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PHYSICAL AND TECHNICAL ENERGY PROBLEMS

TEMPERATURE SENSOR FEASIBILITY STUDY OF WIRELESS SENSOR NETWORK APPLICATIONS FOR HEATING EFFICIENCY MAINTENANCE IN HIGH-RISE APARTMENT BUILDINGS

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Cities are responsible for 60%–80% of the world's energy use and for approximately the same percentage of greenhouse gas emissions. The existing multi-apartment buildings of multifamily housing sector are often energy inefficient, and the heating system does not ensure optimization of heat distribution of individual apartments. Heat distribution, heating system balancing, heat loss detection and calculation, individual heat energy accounting are difficult tasks to accomplish. This article deals with the temperature monitoring system designed to retrieve temperature differences necessary for overall building heat monitoring and individual apartment monitoring. The sensor testing case study process and its measurements are analysed.

Keywords: *sensors, individual heat consumption, temperature measurements, wireless sensor networks.*

1. INTRODUCTION

In multi-apartment buildings, where heating systems with vertical heat carrier distribution are used, the heat amount consumed by individual apartments cannot be measured directly. It means that heat meters, which are widely used with horizontal heating systems, cannot be applied here. To solve this problem devices, which measure the relative heat amount supplied by each radiator, are used. Unfortunately, precision of this solution is disputable, as it ignores the heat amount supplied by the vertical risers that go through apartments.

Recently a new approach has been developed [1], where individual heat consumption is obtained by measuring temperature and mass flow rate of heat carrier in each riser. In this method, the heat amount supplied by a given riser is said to be proportional to the average temperature drop of heat carrier and to the total volume of the heat carrier that has passed through this riser in a certain period of time (see Fig. 1).

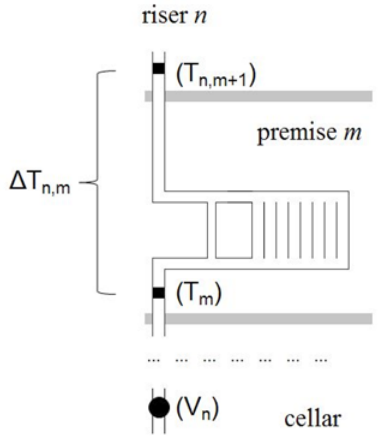

Fig. 1. Temperature T and flow rate V measurement places in a riser to determine the relative heat consumption of a premise in a building with a vertical heating system.

The total heat consumption of the building is measured by a heat meter in kWh. A part of the total amount then is attributed to the individual premises in the building. The average temperature drop of the heat carrier multiplied by the mass flow rate of the heat carrier is used as a dimensionless coefficient that determines the individual heat usage factor from the total energy consumed. For a given period, the coefficients can be expressed as follows:

$$c_{n,m} = \frac{V_n \Delta T_{n,m}}{V_B \Delta T_B}, \tag{1}$$

where: $c_{n,\,m}$ is the consumption coefficient from the riser *n* in the premise *m*;
V_n is the volume of heat carrier that has passed through the riser *n*;
$\Delta T_{n,\,m}$ is the average temperature drop of the heat carrier in the riser *n* in the premise *m*;
V_B is the total volume of heat carrier that has passed through the building heating system;
ΔT_B is the average temperature drop of the heat carrier in the building heating system.

Then the actual heat consumption (in kWh) can be obtained as follows:

$$q_{n,m} = c_{n,m} \cdot Q_B, \tag{2}$$

where: $q_{n,m}$ is the heat amount supplied by the riser *n* and attributed to the premise *m*;
Q_B is the total heat amount consumed by the building.

The heat consumption of a certain apartment is calculated as a sum of consumption of all heated premises in this apartment.

To correctly obtain these coefficients, it is necessary to ensure that temperature and flow measurements are made with high precision. The calculation periods of heat consumption can vary from several months or years to one hour and less; this means that measurements should be read as often as possible.

2. TRIAL RESULTS

A trial project was carried out to test the described approach and to validate the method of determining individual heat consumption of premises in buildings with vertical heating systems. The trial was carried out in a 9-storey, 3-section multi-apartment building of type No.602 in Riga. During the last months of a heating season, temperature and flow data were collected from one riser.

