.1 °C. And they changed with the different period of the day depending on the consumption of hot water.

However, the measurements also proved the same tendency of the pipeline to reaching the lowest and highest temperatures just like the results of measurements in the uninsulated feed pipeline showed. The lowest temperatures were also recorded in the periods of the day when the tenants used hot water more frequently than in other periods of the day. The temperatures of hot water in the uninsulated circulation pipeline also reached their lowest point in the morning, between 6 a.m. and 9 p.m., and in the evening, between 8 p.m. and 11p.m.

And the highest temperatures in the uninsulated circulation pipeline were registered between 3 a.m and 6 a.m. caused by the fact that most tenants did not use hot water at this time of the night. Therefore, hot water was only circulating in the distribution network of the hot-water pipeline system.

b.) Thermal properties of the insulated hot-water pipeline system

In the second phase of the research, the experiments were carried out on the insulated hot-water pipeline system. The thermal insulation used for the purposes of this paper was the synthetic rubber (EPDM) without additives and without PVC Freon which can be used for the work temperatures ranging from - 40 °C to + 90 °C. That is the range of the work temperatures of the hot-water pipeline we used for the experimental purposes.

The thermal conductivity of the insulation used is 0.039 $W.m^{-1}.K^{1}$. And the thickness of the synthetic rubber (EPDM) insulation without additives and without PVC Freon for this experimental examination was set to 10 mm.

The measurements were conducted during the early stages of the heating season in 2021 in the mode of the continuous operation of the system. The experiments were performed in the regular intervals of 30 minutes in the period from June25th to August 26th, 2021.And a one-week excerpt from the overall measurements of hot water temperatures in the feed pipeline fitted with an extra layer of insulation is illustrated in Figure 3.

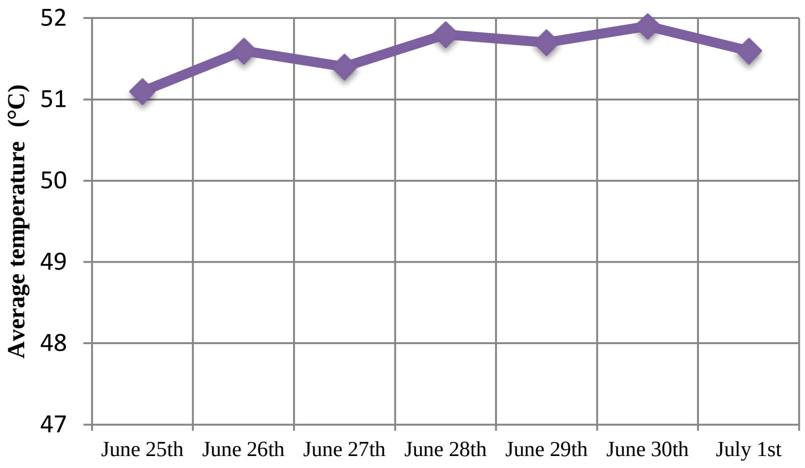

Figure 3.The course of the average temperatures of hot water measured in the insulated feed pipeline in the week from June 25th to July 1st, 2021

The course of the hot water temperatures in the insulated feed pipeline also showed a very irregular course of their thermal properties during the day-time operation just like the results of the measurements showed in case of the uninsulated feed pipeline. The average temperatures were in the range of 51.1 °C to 51.9 °C.

When comparing the course of the uninsulated feed pipe shown in Figure 1 with the one of the insulated feed pipe shown in Figure 3, the differences are very visible. The course of temperatures of the uninsulated feed pipeline moved within the thermal range of several °C and showed a higher rate of fluctuations than the course of temperatures of the insulated feed pipeline which moved within the range of a single °C.

The results of the measurements of the insulated circulation were performed in the same period of time and are illustrated in Figure 4which presents a one-week excerpt from the overall measurements of hot water temperatures in the insulated circulation pipeline.

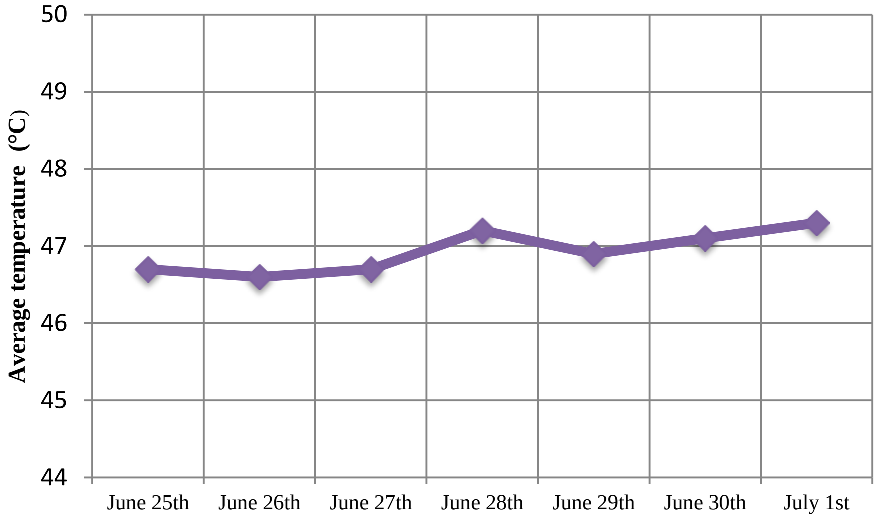

Figure 4.The course of the average temperatures of hot water measured in the insulated circulation pipeline in the week from June 25th to July 1st, 2021

The temperatures of hot water in the insulated circulation pipeline were in the range of 46.6 °C to 47.3 °C.When comparing the course of the uninsulated circulation pipe shown in Figure 2 with the one of the insulated one shown in Figure 4, the differences are also obvious just like in case of the insulated and uninsulated feed pipelines.

