E3S Web of Conferences **45**, 00099 (2018) https://doi.org/10.1051/e3sconf/20184500099
INFRAEKO 2018

Hot water tanks from the point of view of temperature and energy confrontation

Zuzana Vranayova[1,*], *Daniela* Kaposztasova[2]

[1] Faculty of Civil Engineering, Institute of Buildings and Environment, Department of Theory and Environment of Buildings, Vysokoskolska 4, Kosice 04 200, Slovak Rebublic
[2] Faculty of Civil Engineering, Institute of Buildings and Environment, Department of Theory and Environment of Buildings, Vysokoskolska 4, Kosice 04 200, Slovak Rebublic

Abstract. The main cause of outbreaks of Legionnaires' disease is from contaminated water sources. About 3 in 10 cases of Legionnaires' disease are due to poorly maintained water storage in buildings. A Tankless water heater can reduce your water-heating bill by five percent to fifty percent or more. A Tankless water heater is a continuous flow of hot water because it instantly heats the water as it goes through the heater. The question is if the Tankless water heater is more efficient than the tank water heater? In our experiment, using Water Quality Management methods, the water heater tank was verified as a source of ubiquitous bacteria's that can cause health problems to users. Are the solar hot water systems also dangerous? The use of solar energy is very prospective and in the future it will be used in various sectors. The subject of the paper is a simulation of the operational modes of hot water preparation focused on its temperature and energy impact.

1 Introduction

The water pipeline belongs to the technical systems currently used by people to ensure their supply of drinking and hot water. Also important is its quality, which can be affected not only by the piping material, but also by the chemical composition of water or by bacterial colonization. There is another factor in the preparation of hot water, namely the water heating technology, which can also be a source of bacteriological colonization. When water is heated in storage tanks, there are ideal conditions for the growth of bacteria, e.g. if they are not delimed, or in the water mains by plate exchangers. Here it is not possible to capture the sludge or to remove it. Just this sludge is one of the factors that promote bacterial growth. However, the main point is the occurrence of biofilm on the walls of the distribution pipeline and the influence of the material. Inside the water supply distribution networks, the *legionella* bacteria colonizes the inner sides of the pipeline, the fittings and their seals, the aerators of the mixing batteries, the hoses, and the shower ends [1].

* Corresponding author: daniela.kaposztasova@tuke.sk

Global trends include reducing the energy consumption connected with the preparation of hot water. The role of the hot water preparation facilities is to provide the residents of the household with the necessary amount of hot water, preferably without waiting. These facilities must also meet other criteria such as output water temperature control, operational safety and the hygienic quality of water [2, 3]. The storage water heater is the second largest household energy consumer right after the heating / cooling system. By adjusting or modifying them, we will be able to significantly reduce the cost of annual energy consumption. Why have a tank full of hot water, 24 hours a day, when the need for domestic hot water is less than one hour per day? Figure 1 shows the average consumption of potable water in Slovakia. Another type is the Heat Pump Water Heater. Heat pumps transfer energy from the surrounding air to water in a storage tank and they are much more efficient than electric resistance water heaters (most effective in warm climates with long cooling seasons). Solar water heating systems require a conventional water heater as a backup water heating source to ensure hot water is available when solar energy is not [4, 5]. There is the question of confronting heat and energy from the point of view of the use of storage tank heaters and the no-storage-flow systems, so called “Tankless” systems or instantaneous water heaters, which are common in the world in terms of reducing energy in the preparation of hot water.

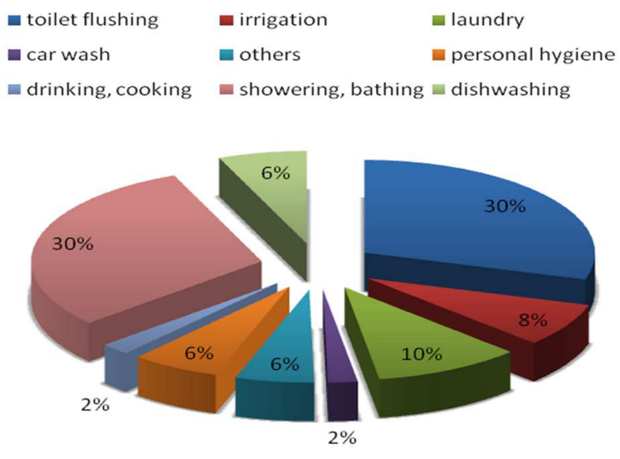

Fig. 1. Average consumption of potable water in Slovakia according to end purpose water use per person [3].

