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CUSTOMER UNIT SUBSTATION OF COLLECTIVE HEAT DISTRIBUTION SYSTEM: BENCHMARK OF HOT WATER COMFORT TEST STANDARD AND METHODOLOGIES

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ABSTRACT

The performance assessment of dwelling heating substations in terms of level of comfort is usually studied regarding temperature overshoots, stationary temperature deviations and settling time among other parameters. In fact, several standards and test methods can be found focusing on a specific target or technology. However, these methods do not always provide clear information about hot water comfort. As a result planners, developers and customers have difficulties to compare a substation product with products using other technologies for the heating of sanitary hot water. The study investigates the compatibility of already existing methods and intends to evaluate their applicability to systems where the sanitary hot water is prepared in an instantaneous way by using a heat exchanger in a district heating substation. In order to achieve that aim, a dynamic simulation model of a test setup (using TRNSYS) has been developed. The test procedures, as well as the simulation results, are described and discussed. This analysis is expected to provide the basis for an integrated performance assessment test of this kind of devices.

KEY WORDS: Dwelling heating substations, Hot water comfort assessment, Testing hot water comfort

SUBESTACIÓN LOCAL DE SISTEMAS COLECTIVOS DE DISTRIBUCIÓN DE CALOR: ANALISIS COMPARATIVOS DE ESTÁNDAR Y METODOLOGIAS DE EVALUACION DEL CONFORT Y FUNCIONAMIENTO

RESUMEN

La evaluación del funcionamiento de las subestaciones locales de calefacción en términos de nivel de confort del servicio suele estudiarse en relación con excesos de temperatura, las desviaciones o fluctuaciones de temperatura y el tiempo de esperado hasta alcanzar la temperatura de confort entre otros parámetros. De hecho, varias normas y métodos de ensayos pueden encontrarse, sin embargo estas se centran en un objetivo o tecnología específica. Consecuentemente, estos métodos no siempre proporcionan información clara acerca del confort de agua caliente suministrada. Como resultado los planificadores, los fabricantes y los clientes tienen dificultades para comparar un producto "subestación" con productos que utilizan otras tecnologías para la preparación y el calentamiento del agua sanitaria. El estudio investiga la compatibilidad de los métodos ya existentes y evalua su aplicabilidad a sistemas en los que el agua caliente sanitaria se prepara en una forma instantánea mediante el uso de intercambiadores de calor. Con el fin de lograr ese objetivo, se ha desarrollado un modelo de simulación dinámica de una configuración de subestaciones locales para sistemas de calefacción (usando TRNSYS). Los procedimientos de ensayo, así como los resultados de la simulación, se describen y discuten. Se espera que este análisis proporcione la base para un metodologías de pruebas y evaluación de rendimiento y el cumplientos de las normas de confort de este tipo de dispositivos.

PALABRAS CLAVES: Subestaciones local de calefacción, Evaluación de sistemas, Confort de agua caliente

INTRODUCTION

The performance assessment of dwelling heating substations in terms of level of comfort has become an important issue for planners and customers related to aspects of the reliability of hot water supply. During the last years several standards and test procedures have been developed for the determination and assessment of hot water comfort aspects for systems for sanitary hot water production. However, some procedures depend on the type of technology used for hot water preparation. Moreover, the existing test procedures are very limited regarding the system configuration and/or boundary conditions. In addition, the different test methods focusing on specific targets or technologies do not always provide information about hot water comfort in a way that enables planners and customers to compare a specific thermal heating interface product with products using other technologies for heating of sanitary hot water.

As defined by ISO, a standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose [1]. Hence, the role of standards is to serve as common sets of rules, conditions or guidelines, serving industry, government, and other stakeholders defining both products and processes, supporting interoperability and best practices dissemination [2]. The present paper aims to provide an appropriate clarification of the terms and methods for the assessment of the hot water comfort. The study investigates the compatibility of existing methods and evaluates their applicability to systems where sanitary hot water is prepared in an instantaneous way by using a heat exchanger in a district heating substation.

EXISTING STANDARDS FOR ASSESSMENT OF PERFORMANCE OF HOT WATER DELIVERIES

A review of existing directives and standards and other documented methods has been carried out not only to characterize the state of the art in international standardization, but also to set a basis for the definition of a suitable test procedure On the European level of CEN-standardization actually there are several examples of such test procedures. Table 1 summarizes these standards.

