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Consumption Measurement and Failure Detection in Hot Water Recirculation Systems

J. Šípal
Department of Machines and Mechanics, University of Jan Evangelista Purkyně in Ústí nad Labem, Ústí nad Labem, Czech Republic, phone: +420 475 285 515, e-mail: sipal@fvtm.ujep.cz

Introduction

Heat energy and hot water are considered as basic comfort services in modern housing. Both must be provided to consumers in sufficient quantities at all times. [1, 2] In modern urban areas, heat energy and hot water are supplied from district heat exchanger stations. Each district heat exchanger station typically covers the consumtion of one or more blocks. Heat energy and hot water are typically supplied using a four-pipe system as depicted in Fig. 1.

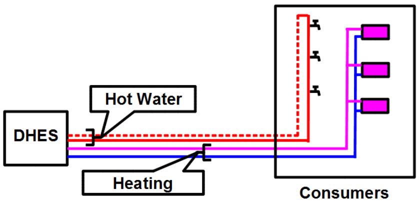

Fig. 1. Four-pipe supply system for hot water and heat energy

One of the main tasks of the supplier is the measurement of the energy consumed. The measurement must be accurate and fair. In the case of heat energy, the mesurement is relatively simple, because the heat energy is in a closed circuit and the losses of the heat carrier are minimal. Thus, the district heat exchanger station only supplies energy.

The measurement of hot water is significantly more challenging, because the supply system is an open circuit. As a result, the district heat exchanger station supplies both, energy and heat carrier. The supplied heat carrier covers the hot water consumption in the block. The supplied energy corresponds to the losses associated with the recirculation of heat carrier in the circuit. The recirculation of the heat carrier is a necessary task due to comfort requirements but it also is quite costly. Thus, the precise measurement of the energy used for hot water circulation in a particular building is necessary so that the associated costs can be billed in a precise and fair manner. Such measurement is often referred to as measurement at the building entry.

Currently, the measurement of hot water at the building entry is standardised by the EU Directive on Energy Performance of Buildings (DEPB) (2002/91/EC), which is then implemented in local legislative and standards, e.g. Czech Standard MPM 22-07 "Methodical Directions for Metrology – metrological expertise of methods for for measurements of hot water", which defines two allowed methods for the mesurement of hot water at the building entry in a four-pipe system according to Fig. 1.

This paper reviews the two approved methods. Based on experience with real measurement systems, this paper discusses the advantages and disadvantages of both approaches. Also, the paper points out that the more popular method (popular method in the Czech Republic) incorporates some health and safety risks not considered at the time of standardisation.

Based on real life measurements, the paper also explores possible enhancement of both methods so that they can be used as an indicator of maintenance requirements in the system.

Challenges in hot water measurements

The main objective of the measurements is to determine the exact and fair price for water. The price for water can be split into two basic components – the cost of the cold water and the cost of the energy used to heat the water. As mentioned in the introduction, the energy component can further be split into two components. Firstly, it is the energy required to heat the cold water to the required temperature. The second component covers the energy losses introduced by the circulation of the cold water. The task of a supplier is to split the second component among consumers in "a fair split". This is quite challenging if the "fair split" has to consider that the circulation losses vary with building. The standard approach to solve this issue is introduced in this section.

The total energy consumed in time period T can be calculated using following formula [3]

$$W = \int_{t}^{t+T} [\rho_{cold}(\tau) c \cdot (\theta_{hot}(\tau) - \theta_{cold}(\tau)) + \rho_{ret}(\tau) c \cdot (\theta_{hot}(\tau) - \theta_{ret}(\tau))] d\tau , \quad (1)$$

where W is the total consumed energy over time period T; ρ_{cold} is the mass flow of cold water entering the system; ρ_{ret} is the mass flow of water returned from the object; c is the specific heat capacity of water; θ_i is the temperature of *hot* water, *cold* water and water *returned* from the object

In a standard measurement setup in a system from Fig. 1, the quantities from (1) are acquired at three levels.

