Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 771 – 776

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Analysis of devices for thermal energy consumption monitoring and design of a bench test for their characterization

S. Mosso[a]*, M. Di Meo[a], V. Squizzato[a], D. Suino[a], A. Cortazzo[b]

[a]Telecom Italia, via Reiss Romoli 274, 10148 Torino, Italy
[b]Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129Torino, Italy

Abstract

The mandatory introduction in Italy of the accounting of consumption for heating and domestic hot water in centralized heating systems has determined the introduction on the market of many commercial solutions based on different measuring principles. In order to find a proper method for testing the solutions proposed by the vendors, in the present work the uncertainty of the results reachable with the different types of measuring devices has been evaluated. Based on the best theoretical results achievable with the different types of devices the scheme of a test bed for the characterization of commercial systems is proposed.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: thermal energy consumption; energy monitoring; devices; test

1. Introduction

In order to find a proper method for assessing the performances declared by the manufacturers of commercial products for thermal energy consumption monitoring, in the present work we examined the different technologies actually available and compliant with European and Italian standards [1-6]. The uncertainty of the results obtainable by the three categories of devices actually available, that are based on different measuring principles and are represented by heat meters, heat cost allocators and insertion time counter compensated with the degree-days of the building unit, has been evaluated. At first we performed a sensitivity analysis on coefficients and parameters used in the equations to calculate the thermal energy consumption. The economic impact of the errors due to the different

* Corresponding author. Tel.:+39-011-2285086; fax: +39-00-2285224.
E-mail address: sabrina.mosso@telecomitalia.it

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.092

parameters by taking into account the acceptable tolerance has also been estimated. Based on the best theoretical results achievable with the different types of devices the scheme of a test bed for the characterization of commercial systems is proposed, together with a test procedure.

2. Devices for thermal energy consumption monitoring

2.1. Heat meters

They are used for direct heat metering in presence of horizontal distribution circuits of the thermal medium. The requirements are specified by the European standard UNI EN 1434 Part1-6 [1,6]. The components parts are a flow sensor, a temperature sensor pair and a calculation unit.

The reference standard [1] establishes the maximum permissible relative error of sub-assemblies (calculator, temperature sensor pair and flow sensor) by means of specific formulas. By calculating the Maximum Permissible Relative Error (MPE) it can be demonstrated that the most effective factor in determining the total error is the ratio q_P / q between the permanent flow-rate (the highest flow-rate at which the heat meter shall function continuously without the maximum permissible errors being exceeded) and the flow-rate (the energy-conveying passing through the heat meter). The best performance of this kind of device is obtained when $q_P \equiv q$, for which the error varies from 1% to 3%, for devices of class 1 and 3 respectively. Nevertheless even in the worst case the error is within 10%.

2.2. Heat cost allocators

In presence of vertical distribution circuits of the thermal medium it is not possible to use direct metering systems. Generally in these cases, typical of almost all old buildings, heat cost allocators are the indirect metering systems commonly used to capture the proportionate thermal output of radiators in consumer units [2]. They operate a registration of the temperature integral with respect to time, being the temperature the basis for the determination of the heat emission of the room heating surfaces on which the heat cost allocators or their sensors are installed.

The proportionality between the thermal energy output of radiators and the measured parameters (temperature of surface radiator and air temperature) is established through three coefficient: K_Q, K_C, K_T.

We performed a sensitivity analysis on each of these parameters, with the aim of evaluating the influence on the total error and the corresponding cost in euro.

The error due to K_Q, the rating factor for the thermal output of the radiator, is linked to the uncertainty on the nominal value of the radiator power. Considering an error of 60W, that is the maximum error established by the UNI EN 834 [2] for 3kW radiators (or in alternative 5% of the nominal power value), the error and the consequent economic impact increases linearly with the hours for which the heating system is switched on. For a flat with 7 radiators the maximum error on K_Q is estimated to approximately correspond to 50 €/year [3]. It is important to notice that this error is not directly due to the measuring device, since it is dependent on the radiator properties and behavior.

K_C is the counting factor and it is the result of different thermal coupling of temperature sensors with different radiant surfaces. This values is measured by the producer for each type of radiator and it is reported on the data sheet of the product, with two decimal places. An error of 1% on K_C generates an economic impact of 10-20 €/year on the heating cost for a flat.

K_T applies in case of single sensor heat cost allocators to take into account indoor temperatures below 20°C and avoid under estimation of the heat released by the heating surface. The difference between the counting rate U_R calculated with and without K_T decreases as the indoor temperature gets close to 20°C, passing from 20 units for 10°C to less than 5 units for 18°C.

