Digitalization of housing and communal services using the example of apartment buildings

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Abstract. The possibility of digitalization of housing and communal services is mathematically considered using the example of apartment buildings. The approaches discussed in the paper can be used in the construction of new apartment complexes, as well as in the overhaul of the existing housing stock. In addition, the applied approaches can be easily adapted for use in office buildings and business centers.

1 Introduction

Improving the quality of service and transparency in the provision of communal services is one of the key tasks of reforming the housing and communal services system. The goal of the national project “HOUSING AND URBAN ENVIRONMENT” is not only to provide affordable housing and improve the comfort of the urban environment, but also a digital transformation and automation of processes, comprehensive improvement of the efficiency of urban infrastructure. First of all, we are talking about improving the energy efficiency of end users [1-6].

Digitization of housing and communal services involves the introduction of applied technologies to automate various processes: forecasting and modeling; accounting for resource consumption; allocation of resources for overhaul, etc. Let us consider one of the approaches to forecasting, modeling and accounting for resource consumption using the example of apartment buildings.

In this paper, a mathematical model for calculating individual heat consumption in a building containing a large number of rooms is proposed and investigated.

2 Mathematical model

Let’s consider the distribution of heat between rooms that have heating devices connected in series (vertical wiring system, Fig. 1). The figure conventionally shows heating devices (Device 1 – Device 5), temperature sensors (t₁ – t₆) and a device for determining the amount of energy consumed (Q).

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Fig. 1. An example of a heating system for the calculation of individual consumption.

The calculation of the amount of energy consumed from the coolant in a specific heating device can be made according to the well-known formula

$$Q_i = cm\Delta T_i,$$

where $c$ – specific heat of thermal energy carrier, $m$ – mass of the heat carrier passed through the heating device, $\Delta T_i$ – temperature difference between the heating medium at the inlet and outlet of the heater ($\Delta T_1 = T_2 - T_1$, $\Delta T_2 = T_3 - T_2$, …, $\Delta T_5 = T_6 - T_5$, for the example shown in fig. 1) [7, 8]. The total consumption determined by the meter of $Q$ is also the sum of consumption by heating devices $Q = \sum Q_i = cm \sum \Delta T_i$. It is easy to obtain individual consumption from the relationship of individual consumption to total consumption:

$$Q_i = Q \frac{\Delta T_i}{\sum \Delta T_i}$$

Thus, it turns out that it is quite simple to determine the individual consumption of heat energy from the heating system by the premises.

To implement this approach, it is necessary to provide the heat supply system with the required number of temperature sensors (one more than heating devices) and a general metering device for consumed energy.

A device that can interrogate a system of temperature sensors distributed in space and accumulate information will help automate such a process.

Suppose that the temperature sensors are polled at time intervals $\Delta t_j$. Then, with each count, some heat energy of the individual consumer $Q_j$ will be obtained. If $N$ counts are received during the time $t$, then the total consumption will be $\sum Q_j$. Therefore, similarly to (2), one can get:

$$Q_i = Q \frac{\sum \Delta T_{ij}}{\sum \Delta T_{ij}}$$
where the value $Q$ still reflects the total consumption of all heating devices, and $\Delta T_{ij}$ gives $j$ counting of the temperature difference at the $i$ consumer.

Let's check the correctness of the proposed mathematical model. Let a stationary flow of coolant (water with heat capacity $c = 4.19 \cdot 10^3 \frac{J}{kg\cdot ^\circ C}$) pass through the heating system at the speed $2 \frac{m}{min}$, the temperature is measured every 5 minutes and for the example shown in Fig. 1, for the time $1h$, is presented in table 1.

### Table 1. Measuring the temperature at the inlet and outlet of the heater.

| Measurement number | $T_1$, °C | $T_2$, °C | $T_3$, °C | $T_4$, °C | $T_5$, °C | $T_6$, °C |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 ($t = 0$)       | 60        | 59        | 58        | 57        | 56        | 55        |
| 2 ($t = 5 min$)   | 60        | 58        | 57        | 56        | 54        | 52        |
| 3 ($t = 10 min$)  | 59        | 58        | 56        | 54        | 53        | 52        |
| 4 ($t = 15 min$)  | 59        | 58        | 56        | 54        | 53        | 52        |
| 5 ($t = 20 min$)  | 60        | 59        | 58        | 57        | 56        | 55        |
| 6 ($t = 25 min$)  | 59        | 58        | 56        | 54        | 53        | 52        |
| 7 ($t = 30 min$)  | 60        | 58        | 57        | 56        | 54        | 52        |
| 8 ($t = 35 min$)  | 59        | 58        | 56        | 54        | 53        | 52        |
| 9 ($t = 40 min$)  | 59        | 58        | 56        | 54        | 53        | 52        |
| 10 ($t = 45 min$) | 60        | 58        | 57        | 56        | 54        | 52        |
| 11 ($t = 50 min$) | 60        | 59        | 58        | 57        | 56        | 55        |
| 12 ($t = 55 min$) | 59        | 58        | 56        | 54        | 53        | 52        |
| 13 ($t = 1 h$)    | 59        | 58        | 56        | 54        | 53        | 52        |

