Temperature Fluctuations in Shower Mixing Valves

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Abstract

Temperature fluctuation of mixing water is a well-known phenomenon in large commercial buildings and residential buildings. Rapidly fluctuating temperatures in a shower often result in frustration and confusion. This study tries to identify the temperature fluctuations in the shower head and the cause of temperature fluctuations are generated in water systems. The final goal is to determine some guidelines for technicians to avoid the temperature fluctuations. The building used for the investigation is equipped with a cold water supply and pressure system located in the basement. The hot water production contains a storage vessel located on top of the building and the hot water is distributed by a circulation pipe system. The shower mixing valve is connected to both the cold and hot water systems. Although the fluctuations have a small difference in water temperature and the exposure time is very short the sudden fluctuating temperatures are very inconvenient for the users because they fear for thermal shock and scald burns. In many cases people complain about the temperature fluctuations, but the technician is unfamiliar with the phenomenon and doesn’t know how to solve and prevent this problem.

Keywords

Shower mixing valves, Thermostatic shower mixing valves, Temperature fluctuations

1. Introduction

Motivated by the demand for hygienic water systems there is an increasing trend to design water systems with smaller pipe diameters. This is the result of a new, more realistic method to determine the water demand for hot and cold water. Moreover, water saving showers are widely used in buildings and they also contribute to the trend of smaller pipe diameters.

In large and more complicated buildings, for instance in hotels, hospitals and retirement homes, the water supply system is applied with many faucets. These faucets vary in design flow rates. The cold water used elsewhere in the building causes a pressure drop in the cold water system. The hot water system pressure remains relatively constant resulting in a change of the hot to cold water ratio and thus the temperature of the shower changes and becomes hot. The opposite happens when the usage of hot water is increased – the hot water pressure drops and there is a corresponding change in the mixed water ratio causing a burst of cold water. This sudden change in temperature at the showerhead is referred as thermal shock. One risk of thermal shock is that it may cause the affected user to react suddenly, resulting in a slip-and-fall incident. When persons using the shower fall as a result of a thermal shock, it is common for them to hit or grab the shower controls on their way down possibly turning the controls to hot and causing a scalding injury. In some extreme cases the person is seriously injured by the fall and cannot get out of the flow of hot water.

During the investigations it appeared that the cause for the temperature fluctuations is a complex problem, influenced by many parameters. This paper is a preliminary report. The study will be continued.

2. Complaints about Temperature Fluctuations are Well–known

Complaints about temperature fluctuations are well-known. For many years users of shower mixing valves have complained about wildly fluctuating temperatures. This phenomenon is associated with the application of water saving shower heads. This effect was reported mainly in large collective hot and cold water systems as used in hotels, health care [hospitals] and multi-storey dwellings, especially when the traditional shower head was replaced by a water saving shower head. Based on measurements in 1997 in buildings serviced by the Waterworks Company in Amsterdam it has been determined that if the pressure loss in the shower mixing valve, shower hose and shower head is lower than the pressure loss in the hot and cold water supply there is no remarkable problem. But if the pressure loss caused by the shower mixing valve, shower hose and water saving shower head is higher an undesirable temperature fluctuation of the mixing water occurs. On request of Uneto-VNI in 1999 KIWA made some small scale investigations on three traditional shower heads and three water saving shower heads [1]. One model was tested with a traditional shower head and with a water saving shower head provided with an in-line flow restrictor supplied by the manufacturer. During the test the pressure in the cold water supply changed while the pressure in the hot water supply was almost constant. Figures 1 and 2 show the fluctuations of the mixing water temperature caused by the changes in the pressure of the cold water supply. The shower head without in-line flow restrictor shows a pressure change of 35 to 50 kPa and a temperature fluctuation of approximately 5 ℃ . With an inline flow restrictor in the shower head the temperature fluctuation varies between 10 ℃ to 25 ℃ at a pressure change of 40 to 60 kPa. The measurement results of the other shower heads show similar significantly large differences, both the traditional shower head and the water saving shower head. The fluctuation in temperature of the water saving shower heads is significantly higher than that of the traditional shower heads.