Other important sources of errors are the positioning errors and the temperature measurement errors. In Fig 1 are shown the effect of the temperature measurement errors on UR obtained by basing the calculation on experimentally measured surface temperature of a cast iron radiator located in a domestic environment.

Concerning the positioning errors, the device installation height is established by the standard UNI EN 834 [2]. In the respect of the standard, the producers generally specify the exact height for positioning. In case of attachment position specified by the manufacturer with a tolerance of ± 10 mm the error is not relevant if compared to the other error sources. In case of a device installation between 66% and 80% of the radiator height, as specified by the standard [2], for a single sensor device and a single radiator composed by 11 elements switched on for three hours/day, the error can be of the order of magnitude of 100-150 €/year.

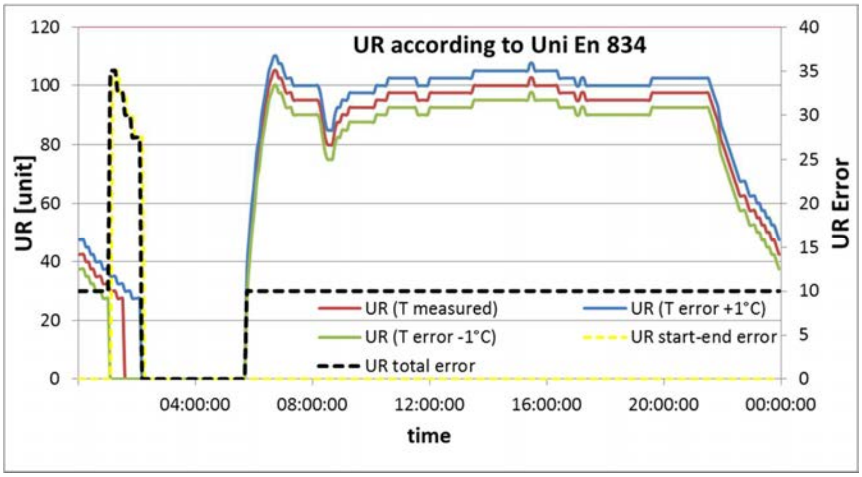

Fig. 1. UR curves in case of exact temperature measurement and temperatures measured with an error of + and – 1°C. UR is expressed as a non-dimensional number proportional to the thermal output of radiators.

2.3. Insertion time counter compensated with the degree-days

Insertion time counters compensated with the degree-days are indirect metering system based on the counting of the insertion time of each heating element, according to the equation described in the Italian standard UNI9019 [3]. The thermal energy output of radiators is proportional to the opening time of the valves operated by the control unit. In table 1 is reported (for a specific commercial radiator), in a scenario of different operating modes of the heating system, the annual cost in euro due to the errors associated with the parameters in the equation that applies to this kind of devices for thermal energy calculation [4].

Table 1. Economic impact for a single radiator of the error on the thermal energy value for different starts values.

	Number of starts	no starts	1	2	3	4	6
Error due to transient phase for a commercial radiator with τ=0,9 hours	Error %	0.05%	7.35%	12.41%	16.03%	18.46%	20.57%
	Impact €/y	€0.03	€4.59	€9.17	€13.68	€17.86	€24.36
Error due to an uncertainty of 10% on the power of the heating element	Impact €/y		€11.67	€13.83	€15.98	€18.10	€22.12

Both the error on the temperature decaying time of the heating element (τ), that is related to the thermal capacity of the radiator and the uncertainty on the heating element power increase with the number of starts/day, being important in the transient phase of the heating system. It should be highlighted that the uncertainty on τ values for different commercial heating elements can reach values up to 25% (aluminum) and 33% (radiant ceiling).

The error on the time of valve opening expressed through the parameter t_k is not considered in the table above since it is negligible with respect to τ, being of the order of magnitude around 1% as required by the standard UNI/TR 11388 [5].

Finally, the error on the temperature in the equation that describes the thermal energy consumed in the counting period determines a different estimation of the kWh consumed by each apartment but not a different cost sharing.

For a flat with 7 radiators the economic impact could reach values from 114 €/y for 1 start up to 325€/y for 6 starts.

3. Test bed for the characterization of commercial systems

Based on the results of the analysis of the different solutions for the accounting of heat and hot water consumption discussed in previous paragraphs a scheme (Fig.2) of a test bed for the characterization of the different commercial devices has been developed. The following requirements have been taken into consideration:

- possibility to test all kinds of devices, represented by heat meters, heat-cost allocators and insertion time counters compensated with the degree-days;
- the test system should include different heating systems, such as radiators, fan-assisted air heaters and heating elements of new design;
- possibility of running the tests in different operating condition of the heating systems
- use of certified heat meters in order to quantify the error of the tested devices by comparing the indirect measurements with a direct certified measurement.