Main objectives of the trial project were to obtain the vertical distribution of temperature of heat carrier in a riser and the minimum temperature difference between any two floors and to verify the environmental impact on radio transmission for the given application.

A. Devices

A wireless sensor network was applied in the trial project. To obtain flow rate of heat carrier, a water meter was mounted on the riser. There were six radio devices used for temperature readings and one radio device was used for reading the water meter. Two concentrators collected the data and stored the readouts in their internal non-volatile memory (Fig. 2).

Fig. 2. Wireless data concentrator with non-volatile memory.

The temperature measurement unit consisted of a radio module placed in a square plastic case and a platinum resistance temperature sensor PT1000 attached to it with a wire (Fig. 4). Similarly, the unit for remote water-meter readings consisted of a radio module placed in a cylindrical plastic case and an impulse sensor attached to it in a wire (Fig. 3). Radio transmission in the licence-free frequency band of 868–870MHz was used.

Fig. 3. Wireless impulse counter kit for water meter reading.

Temperature sensors were placed in sockets of metallic T-pieces that were mounted in advance. The mounting position ensured that sensors were placed in the middle of the riser and in the flow of heat carrier but were not in a direct contact with it. The sensors in the riser were placed in six points: in the attic and at a floor level in five apartments; heat carrier flow was measured in the cellar; one data concentrator was located in a first-floor apartment and the other in the attic of the building.

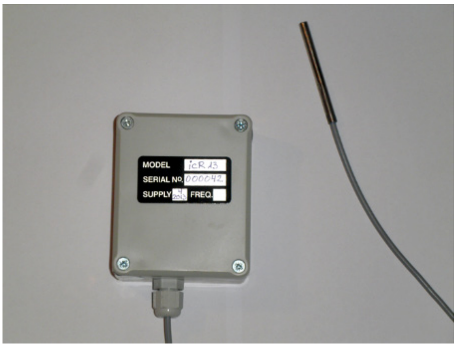

Fig. 4. First generation PT1000 wireless temperature measurement unit.

The measurement data of the temperature sensors were registered as a pair of values: the number of current measurements starting from the initialization of the temperature measurement unit microcontroller; the temperature sum. This approach allowed obtaining a correct average temperature value over a certain period even if some transmissions were lost; transmission period was 12 minutes. In the device for water meter reading, the detected impulses were incremented and their total count transmitted every 10 minutes. The total data packet sent by a reading device consisted of timestamp, device serial number and measurement values; the intensity level of radio signal was added to the packet by a data concentrator before saving all the information in the concentrator memory. During the trial project, the data collection was in offline mode – the concentrator device stored the transmitted messages in its internal non-volatile memory, and for further analysis they were transmitted to a PC via a USB interface.

B. Sensor Verification

Before temperature measurements could be performed in the building, the temperature sensors were compared relative to each other.

The analogue platinum resistance temperature sensors PT1000 were used with 1000Ω resistance at 0°C and reading precision of 0.01Ω, which corresponds to 0.0026°C in the temperature range of 0–100°C.

The amount of heat given off by the heat carrier is proportional to the temperature difference; thus, it is important to ensure measurement precision of temperature differences as high as possible. For overall temperature monitoring precision of 1°C is sufficient. This means that absolute calibration is not necessary because the sensor manufacturer ensures measurement precision of 1°C.

To measure the relative temperature differences with high precision, an experiment was performed. All sensors (11 in total) were placed under the same conditions in dry air and their readings were recorded. While analysing the data, a period of time, where readings were almost constant, was selected and the average measurement values were calculated. The sensor with the lowest value was chosen for reference. For each sensor the average temperature difference with the reference sensor was recorded and used for correction. These differences varied from 0.02Ω to 1.0Ω (which corresponds to 0.005°C and 0.26°C respectively). The difference of 0.26°C demonstrates the importance of this experiment because a measurement error of this scale is much too high to be used for the monitoring of heat energy consumption by an individual apartment; the temperature differences in a riser between floors can at times be lower than one third of a degree.

In Fig. 5, the data from a similar experiment are shown. Five sensors were placed in a confined space in a basement room, where air temperature is almost unchanged. Each curve corresponds to one sensor and rises and falls within a range of 0.8Ω (which corresponds to 0.2°C). A similar nature of the curves shows that these are the actual temperature changes. It can be seen that each curve also possesses random fluctuations in a range not wider than 0.1Ω (which corresponds to 0.03°C); this can be used as a simple estimation of the measurement error.