Table 1 Summary of Standards

Name	Standard Code
Gas-fired water heater, performance assessment	EN 13203-1:2006
Gas-fired water heater, energy use assessment	EN 13203-1:2006
Efficiency of electric storage water-heater	prEN 50440
Electric storage water heater, performance, methods	EN-IEC 60379:2004
Indirect cylinders	EN12897: 2006
Indirect cylinders, energetic assessment	prEN15332: 2006
Sanitary hot water heat pumps	EN 255-3: 1997
Gas-fired storage water heater	EN 89: 1999
Gas-fired instantaneous water heater	EN 26: 1998
Electrical instantaneous water heater, performance	EN 50193: 1997
Thermal solar system, general requirements	EN 12976-1: 2001
Thermal solar system, test methods	EN 12976-2: 2001
Solar heating – Domestic water heating systems	ISO 9459-3

A comprehensive summary of different standards which take into account the performance assessment of hot water deliveries can be found in [3]. These standards, which are stated to a specific technology, have been considered when developing the basis of the EU energy labeling according to the EU Eco design directive. However, they show small variations depending on the applied technologies when considering the hot water comfort assessment. Apart from these standards, other groups of test methodologies or procedures ought to be considered. Below, there is a list of the available methods for the performance assessment of hot water deliveries:

- DFS hot water performance test (German method) [7]
- NL-Number according to DIN 4708-3 [7]

- SPF hot water performance test (Swiss method) [3,6]
- SPF procedure for external domestic hot water modules [6]
- General guideline VDI 6003 [4,7]
- Gas-fired water heater, performance assessment EN 13203-1:2015 [4]
- Heat exchangers- Test procedures for establishing the performance data EN 1148 [5,8]

In the following paragraphs a brief overview of some of the existing methods is given based on [3-8]. First of all, it is worth noting that the methods can be classified in two groups: (1) those which consider a thermal storage unit and (2) those based on instantaneous preparation using heat exchangers. Another classification would be possible when considering whether or not the hot water comfort is independently evaluated from the technology. In this study, the priority has been given to those methods, which evaluate systems without storage tank i.e.: VDI 6003, EN 13203-1:2015, EN 1148 and EU Eco design directive. For readers interested in the features of the other procedures, including those methods only suitable for systems with storage tank, a more comprehensive description of each method can be found in [3-8].

The VDI 6003 is considered as a technology independent guideline for comfort criteria and performance levels for planning, evaluation and implementation of water heating systems. Relevant aspects of the VDI 6003 are developed in the European standard EN 13203 for the assessment of hot water comfort of gas-fired domestic appliances producing hot water. In this guideline a general definition of the term “hot water comfort” is provided: “A high comfort level for hot water is given when the required volume of hot water and mass flow is available at each draw-off point, at any time and at the desired temperature” [7].

This statement highlights two major questions: (1) the ability to cover the load by means of the hot water deliveries system and (2) the temperature stability of the withdrawn water during the draw-off. The former refers to the capability of the systems to provide the required volume of hot water and the required thermal power according to the needs of the user without delay. Notes that, in addition to the temperature conditions, customer comfort satisfaction is influenced by time required for SHW to reach a fixed temperature level after tapping was started, the so called waiting time, recovery time or tap delay. The European standard EN 13203-1:2015 defines the waiting time tm (s) as the time taken to reach, at appliance outlet, a hot water temperature higher than 44°C. These feature are minimum conditions regarding comfort level for hot water delivered.

Method according to EN 13203-1:2015

The standard EN13203-1 targets “Gas fired domestic appliances producing hot water – Part 1: Assessment of performance of hot water deliveries”. It introduces a method for the assessment of the energy use of the hot water preparation unit. The standard sets out in qualitative and quantitative terms the performance in delivery of domestic hot water for a selected variety of uses and gives a system for presenting the information to the user. This standard applies not only to instantaneous and storage appliances, but also water-heaters and combination boilers that have heat input not exceeding 70 kW; and hot water storage capacity (if any) not exceeding 500 l [4]. Hot water comfort is assessed by an “Overall performance factor F”. This factor is determined on the basis of tests that gain information about the following performance indicators:

- Waiting time,
- Variation of the temperature according to the water rate,
- Temperature fluctuation at a constant water rate
- Temperature stabilization time in case of variation of the water rate,
- Minimum nominal water rate,
- Temperature fluctuation between successive deliveries,

Method according to EN 1148

The standard EN1148 targets “Heat exchangers - Water-to-water heat exchangers for district heating- Test procedures for establishing the performance data”. This standard applies to series-produced water-to-water heat exchangers for district heating appliances, and its purpose is to establish uniform methods to test and ascertain product identification, performance characteristics and pressure drop [5,8] . The test method is intended to reflect the different operating cases for the district heating supply system and the building's energy use. The following two kinds of test are defined:

- Static performance tests of the space heating and domestic hot water part of the unit.
- Dynamic performance tests of the domestic hot water function, with special function requirements for domestic hot water comfort for substation units for detached houses.

These two types of tests apply to several combinations of domestic hot water flow rates and time intervals. Based on this standard, the Swedish District Heating Association has developed the technical regulations F: 103-7e [8], a detailed implementation of the procedure. In the national regulation the following profiles: 0 l/s 100s - 0,1 l/s 300s - 0,2 l/s 300s - 0,1 l/s 300s - 0 l/s 300s is proposed. The requirement is that the temperature of the domestic hot water shall stabilize within 100 s from the heat exchanger to its point of delivery. In this context, 'stabilization' permits a variation in the temperature of ±1 °C from the expected mean value within the specified temperature range, without domestic hot water circulation.