A certified heat meter will be used as reference for heat meters under test and as comparison for indirect measurements obtained from other types of devices. In addition to the parameters measured and collected in the table below (table 2), the test bed will be equipped with a temperature sensor for the measurement of the external controlled temperature (climatic chamber) and a temperature sensor for the measurement of the indoor temperature.

Table 2. Bench test- Measured parameters for the different types of systems.

Test bed instruments	Measured parameters
Heat meters	T_i flow temperature, T_0 return temperature, V volumetric flow rate
Single sensor heat cost allocators	T_R surface radiator temperature
Double sensor heat cost allocators	T_R surface radiator temperature, T_a air temperature
Insertion time counter	t_K opening valve time

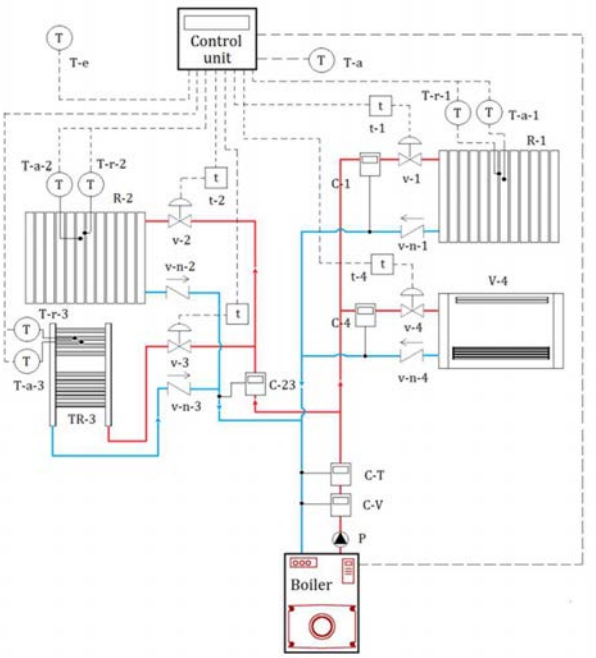

Fig. 2. Scheme of the test bed for the characterization of commercial devices.

It is possible to equip the test bed in Fig. 2, that is very basic, with components able to create thermal and radio interferences, such as external heating sources that simulate the effect of direct action of sunshine rays, to test the behavior of the devices in critical but realistic situations.

The error introduced by the test bed is calculated by taking into account the directly measured parameters.

The influence of the uncertainty due to the parameters not directly measured on the overall accuracy of the determination of the thermal energy consumed has been already discussed in previous paragraphs. The approach adopted in projecting the test bed is to choose only certified radiators measured by the producer, in order to minimize the uncertainty due to parameters not experimentally measured.

For heat cost allocators the total error depends on the temperature accuracy measurement and on the beginning and final counting error. As an example in Fig. 3 are reported the error curves for single and double sensor heat cost allocators for different temperature measurements accuracy. As can be seen in the graphs, in certain condition the error can be very high, close to 60%. For this reason the test bed will be equipped with temperature sensors with an accuracy of 0,1°C, in order to guarantee an error in the range 0.17% - 2% for single sensor devices and 0.5% - 0.67% for double sensor devices.

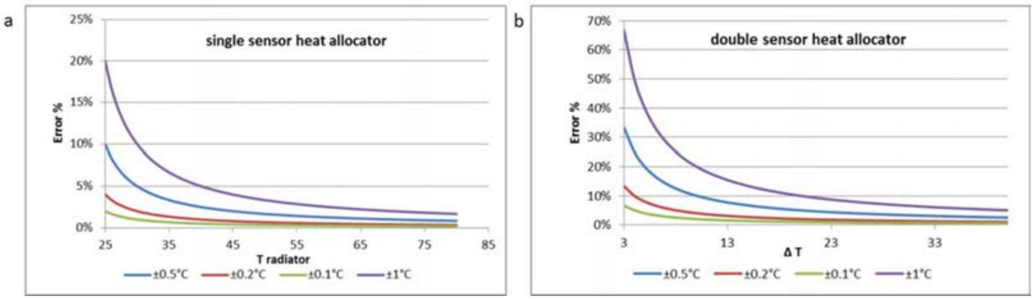

Fig. 3. Test bed error in function of temperature measurement accuracy for single (a) and double (b) sensor heat allocators

Both for temperature and time measurement only calibrated instruments with known accuracy will be used.

The experimental measurement error of the test bed for the heat meters is comprised between 2.1% and 8.5% for a class 1 device.

For insertion time counter compensated with the degree-days the error introduced by the test bed on the time measurement is much lower than the accuracy of ± 1% required by the standard UNI/TR 11388 [5] if certified chronometers are used.