2 Tankless flow water heaters versus storage tank water heaters

The use of flow water heaters has been discussed in many studies in the world [6, 7, 8, 9, 10, 11, 12, 13] and from an energy point of view in for example [10, 13, 14, 15, 16]. Flow water heaters are compact in size and provide a constant supply of hot water for as long as necessary. Gas flow water heaters are more energy efficient than conventional water heaters because Tankless models eliminate the need for the reheating of accumulated water. In most cases, an electric Tankless water heater will be more expensive to operate than a gas water heater. Depending on which model we choose, a modern flow heater can provide unlimited hot water supply in households with 1, 2, 3 or even more bathrooms. When the water is heated and stored in the tank, sludge and sediments start to deposit inside. A waterstone at the bottom of the tank can reduce the efficiency of the heating and, together with possible corrosion, also shorten the life of the heater.

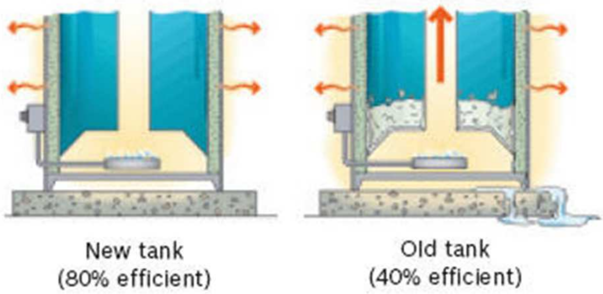

Fig. 2. Comparison of effectivity of new and old tank water heater [2].

Some types of Tankless water heaters are thermostatically controlled. They can vary their output temperature according to the water flow rate and the inlet water temperature. This is useful when using a solar water heater for preheating inlet water [6]. In some cases [7] (depending on size, fuel type availability, energy efficiency, cost) it is recommended to replace the storage tank water heater with a flow water heater for the aforementioned aspects. However, it is very important to realize how much hot water is used by the specific household. In some cases, one flow heater may be insufficient, and then it is necessary to combine the use of two heaters. Manufacturers provide ready-made models according to the collection points.

Table 1. Comparison of water heaters according [4].

Water Heater Type	**Energy Savings [%]**	**Expected Lifetime**	**Major Advantages**
High Efficiency Storage (Tank) (Oil, Gas, Elec.)	10 to 20	8 to 10 Years	Low investment cost
Demand (Tankless) Using Gas or Elec.	45 to 55	20 Years	Unlimited supply of water
Heat Pump	60	10 Years	Most efficient electric fuel option
Solar with Electric Back-Up	75 to 90	20 Years	Largest energy savings using a renewable energy source

The storage system, in some ways inefficient for consumers, serves as a system that does not increase the demand for energy when being consumed. The peak consumption is still the same and the amount of energy needed for heating the water is spread over a much longer period of time. The storage tank serves as a thermal mass capacity memory device. Tankless systems, on the other hand, raise consumption to a peak during the period of use. Total usage may be by 60% lower, but peak consumption is higher. If thousands of people in the consumer point (village) started showering at once, a real problem could be created for the electrical network. In the case of a decision to use an electric flow heater, the energy consumption to produce hot water will decrease though, but the price for electricity will increase. To achieve the desired effect, it is recommended using a gas flow heater in combination with non-traditional energy sources. With such a combination, even 60% savings can be achieved [17, 18]. From a hygienic point of view, flow heaters are better suited as they do not create suitable conditions for bacterial growth, which we have also demonstrated in our research.

3 Influence of temperature in storage tank heater on the growth of *Legionella* bacteria

Legionella bacteria are found throughout all nature, but their reproduction is predominantly dependent on water temperature. The normal rate of their reproduction compared to other similar bacteria is slow. However, if appropriate conditions are created, there will be a rapid exponential growth of these bacteria. On the contrary, they die very quickly when their nutritive environment is dried up [19, 20]. By using modern simulations, it is possible to point out in advance the possible places of occurrence of this bacterium in the storage tanks. Generally speaking, *Legionella pneumophila* bacteria need a suitable temperature in the range of 20 ° C - 50 ° C for their reproduction, and a suitable nutrient substrate such as biofilms, sediments and stagnant water [19, 20, 21, 22, 23].