- The first level is the measurement in the district heat exchange station. At this level, the mass flow of cold water entering the system is measured and the total energy consumed over the period T.
- The second level is measurement at the building entry. Its intention is to determine the energy the losses due to hot water circulation in a particular object.
- The third level is conducted at the individual customer and the objective of this measurement is to determine the actual consumption of each consumer.

Measurements at the first and the third level are the standard measurements that are well described in literature, e.g. in [2, 3]. The difference between the results obtained at these two levels gives the total circulation losses of all the consumers of the district heat exchanger station. The split among individual building is calculated using the data acquired from the measurement at the building entry.

The measurement at the entry to the building is, however, quite challenging. At a glance, one could think that it would be sufficient to measure the mass flow entering the building and the mass flow returned from the building. With the knowledge of the temperature of the hot water entering the building and the temperature of the water returned from the circulation, the energy consumption of the building could be calculated. When the consumption of all consumers is known (level three in the system), the problem is simplified to a subtraction.

Even though, the idea above is true, the actual implementation is a difficult engineering challenge. Quite simply, standard mass flow meters have, according to standards, an uncertainty of 3% [4, 5]. The ultimate objective of the measurement is to determine the difference measured by the input and output flow meter. The ratio between the "consumption mass flow" and the "recirculation mass flow" lies in typically the interval from 1:4 to 1:6 (these values are based on real measurements that will be presented in the last section of this paper). Assuming the independent nature of uncertainties of the two flowmeters and the low difference between the values measured by the two flowmeters (approx. 20%) the uncertainty of such measurement yields 20% ($\frac{1}{0.2} \times \sqrt{0.03^2 + 0.03^2}$).

Such, uncertainty of the measurement is not acceptable for a precise and fair measurement. Therefore, methods to solve this issue have been developed. Currently on the Czech market, there are only two methods accepted as compliant with the legislation and standards. These methods will be introduced in the following section and their advantages and disadvantages will be discussed.

Measurement at the building entry

As mentioned above, there are two methods that are accepted as compliant with the current Czech legislations which is based on a wider European Directive – DEPB. The first method is based on circuit separation whereas the second method is based on the use of precise paired flowmeters.

The circuit separation method. The block diagram of the method based on the circuit separation is presented in Fig. 2. The circuit is split in two circuits by a heat exchanger. The heat exchanger is used to cover the energy losses due to water circulation. This energy is then measured with the standard methods used in water-water heat exchangers [3]. However, the two circuits cannot be fully separated as the consumed hot water must be refilled to the system. The refill is performed by the additional branch. The volume of consumed water in this branch can be measured by a standard flowmeter.

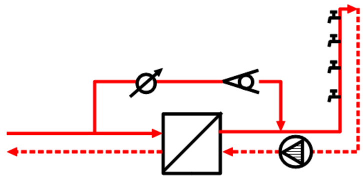

Fig. 2. Measurement based on circuit separation

The main advantage of this method is the fact that the consumption of hot water and the energy loss due to circulation can directly be measured with standard measurement equipment.

On the other hand, there are two main disadvantages. Firstly, additional pump must be employed in the secondary circuit to compensate the separation by the heat exchanger. This represents additional cost that will be billed to the consumers. Another cost is implied by the efficiency of the heat exchanger. Secondly, there is and issue of health and safety. Due to the separation of the secondary circuit by the heat exchanger, there exists a circuit of hot drinking water that cannot be treated by thermal eradication to prevent the spread of legionella pneumophila. To the author´s best knowledge, this issue has been overseen during the approval of this method. Therefore, the risk imposed by the potential spread of legionella pneumophila needs to be assessed.

Method of paired flowmeters. Block diagram presenting the implementation of this method is presented in Fig. 3. The main idea of this measurement method is the use of two precise flowmeters and the calculation of the building energy consumption as the difference determined by both flowmeters. Compared to the case presented in preceding section, the emphasis is given on the precision of the individual flowmeters. The uncertainty for each device is reduced to 0.2%. As a result, the total uncertainty of the difference is kept below 3% which is acceptable value for.