COMPARATIVE ANALYSIS

First of all, it is necessary to carry out the benchmarking to specify the degree of similarity between test methods to be compared. Secondly, it is imperative to define the variables to evaluate the test methods. Based on current standards and applied test methods, as was aforementioned, this paper identifies different categories of procedures according to the domain of application. On the one hand, the test procedures can be grouped according to the characteristics of the target device in function of the way in which DHW is prepared, for instance, based on instantaneous preparation using heat exchangers or devices with hot water storage tank. On the other hand, the test methods can be classified considering whether or not the hot water comfort is evaluated independently of the technology. Accordingly, regarding the degree of similarity, the present study focuses on collective heating substation with direct heating without storage of DHW or without including a specific heat source technology. Concerning the variables to carry out the analysis, the test methods are examined according to their ease of use, applicability to different device configurations, ability to discern effects of mechanical and electronic control device and ability to discriminate between devices with various levels of warm-up functionalities.

Considering the above mentioned elements, this paper developers a methodology, which combines aspects of several procedures. This methodology intends to address the interest in guidelines of different stakeholders when comparing the performance of systems under different boundary conditions. Accordingly, a specific demand profile which allows the estimation of the "Overall performance factor F" is proposed in accordance with the EN 13203-1:2015 definitions. In addition, the profile includes the uniform methods to test and ascertain product identification, performance characteristics and pressure drop as prescribed in EN1148. As an example, Figure 1 displays the sequence of the first day profile. It should be noted that from midnight till 8:00 hours in the morning the flow rate is 0, similarly from 21:00 hours till 24:00 the flow rate is zero, as well.

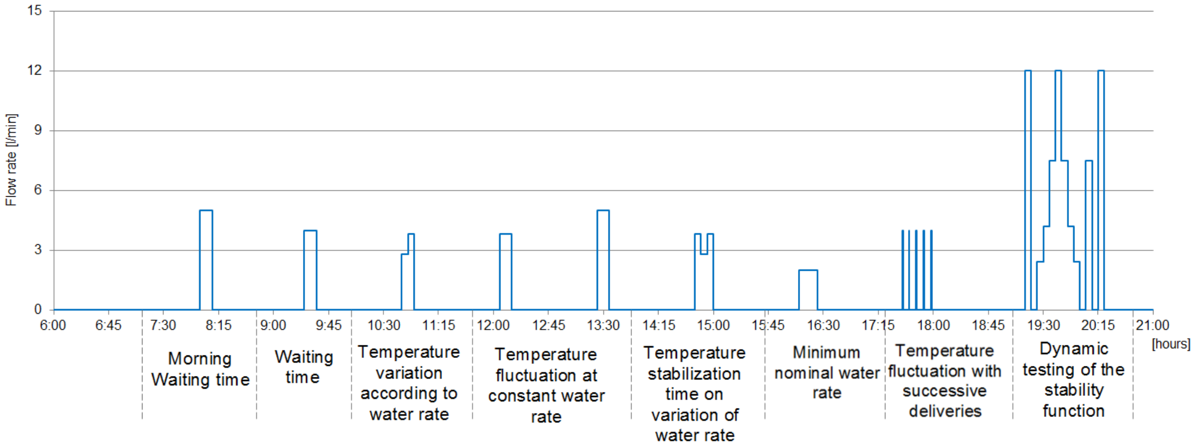

Figure 1 Load profile of 24 hours, (110 l/day) according to [4, 8].

MODELLING AND SIMULATION

A dynamic simulation setup using TRNSYS has been developed in order to investigate the compatibility and integration of existing methods. The simulation model intends to evaluate the applicability of existing procedures to systems where the domestic hot water is prepared in an instantaneous way. Major components of a dwelling heating substation, as well as the basic functionality of control concepts are implemented:

- Heat exchangers
- Pipes
- PI controls for valves and pumps

The dynamic simulation model was built in accordance with the methodology explained in [10; 11 and 12]. In the following lines, the main components of the model are described based on the mathematical reference user guide of TRNsys [9]. The heat exchangers (TRNSYS Type 5) are used in the domestic hot water circuits. Type 5 relies on an effectiveness minimum capacitance approach to modeling a heat exchanger. Under this assumption, it is necessary to provide the UA and inlet conditions of the heat exchanger. The model then determines whether the cold (load) or the hot (source) side is the minimum capacitance side and calculates an effectiveness based upon the specified flow configuration and on UA. The capacitance is computed according to equations Eq. (1) and Eq. (2).

$$C_c = \dot{m}_c C_{pc} \tag{1}$$

$$C_h = \dot{m}_h C_{ph} \tag{2}$$

Where C_c and C_h are the capacity rate of fluid on the cold side and hot side respectively. C_{pc} and C_{ph} are the specific heat of cold and hot side fluid and mc and mh are the flow rate of fluid on the cold side and hot side respectively.

