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Experimental Measurements of Hot Water Stratification in a Heat Storage Tank

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Abstract. The contribution focuses on the experimental measurement of the method of accumulation of hot water with its temperature layer in storage heaters using elementary cone elements. The basic principle of these elements is the automatic temperature distribution of water temperatures according to the temperature and flow rate for a specified storage time of heat energy from different heat sources in the heating system and hot water preparation. The thermal stratification in the stratified storage tank ensures maximum energy savings of up to 60% compared to standard storage tanks. The values of measurement were processed in a simulation fashion and compared to the real measured values. The aim of the experiments was to prove maximum energy savings and to determine the actual efficiency of elementary elements in stratification storage heaters with different heat sources. Storage of heat energy and its use is an important way of energy saving systems under Directive 2010/31 / EU of the European Parliament and of the Council on the energy performance of buildings. Stratification storage systems are used for different types of heating and also for domestic hot water preparation in all types of buildings. Their importance is evident when there is a need for efficient use of thermal energy in low-energy buildings and buildings with zero energy consumption, where they can be used for common use of hot water (50 - 60 °C) with different temperatures for heating (e.g. floor heating, convective heating, etc. ranging from 25 to 60 °C). The most efficient way is to combine stratified heat storage tanks with solar heating systems, heat pumps, or boilers. Every building must be assessed individually in terms of requirements for heating and the method of domestic hot water preparation and distribution. Furthermore, when engineering a heating system for any building, the use of a renewable energy source has to be taken into consideration too.

1. Introduction

The accumulation of thermal energy in water is currently used for heating as well as for hot water preparation. Accumulated heat has a significant impact on the energy efficiency of heating and hot water preparation. Heat storage utilization in storage tanks is nowadays used in low-energy buildings and buildings with energy consumption close to zero. Over the last few years it has gradually been turning into a standard in heating systems and hot water production in EU countries. One way of accumulating heat into the tank is by means of stratification in a stratified storage [1][2][3]. This principle ensures maximum savings in thermal energy storage and its subsequent use for energy efficient systems making use of renewable energy sources.

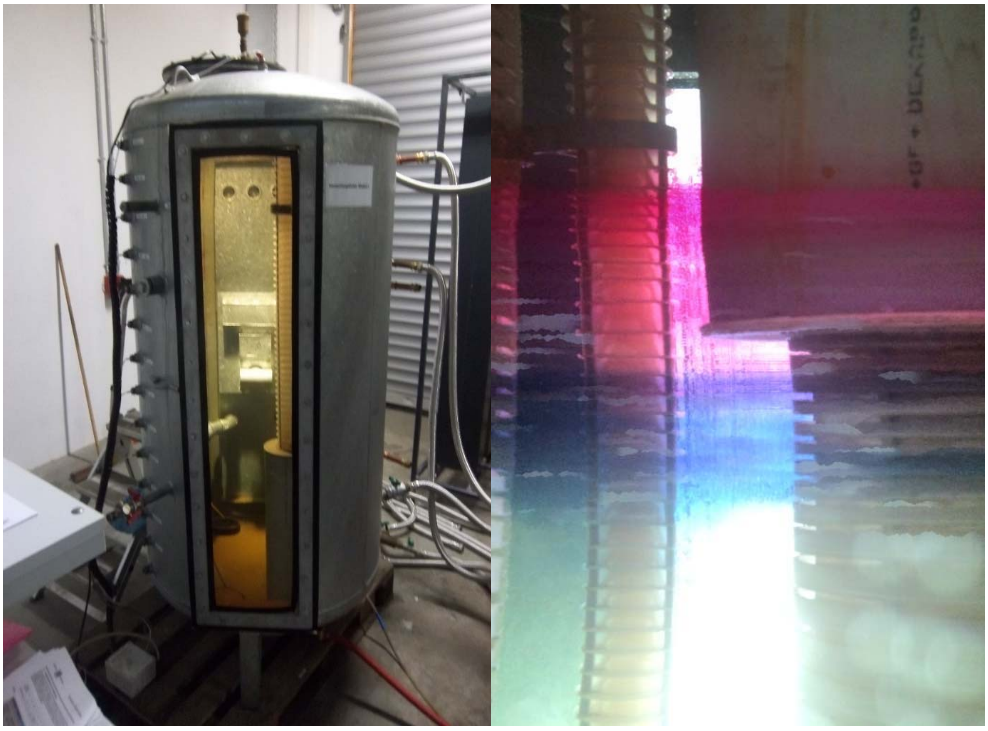
2. The process of stratification

The storing of thermal energy is differentiated according to the selected physical principle. In order to utilize more energy from solar collectors and other heat sources, the principle known as *thermal stratification*, i.e. thermal layering – for example in a stratified heat storage tank – is made use of water stored in stratified heat storage tanks, forms naturally, as a result of gravity, layers of different temperature affecting its weight. The way water circulates in this kind of heat storage tanks depends on the temperature of heating circuits heated by heat sources. Therefore, there are low temperature systems (40 – 60 °C) and high-temperature systems