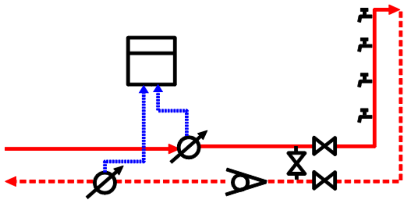

Fig. 3. Method of paired flowmeters

The reduced uncertainty of measurement is a difficult engineering challenge and has been made possible due to fall of the prices of microcontrollers. Commercial products typically employ means of software control. For instance, the error of each flowmeter is precisely determined already in the production and a unique compensation is built in the software. Additionally, precise thermometers are used to determine the temperatures of water flowing through both flowmeters. This information is used to compensate the density dependency on temperature. Legislation also requires that the match between the flowmeters must be automatically tested at least once a day. This is conducted with the help of the additional valve that can bypass the building. Commercial products can control all three valves in the system electronically and conduct such testing typically every 15 minut. The precision of the measurement can further be increased when modern algorithms estimating the reliability of the emasurement device are included, e.g. [4, 5].

The advantages of this method compared to the first one are: more simple installation of the measurement system, no additional associated costs due to pump or heat exchanger efficiency, and mainly the fact that there are no separated circuits. Hence, the district heat exchanger station can be used to conduct thermal eradication of legionalla pneumophalis.

The disadvantage is the additional effort associated with securing sufficiently low uncertainty of the measurement devices. For the first method, standard measurement devices can be used, whereas this method requires specific precise measurement devices. As a result, the initial investment may be slightly higher.

Proposal of failure detection system

The preceding section has introduced two methods that can be used for a precise measurement of hot water consumption at the building entry. This section explores the possibilities of further software enhancements that can use the measurement data to detect failures in the systems.

Typically, a district heat exchanger station supplies several buildings within a block. This is presented in block diagram in Fig. 4.

Flowmeter P measures the consumed cold water. Variables O_i represents the consumption of builings supplied by hot water. O_i represents the pure consumption that can be determined by either of the methods introduced above. In an ideal system, the sum of all O_i should be equal to the consumption determined by flowmeter P.

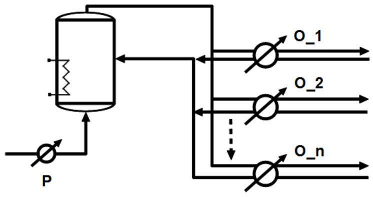

Fig. 4. Boiler of a district heat exchanger

This paper suggests a software enhancement to the measurement that will periodically compare both quantities. If the uncertainties in the system are considered, three cases can be defined:

$$\left|P - \sum_{i=1}^{N} O_i\right| \le \varepsilon , \qquad (2)$$

$$P - \sum_{i=1}^{N} O_i \succ \varepsilon , \qquad (3)$$

$$P - \sum_{i=1}^{N} O_i \prec -\varepsilon , \qquad (4)$$

where ε is a positive real number that represents the maximum tolerable error caused by uncertainties of measurements of P and O_i.

Case 1 (2) represents a normal state of operation, the difference between t he two quantities is sufficiently small so that no failure is indicated.

Case 2 (3) represents the situation when the boiler uses more water than it is actually consumed by the consumers. This case is an indication of failure. The most probable failure is a leak in the pipe system between the boiler and the supplied block.

Case 3 (4) represents the situation when the volume of water in the system is increased. In practical situations, there are two realistic scenarios. Firstly, the heat carrier from the boiler leaks to the hot water system. Secondly, such mesurement can be observed after repair works when the water in the system was refilled and the flowmeter P was out of the loop. Facility managers are usually aware of the second situation, thus this case can also be used as an indicator of failure.

To conclude, it has been postulated, that a simple software extension in an existing system using measurement of hot water at the entry to a building can be used as indicator of system failures. Also, the severity of the failure can be evaluated and the facility manager can decide whether it is feasible to conduct repair works, because some leaks may cause only marginal losses.