Our previous investigation in past years was aimed at the *Legionella* present in hot water tanks in residential buildings. *Legionella* contamination was represented by the collection of more than 50 water samples from private homes, and a boiler houses in Kosice, a representative city in Eastern Slovakia [21]. Selection was made on the basis of the water distribution systems inside the town and buildings and heater types in each area. In the paper, we discuss the issue of temperature distribution in standing storage heaters, namely we point out the critical places in the storage tanks, using simulations of the water flow velocity during two operational states [22, 23]. An actual functional storage water heater was investigated where microbiological contamination was confirmed.

3.1 Simulation of operational states of storage tank

A water heater tank with a capacity of 6300l is designed for heating and hot water accumulation. The storage was simulated with the Fluent 6.3software. This is a non-isothermal 3D model where thermal radiation is considered. The change of water density and temperature is given by the regression function –5th degree polynomial. When used for simulating the RNG k – epsilon turbulence model and the thermal radiation has been modified into models of radiation [22, 23].

Two states were simulated. State A for the normal operation of the storage tank and state B for its thermal disinfection [23].

State A - heating at the selected state of normal operation

- The first operational state is defined by the boundary conditions:
- Flow rate: 0.008 kg/s,
- Inlet temperature: 10 °C,
- Storage tank insulated by insulating of thickness of 10 cm and :λ: 0,04 W.m-1.K-1,
- Boiler temperature: 15 °C,
- Heating element temperature: 80 °C,
- Outlet temperature: 51 °C.

Based on the first simulation of temperature stratification shown in Figure 3, just the bottom of the storage tank belongs to a temperature range from 35 °C to 45 °C, which is at risk.

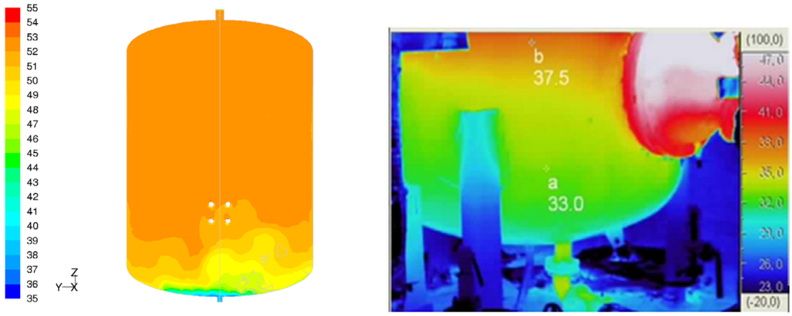

Fig. 3. Temperature stratification in the storage tank – state A and the bottom part of the storage tank after removal of the insulation [23].

To verify the simulated state of the temperature distribution, the investigated storage tank, a scan was done with a thermal camera. After removing the insulation, the bottom part of the storage tank was scanned under normal operation (Fig. 3). Simulated temperatures are the same as the actual state. The simulated model can be used as a general model (tolerance ± 2 °C) of the temperature distribution for vertical storage tanks (boundary conditions can be changed as needed). In conjunction with the sediment and the incrustation located at the bottom of the tank, the closed casting throat and the drinking water supply area become the most risky places.

State B – thermal disinfection of the storage tank

The second operational state - the condition for thermal disinfection is defined by the following boundary conditions. The requested temperature in the storage tank 75 °C measured in all side blind connections (right and left):

- Flow rate: 0,008 kg/s,
- Inlet temperature: 10 °C,
- Storage tank insulated by insulating of thickness of 10 cm and :λ: 0,04 W.m-1.K-1,
- Boiler temperature: 15 °C,
- Heating element temperature: 80 °C,
- Temperature in controllable points of the storage tank: 75 °C.