(60 – 90 °C) [4]. Thermal stratification is practically storage volume layering by means of controlled storing of thermal energy into layers with the same or similar temperature. Colder and heavier water remains close to the bottom, whereas warmer water rises upwards. In other words, water with density ρ is always supplied under the layer which has a lower density. The remaining layers maintain their respective temperatures, due to the low thermal conductivity of water. In order to support the preservation of natural thermal layers by means of buoyancy forces, vertical storage tanks are used in most cases [5].

3. Experimental measurements in laboratory conditions

The experimental measurements were carried out in the testing laboratory of SAILER GmbH (Ehingen, Germany), a company dealing with research and production in the area of thermal energy layering in storage tanks [5]. These experimental measurements took place from April 20th 2017 to May 31st 2017 in the company's research laboratories. The measurement module consisted of a 1,050 l layering accumulation tank 'figure 1', heat exchanger, pump system, control units and heating circuits. There were two heat sources used for water heating: the first one consisted of 10 solar collectors with an absorption area of 10 x 2.81 m^2, the second one was a gas condensing boiler with a heat output of 30 kW. Heated water was being supplied from these heat sources at a temperature of max. 60 ° C through a hydraulic measuring system into a layered storage tank 'figure 2'. The heating water was supplied to the measuring device through a copper pipe with a nominal lightness/diameter DN 20 (22 x 1.0 mm).



a) **b)**

Figure 1. Stratified storage tank in laboratory conditions
a – Stratified storage tank with acapacity of 1,050 l in laboratory,
b – Color distinction of individual hot water layers in the stratified storage tank