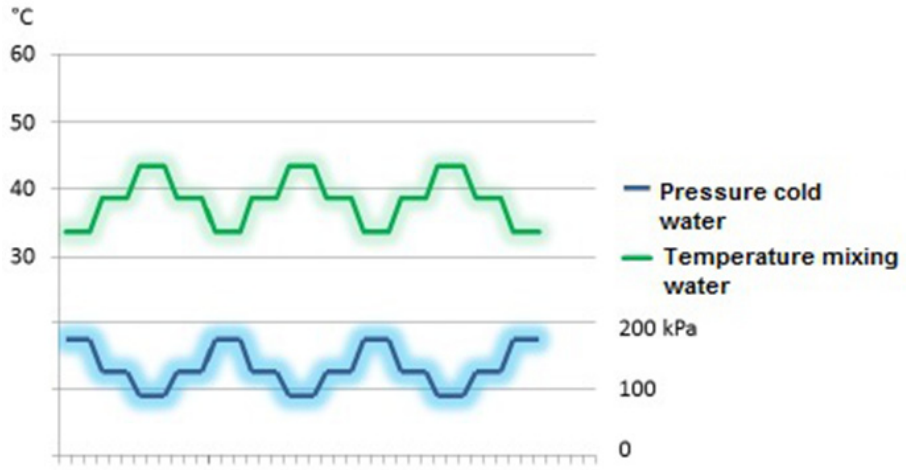


Figure 1. Pressure on the cold water supply (blue) and the temperature of the mixing water (green). Traditional shower head.

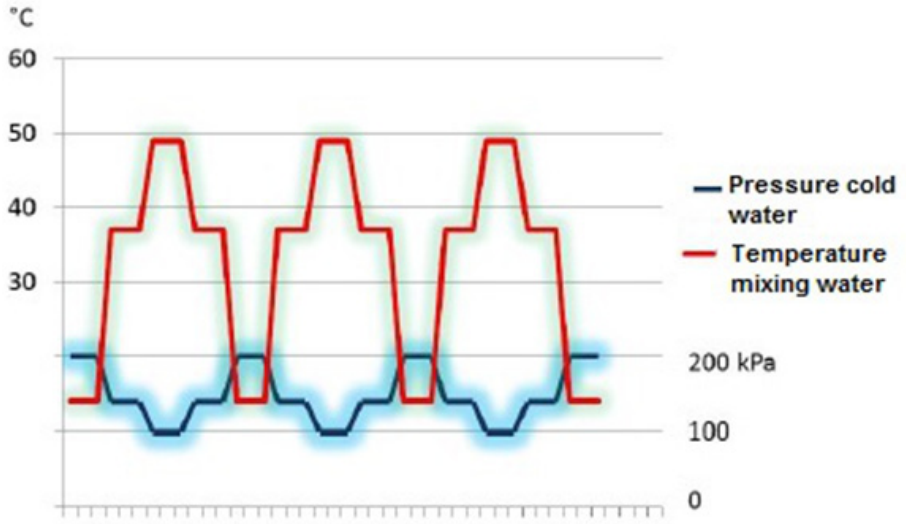


Figure 2. Pressure on the cold water supply (blue) and the temperature of the mixing water (green). Water saving shower head.

Also in Switzerland temperature fluctuation problems have been recognized when water saving shower heads are being applied in combination with a shower mixing valve. Also in Switzerland the question arises what causes the increase of the temperature fluctuation of the mixing water when water saving shower heads are being applied. Students of the University of Luzern [2] did research on this topic. They found that there is a lack of knowledge on the topic of temperature fluctuations in water supply systems. The students focused on water supply systems in dwellings. Measurements in a laboratory test facility confirmed that the application of water saving shower heads leads to significantly higher temperature fluctuations than with conventional shower heads.

At the same pressure drop in the cold water system caused by filling a toilet cistern while the shower is running, the mixing water temperature increases at a maximum of 8 ℃ with a water saving shower head while only 2,5℃ with a traditional shower head. As major contributor they indicated the in-line flow restrictor in the

shower head. In the mixing chamber of the mixing valve both cold and hot water are mixed and determine the mixing water temperature. The pressure imbalance in the water supply leads immediately to significant temperature fluctuations on the outlet of a shower head equipped with an in-line flow restrictor.