In accordance with (1), it is possible to determine the total heat consumption by all heating devices in each calculated period of time and the individual energy consumption by each consumer. It should be noted here that in fact, averaging of the consumed energy occurs, since the temperature of the coolant does not remain constant and changes. More accurate calculations will be obtained in the case of a larger number of temperature points or the use of numerical methods for integrating experimentally specified functions $\Delta T(t)$. In this case, the sum over the index $j$ will be transformed into an integral $\sum_j \Delta T_{ij} \rightarrow \int_{t_1}^{t_2} \Delta T_i dt$, and instead of formula (3), we get the following expression:

$$Q_i = Q \frac{\int_{t_1}^{t_2} \Delta T_i dt}{\sum_j \int_{t_1}^{t_2} \Delta T_i dt}$$  \hspace{1cm} (4)

So, in accordance with (1), we get:

$$Q = 3.6872MJ, \quad Q_1 = 670.4kJ, \quad Q_2 = 838kJ, \quad Q_3 = 838kJ, \quad Q_4 = 670.4kJ, \quad Q_5 = 670.4kJ,$$  \hspace{1cm} (5)

and in accordance with (3), assuming the given value $Q$, we obtain the individual consumption of heating devices:

$$Q_1 = 670.4kJ, \quad Q_2 = 838kJ, \quad Q_3 = 838kJ, \quad Q_4 = 670.4kJ, \quad Q_5 = 670.4kJ,$$  \hspace{1cm} (6)

which fully confirms the correctness of the proposed mathematical model.
The proposed mathematical model can be implemented in an automatic mode in the case of using a device that accumulates information about the temperature modes of operation of heating devices and transmits it to any computing module (computer). The structure of the automatic system is shown in Fig. 2. Here “Controller I” collects temperature data from heating devices and transfers them to a remote server. Each controller serves a specific area of the system. The remote server is an ordinary computer with preinstalled software capable of storing the received information in the form of a database and performing calculations according to the presented mathematical model. The operator starts the calculation of individual consumption and uses the obtained results further. The number of controllers connected to one computer is not limited to those shown in Fig. 2 and depends on the computing capabilities of the system used.

In this case, the mathematical model implies the presence of two stages:

- primary accumulation of information from temperature sensors;
- calculation of individual heat consumption according to formula (3) or (4) on a given array of temperature data and the total amount of consumed energy.

To perform the first stage, it is necessary to have a device (in Fig. 2 – a controller) capable of periodically collecting information from a network of temperature sensors distributed in space and sending it to a server that accumulates it in the form of an information database. Such a device can be made on the simplest microcontrollers with low power consumption and sufficient performance for the performed actions. For example, microcontrollers of the STMicroelectronics company [9] or any others can be used, which have a sufficient number of communication interfaces for communication with a network of temperature sensors and with a remote server of a computer.

As temperature sensors, it is most convenient to use digital devices that receive power from a microcontroller and do not require a lot of wiring. Thus, it is recommended to use a
network with a “common bus” topology, which will simplify the installation of the system: the wire of the network of temperature sensors can be laid parallel to the pipes of the heating system. One of the possible options for implementing a network of distributed sensors will be the use of a single-wire network developed by Maxim Integrated Products, for example, MAX31820 [10], or similar.

Examples of the implementation of the devices described above can be found in [11-15].

The accumulation of information is carried out for some time (depending on the specific requirements of the system user) and, upon request, the individual consumption is calculated.

4 Algorithm for calculating the individual consumption of heat energy

In accordance with the above mathematical model, the calculation is performed as follows:
- the difference $\Delta T_{ij} = T_i - T_{i+1}$ is determined, where $T_i$ is a temperature at the inlet and $T_{i+1}$ at the outlet $i$ of the heater, temperatures correspond to the $j$ count (line-by-line data differences in Table 1);
- calculation by formulas (3) or (4) using the obtained differences $\Delta T_{ij}$ and the value of the total energy consumed by all heating devices.

The calculation according to the above algorithm does not pose any difficulties for a modern electronic computer. The output is the values of individual heat consumption $Q_i$.

Consider the algorithms for the above actions. The algorithm for collecting temperature information is a simple cyclical polling of all sensors after a given time interval. This period of time should be at least the polling time of all temperature sensors. The algorithm is shown in Fig. 3.

**Fig. 3.** The algorithm of the controllers.
To save the data received from the temperature sensors controller, and calculating individual consumption, the computer must be running software that performs the algorithm shown in Fig. 4. In accordance with fig. 2 the operator sets the necessary data for the calculation and starts the calculation for execution. In this case, the server continues to receive and accumulate information from the temperature sensor controllers.

![Fig. 4. Algorithm of the software on the server.](image)

5 Conclusion

The proposed scheme and model make it possible to receive and process information from the heating system of an apartment building as quickly as possible, take into account resource consumption, work on charges and payments, provide services and individualize informing residents.

First of all, automation will give positive results in the service for residents and increase the energy efficiency of the house, which means reducing the financial costs for citizens.

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