Effect of Heat Transfer between Potable Water Cold and the Environment Inside Building on Water Quality

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Abstract. In the face of a coronavirus pandemic, many buildings or facilities are closed. The sudden closing of schools, factories or offices has caused a reduction in the water consumption inside buildings. The lack of chlorinated water flowing through the pipes, combined with temperature changes, poses a real risk to potable water from the bacteria multiplication point of view. The contribution focuses on the requirements for the temperature of potable water cold (PWC) in the water pipeline system inside buildings. The main goal of the research is to evaluate the effect of heat transfer between the PWC and the surrounding air during the water stagnation. Temperature differences between the PWC and the indoor air in building are leading to the heat transfer by convection. The result of the heat transfer is an undesired increase of the PWC temperature. The paper assesses the increase in PWC temperature over time using two methodologies - mathematical analysis and computer simulation. The results show that with an increasing pipe diameter and insulation thickness, the temperature of PWC during stagnation increases more slowly. The article points out the fact that the first 10 mm of insulation has the greatest impact on preventing the heating of PWC from the surrounding environment. Regarding the material design of the pipeline, only small deviations in the results were calculated between steel and plastic pipe. Mathematical analysis and computer simulation show that the issue of PWC stagnation in the pipeline has a significant effect on the temperature and thus the quality of water in buildings.

1. Introduction

With temperature differences between the fluid and the environment, heat transfer occurs between them. Heat transfer occurs in different ways: by conduction, convection and radiation. In the issue of distribution of Potable Water Cold (referred as a PWC), heat transfer is demonstrated primarily by an increase in its temperature due to heating of water from the environment (heat transfer by convection). If the temperature of the environment is higher than the PWC temperature in the water pipe, the temperature exchanges occurs and the PWC temperature increases.

The optimal PWC temperature is important not only from the comfort of the end users’ point of view, but also from the possibility of the bacterial growth risk. Within 30 seconds of the opening of the water tap, the temperature of PWC must not exceed 25 °C [1]. During the PWC distribution in the building, the water stagnates. Stagnation of water in combination with a high ambient temperature causes the heating of PWC. Therefore, the pipes should be sufficiently insulated. Recommended minimum thicknesses of cold-water pipe thermal insulation layers are given in Table 1.
Table 1. Recommended minimum thicknesses of a thermal insulation layer of cold-water pipes [2].

| Pipe laying                                                                 | Thicknesses of insulation if $\lambda = 0.040 \text{ W/(m.K)}$ |
|----------------------------------------------------------------------------|---------------------------------------------------------------|
| Cold water pipes laid in unheated rooms, ambient temperature ≤ 20 °C (only condensation protection) | 9 mm                                                          |
| Cold water pipes laid in shafts, floor ducts and suspended ceilings, ambient temperature ≤ 25 °C | 13 mm                                                         |
| Cold water pipes laid in technical room, shafts, channels, suspended ceilings, with heat loads and ambient temperature > 25 °C | Thickness is equal to the pipe internal diameter |
| Floor connection pipes and single connection pipes in pre-wall installations | 4 mm or in a protective tube                                    |
| Cold water pipes in an underfloor installation, laid without hot water pipes | 4 mm or in a protective tube                                    |
| Cold water pipes in an underfloor installation, laid with hot water pipes  | 13 mm                                                         |

The aim of the paper is to determine the change in PWC temperature in the water pipeline during stagnation, using a mathematical analysis and computer simulation, depending on the stagnation time, pipe diameter, pipe material and insulation thickness.

2. Mathematical analysis of the increasing of PWC temperature over time

The mathematical analysis of the effect of heat transfer between the PWC and the surrounding environment is based on the calculation of heat gains. The heat gain in a circular pipe is caused by heat transfer of the environment to the individual layers of the pipe and insulation. To determine the heat gains of a pipe, it is necessary to know the heat flux of the water pipe $q (\text{W/m})$. The heat flux was calculated according to the standard ISO 12241 [3]: Thermal insulation for building equipment and industrial installations, calculation rules. The resulting PWC temperature in water pipe $\Theta_{\text{PWC}} (\text{°C})$ was determined according to standard STN EN 15316-3-2 [4]: Energy performance of buildings, Method for calculation of system energy requirements and system efficiencies - Part 3: Space distribution systems (DHW, heating and cooling), Module M3-6, M4-6, M8-6.