Measurements in the test facility show that when the water flow is restricted at the inlet of hot and cold water of the mixing chamber instead of an in-line flow restrictor in the shower head there is a significant improvement in the mixed water temperature.

With a relocation of the in-line flow restrictor from the shower head – at the outlet of the mixing valve – to the inlet of cold and hot water of the mixing valve the influence of the pressure fluctuations in the water system is reduced significantly. But to limit the influence of the pressure fluctuations in the water system the sizing of the water supply pipes has to be adapted.

Undersized water supply pipes –hot and cold – lead to a reduction of the pressure in the pipe system in case of simultaneous discharges. The higher the pressure loss in the cold water supply pipe during the use of the shower head the higher the mixing water temperature of the water in the shower head. To prevent fluctuations of the pressure in the water supply the bore of the pipe should be sized larger to reduce the pressure loss, and the pipes connected to the inlet of the mixing valve should be sized as small as possible without exceeding the maximum flow velocity. So the pressure loss in the latter pipes should be relatively high.

The students of the school in Luzern concluded: “The higher the ratio of the pressure losses in the pipes with hot and cold water connected to the mixing valve to the pressure loss in the combined water supply the lower the temperature fluctuation of the mixing water”.

Figure 3 shows the ratio as mentioned above and the temperature fluctuation of the mixing water.

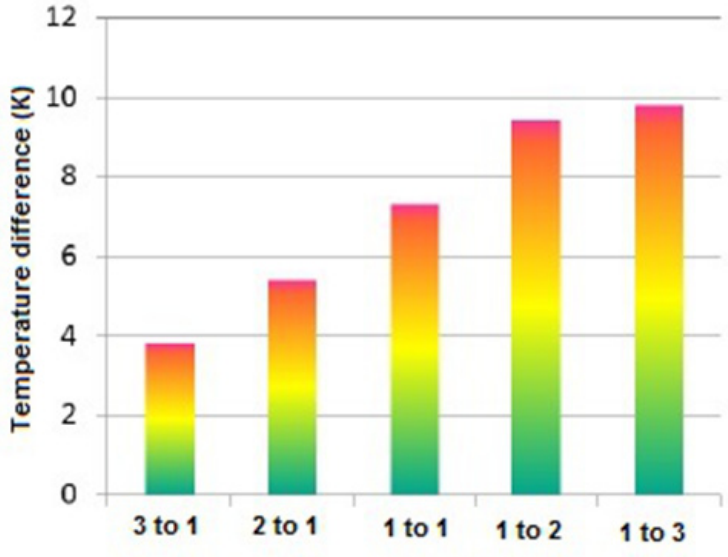


Figure 3 Temperature fluctuations in the shower depends on the ratio of the pressure loss in the inlet pipes connected to the mixing valve and the pressure loss in the combined pipe system.

3. Available Standard EN 1111 for Thermostatic Mixing Valves

Thermostatic mixing valves used in buildings, like the building used for the investigation, have to meet the standard EN 1111 [3]. The EN 1111 emphasizes the comfort: keep the water temperature as steady as possible. The EN 1111 describes a testing method how to test if a thermostatic mixing valve performs well with respect to the risk of scalding. The testing method measures the leakage of hot water in case of a sudden interruption of the cold water. Within 5 s after the interruption of the cold water supply the leakage has to be less than 200 ml and within 30 s less than 300 ml. This requirement applies for thermostatic mixing valves for a shower, bidet, kitchen and a central thermostatic mixing valve for a bathroom.

A revised EN 1111 is under construction. The most recent concept version includes requirements for the mixed water temperature caused by fluctuations of the pressure and temperature on the inlet of cold and hot water. These requirements are mentioned in prEN 1111:2014, annex C, shown by curves. See figure 4 and 5.

These curves are applicable for thermostatic mixing valves for the shower, washbasin and bidet. The deviation of the adjusted mixing water temperature Θmix has to be less than Θx = 3 K within a period of 1 s (t2-t1) for a flow rate of 12 L/min. For lower flow rates (< 9 L/min for a washbasin and bidet and < 12 L/min for a shower) the maximum temperature and minimum temperature drop in the curves will be smaller, for larger flow rates the increase and drops are larger, as long as there is a correct pressure balance between the cold and hot water. Five seconds after the start of the pressure fluctuation (t3-t0) the deviation of the mixing water temperature must be less than 2 K compared to the adjusted water temperature Θo and the temperature difference must be less than 1 K (Θpp <= 1 K).

