5th International Science Congress & Exhibition APMAS2015, Lykia, Oludeniz, April 16–19, 2015

Intellectual System for Controlling the Individual Heat Consumption

R.E. Mironov, Yu.I. Shtern, Ya.S. Kozhevnikov, M.Yu. Shtern* and I.S. Karavaev
National Research University of Electronic Technology — MIET,
Bld. 1, Shokin Square, Zelenograd, Moscow, Russia, 124498

A new concept for determining the individual heat consumption in the heating systems of the apartment houses, which was realized in the intellectual system, developed by authors, for controlling the individual heat consumption, is proposed. Concept is based on the use of virtual measuring channels, determined by the technology of intellectual precise temperature sensors and flow meters for heat carrier in heating systems. Configuration of measuring channels is determined by software means, and can be operatively changed during exploitation. Methods and mathematical models for the calculation of individual heat consumption were determined, including calculation and distribution of total house heat consumption. Design principle of intellectual system for controlling the individual heat consumption was determined. Original design solutions, and hardware and software means for electronic components were developed. System carries out direct measurements of heat consumption, and performs data reception and transmission from electronic measuring and controlling components using radio channel at frequencies of 434 or 868 MHz, then it is performing calculations and displaying results. Results of calculations in real measuring units are displayed on the local retranslator and apartment monitor. Exclusive feature of this concept is associated with the possibility of measuring of total house heat consumption. Estimation of confidence limits of systematic measurement error of the individual heat consumption was carried out. It was shown that average weighted error for determination of heat consumption by one apartment during the heating season does not exceed 6.5%.

DOI: 10.12693/APhysPolA.129.782
PACS/topics: 84.40.Xb

1. Introduction

The dissemination of energy saving technologies is unfeasible without exact accounting of energy consumption like that of heat, gas, electricity etc. It is especially essential to measure energy consumption of every single apartment because that encourages people to save energy. When analyzing the state-of-art measuring systems and instrumentation, it should be noted, that the individual heat consumption metering is a complicated and evolving task [1]. Many R&D divisions and research laboratories across the world have been trying to develop techniques and systems for high accuracy measurement of heat consumption in any type of heating system, but there have been no satisfactory results yet.

The authors have developed and have been deploying a new Intellectual System for the individual energy consumption metering in various buildings. In this system, special attention is given to measurement of heat consumption.

The System is based on a new patented [2] conception for the individual heat consumption metering in the multi-unit apartment buildings' heating systems. The conception is built on using software-configurable measuring channels which are equipped with high-precision smart temperature sensors with a wireless communication interface. Measuring and controlling devices [3] and software were developed by the authors to allow the system operation.

*corresponding author; e-mail: m.y.shtern@gmail.com

2. The structure of the Intellectual System

The System represents a unified information and measuring entity which consists of measuring and controlling devices, hardware and software.

The Intellectual System automatically performs the following operations: continuous monitoring of the thermodynamic parameters of an energy-conveying liquid, which are measured by wireless sensors; calculation and transmission of measured parameters to a database for accumulation and storage; sending commands to controlling devices like wireless radiator thermostats; display of the data on various devices; database management of the consumption data. The System is designed for the direct measurement of heat consumption and also for hot and cold water consumption metering. The Intellectual System measures and calculates these consumption data and then transmits the data to a billing center. The System can be used in one building, several buildings, a district or even a region; thus, it is possible to create a unified informational and analytical network. Receiving and transmitting of the information between the system's devices is carried out in the 433 and 868 MHz ISM frequency bands.

The Intellectual System consists of the following components: high-accuracy temperature sensors, pulse counters of hot and cold water consumption, wireless repeaters (WR) and apartment monitors (AM). Wireless temperature sensors (WTS) are used to measure the temperature of the energy-conveying liquid (coolant) with an accuracy of $\pm 0.05\,^{\circ}$C. The variety of WTS' designs allows to cut them into pipes of the heating system or to install them on the surface of the pipes without depressurization of the heating system. Flow meters of hot and cold water are connected to dual channel wireless pulse counters (WPC–2C). Flow meters which measure the energy-conveying liquid rate are connected to single channel wireless pulse counters (WPC–1C). The thermometers and pulse counters are installed on pipes of heating and water-supply systems.