The experiment results showed that PT1000 sensors provided temperature data with measurement error less than 0.03°C; this precision is sufficient for applications in building heating systems.

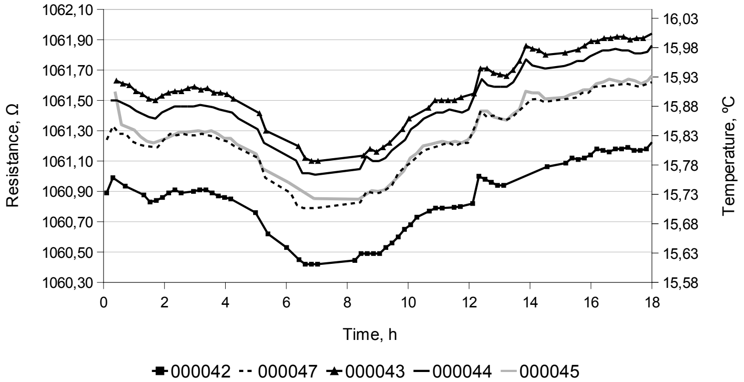

Fig. 5. Data of five temperature sensors demonstrating high precision of temperature measurements by analogue sensors PT1000.

C. Results

Twenty-four-hour temperature measurements of heat carrier in the riser are shown in Fig. 6.

The test experiment was carried out during very last days of a heating season, when in the daytime heating was automatically switched off. Frequent measurements of heat carrier flow show those moments clearly as can be seen in Fig. 7, where a cumulative graph of the volume of heat carrier flown through the riser is depicted; the increase is even when heating is on but increase stops and the graph is flat when heating is switched off.

Temperature and flow data have to be analysed together; Fig. 6 and Fig. 7 show that during the periods when heating is on, the temperature curves of sensors are arranged in the order of sensor placement on the riser, as it was expected. During periods when heating is switched off, some of the curves cross due to different cooling circumstances in premises.

Table 1

The Average Temperature Differences between Floors

Sensor placement	Sensor No.	Temperature, °C	Temperature difference between sensors, °C	Average temperature difference between floors, °C/floor
Attic	000047	35.8	0.82 *(Attic – 7th floor)*	0.27
9th floor	-	-	-	0.27
8th floor	-	-	-	0.27
7th floor	000045	35.0	0.26 *(7th floor – 6th floor)*	0.26
6th floor	000042	34.7	0.50 *(6th floor – 5th floor)*	0.50
5th floor	000044	34.2	1.14 *(5th floor – 3rd floor)*	0.57
4th floor	-	-	-	0.57
3rd floor	000041	33.1	0.72 *(3rd floor – 2nd floor)*	0.72
2nd floor	000043	32.3	-	-

Temperature sensors in the riser were installed in six places: at the floor level in premises on the 2nd, 3rd, 5th, 6th, 7th floors and in the attic. The average temperatures were calculated for the periods when the heating was switched on, see Table 1.

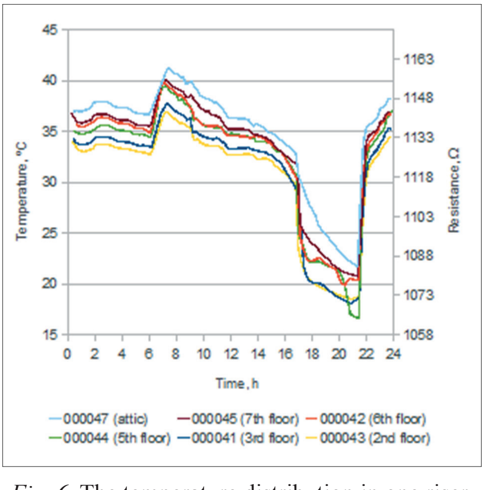

Fig. 6. The temperature distribution in one riser.