Failure detection – case study

To explore potential and functionality of the proposed system for failure detection, real field measurements from seven district heat exchanger stations in the city of Usti nad Labem, Czech Republic, were evaluated. The measurements were conducted in the period January 2009 – April 2010. The hot water measurement at the entry to a building used the method of paired flowemeters.

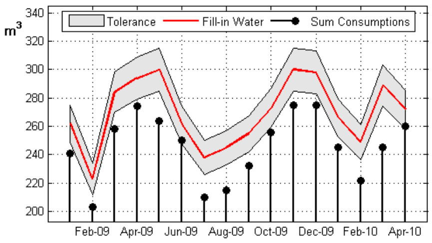

Fig. 5. Water leaks away from the pipes

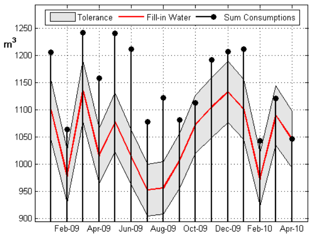

Fig. 6. Primary medium leaks away in the boiler

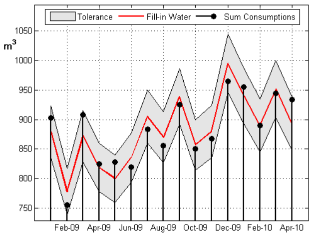

Fig 7. Good balance of the measured value

In the measurements, all three cases as presented above were discovered. Two systems appear to have leaks in the pipes between boiler and the consumers. This is illustrated by Fig. 5 comparing P and the sum of O_i for one of these systems. One system, presented in Fig. 6, seems to have a leak in the boiler so that heat carrier enters the hot water.

This failure was indeed discovered and repaired in February 2010. Data for the remaining of systems do not indicate any failure as the measured values falls within the tolerance limit ε. Data from one of these systems is presented in Fig. 7.

Conclusions

This paper has studied the issue of hot water measurement, especially the precise measurement of energy consumed to cover the heat losses due to hot water recirculation. These losses must be measured so that they can be billed to the consumers in a fair manner. The paper has identified the main challenge of such measurement and reviewed two methods that are approved for such measurements. The advantages and disadvantages of both methods have been discussed. Especially, the method of separated circuits has been found unable to use the thermal eradication which is the most common measure against the spread of legionella pneumophila.

Additionally, the paper has introduced a simple enhancement of the measurement software that can be used with either of the two methods to detect failures in the hot water systems such as leaks. As a result, it can be used to reduce costs associated with such failures. The system has been tested on real data from seven district heat exchanger stations.

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Measurement of energy to cover heat losses due to hot water recirculation must be precise so that the associated costs can be split among the consumers in a fair way, but it is very challenging due to the low ratio of consumed water to recirculated water. This paper reviews two approved methods of measurement and discusses their advantages and disadvantages. Additionally, it introduces a software enhancement of measurement system that can be used to detect failures in the system, such as leaks. Test of the system and its ability to indicate failures is explored using real data. Ill. 7, bibl. 5 (in English; abstracts in English and Lithuanian).

J. Šípal. Recirkuliacinės karšto vandens sistemos energijos sąnaudų ir gedimų nustatymas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 10(106). – P. 109–112.

Būtina atkreipti dėmesį į energijos sąnaudas recirkuliacinėse karšto vandens sistemose ir jas sąžiningai paskirstyti vartotojams. Uždarose recirkuliacinėse sistemose karšto vandens suvartojima nedaug, todėl tai padaryti sunku. Apžvelgti du taikomi metodai, aprašyti jų pranašumai ir trūkumai. Gedimams (pvz., vandens nutekėjimui) aptikti pasiūlyta programinė įranga. Atlikti sistemos bandymai su praktiniais duomenimis. Il. 7, bibl. 5 (anglų kalba; santraukos anglų ir lietuvių k.).