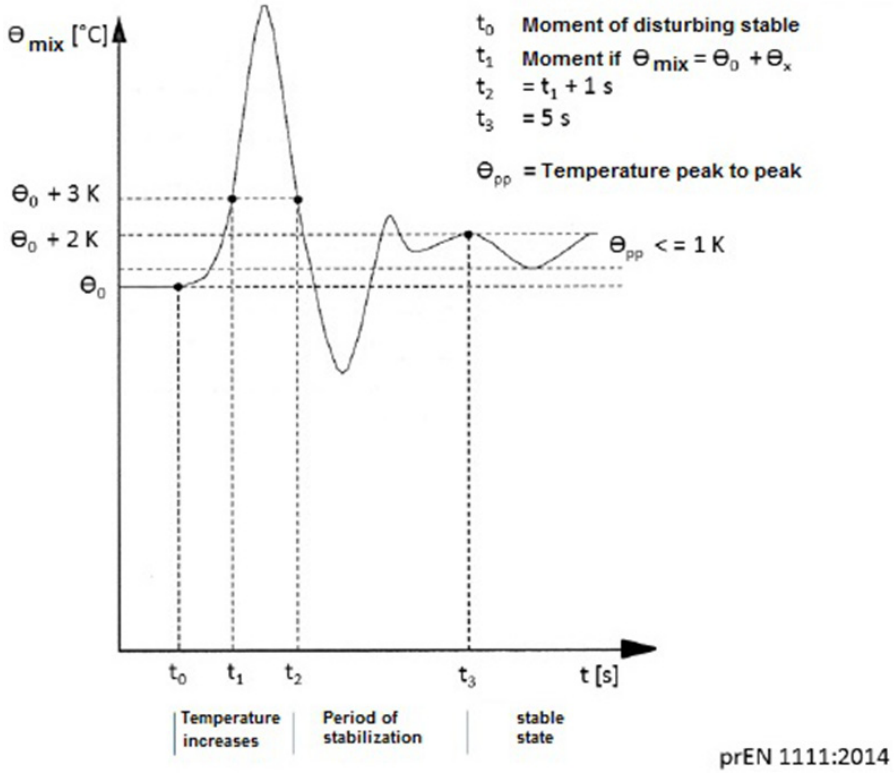


Figure 4 Increasing water temperature caused by pressure fluctuations in the cold or hot water supply. Application of thermostatic mixing valves for households.