Considering the heat exchanger configuration, the heat exchanger effectiveness (ε) at each time step is calculated with the well-known expression:

$$\varepsilon = \frac{1-\exp\left(-\frac{UA}{C_{\min}}\left(1-\frac{C_{\min}}{C_{\max}}\right)\right)}{1-\left(\frac{C_{\min}}{C_{\max}}\right)\exp\left(-\frac{UA}{C_{\min}}\left(1-\frac{C_{\min}}{C_{\max}}\right)\right)} \tag{3}$$

Once the effectiveness is estimated, the outlet temperature and actual heat transfer are determined.

$$T_{ho} = T_{hi} - \varepsilon\left(\frac{C_{\min}}{C_h}\right)(T_{hi} - T_{ci}) \tag{4}$$

The actual heat transfer Q_T is thereby depending upon the user specified heat exchanger characteristics and inlet conditions

$$Q_T = \varepsilon C_{\min}(T_{hi} - T_{ci}) \tag{5}$$

The pipe model (Type 709) models the thermal behavior of the pipe by splitting the pipe in a number of fluid segments at different temperatures. The calculation of the temperature in each segment takes into account the heat losses to the environment by solving a differential equation at every time step.

The substation models implemented in TRNSYS were tested with actual measured values. In TRNSYS simulation, models are develop in a modular way by combining the different components of the systems. The model contains the control scheme of the different components of the substation. Two PI control (Valve DHW and Pump) are used to guarantee the hysteresis behavior of the control strategy. To handle the appropriate temperature and flow rate for domestic hot water and space heating, both mixing and diverter hydraulic components have been used.

As observed in [14], in thermal system simulation software each component itself may be simple to model and understand. However, the interconnection of components, and control functions, makes it far more challenging to see the connections between output, input, and component parameters. A comparison of the simulation results and the calibration of the model with information available from the manufacturer is presented in Figure 2. The graph clearly shows the ability of the model to describe adequately the actual performance of the substation. Both, heating demand and domestic hot water behavior, render similar results. Figure 3 shows a schematic representation of the substation.

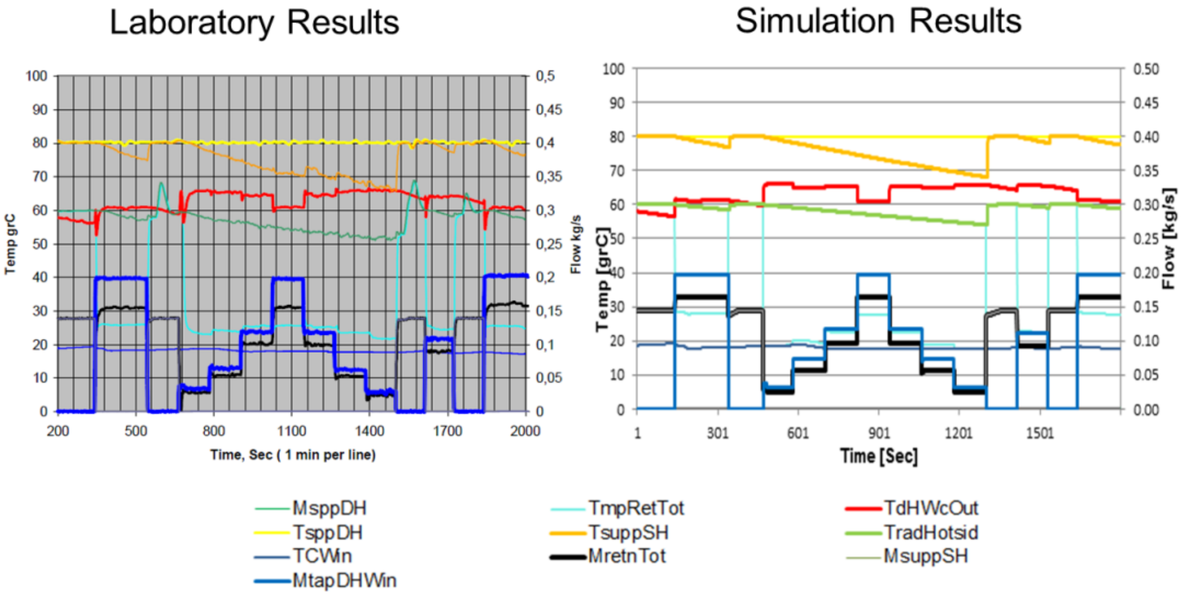

Figure 2 Calibration of the TRNSYS model of the DSH substation

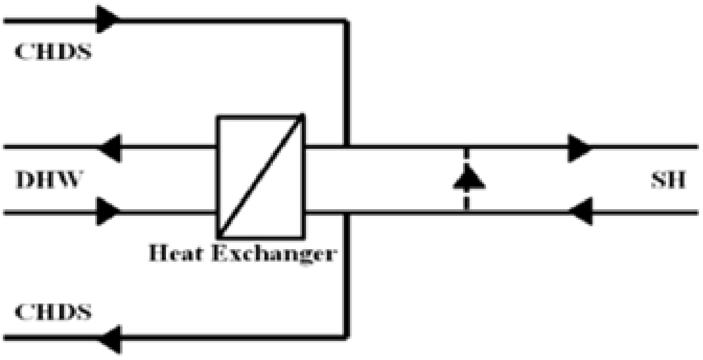

Figure 3 Schematic representation of the substation (CHDS = Collective Heat Distribution System; DHW = Domestic Hot Water; SH = Space Heating).