Using this mathematical analysis, the PWC temperature changes over time depending on the ambient temperature and the length of time water stagnation was calculated. For the calculation these data were changing: time of PWC stagnation in the pipe (from 0 to 8 hours), pipe dimensions (from DN 15 to DN 80), pipe materials (steel and plastic pipes were compared) and insulation thicknesses (from 0 to 40 mm). The initial temperature of the PWC in the pipe was considered 10 °C and the ambient temperature was considered 24 °C (usual temperature in the bathroom). The length of pipe was 1,0 m.

2.1. Results of mathematical calculation for STEEL cold-water pipes

Figures 1 to 3 show the increase in PWC temperature in a stainless-steel water pipe as a function of time, pipe dimension and insulation thickness, at a constant ambient temperature of 24 °C and an initial PWC temperature of 10 °C. The stainless-steel water pipe was considered with the following parameters:

- specific heat capacity of the stainless-steel pipe: $c_p = 0.500 \text{ kJ/(kg.K)}$,
- thermal conductivity of the stainless-steel pipe: $\lambda_p = 15 \text{ W/(m.K)}$,
- pipe insulation was considered from rubber (caoutchouc), $\lambda_{\text{ins}} = 0.035 \text{ W/(m.K)}$.

The results in Figure 1 to 3 show that with an increasing pipe diameter and insulation thickness, the temperature of PWC during stagnation increases more slowly. The results point out the fact that the first 10 mm of insulation has the greatest impact on preventing the heating of PWC from the surrounding environment. When insulating pipes with a thickness of 9, 13, 20 and 30 mm, only small differences in the rate of PWC temperature rise were calculated.
Figure 1. PWC temperature in steel pipe DN 25 during stagnation, at different insulation thicknesses

Figure 2. PWC temperature in steel pipe DN 50 during stagnation, at different insulation thicknesses

Figure 3. PWC temperature in steel pipe DN 80 during stagnation, at different insulation thicknesses
2.2. Results of mathematical calculation for PLASTIC cold-water pipes

Figures 4 to 6 show the increase in PWC temperature in a plastic cold-water pipe as a function of time, pipe dimension and insulation thickness, at a constant ambient temperature of 24 °C and an initial PWC temperature of 10 °C. The plastic water pipe was considered with the following parameters:

- specific heat capacity of the plastic pipe: \( c_p = 2.3 \text{ kJ/(kg.K)} \),
- thermal conductivity of the plastic pipe: \( \lambda_p = 0.35 \text{ W/(m.K)} \),
- pipe insulation was considered from rubber (caoutchouc), \( \lambda_{ins} = 0.035 \text{ W/(m.K)} \).

The results for plastic pipe are very similar to those for the steel pipes - with an increasing pipe diameter and insulation thickness, the temperature of PWC during stagnation increases more slowly. The first 10 mm of insulation has the greatest impact on preventing the heating of PWC from the surrounding environment. Small deviations in the results were calculated between the steel and plastic pipes, in the plastic pipe compared to the steel pipe the water heating is slower by about 0.5 °C (due to better thermal insulation properties of the plastic material).

![The course of PWC temperature in the plastic pipe DN 25 during water stagnation, at different insulation thicknesses](image)

**Figure 4.** PWC temperature in plastic pipe DN25 during stagnation, at different insulation thicknesses

![The course of PWC temperature in the plastic pipe DN 50 during water stagnation, at different insulation thicknesses](image)

**Figure 5.** PWC temperature in plastic pipe DN50 during stagnation, at different insulation thicknesses
3. Mathematical-computer simulation of the increasing of PWC temperature over time

The second methodology used to model the behaviour of PWC temperature over time is computer CFD simulation in the program Ansys Fluent. The program is based on the numerical solution of a partial differential equations that express the law of conservation of mass (continuity equation), the law of conservation of momentum (Navier-Stokes equations) and the law of conservation of energy (energy equation - heat transfer by convection, conduction or radiation).