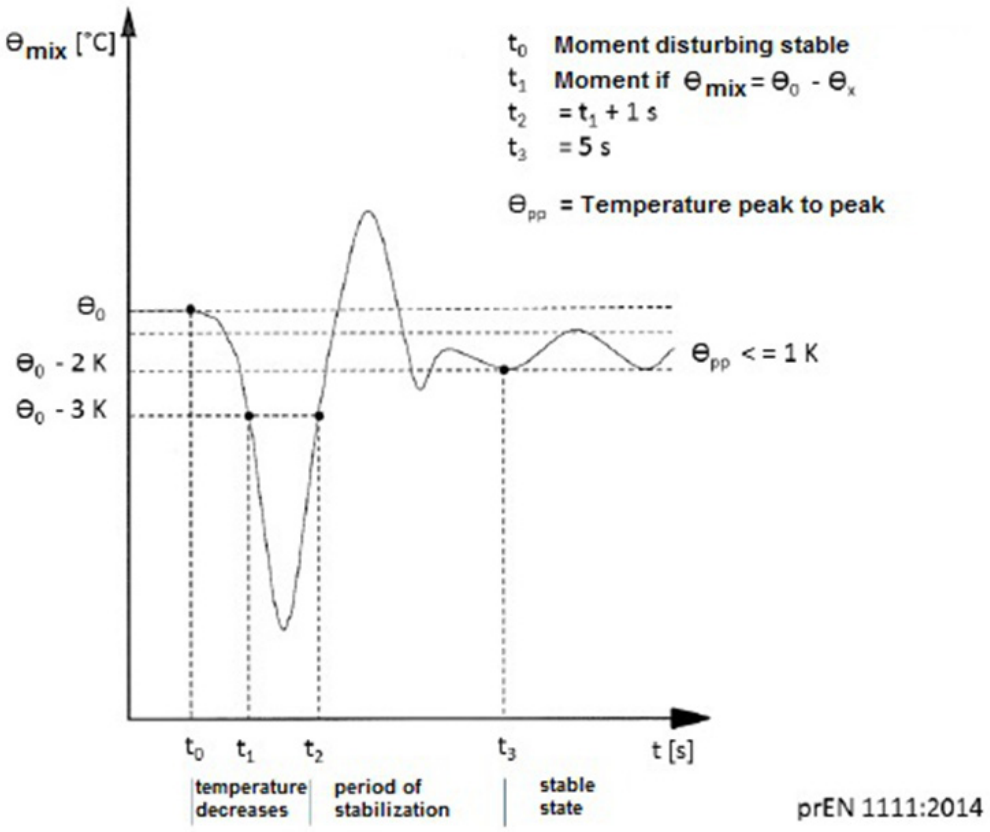


Figure 5 Decreasing water temperature caused by pressure fluctuations in the cold or hot water supply. Application of thermostatic mixing valves for households.

4. The Investigated Water System; Response of a Thermostatic Shower Mixing Valve in Practice

4.1 Hot and cold water system

For the practical investigation we selected a hot and cold water system regarding the next criteria:
(1) A collective hot water system
(2) Complaints about temperature fluctuations on the shower head
(3) Technical drawings available
(4) Prepared to cooperate

The investigation site contains a hot and cold water supply system for some houses linked to a care home. The water supply system consists of pressure booster pumps and the cold water supply pipe is located in an attic on the upper floor above the houses. This cold water supply pipe feeds the hot water tank also located on the in the attic on the upper floor. The hot water production provides two different groups. There is a continuous flow of water from the hot water tank around the distribution circuit and back to the hot water tank. This ensures that the hot water is quickly available at any of the taps, independent of their distance from the hot water tank. Copper pipes are applied for the distribution circuit. See figure 6.

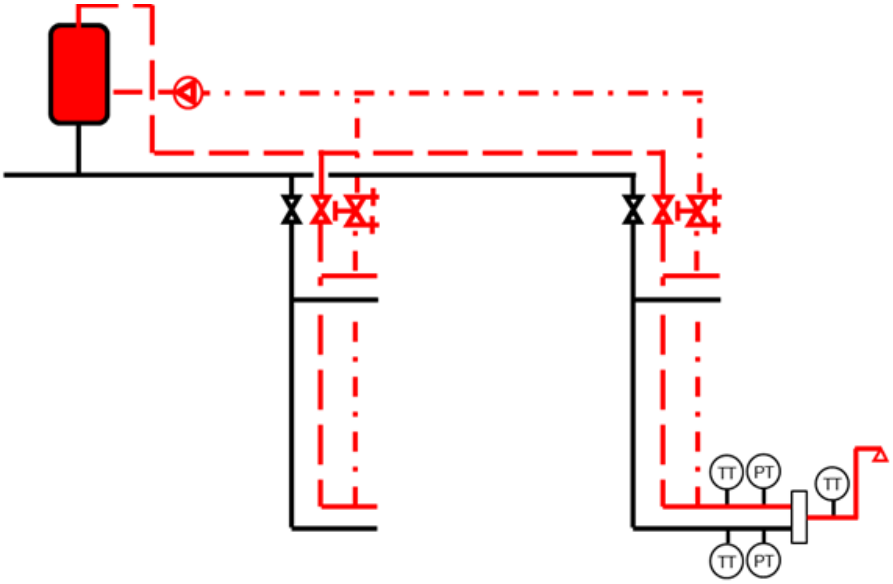


Figure 6 Scheme of the cold and hot water supply.

4.2 Temperature and pressure measurements

In order to investigate the influence of a change in pressure or temperature in the water supply on the mixed water temperature the pressures and temperatures at the inlet of the hot and cold water to the shower mixing valve were measured.