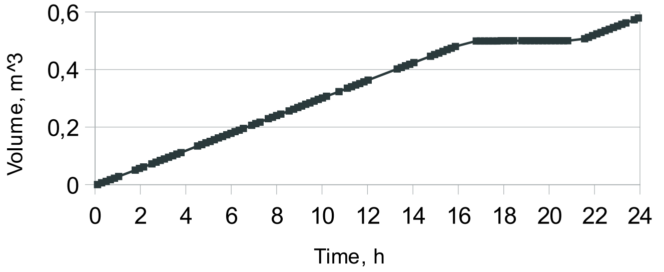

Fig. 7. The amount of heat carrier flown through the riser.

3. CURRENT APPROACH

The trial experiment was carried out at the very end of the heating season when temperature differences in risers between floors was the smallest possible and showed that these differences were not less than 0.25°C. This means that for measurements of average temperature also sensors with somewhat worse accuracy than that of an analogue PT1000 sensor (0.03°C) would be appropriate. The temperature measurements during the trial experiment were performed in sockets of metallic T-pieces that were placed in flow of heat carrier to provide the same conditions for all sensors installed in the riser. An alternative approach can be used where surface temperature sensors are placed under layers of thermal insulation.

Taking both aspects into account, another model of remote temperature measurement units was developed, where digital surface temperature sensors were used, thus reducing the costs of both device production and sensor instalment.

The new temperature measurement unit consists of a radio module placed in a relatively small plastic case and a digital surface temperature sensor DS18B20 attached to it in a wire (Fig. 8). The reading precision of the sensor is 1/16°C.

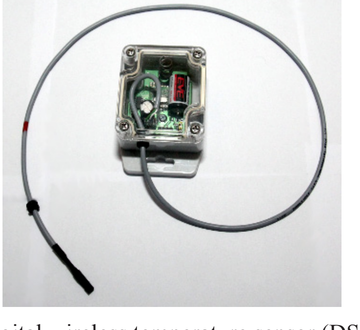

Fig. 8. Digital wireless temperature sensor (DS18B20).

The temperature measurement units with digital surface temperature sensors are currently being tested in another 9-storey building of type No.602 in Riga. New data concentrators with connection to the Internet are being used as well, and several antenna solutions for receivers (concentrators) and data repeaters are being tested. Currently approximately 50 temperature measurement units are being applied to the heating and hot water system in the cellar and attic, and approximately 100 units are being applied to the heating system in apartments of this building.

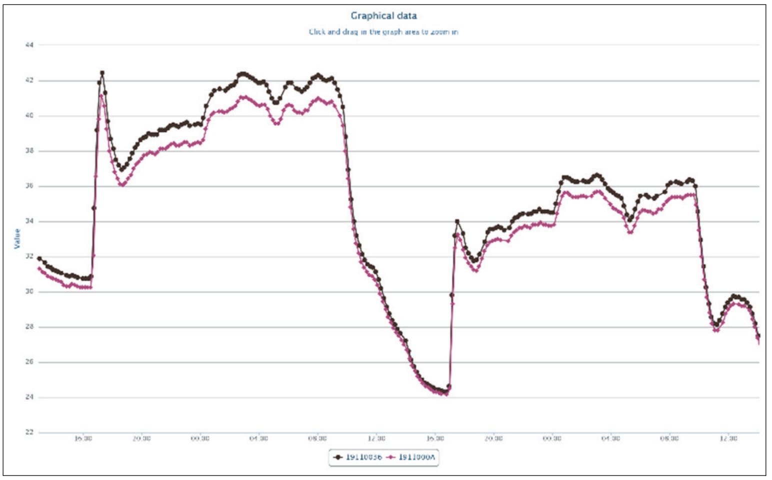

Fig. 9. Temperature of heat carrier in a riser as detected by insulated digital temperature sensors that are applied to the riser surface; data is shown over a time period of 48 hours.

An example of current temperature measurements is show in Fig. 9. The measurement precision of the digital sensors is sufficient and allows detecting the temperature differences between separate points on a riser as well as temperature differences between risers. The temperature differences acquired from one riser then can be used to calculate the heat consumption, and the temperature differences between risers can be used to balance heating system; both options are of great importance in building management.

4. CONCLUSIONS

The approach to obtain the individual heating consumption by measuring temperature and mass flow rate of heat carrier has been successfully tested and the method can be applied in multi-apartment buildings. The analogue PT1000 sensor or digital DS18B20 sensor accuracy is sufficient and the error deviation is tolerable for this particular application.