RESULTS AND DISCUSSION

In this study, a direct substation has been selected to evaluate the suitability of the proposed test methodology. In a directly connected substation, the heat is transferred to the house space heating system from the primary water flow. While the direct substation is equipped with a heat exchanger to transfer heat from the network to the tap water, the individual SH systems are supplied with hot water from the collective network. The return pipe of the space heating has a bypass which allows the regulation of the flow rate in function of the heat demand and required supply temperature. Figure 4 shows more detail of the substation configuration.

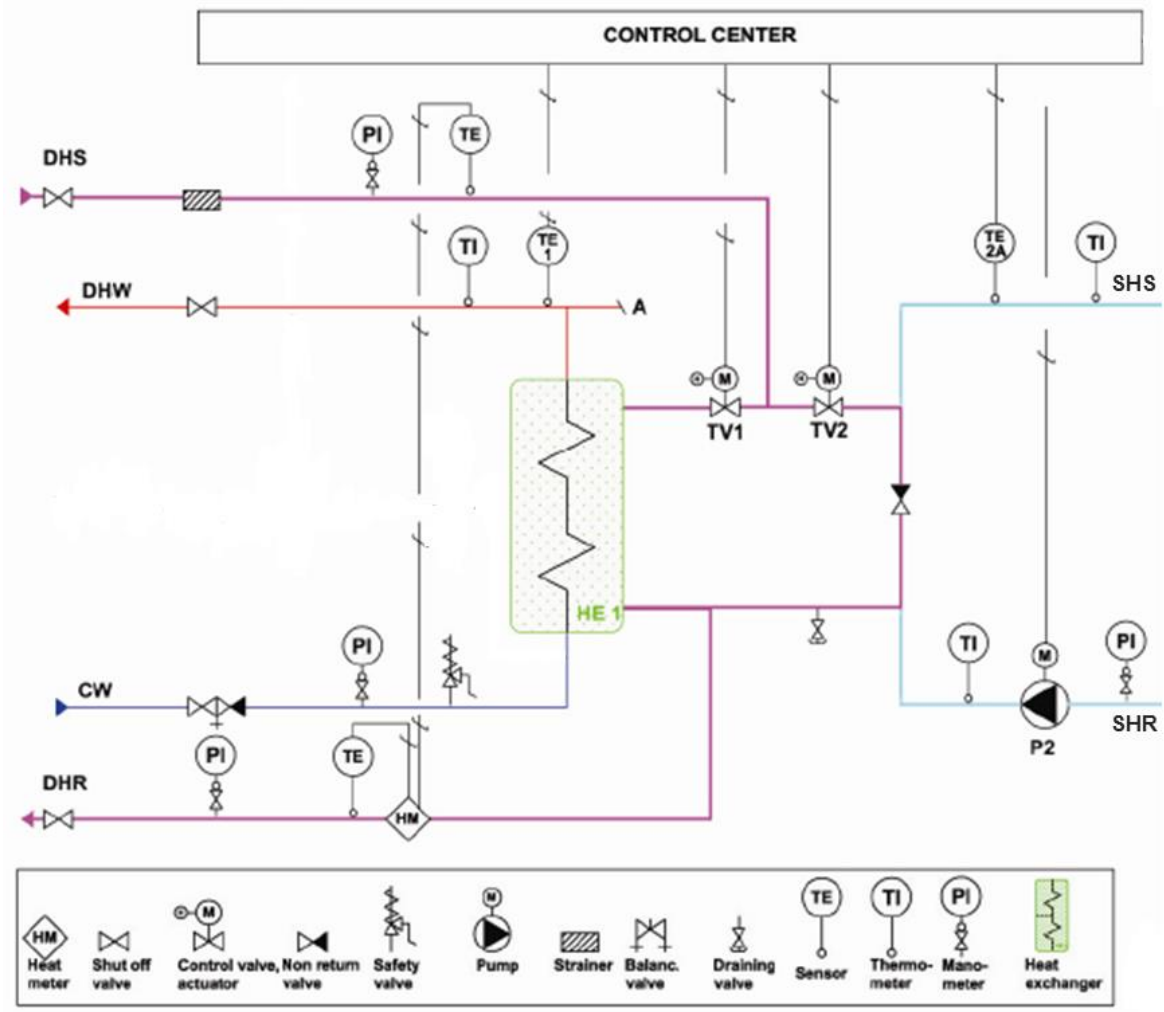

Figure 4 Substation configuration (DHS=District Heating Supply; DHR= District Heating Return; CW= Cold Water; DHW= Domestic Hot Water; SHR= Space Heating Return; SHS Space Heating Supply) [15]

As was aforementioned, the domestic hot water comfort can be quantified using several performance indicators. Many of them are related to temperature fluctuations and the time required for DHW to reach a fixed temperature level after tapping was started, that is the so called waiting time. The sequence of the proposed profile allows to obtain parameters for the determination of different hot water comfort performance indicators. The simulation was carried out assuming a heat source which supply heat at temperature of 65°C to the substation. In the secondary side it is assumed that the design temperatures for the substation are domestic hot water supply of 60°C and domestic hot water return of 25°C for DHW production, as well as, 60°C for space heating supply and 40°C for space heating return. The cold water entering to the substation have a temperature of 10°C. The simulation was carried out with a time-step of 3 s.