By simulating a state of thermal disinfection, the temperature stratification has changed, but the risk points have not changed (Fig. 4). In the closed casting throat, the temperature is about 3 to 4 K lower than the temperature in the storage tank. It is therefore very probable that at these sites the bacteria manage to survive and after thermal disinfection they will continue to colonize the system [23].

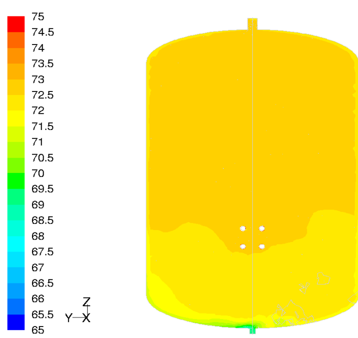

Fig. 4. Stratification of water temperature in the storage tank during thermal disinfection [23].

3.2 Legionella and its occurrence in solar water tanks

The sun is considered to be the most natural and cheapest heat source. A solar system can save 50% to 75% of the cost of producing hot water. The solar system actively utilizes solar energy and transforms it into thermal energy. In terms of investment costs, flat-faced solar collectors with a selective conversion layer are the most suitable for the year-round preparation of hot water. One part of the solar system is a solar boiler or heat storage. For smaller solar systems, water heaters with a larger heat exchange surface of a solar exchanger are used more than those connected to the central heating boiler. The boiler volume is selected according to the assumed hot water consumption [20]. When heating hot water, it is necessary to focus not only on reducing energy costs but also on the quality of the supplied hot water. In the case of solar heating, hot water is stored in solar boilers and heat storage tanks. Hot water distribution is possible for any number of collection points, but this increases the risk of creating appropriate conditions for legionella breeding. Just at temperatures in the range of 35-45 °C the risk is greatest. For reasons of reducing heat loss and minimizing the risk, it is advisable that the length of the pipe from the collectors to the tank (primary circuit) and from the storage tank to the collection points is as short as possible and that the pipes are sufficiently heat-insulated. These are mainly large solar storage tanks or boilers over 400 litres.

Systemic contamination cannot be removed by simply rinsing from the outflow sites. Chemical or thermal disinfection is required; however, their combination is most appropriate. In the event of the positive finding of legionella in the distribution system it is necessary to carry out disinfection measures (thermal disinfection, UV disinfection, chemical disinfection or their combination) [20].

4 Discussion and Conclusion

The achieved results of operating simulations of the operating states provide insight from the point of view of temperature stratification in a vertical storage tank. Due to the insufficient overheating during thermal disinfection and near zero water flow, the riskiest place is clearly the lower part of the storage tank – the so called casting throat. Here the suitable conditions for the growth of Legionella bacteria are maintained and, in the event of a decrease in temperature in the storage tank, they can colonize the whole system. These problems cannot occur when using a flow heater. The global views of experts differ in assessing and determining the type of heater. There are studies that negate the flow heating efficiency and point to errors and costs that may arise during operation – e.g. valve problems, maintenance costs. Despite the fact that manufacturers are reporting a continuous supply of hot water, the measurements have shown that cold water was also flowing to the users when the system was exhausted [13]. In choosing the right type, it is therefore necessary to prioritize, consider the conditions and the amount of water needed (equipment) and consult with experts. However, the choice of the type of storage tank remains up to the consumer and it is for them to consider what specific type of product they choose, and which benefits they prefer. These days, when it is environmentally friendly to use solar boilers, the question arieses of choosing the type of heater. Despite the fact that the sophisticated technology of a mflow heater ensures their smaller size, increased function and energy benefits, the opinions of experts differ. The Tankless heater is about a third of the size smaller than the storage heater, leaving room for water softeners or extra storage. The digital display makes it easy to set the correct water temperature or to monitor the unit when it is heated. To achieve the desired effect, it is recommended using a gas flow heater in combination with renewable energy sources. With such a combination, even 60% savings can be achieved [24]. Despite the manufacturers' claims, it is still unclear whether such a flow heater is able to meet 100% of all consumer requirements for the temperature of the supplied hot water as well as for the energy intensity of its preparation.

This work was supported by the Slovak Research and Development Agency under contract No. VEGA 1/0697/17 Hygienic water audit platform as a transition tool to Legionella-free water and HVAC systems in hospitals.