Wireless temperature sensor network built with either of those sensors together with a real time data stream provides a feasible solution for monitoring the heating system and for balancing risers in multi-apartment buildings.

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TEMPERATŪRAS SENSORU PIELIETOJAMĪBAS IZPĒTE BEZVADU SENSORA TĪKLA IZVEIDEI ENERGOEFEKTĪVAS APKURES SISTĒMAS NODROŠINĀŠANAI DAUDZDZĪVOKĻU ĒKĀS

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Kopsavilkums

Lielākā daļa daudzdzīvokļu ēku ir ar zemu energoefektivitāti, norēķini par apkuri tajās nenotiek pēc individuālā patēriņa, un apkures sistēmām nepieciešama balansēšana. Vairumā šo ēku tiek izmantota apkures sistēma ar vertikālo siltumnesēja sadali, tāpēc siltumenerģijas skaitītāji individuāliem dzīvokļiem nav izmantojami. Šobrīd tirgū pieejamais risinājums – siltuma maksas sadalītāji jeb allokatori, kas nosaka radiatoru atdoto siltumenerģijas daudzumu, ir neprecīzs, jo neievēro caur dzīvokļiem ejošo stāvvadu atdoto siltumenerģijas daudzumu.

Rakstā minēts jauns paņēmiens dzīvokļu individuālā siltumenerģijas patēriņa noteikšanai, izmantojot siltumnesēja temperatūras un plūsmas mērījumus apkures stāvvados (LR patents Nr.14639 “Telpu siltumenerģijas patēriņa noteikšanas paņēmiens ēkās ar vertikālo siltumnesēja sadales sistēmu, izmantojot siltumnesēja temperatūras mērījumus”). Saskaņā ar šo metodi uz dzīvokli attiecināmā siltumenerģijas patēriņa daļa no konkrēta stāvvada ir proporcionāla siltumnesēja temperatūras krituma šajā stāvvadā šajā dzīvoklī un siltumnesēja plūsmas stāvvadā reizinājumam. Patēriņa koeficientu noteikšanai nepieciešami precīzi temperatūras un plūsmas mērījumi.

Metodes pārbaudei tika veikts eksperiments 9-stāvu 602.sērijas ēkā Rīgā. Tā mērķis bija iegūt informāciju par temperatūras sadalījumu stāvvados un temperatūru

starpībām starp stāviem, kā arī pārbaudīt datu radiopārraides apstākļus. Publikācijā aprakstīta eksperimenta gaita un rezultāti, tai skaitā eksperimentā izmantotās iekārtas datu attālinātai nolasīšanai un sensoru izvēles pamatojums. Eksperiments noritēja apkures sezonas beigās, kad temperatūras kritums stāvvados ir neliels. Iegūtās siltumnesēja temperatūras krituma vērtības ir diapazonā no 0.27-0.72°C. Eksperimentā tika lietoti radioraidītājam pieslēgti analogie temperatūras sensori PT1000, kuri tika ievietoti stāvvados iemontētos trejgabalos ar ligzdām. Sensoru mērījumu kļūda tika noteikta ne lielāka par 0.03°C. No eksperimenta datiem redzams, ka vienlaicīgi un bieži siltumnesēja temperatūras un plūsmas mērījumi, nodrošina apkures sistēmas monitoringu.

Šobrīd notiek temperatūras datu iegūšana citā 9-stāvu 602.sērijas ēkā Rīgā, izmantojot nākamās paaudzes iekārtas, t.i., temperatūras nolasītājus ar digitālajiem sensoriem DS18B20 (precizitāte 1/16°C), retranslatorus un datu koncentratorus ar pieslēgumu internetam. Temperatūra tiek mērīta, apmēram, 50 punktos ēkas pagrabā un bēniņos un 100 punktos dzīvokļos; sensori, pievienoti stāvvadu virsmai un nosegti ar siltumizolāciju. Secināts, ka arī šāda mērījumu precizitāte ir pietiekama un temperatūru starpības, kas iegūtas no viena stāvvada, var tikt izmantotas individuālā apkures patēriņa noteikšanai, un temperatūru starpības, kas iegūtas starp dažādiem stāvvadiem, var tikt izmantotas stāvvadu balansēšanai. Abi aspekti ēku apsaimniekošanā ir ļoti nozīmīgi.

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