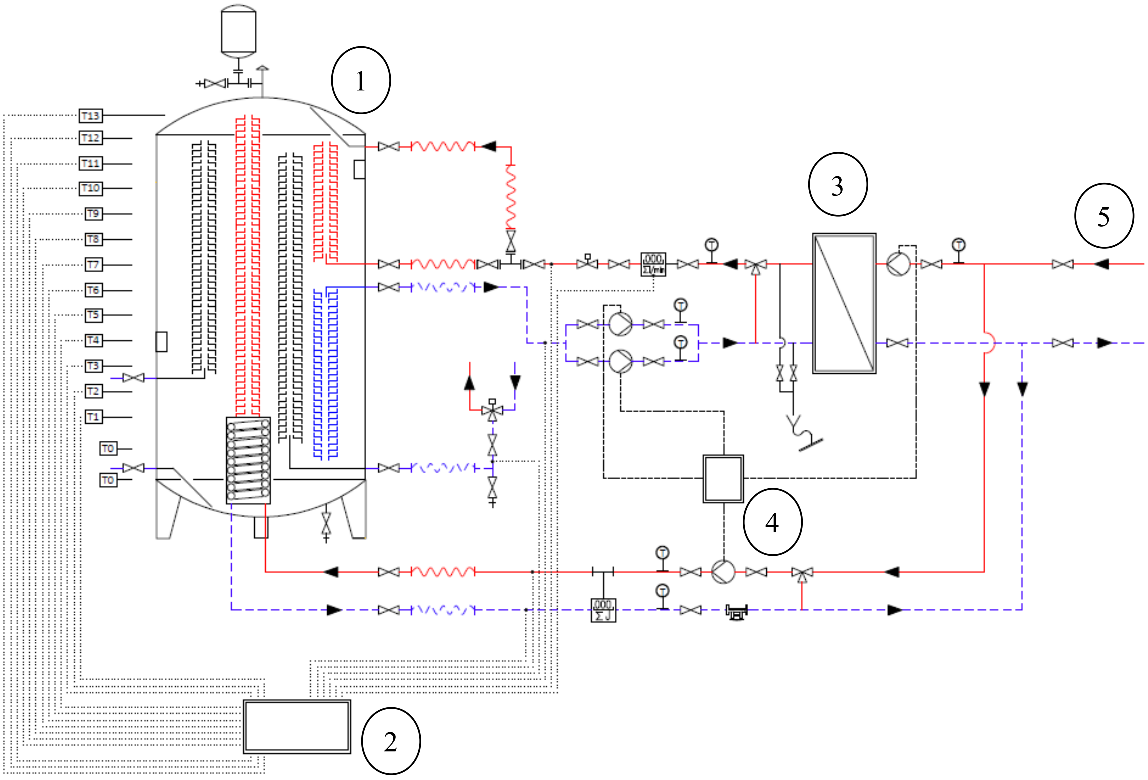


Figure 2. Hydraulic scheme of the connection of stratified storage tank during the experimental measurements
1 – stratified storage tank (1,050 l), 2 – control unit with a data saving ffeature,
3 – plate heat exchanger, 4 – pump control unit, 5 – heating system from solar collectors or gas boiler

The stratified storage tank is supplemented with a 35 l expansion tank equipped with an automatic venting valve and a top-down discharge valve. The storage tank uses convection elements for fixed temperature layering, figure 1b. The process of thermal energy storage inside the tank was recorded by means of temperature sensors that were placed at various height levels of the tank 10 centimetres away from each other and are marked as T ranging from T1 to T13 Table 1, figure 2. In individual parts of the measuring system, the temperature sensors were located on the supply and return pipes of the heating water. The pump system was controlled by a unit enabling constant water flow adjustment for experimental measurements.

Table 1. Example of water temperature change in the tank at the flow of 1,000 l/h

Time (min)	**Sensor temperature in individual layers in °C**												
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**T_10**	**T_11**	**T_12**	**T_13**
0	35.50	35.50	35.50	35.50	35.50	35.50	35.51	35.71	38.98	51.39	56.34	56.60	56.60
1	35.50	35.50	35.50	35.50	35.50	35.50	35.52	35.97	41.76	50.83	56.24	56.58	56.60
2	35.50	35.50	35.50	35.50	35.50	35.50	35.53	36.94	44.10	50.58	56.24	56.54	56.58
3	35.50	35.50	35.50	35.50	35.50	35.50	35.63	38.48	45.86	50.48	55.54	56.49	56.50
4	35.50	35.50	35.50	35.50	35.50	35.53	35.83	41.06	47.07	50.50	54.80	56.39	56.42
5	35.50	35.50	35.50	35.50	35.50	35.50	35.76	43.26	48.21	50.39	53.80	56.33	56.38

4. Measurement process

At the beginning of the measurement, the initial temperature in the 1,050 l storage tank was 35 °C throughout its entire capacity. A heat source, solar circuit, was used to supply water at the temperature of 60 °C to the upper part of the tank. The progress of thermal energy layering at individual storage tank height levels was recorded every 60 minutes at selected volume flow rates of 500 l/h (8,3 l/min), 750 l/h (12,5 l/min), and 1,000 l/h (16,3 l/min). The measuring device recorded temperature values every second. Therefore, there were 3,600 pieces of data recorded per hour by each sensor, which means 46,800 measured temperatures for each flow that was being measured. The actual measured water temperature values at the height levels from T-1 to T-13 ‘figure 2’ are shown in graphs ‘figure. 3,4,5’, where the water temperature during the water layering in 60-minute intervals can be seen. At the set flow rates, the warm water in the storage tank did not fall below 35 °C, which was also the initial value at the beginning of the measurement throughout the entire tank capacity. The maximum water temperature in the tank reached about 59 °C ‘figure 5’ in the topmost layers, whereas the aim was to heat the water in the lowest layers of the tank to the temperature level of 35 °C.