In order to measure the mixing water temperature a temperature transmitter was placed in the mixing water outlet of the shower mixing valve. The sample time was 1s. The pressure transmitters have a measure range between 0,1 and 1 MPa and the temperature transmitters are PT100 transmitters.

The data for the pressures and temperatures were monitored for one day. Figure 7 shows the measured values. It appears that the shower is used from 12,000 to 13,000 s. The curves also show some dips and peaks for the water pressure at the cold and hot inlet of the shower mixing valve. The pressure in the cold water inlet varies between about 300 and 700 kPa and in the hot water inlet between about 500 and 600 kPa. How will the shower mixing valve respond to these fluctuations?

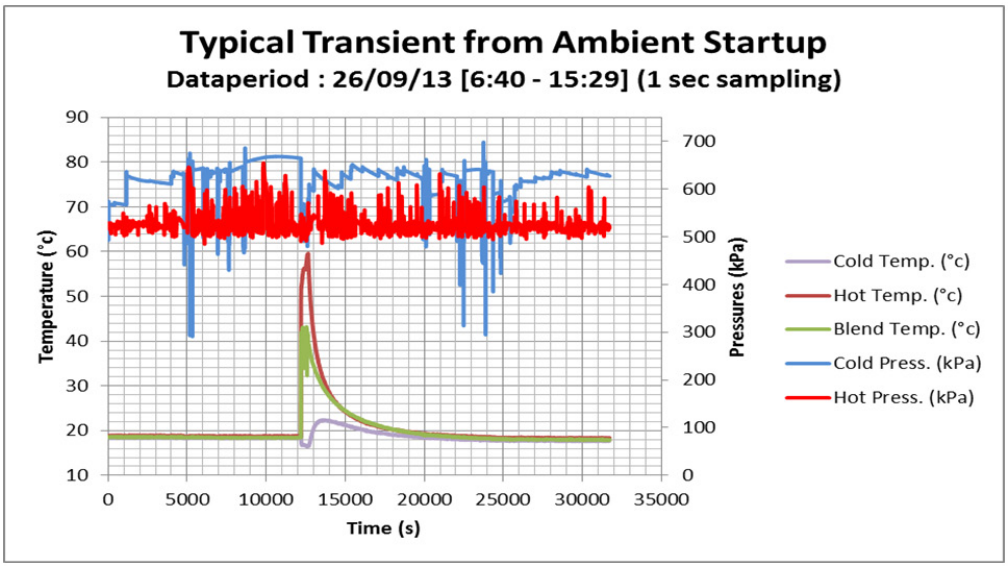


Figure 7 Measurement results at the inlet and outlet of the shower mixing valve. Date 26-09-2013.