References

1. INOGY Energy. Available online: www.setrimeenergiu.sk (accessed on 25/02/2018)
2. RHEEM Gas. Available online: http://www.cporheem.com (accessed on 20/02/2018)
3. Human Development Report, (2006). Available online: http://hdr.undp.org/en/content/human-development-report-2006 (accessed on 20/04/2017)
4. High Efficiency Water Heaters. Available online: https://www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf (accessed on 27/05/2018)
5. J. Fryer. The complete guide to water storage: how to use gray water and rainwater systems, rain barrels, tanks, and other water storage techniques for household and emergency use. ISBN 9781601383631. (2012)
6. Demand (Tankless or Instantaneous) Water Heaters:

   Available online: https://dea.human.cornell.edu/sites/default/files/pdf/copy-of-demand-h-water-htrs.pdf (accessed on 27/05/2018)
7. Tankless or Demand-Type Water Heaters:

   Available online https://www.energy.gov/energysaver/water-heating/Tankless-or demand-type-water-heaters (accessed on 27/05/2018)
8. "Tankless Water Heaters," Consumer Reports, (51:1) pp. 53-55, January 1986
9. N. Nisson. Seisco Tankless Electric Water Heater Sets New Standard. Energy Design Update, (17:5) pp. 14-16, May 1997.
10. J. Harris . Extended Range Tankless Water Heater. In: Harmony Thermal Co., 1993. 33 pp. Available from National Technical Information Service (NTIS), Email: orders@ntis.gov. Order Number DE 93013327
11. Z. Gaulkin. A Tankless Job, In: This Old House, pp. 60-62, June 2001.
12. R. Layne. Never-Ending Hot Water and Energy Savings: Popular Science, (228:4) pp. 106-08, 150-51, April 1986.
13. L. A. Edgar. Demonstration of Tankless Water Heaters in Army Family Housing. U.S. Army Construction Engineering Research Laboratories National Technical Information Service, distributor (1992)
14. J. Wang., Y. Shi; K.Fang; Y. Zhou,; Li. A Robust Optimization Strategy for Domestic Electric Water Heater Load Scheduling under Uncertainties. Appl. Sci. 2017, 7, 1136.
15. Z. Yin, Y .Che, D .Li, H. Liu, D. Yu. Optimal Scheduling Strategy for Domestic Electric Water Heaters Based on the Temperature State Priority List. Energies. 2017; 10(9):1425.
16. A. K. Bhakta; N. K.Panday; N. S. Singh, 2018. "Performance Study of a Cylindrical Parabolic Concentrating Solar Water Heater with Nail Type Twisted Tape Inserts in the Copper Absorber Tube." Energies11, no. 1: 204.

17. What to know before you buy a heater. Available online:http://www.cporheem.com/what_you_need_to_know_before_you_buy.html (accessed on 20/02/2018)
18. P. Friedman Plumbing – 301-881-8660. Available online: http: //www.google.sk/imgres?imgurl=http://friedmanplumbing.com/ (accessed on 20/02/2018)
19. Technical management TC 164 WI 164353 - Recommendations for prevention of Legionella growth for installations inside buildings conveying water for human consumtion.
20. Z. Pospichal. Ochrana vnitřního vodovodu z pohledu mikrobiologie/ Protection of the internal water supply from the point of view of microbiology. Chapter 3, (Designer Workbook - Work Basics, Bratislava, Společnost pro techniku prostředí –STP,2005)
21. P. Sinčak, J. Ondo J, D. Kaposztasova, M. Virčikova, Z. Vranayova, J. Sabol. Artificial Intelligence in Public Health Prevention of Legionelosis in Drinking Water Systems. International Journal of Environmental Research and Public Health. 2014; 11(8):8597-8611
22. D. Ocipova. Legionella pneumophila versus save water distribution systems. Available online http://www.irbnet.de/daten/iconda/CIB_DC24016.pdf
23. D. Ocipova. Theoretical and experimental analysis of hot water distribution systems, Dissertation thesis (Technical Univesity of Kosice, 2010)
24. D. Kosicanova. The Energy Efficiency of Thermal Disinfection, In: Proceedings from the 12th Inter. Conference Sanhyga, p. 53 – 58, Trenčianske Teplice 30 and 31 of October (2007)