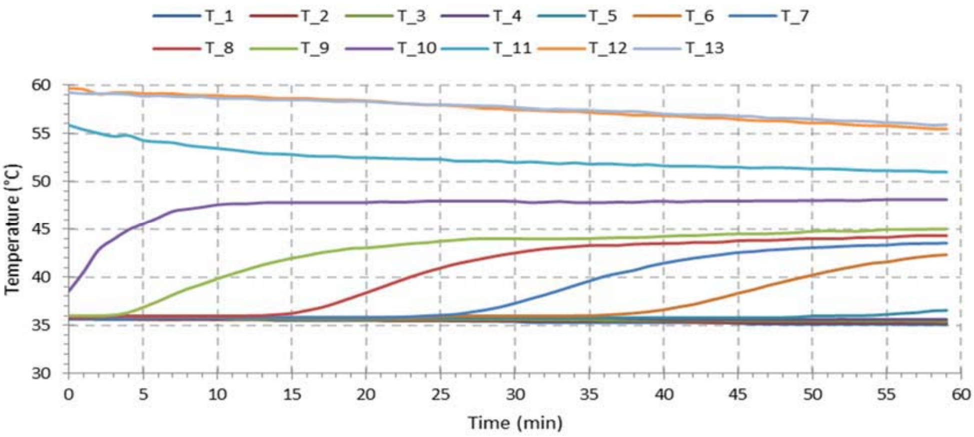


Figure 3. Change in heat energy layering by temperature at the flow of 500 l/h

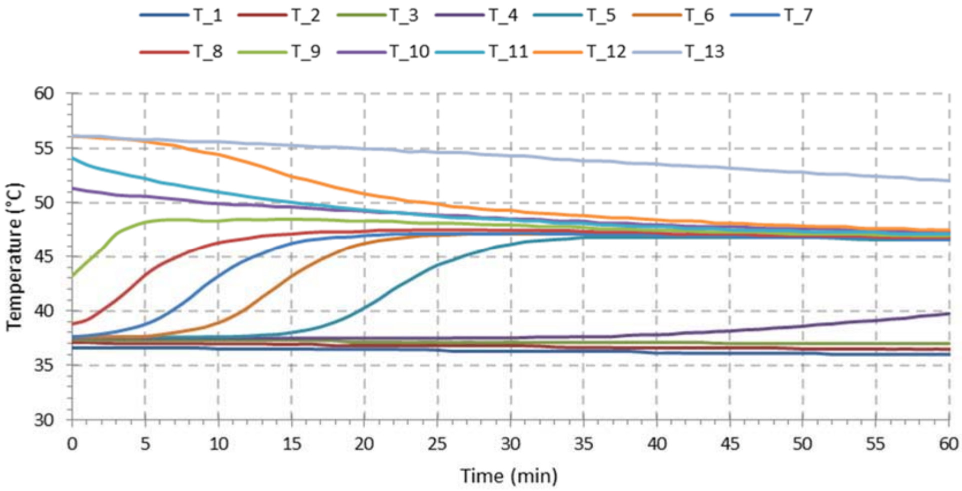


Figure 4. Change in heat energy layering by temperature at the flow of 750l/h

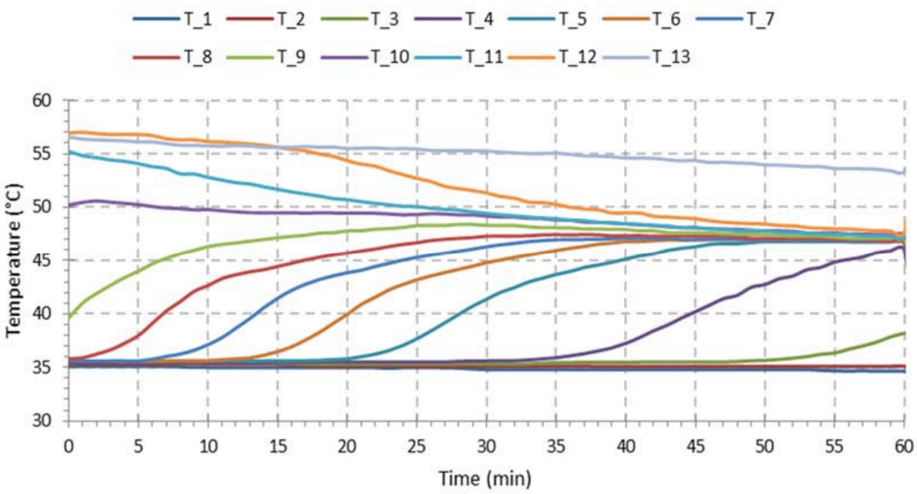


Figure 5. Change in heat energy layering by temperature at the flow of 1,000 l/h

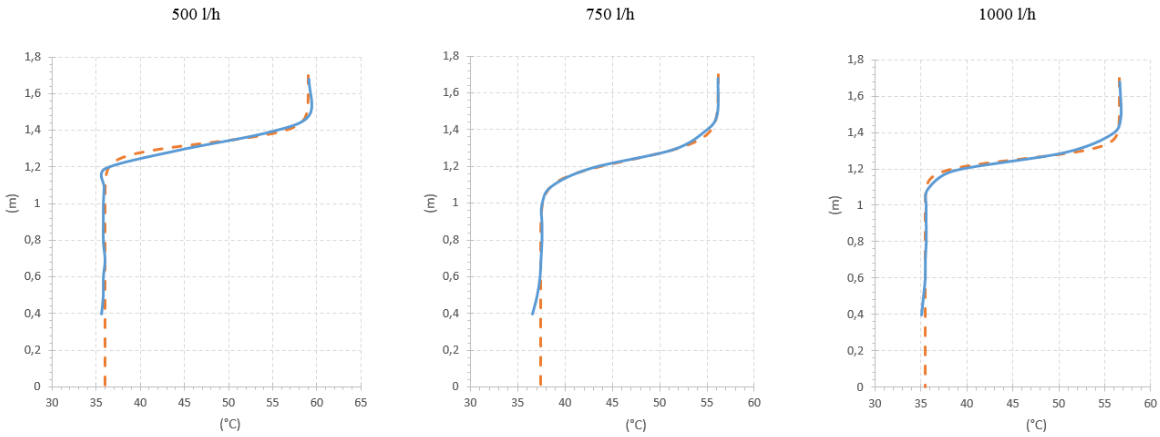


Figure 6. Change in temperature at various flow rates at the individual height levels in the stratified storage tank

5. Results

The experiment points out the functionality of heat energy layering through elementary elements at the individual storage tank height levels ranging from 0.4 to 1.7 m, figure 6. The flow rates selected for the experiment were 500, 750 and 1,000 l/h. The temperatures measured at the height levels of 0.4, 1.2 and 1.7 m are shown in Table 2. Figure 6 and Table 2 clearly show that the biggest temperature changes in the 1,050 l storage tank within the interval of 1 hour occurred at height levels from 1.18 to 1.57 m, when the water was being layered at the flow rate of 500 l/h (temperature difference ca. 26 K), at height levels from 1.05 to 1.49 m, when the water was being layered at the flow rate of 750 l/h (temperature difference ca. 22 K), at height levels from 1.00 to 1.4 m, when the water was being layered at the flow rate of 1,000 l/h (temperature difference ca. 20 K). The graphs show that the water temperature in lower layers does not change up to the height of 1.0 m and the increase of the temperature only starts to occur in the upper half of the storage tank. At the height level 1.4 m and above, the water temperature in the layers remains constant.

Table 2. Water temperature at different height levels of the storage tank with different flows of water

Flow (l/h)	**500**			**750**			**1,000**		
Sensor height (m)	0.4	1.2	1.7	0.4	1.2	1.7	0.4	1.2	1.7
Temperature (°C)	35.60	36.00	59.20	35.10	38.60	56.60	36.60	42.80	56.20

6. Conclusion