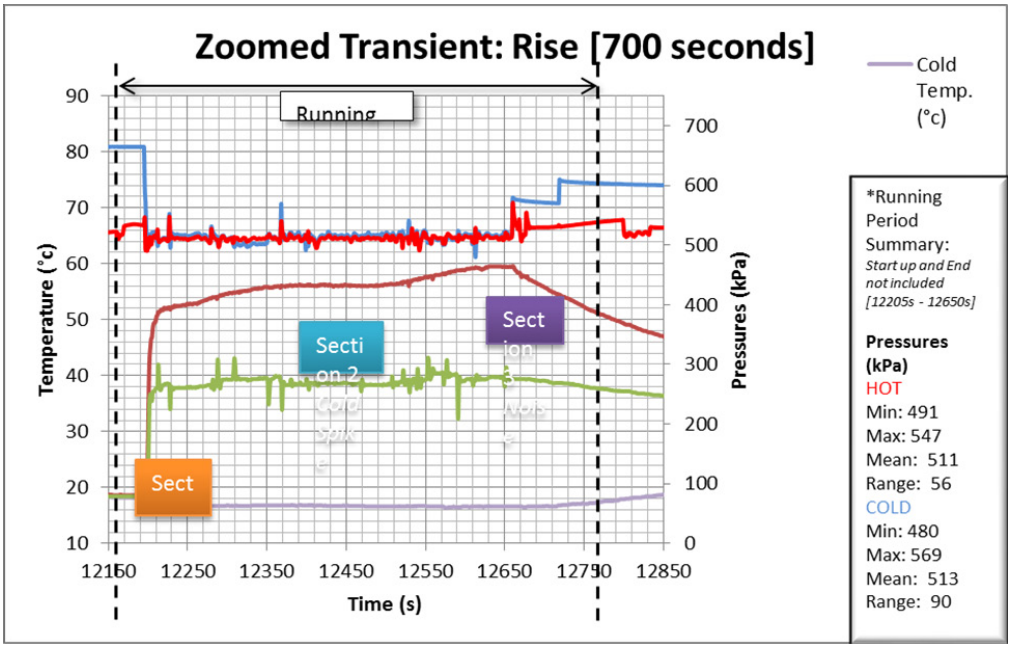


Figure 8 Measurement results from 12,150 to 12,850 s

To determine what's going on in the period the shower is used we zoomed in on the period from 12,150 to 12,850 s (See figure 8). During the use of the shower the cold water temperature is steady at 18 ℃ . The hot water temperature is immediately 52 ℃ and increases slowly to 60℃ . No short term fluctuations are noticed.

At the start the pressure of the cold water is rather high (660 kPa). Just after the start the pressure at the cold water inlet decreases to and stabilizes at about 500 kPa and in the hot water inlet to about 510 kPa. During the shower period there are short terms pressure fluctuations; for the cold water 50 kPa and for the hot water

70 kPa. In addition the green curve for the mixing water temperature shows a dip of about 6 K. To study the response of the thermostatic shower valve on rather small pressure fluctuations (37 and 45 kPa) we zoomed in for the period of 100 s from 12,550 to 12,650 s. See figure 9.

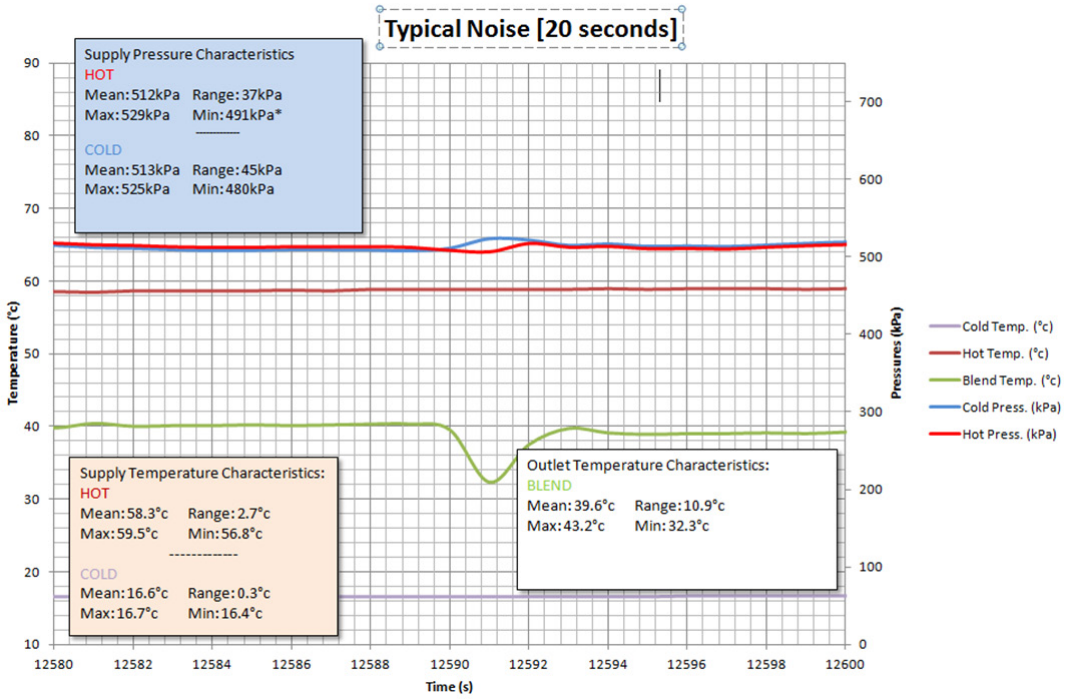


Figure 9 Measurement results between 12,550 and 12,650 s

It strikes that a pressure peak of just 20 kPa in the cold water inlet results in a 8 K dip of the mixing water temperature during a period of 1s. That is rather a large difference in mixing water temperature in relation to the change in pressure at the cold water inlet. For the user such fluctuations in the mixing water temperature are very inconvenient, or worse may be the user is startled [4].