For all types of devices the measurements performed with the proposed test bed are characterized by an error equal (heat meters) or lower than the best theoretical results achievable for the evaluation of the thermal energy obtained introducing in the equation the minimum uncertainty on parameters required by the standards.

4. Test procedure

For the heat meters the test procedure is established by the standard UNI EN 1434-5 [6].

For the other two indirect metering systems, in respect of the standards UNI EN 834 [2] and UNI 9019 [4], two types of test are proposed:

- Evaluation of the accuracy of device measurements (temperatures for heat cost allocators and valve opening time for insertion time counters compensated with the degree-days).
- Evaluation of the measurement error (for heat cost allocators and for insertion time counters compensated with the degree-days) with the heating system working as in a typical day.

For heat cost allocators, to evaluate the accuracy of device sensor temperature measurements, the test will be performed in stationary condition and far from the beginning and the end of the allocator measurement period.

The test will be repeated for four T_R values conveniently spaced in the range T_z+5K e T_{max} in case of single sensor devices and for four $\Delta T=T_R-T_a$ values in the range ΔT_z+2K e ΔT_{max}. (T_z= start temperature, T_{max}= upper temperature limit of the heating surface, K=Kelvin degrees) in case of double sensor devices.

For the evaluation of the error that occurs when the heating system is let been working as in a typical day, it is reasonable to perform the test by doing measurements continuously for 24 hours. During this period the test bed has to be operated to simulate a common domestic environment, having set the indoor temperature to 20°C (measured by the sensor T_a in Fig. 2) and with the heating system switched on from 7:00 in the morning until 22:00 in the evening. For insertion time counters the opening time of the valves of the heating elements will be commanded by the control unit (Fig.2) and the values measured by the devices under test will be compared with the references value obtained with opportune certified time sensors. The test will be executed for different times of valve opening (possible values 15 min, 30 min, 1hour, 2 hours, 3 hours and 4 hours) to obtain the curve of the error as a function of the valve opening time. For the evaluation of the error during a typical day the same procedure described before for heat cost allocators can be applied, with the additional requirement of repeating the test for different trends of the external temperature. In all cases the values measured by the devices under test are read on the proprietary software platform used to collect the data, in order to verify also the transmissive behavior of the systems, in end-to end configuration.

In addition to the test described above also functional tests should be performed, by operating in a configuration end-to-end, in order to assess the correct data transmission, the behavior in condition of power failure, the protection against tampering, etc.

5. Conclusions

The estimation of the results uncertainty reachable with the different types of measuring devices confirms that the heat meters represent the most accurate and reliable systems. The commercial alternatives actually available, represented by indirect metering systems like heat cost allocators and insertion time counters compensated with the degree-days are affected by an higher uncertainty on heat usage.

An important issue that should be addressed to is the case of heating systems not based on radiators but for example on fan-assisted air heaters, for which heat cost allocators can’t be used. This type of heating is extremely diffused in office buildings, commercial buildings and public administration buildings; actually the only possible solution with this kinds of heating systems, in presence of a vertical distribution circuits of the thermal medium, is represented by insertion time counters compensated with the degree-days.

The economic impact of the estimated error can amount, for a flat having 7 radiators, to 60-70 € in case of heat cost allocators up to 114-325 euro € for insertion time counters compensated with the degree-days. For this evaluation just the theoretical uncertainty on the parameters in the equation for the calculation of the heat released has been taken into account. All the other sources of errors commonly present in practice like painting layers on radiators, calcification inside the radiator elements, etc. increase the economic impact of indirect metering systems due to the error on the evaluation of the thermal energy.

In the paper a scheme of a test bed for the characterization of commercial systems is proposed keeping in mind that the measurement set-up and the test procedure presented is thought not for the evaluation of the devices behaviour in complex situations but for the assessment of the performances declared by the manufacturers in end-to-end configuration.

References

[1] UNI EN 1434-1 Heat meters Part 1:General requirements; 2007.
[2] UNI EN 834 Heat cost allocators fort he determination of the consumption of room heating radiators – Appliances with electrical energy supply; 2013.
[3] I. Delfino. Tesi di Master Universitario di II livello, Edilizia sostenibile ed efficienza energetica; 2014.
[4] UNI 9019 Sistemi di contabilizzazione indiretta basati sul totalizzatore di zona termica e/o unità immobiliare per il calcolo dell’energia termica utile tramite i tempi di inserzione del corpo scaldante compensati dai gradi-giorno dell’unità immobiliare; 2013.
[5] UNI/TR 11388 Heat costs allocation based on heat unit shut-off valves and insertion time counter
[6] UNI EN 1434-5 Heat meters Part5: Initial verification tests