The scheme of the System is shown in Fig. 1. The measured data is transmitted wirelessly from WTS, WPC–2C and WPC–1C to WR and then received by a main repeater (MR) which is configured on an industrial computer. MR processes, archives and then transmits the data to a central server over the Internet where the heat and water consumptions are calculated and displayed by proprietary software. The consumption data is stored in the database on the central server and is available on WR's and AM's displays and on other devices (smartphones, tablets, PCs etc.) over the Internet.

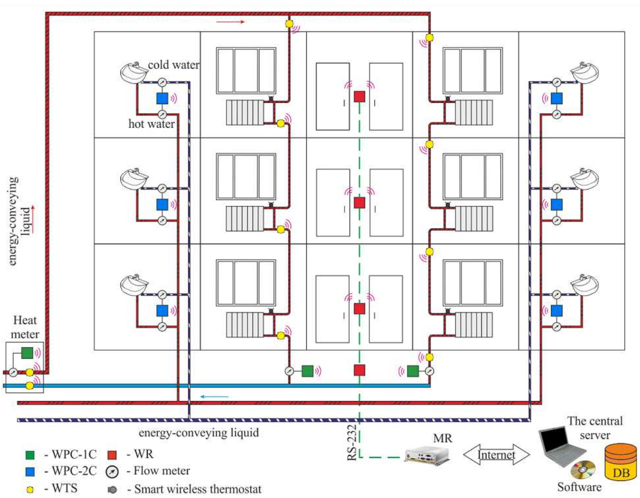

Fig. 1. The scheme of the Intellectual System installed on the one-pipe heating system.

The Intellectual System implements a new technique for individual heat metering which relies on the conception of using measuring channels which consist of WTS, WPC–2C and flow meters. Therefore, it is possible to measure heat consumption of any section of the heating system inside a building, where measuring sensors were installed. The topology of the measuring channels is specified by an arrangement of WTS and flow meters on pipes of the heating system.

It should be noted that the measuring channels can be configured by the software either during the design or the operation of the Intellectual System. This capability to build the software-configurable measuring channels is a significant advantage of the proposed System, because that allows measuring heat consumption not only in apartments but also in public places like stairwell, basement, etc.

Schemes of the measuring channels for the one-pipe heating system are shown in Fig. 1. In this case, WTS are placed on pipes near the ceiling or at the outlet of a heat exchanger and the flow meters, which are connected to WPC–1C, are placed on pipes in the basement. In case of the two tube heating systems, WTS are installed at the inlet and outlet of the heat exchanger, as WPC–1C are installed at the outlet of every heat exchanger. Hence, in that case, the measuring channels represent compact heat meters.

All the components of the Intellectual System and the System itself were tested and then have been certified by Federal Agency on Technical Regulation and Metrology (Rosstandart). The technique of individual heat consumption metering has been patented.

3. The technique of the individual heat consumption metering

The amount of heat energy which is consumed and must be charged to occupants consists of two parts. The first part is the heat energy consumed by apartments and the second part is the heat consumed by the public places and allocated to each apartment.

The heat consumption Q over an accounting period L on the controlling section of any type of the heating system is measured in accordance with measuring technique for heat meters (presented in EN1434–1:2007 standard) in which numerical integration is performed by totaling measurement periods:

$$Q = \sum_{k=1}^{N} V_k \rho_k \Delta h_k, \tag{1}$$

where k is an index of measurement, N — a number of measurements over accounting period; $\Delta h_k = h_{1k} - h_{2k}$, h_{1k} and h_{2k} — are the specific enthalpies of the energy-conveying liquid at the inlet and outlet of the controlled section respectively; ρ_k — density of the energy-conveying liquid; V_k — volume of the heat-conveying liquid passed through the flow meter over the duration of the measurement period $\Delta\tau$, which is given by

$$V_k = wI_k, \tag{2}$$

where I_k — the number of pulses from a flow meter which is connected to WPC-1C, w — "weight" of the pulse.