The aim of the experimental measurements was to give evidence of thermal energy storing, find out, how the water temperature changes inside the storage tank, and explore the functionality of elementary elements of stratification tanks using different kinds of heat sources (solar collectors and condensing boiler) [6][7]. The temperature measurement outcomes confirm the fundamental difference between a standard tank and a stratified storage tank. In a standard heat tank, hot water is continuously being mixed throughout the entire tank capacity, whereas a stratification storage tank uses internally directed stratification system based on temperature. The stratification of hot water [8] allows for discharging hot water of various temperatures from the storage tank and thus adapt to different use cases. Some of the examples include floor heating, convection heating, wall heating, and hot water preparation using different temperature gradients. An important part of the equation is to set an optimum volume flow rate of water supply from the heating circuit to the tank, reflecting the required operating conditions.

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References

[1] A. Zachár: Investigation of a new tube-in-tube helical flow distributor design to improve temperature stratification inside hot water storage tanks operated with coiled-tube heat exchangers, In: International Journal of Heat and Mass Transfer, 2013, pp. 150-161

[2] M. K. Anuar Sharif, A.A. Al-Abidi: Review of the application of phase change material for heating and domestic hot water systems, In: Renewable and Sustainable Energy Reviews, 2015, pp.557-568

[3] M. Gasque: Study of the influence of inner material on thermal stratification in a hot water storage tank, In: Applied Thermal Engineering 75, 2015, pp. 344-356

[4] M. Krafčík: The accumulation of hot water in the stratified heat storage tanks. In: E-NOVA 2017, 2017, pp. 397-402

[5] J. Peráčková, M. Krafčík: The stratified heat storage tanks, In: Magyar Épületgépészet, 2017, pp. 30-33

[6] STN EN 15316-3-3: Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 3-3: Domestic hot water systems, generation. 2009.

[7] STN EN 806-2: Specification for installations inside buildings conveying water for human consumption. Design

[8] Company references SAILER – www.sailer.sk a www.sailergmbh.de online 05/2018.