The first simulation performed is a simulation of the course of the PWC temperature over time, in 2D space when water pipe is installed separately. The simulation in 2D space was chosen in order to the geometry simplification, the smaller size of the mesh and the faster and more accurate calculation process. Using a computer simulation, the course of the PWC temperature in steel and plastic pipes over time was simulated, depending on the ambient temperature and the time of water stagnation. The same input data as for the analytical calculation were entered to the simulation. The graphs show the course of the PWC temperature with an initial temperature of 10 °C at an ambient temperature of 24 °C.

The individual graphs show the course and distribution of temperature during the stagnation time of:

- 1 hour,
- 4 hours,
- 8 hours of water stagnation in the pipeline.

For each time interval, the resulting PWC temperature after a certain time interval of the stagnation $\theta_{PWC}$ was calculated (°C).

3.1. Results of computer simulation for STEEL cold water pipes

Figure 7 shows the heat transfer between the surrounding environment, which is air with a temperature of 24 °C and cold water distributed by a stainless-steel pipe DN 50, with an initial temperature of 10 °C. In Figure 7 (a) the temperature profile for uninsulated pipe is shown. The figure shows that in an uninsulated pipe of DN 50, after 1 hour of water stagnation, the PWC temperature increases from an initial value of 10 °C to 17.2 °C. After 4 hours of stagnation, the PWC temperature increases to 23.34 °C and after 8 hours the temperature in the pipe reaches almost the ambient temperature of 24 °C. Figure 7 (b) shows the temperature course of the pipe with insulation thickness of 13 mm: after 1 hour of water stagnation, the PWC temperature rises from 10 °C to 11.46 °C, after 4 hours of stagnation, the cold water temperature rises to 16.11 °C and after 8 hours the temperature in the pipe reaches 19.7 °C.
a) STEEL PWC pipe DN 50, insulation 0 mm
- 1 hour of stagnation, $\theta_{PWC} = 17.2 \, ^\circ C$
- 4 hours of stagnation, $\theta_{PWC} = 23.34 \, ^\circ C$
- 8 hours of stagnation, $\theta_{PWC} = 23.97 \, ^\circ C$

b) STEEL PWC pipe DN 50, insulation 13 mm
- 1 hour of stagnation, $\theta_{PWC} = 11.46 \, ^\circ C$
- 4 hours of stagnation, $\theta_{PWC} = 16.11 \, ^\circ C$
- 8 hours of stagnation, $\theta_{PWC} = 19.70 \, ^\circ C$

**Figure 7.** PWC temperature in a steel pipe DN 50 during stagnation, at different insulation thicknesses (a) insulation 0 mm, (b) insulation 13 mm
3.2. Results of computer simulation for PLASTIC cold water pipes

Figure 8 shows the heat transfer between the surrounding environment, which is air with a temperature of 24 °C and cold water distributed by a plastic pipe DN 80, with an initial temperature of 10 °C. In Figure 8 (a) the temperature profile for uninsulated pipe is shown. Figure 8 (b) shows the temperature course of the pipe with insulation thickness of 13 mm.