5. Thermostatic Shower Mixing Valve in a Test

5.1 Temperature fluctuation mixing water depends on the water flow

It appears that the response to larger and smaller pressure fluctuations of a thermostatic shower mixing valve (TSV) in practice does not comply with the pressure fluctuations as described and shown in prEN 1111:2014 annex C. Small and slow pressure fluctuations in the hot and cold water supply at a small water flow rate leads to a large temperature fluctuation of the mixing water [See figure 9]. The Dutch certification organization KIWA recognizes this response but states that there are no requirements for this type of fluctuations. Regarding the lack of knowledge with respect to the temperature deviation at TSV’ s in practice a test has been executed with three TSV’ s corresponding with the type as used in the investigation in the house. At a mixed water flow rate twice as large as mentioned in the standard prEN 1111:2014, the cold water pressure on the inlet is reduced from 300 kPa to 200 kPa and then increased back to 300 kPa. After the response period the overshoot of the mixing water temperature is 2 K. See table 1. With a mixed water flow rate of 11.8L/min (100%) the temperature overshoot is 3.6 K and at a mixed water flow rate of 6.1L/min (50%) the temperature overshoot is 4.7 K.
If the pressure at the hot water inlet decreases from 300 to 200 kPa and then increases back to 300 kPa, the

negative mixing water overshoot temperature is 0.6 K at a water flow rate of 23.6L/min (200%), 0.7 K at a 100% water flow rate and 2 K at a 25% water flow rate. It turns out that the water flow has a significant influence on the mixing water temperature after the stabilization period. The smaller the water flow, the higher the influence on the mixing water temperature.

Table 1. Test results with three TSV's in practice

Mixing water flow (L/min)	Pressure cold and hot water 300 kPa	
	After pressure dip cold water from 300 to 200 and back to 300 kPa; Positive temperature overshoot (K)	After pressure dip hot water from 300 to 200 and back to 300 kPa; Negative temperature overshoot (K)
23.6 (200%)	2.0	0.6
11.8 (100%)	3.6	0.7
6.1 (50%)	4.7	2.0

The overshoots in the increased mixing water temperature are larger in case of a pressure drop at the cold water inlet than a pressure drop at the hot water inlet. After a pressure drop at the cold water inlet in combination with a small flow rate, the temperature increase does not meet the requirements as described in prEN 1111:2014, annex C.

5.2 Improvements of the TSV's

Unexpected changes of the water temperature could lead to a thermal shock and scalding. Users could be startled while having a shower on a wet floor surface. In addition to the risk for scalding, reacting abruptly by moving away from the flowing water can cause a serious injury as a result of a slip or fall. Moreover there is a risk for scald burn when people are exposed to hot water. Table 2 shows the relation between the risk of scalding, exposure time and water temperature. The manufacturers of TSV's recognize the risk of scald burn and they work on accurate control systems to improve the security of the use of TSV's.

Table 2. Relation between the risk of scalding, exposure time and water temperature

Exposure time(s)	Temperature(°C)
300	49
120	52
30	54
10	57
5	60
1	68

6. Conclusions

Although a TSV meets the EN 1111 it does not provide sufficient protection against thermal shock caused by small pressure fluctuations at the hot and cold water inlet of the TSV.

The water flow rate has a big influence on the mixing water temperature. The test water flow is 12L/min. Usually the flow rate in a water saving shower head is 6L/min. When theoretically a TSV meets the EN 1111 in practice a TSV works with a smaller water flow. So the response isn't correct.

The overshoot in the mixing water temperature is larger in case of a pressure drop at the cold water inlet than a pressure drop at the hot water inlet. We have no explication for this difference. Perhaps it has to do with the construction of the TSV.

The standard EN 1111 has to address temperature fluctuations caused by small pressure fluctuations at the cold and hot water inlet of the TSV.

To determine if in-line flow restrictors at the cold and hot water inlet provide a more steady mixing water temperature additional measurements are necessary.

7. References

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8. Presentation of authors

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