The fluctuations and sharper changes in the course of temperatures of hot water in the uninsulated circulation pipeline were not observed in the course of temperatures of the insulated circulation pipeline which also moved within the thermal range of a single °C. This characteristic seems to be very beneficial in terms of economic and technical profit for the tenants.

And that was because the hot water in the circulation pipeline circulates in an apartment building in order to provide all the tenants with hot water of the required temperature at the outlet of the faucets in their apartments. The physical laws say that hot water loses part of its heat and cools down.

Therefore, it is crucial for hot water which is distributed to the consumers to maintain its temperature and lose as little heat circulating in the pipeline as possible. The elimination of heat losses means reducing extra energy costs for the tenants. This is the main reason the pipeline fitted with a layer of insulation is more profitable as it diminished heat losses.

4. Experimental Results of Heat Loss Calculations

After we had measured and compared the insulated and uninsulated hot water distribution pipelines, we had to determine the savings of energy by quantifying the heat losses in the uninsulated and insulated pipes.

Our basic hypothesis was that the pipelines fitted with a layer of insulation would manifest lower heat losses than those without insulation and show a higher efficiency of hot water distribution[6]:. As the heat losses affect the entire hot water system and the quality of hot water supply for the customers.

Using the aforementioned equations 1 to 14, the heat losses for the uninsulated pipelines system were determined per one meter of the length of the given pipeline. The specific values of heat losses in case of the uninsulated hot water distribution pipeline are shown in Table 1.

Table 1. The heat losses of the uninsulated feed hot-water distribution pipeline

Diameter of the pipe DN (mm)	q (W.m^{-1})	A (m^2)	t_{inside} (°C)	$t_{outside}$ (°C)
15	19.061	0.064	54.951	54.935
20	23.585	0.085	54.954	54.937
25	28.124	0.093	54.952	54.938
32	34.472	0.116	54.952	54.939

Eq. 15 was used to calculate the heat losses of the hot-water pipeline fitted with a 10-mm-sick insulation which are shown in Table 2.

Table 2. The heat losses of the insulated feed hot-water pipeline fitted with a 10-mm-sick insulation

Diameter of the pipe DN (mm)	q (W.m^{-1})	t_{inside} (°C)	$t_{insulation}$ (°C)
15	8.127	54.985	33.348
20	9.401	54.980	33.618
25	10.63	54.981	33.824
32	12.48	54.987	34.048

Comparing the results in the table 1 and table 2 led us to conclude that it was clear that the extent of heat lost in an uninsulated pipe was much higher than in an insulated pipe[7]:. This made us believe that even a very thin layer of insulation can bring on savings of energy and reducing costs heavily. And this is even more valid with the pipes of larges diameters as they had the worst heat losses than those of smaller diameters.

Next, equation 15 was used to compute the heat losses in the uninsulated circulation pipeline, the results are presented in Table 3.

Table 3. The heat losses of the uninsulated circulation hot-water distribution pipeline

Diameter of the pipe DN (mm)	q (W.m^{-1})	t_{inside} (°C)	$t_{outside}$ (°C)
15	17.512	52.955	52.939
20	21.686	52.954	52.942
25	25.863	54.957	52.937
32	31.705	54.956	52.942

Also, Eq. 15 was used to calculate the heat losses of the hot-water circulation pipeline fitted with a 10-mm-sick insulation and the resulted are presented in Table 4. Table 4. The heat losses of the insulated circulation hot-water pipeline fitted with a 10-mm-sick insulation

Diameter of the pipe DN (mm)	q (W.m^{-1})	t_{inside} (°C)	$t_{insulation}$ (°C)
15	7.503	52.951	32.931
20	8.695	52.952	32.939
25	9.869	54.954	32.935
32	11.497	54.953	52.940

Comparing the results of table 3 and table 4 led us to record a very significant drop in temperature on the outer surface of the insulation was visible, achieving up to 20 °C difference between the surface temperature of the uninsulated and insulated pipes.

Fitting both pipelines can add up to a remarkable cost reduction of the whole hot water distribution system. The heat loss drops are much more notable when both pipes are fitted with insulation than they are if we only insulate one of the pipelines, leaving the other uninsulated.

5. Conclusion

The presented experimental data has demonstrated that a thermal insulation can significantly contribute to diminishing the energy demands of a building or edifice. The heat loss of the insulated feed pipeline was lower by 10.9 $W.m^{-1}$ compared to the heat loss of the uninsulated one. It was a higher figure than the value of the total heat loss of the insulated pipe. The temperature measured on the outer diameter of the insulated pipe was lower by 21.6 °C compared to the temperature of the uninsulated one. And the results showed that the heat loss of the uninsulated pipeline tended to increase with increasing diameter of the pipe. The overall efficiency of the system improved significantly when both, the feed and return pipelines, were insulated. Therefore, it is very desirable to fit the pipelines with an insulation to improve the efficiency of the hot water distribution system. After all, saving extra energy invested into heating up hot water is still desired and even more with the energy costs rising and estimated to rise even more in the future.

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