Waiting time

The waiting time has been considered according to the EN 13203-1 [4]. It is defined as the time taken to reach, at the appliance outlet, 90 % of the domestic hot water temperature rise from 10°C to 55°C without subsequently falling below 34°C. This indicator represents an important parameter regarding end user satisfaction. Figure 5 displays an evaluation of this indicator, based on the simulated response to the test sequence.

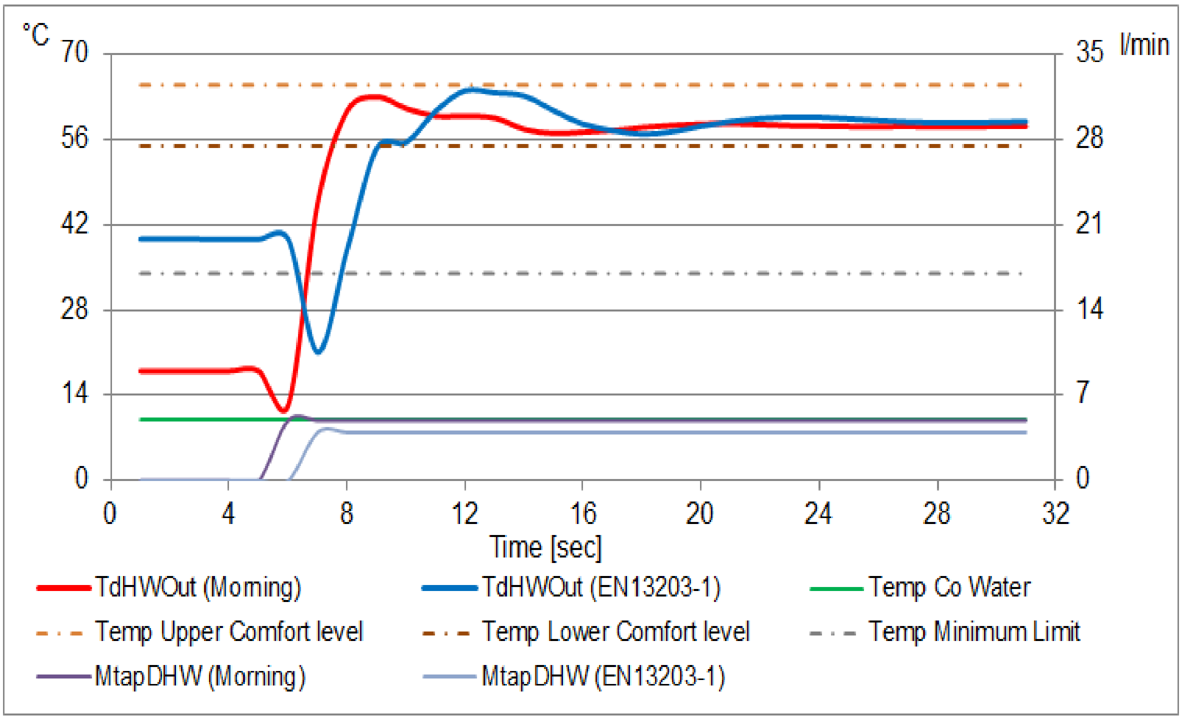

Figure 5 Simulation of the test procedure: results of the morning waiting time and waiting time according to standard EN 13203-1

The graph above renders a different reaction of the system depending of the initial conditions and the flow rate of the two events. For instance, when the initial temperature is 20 °C and the flow rate is 5 l/min in the morning tap, there is a waiting time of 4 seconds until the delivered water reaches a temperature above 55°C. In contrast, in the test based on EN 13203-1[4] conditions, although the initial temperature is 40°C since the flow rate is 4 l/min, the waiting time increases up to 9 seconds. In addition, when the temperature reaches around 65°C it needs more time to return to a steady condition of around 55°C. Other factors that can influence this parameter can be the adaptation of the controller and the recirculation control strategies among others.

Temperature stabilization time in case of variation of the water rate

Temperature fluctuation is an important parameter when assessing the comfort performance of a hot water delivery system, as well. In this case, the test is carried out in three stages. Firstly, a domestic hot water rate is delivered corresponding to 95 % of the delivery reference flow rate (Annex A, table 1). It is checked that the temperature fluctuation is not greater than ΔT = 5°C during the following two minutes after the delay stated by the technical instructions.