- **a) PLASTIC PWC pipe DN 80, insulation 0 mm**
  - 1 hour of stagnation, $\theta_{PWC} = 11.01$ °C
  - 4 hours of stagnation, $\theta_{PWC} = 18.31$ °C
  - 8 hours of stagnation, $\theta_{PWC} = 23.13$ °C

- **b) PLASTIC PWC pipe DN 80, insulation 13 mm**
  - 1 hour of stagnation, $\theta_{PWC} = 10.60$ °C
  - 4 hours of stagnation, $\theta_{PWC} = 13.73$ °C
  - 8 hours of stagnation, $\theta_{PWC} = 16.81$ °C

**Figure 8.** PWC temperature in a plastic pipe DN 80 during stagnation, at different insulation thicknesses (a) insulation 0 mm, (b) insulation 13 mm
With conventional water supply distribution systems inside buildings, cold water, hot water and hot water circulation pipes are most frequently installed together - in a shaft, under the ceiling, in the wall, etc. Adherence to sufficient spacing distances between PWC pipes and hot water pipes and a sufficient thickness of thermal insulation are often underestimated. In further simulations, the method of piping installation (shaft, ceiling) and its effect on the temperature of PWC water will be assessed.

3.3. Computer simulation for pipes installed IN THE SHAFT
In the following simulation there will be analysed the influence of water stagnation in cold water pipe on its temperature when installing in a shaft. In the shaft there are installed: potable water cold (PWC) steel pipe DN 50 insulated with 13 mm insulation, potable water hot (PWH) composite plastic-aluminium pipe DN 40 insulated with 40 mm insulation, potable water hot circulation (PWH-C) pipe of composite plastic-aluminium material DN 20 insulated with 20 mm insulation and drained water (D) plastic pipe D 125. The development of the PWC temperature in the pipe and the air temperatures in the shaft, after a certain time interval of stagnation, is assessed (Figure 9). Hot water is designed with circulation, a constant PWH temperature of 55 °C and a constant PWH-C temperature of 50 °C are considered. The initial temperature of the air in the shaft is set to 24 °C. The initial temperature of PWC was considered 10 °C.

![Figure 9. PWC temperature in steel pipe DN 50 during stagnation, pipes installed in a shaft, PWC – potable water cold, PWH – potable water hot, PWH-C – potable water hot circulation, D – drained water, A – air](image-url)
3.4. Computer simulation for pipes installed UNDER THE CEILING

The last simulation performed is a simulation of the effect of heat transfer between the surrounding ambient and a PWC cold when installation installing under the ceiling. The input data were identical to the simulation performed for the shaft. The simulation results are shown in Figure 10.

![Simulation Results](image)

Figure 10. PWC temperature in steel pipe DN 50 during stagnation, pipes installed under the ceiling, insulated according to normative requirements

PWC – potable water cold, PWH – potable water hot, PWH-C – potable water hot circulation, D – drained water, A – air
4. Conclusions

During water stagnation due to the high ambient temperature the PWC temperature is increasing. Increase of PWC temperature causes end-user discomfort and higher risk of bacteria multiplication. In the paper the result of mathematical analysis and computer simulation of heat transfer between PWC and the environment inside building are presented. The results show that with an increasing pipe diameter and insulation thickness, the temperature of PWC during stagnation increases more slowly. The first 10 mm of insulation has the greatest impact on preventing the heating of PWC from the surrounding environment. Small deviations in the results were calculated between the steel and plastic water pipes, in the plastic pipe compared to the steel pipe the water heating is slower by about 0.5 °C (due to better thermal insulation properties of the plastic material).

When comparing the heat transfer between pipes installed in the shaft and under the ceiling, the arrangement of the pipes in the building structure is very important. In under the ceiling installation the cold-water pipe is located below the hot water pipes and as the heat rises upwards, the hot water pipes heat the air and the cold water more slowly than in the case of a shaft, where the pipes are placed next to each other.

The benefit of the simulation is the view of the exact course of the temperature field in the pipe, which shows that the water temperature is highest at the inner surface of the pipe. At the inner surface of the pipe is also the highest density of biofilm, which in combination with a water stagnation should cause the microbiological contamination of water [5].

The issue of stagnation of potable water in the pipeline system cannot be underestimated. If regular sampling from the water taps is not ensured and if the ambient air temperature is high, it is appropriate to consider automatic flushing of the water distribution system, e.g. using water flushing units or a potable water cold circulation system.

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