It is necessary to take into account the temperature dependence of the heat-conveying liquid (water) density which can be written at a pressure of 1.6 MPa as

$$\rho_k = 1001.35524 - 0.091435 t_{pk} - 0.00305 t_{pk}^2, \tag{3}$$

t_{pk} — temperature which is measured by the nearest to the flow meter WTS. The standard deviation of the density calculation does not exceed 0.03%.

The specific enthalpies are defined as

$$h_k = 1.6371 + 4.1836 t_k, \tag{4}$$

where t_k is temperature of the energy-conveying liquid which is measured by WTC.

The error of the specific enthalpies (of water) calculation at temperatures from 5 to 100 °C is no more than 0.3%. Calculation of the relative error of the individual heat consumption metering is carried out as follows

$$\delta U_Q = k(p)\sqrt{(\delta u_{cm})^2 + (\delta u_{c\Delta t})^2}, \quad (5)$$

where u_{cm}, $u_{c\Delta t}$ are the combined standard uncertainties of the mass ($V_k\rho_k$) and the temperature difference measurements, respectively.

The relative standard uncertainty of the heat-conveying liquid mass metering δ_{ulm} is equal to 2% (corresponds to accuracy of the flow meters). The relative standard uncertainty of the heat-conveying liquid temperature difference metering, relating to an apartment and taking into account the temperature measurement with an accuracy of ±0.05 °C, is equal to 3.4%. In case of the normal distribution with the coverage factor $k(p) = 1.65$ and the level of confidence of $p = 0.95$, the relative standard uncertainty of measurement of the individual heat consumption for an apartment over the heating season was estimated as no more than 6.5% [2], which is rather acceptable. It should be noted that this error is lower than that of the technique of individual heat consumption measurement based on heat cost allocators.

4. Conclusions

A new conception of the individual heat consumption metering in multi-unit apartment buildings' heating systems has been proposed. A new Intellectual System that has been proposed by the authors implements this conception, that is built on using software-configurable measuring channels which are equipped with high-precision smart temperature sensors with wireless communication interface and flow meters. The measuring channels can be configured by software either during the design or operation of the Intellectual System.

Techniques for measurement of individual heat consumption and calculation have been examined. The most important feature of the proposed System is the capability to measure heat consumption not only in apartments but also in public places like a stairwell, the basement, etc. Original design solutions, and hardware and software for electronic components have been developed.

The System carries out direct measurements of the heat consumption, and performs data reception and transmission from measuring and controlling components, using radio channel at frequencies of 434 or 868 MHz, then performs calculations and displays the results.

The relative standard uncertainty of measurement of the heat consumption has been estimated as no more than 6.5%, that is lower than that of the technique of individual heat consumption measurement which is based on heat cost allocators.

Acknowledgments

This work has been carried out under a sponsorship of the Ministry of Education and Science of the Russian Federation project number 14.575.21.0032 (UN RFMEFI57514X0032).

References

[1] D.A. Shnayder, *36th International Conference on Telecommunications and Signal Processing (TSP) Proceedings*, Rome, Italy, 2013, p. 181.

[2] Yu.I. Shtern, Ya.S. Kozhevnikov, V.A. Medvedev, R.E. Mironov, I.S. Karavaev, *Meas. Tech.* **56**, 178 (2013).

[3] Yu.I. Shtern, Ya.S. Kozhevnikov, R.E. Mironov, M.Yu. Shtern, I.S. Karavaev, *Meas. Tech.* **56**, 497 (2013).