In the second stage, the procedure is carried out with the 70 % of the delivery reference flow rate. Finally, in the 3rd stage, the value of the hot water rate of the first stage is re-established. Figure 6 shows the simulation results obtained under these test conditions.

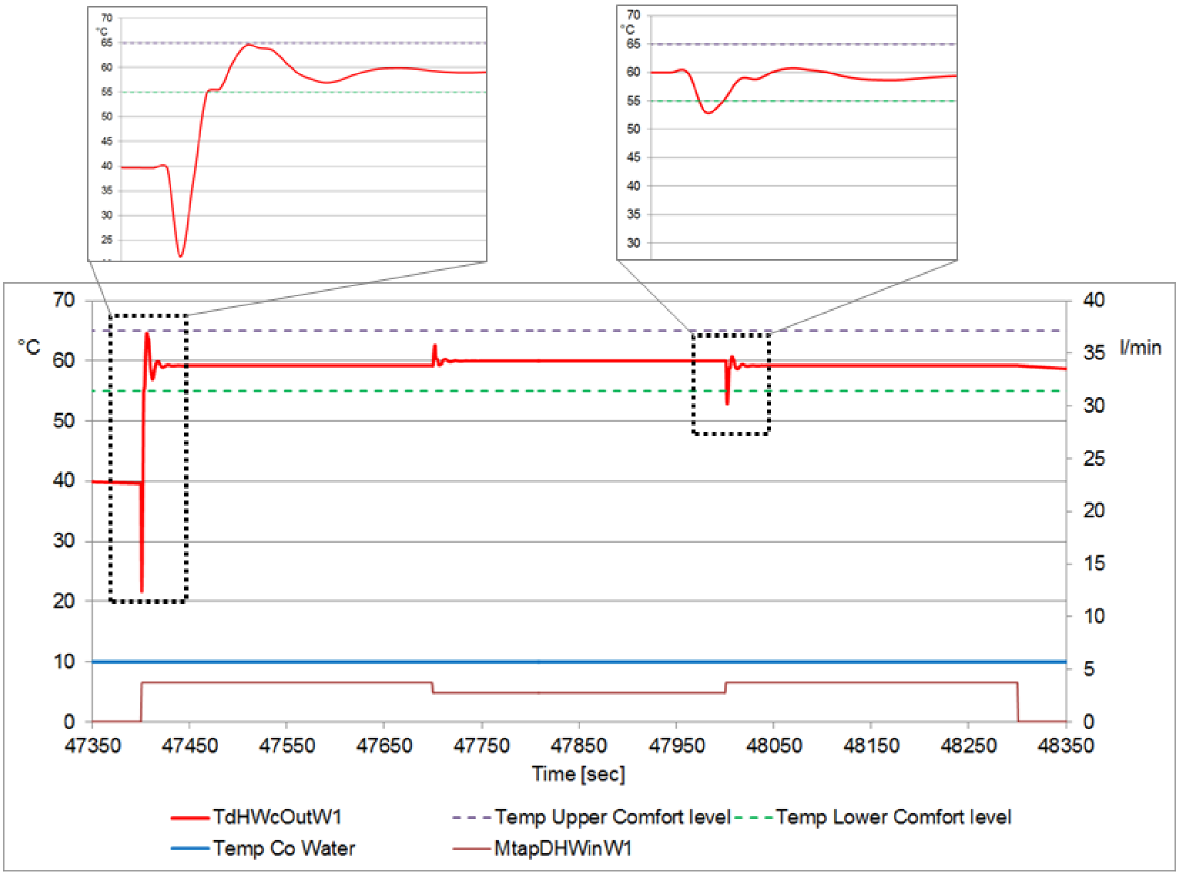

Figure 6 Temperature stabilization time in case of variation of the water rate analysis

Results denote that despite the test was carried out as part of an integrated daily profile, it is able to reflect the impact of the water flow rate variation on the stabilization time of delivered hot water temperature. It should be noted in this specific case that in the first draw off, the stabilization time reaches values of 13s, whereas a similar flow rate in the 3rd stage reaches the stabilization at 6 seconds.

Dynamic testing of the stability function

The dynamic performance tests of the domestic hot water function prescribed in the EN 1148 [5] have also been considered. The proposed procedure is very good at identifying deficiencies in the control system of the hot water preparation heating device.

As have been reported by Ruesch and Frank [13], the specific heat exchanger control (thermostatic, proportional or a combination of both) has a significant influence on the temperature stability of the hot water delivered.

Results render different reactions of the system depending on the draw condition. First of all, the temperature of tap water delivered at small flow rates presents higher values, while this temperature decreases with an increasing flow rate. At small flow rates (e.g. 2 l/min) tap water temperature oscillates significantly. Overshoots as well as undershoots occur at each draw off. These behaviors can be highly sensitive to the controller characteristic of the device. As observed by Thorsen and Boysen [14], on the one hand, the hysteresis of a proportional controller is influencing the fluctuation of water temperature, especially at low tap flows. On the other hand, if the flow part of the thermostatic valve is small, oscillations will occur. However, only the smaller part of the flow will oscillate, which results in insignificant tap temperature peak values [14].

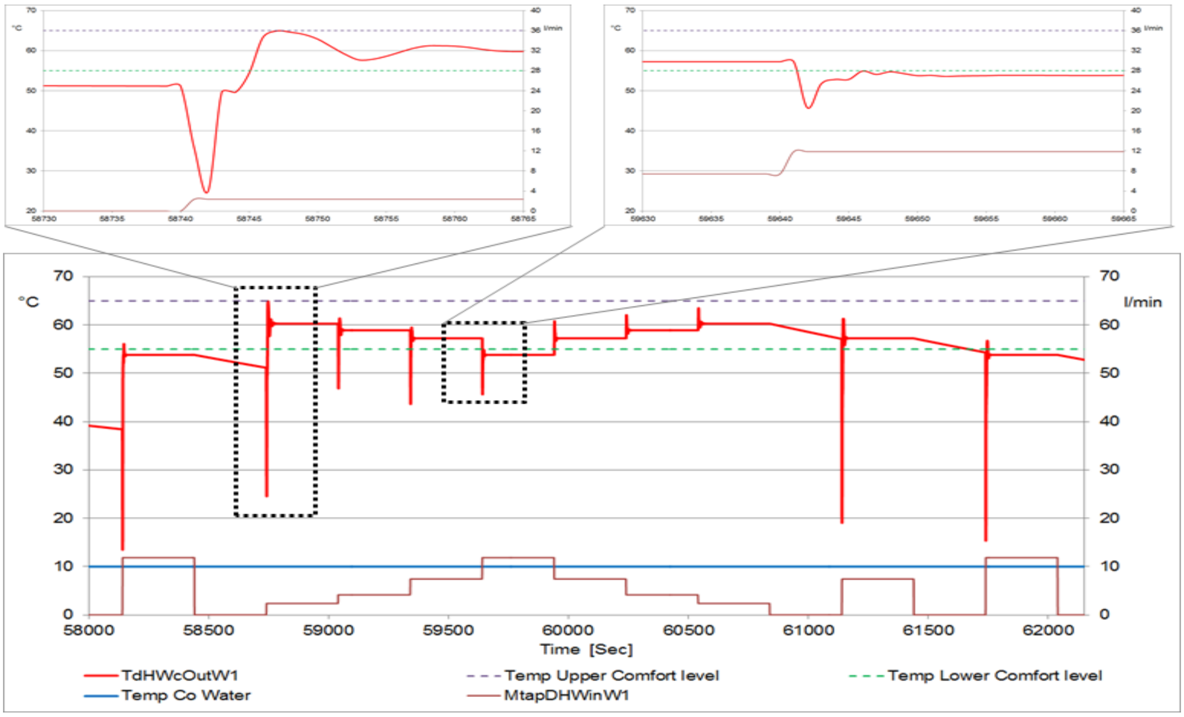

Figure 7 Dynamic testing of the stability function

CONCLUSION

The study focuses on demonstrate the applicability of combined test procedures for performance assessment of dwelling heating substations in terms of level of hot water comfort. To that aim the proposal has been investigated by means of the simulation model of a particular case of dwelling heating substation.

Different existing standards for assessment of performance of hot water deliveries have been examined. A comparison of the different methods was carried out and as a result of this comparison, an integrated and combined test procedure for the evaluation of hot water comfort of dwelling heating substation has been proposed

A dynamic simulation set up of a dwelling heating substation using TRNSYS has been developed. The compatibility and integration of already existing methods has been studied and the applicability of an integrated procedure for the comfort assessment of hot water delivery devices in a direct connected substation with instantaneous preparation of sanitary hot water was demonstrated. The analysis of different sections of the proposed daily profile provides results for the several indicators previously defined. In addition, heat losses in the device can be estimated by measuring the temperature cool down between specific test conditions.

Carrying out the performance assessment of hot water comfort delivery of a dwelling heating substation in an integrated way provides several advantages. First of all, the interest and expectation of different stakeholders will be fulfilled to have a method allowing to compare the performance of systems under different boundary conditions. It is well-known that manufacturers are in need of regulations to provide to the customers with accurate and identical technical data of their components, which should be derived from testing methods established in the standards. While designers need methods to enable a comparison of different heating systems or system configurations in the design process. Further, consumers need a clear indication of the comfort, environmental impact and energy costs as a guideline for their purchase decision, e.g. by transparent labelling. Finally, consultants and policy makers need uniform values to set targets in regulations and directives on the background of climate protection policies. Enabling a unified procedure will provide a reliable reference system.

Moreover the integration and combination of test procedure by using one set up will provide some advantages for the statistical analysis of the recorded data. All the indicators can be estimated at different conditions increasing the freedom degrees of the experiment (test), thus reducing the variance of experimental error.

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