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# Evaluation of energy-saving effect during the installing process of automated heating stations in educational institutions

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# Evaluation of energy-saving effect during the installing process of automated heating stations in educational institutions

**S A Bychikhin, M V Svirin and P A Trubaev**

Department of Energy Engineering of Heat Technologie, Belgorod State Technological University of V.G. Shukhov, Kostyukov St., 46, Belgorod, 308012, Russia

E-mail: trubaev@gmail.com

**Abstract**. The aim of the work is to assess the energy-saving effect after the installation of automated individual heat points that carry out weather regulation of the heating load. The analysis was carried out for 18 educational institutions of the Belgorod region, in which energy service contracts were implemented in 2016. The data of the actual monthly consumption of heat energy during the basic heating season before the implementation of energy-saving measures and data of daily accounting of heat consumption during the two heating seasons after the installation of automated individual heat points were used. The average unit savings for all institutions was 14 per cent. It is established that the greatest value of economy, 20-30%, provides decrease in temperature in buildings to optimum level. Elimination of" overflows " in the autumn-spring period allows to save 5-10% of thermal energy. The decrease in temperature on non-working days is characterized by a small amount of savings, not more than 3%, or its absence.

**Keywords:** heating, energy saving, individual heating station, educational institutions

## 1. Introduction

In practice, there is a noticeable reduction in energy consumption for heating buildings after the installation of automated individual heat points (IHP), which carry out weather regulation of the heating load. Similar behavior of consumption characteristics trends is observed in a number of publications [1-3], which proves the effectiveness of the method.

Energy is the lifeblood of modern societies. In recent decades, world energy consumption and related CO2 emissions grew rapidly due to the increase in population and meet the needs of people [4]. Due to the high energy consumption, energy efficiency in buildings has become a hot topic since 1970. As the effects of human-induced climate change became more pronounced, local and Federal governments began to pursue more aggressive policies to reduce energy use in existing buildings [5]. Energy saving in buildings is a globally important issue also due to the growing attention to the quality of indoor heat, which is directly related to the quality of life. In areas with a cold climate, there is an even greater problem in increasing the energy efficiency of buildings due to the high demand for heat [6].It is believed that good heat supply from heating companies and the mode of operation of institutions plays an important role in reducing energy consumption in buildings [7].

In modern society, people spend more than 90% of their time indoors. Students spend more time at school, so it is important to ensure comfortable temperature conditions in the room. Thermal comfort is associated with the characteristics of the building and energy saving, which provides the necessary conditions and budget savings, so the analysis of consumption and improvement of the characteristics of buildings have become important in recent years [8]. Low-energy buildings are spreading rapidly throughout Europe. The basic concept of energy saving is based on the improvement of building envelope and the use of high-performance equipment. However, thermal comfort in such buildings will not be fully achieved [9].

The authors of many publications believe that the traditional behavioral model, which does not provide for the need to save energy, is one of the reasons for inefficient heating of buildings [10]. In this regard, modeling of energy consumption in buildings is necessary to mitigate current impacts and to develop policies and technical solutions for the future [11]. At the same time, measures taken in developed countries are insufficient to guarantee a significant reduction in energy consumption in buildings in the coming years. Under the current scenario, by 2050 there will be at least a doubling of global energy demand in buildings compared to today. To avoid this prognosis, it is necessary to disseminate and adopt cost-effective methods and technologies, as well as to change the behavior and lifestyle of the population [12]. The creation of a scientific and rational method of comparative analysis of energy consumption in buildings is the key to an objective, fair and accurate assessment of the energy characteristics of the building [13]. In order to successfully save energy, modernization activities should take into account structural transformations of buildings (e.g. improvement of building envelope, automation of energy systems). The allocation of heating costs according to actual consumption can be one possible solution to save energy. The introduction of automated meters allows consumers to pay only for the delivered heat and allows to analyze the actual heat consumption and regulate the supply depending on the weather conditions in real time and thereby reduce the heat consumption in institutions [14].

Forecasting energy consumption in buildings is essential for planning, managing, and conserving energy. Data-based models provide a practical approach to predicting energy consumption [4]. Forecasting is of great importance for heating, ventilation and air conditioning control tasks, such as optimal operation strategies, etc. compared to traditional methods, data-based methods have received more attention because of their flexibility and efficiency [15].

Conventional approaches to energy management have proven to be inadequate for public buildings. Systematic observations of numerous energy-saving projects have shown that four pillars can be identified that are critical to the success of these projects. They should be used as often as possible and can be specified as follows:

1. Technical expertise: knowledge of the specifics of the object and possible savings on the basis of experience.
2. Quality operational data: on-site data collection.
3. Simulation, simulation and optimization: evaluate different options and choose the most profitable one.
4. Methodology: a systematic approach involving all three remaining pillars.

The application of these recommendations provides an effective way of conducting energy-saving projects [16].

Energy consumption in buildings accounts for approximately 35% of the world's final energy. Educational institutions provide 20-40% of heat energy consumption, which makes it necessary to study their energy characteristics [17]. In some cases, they contribute significantly to local government expenditure. The high level of energy consumption is usually due to the low characteristics of buildings, mode of operation, etc. [18]. Reducing energy consumption in educational institutions is a priority specified in the legislative documents [19].

One of the alternatives to reduce energy consumption in buildings is the conclusion of energy service contracts to improve energy efficiency [20, 22]. A number of publications are devoted to the study of energy efficiency for school and pre-school buildings after the introduction of energy service contracts [21]. An energy service contract can provide a cost-effective way to overcome barriers to energy efficiency. Energy service contracts reduce operating costs. Production costs will be determined by a combination of physical characteristics of the power system and the technical efficiency of the relevant organizational measures [22]. Thus, the automation of heating load regulation, implemented on the basis of the energy service contract, allows for energy saving with minimal cost to the consumer [23]. But for development of model of the power service contract it is necessary to have data on size of economy after installation of the automated individual calorific point (AICP) [24].

The estimation of thermal energy saving depends on the efficiency of the reconstructed heating system and requires detailed information on the value of heat energy consumption depending on climatic parameters. Therefore, in practice, the amount of savings is estimated by analogy using the actual results of the installation of AICP. In the literature and regulatory sources the value of savings is estimated in a very wide range-from 3 to 30% (table 1)

**Table 1.** Value of saving on heating costs with the installation of IHP

| Origin | Value of saving |
|---|---|
| Methodical documents in construction 13-7.2000. Recommendations about the priority low-cost actions providing energy resources saving in housing and public utilities of the city. Are approved by the order of the State Committee for Construction of the Russian Federation of 17.01.2000 No. 5. [In Russian] | 3-5% |
| Eremkin A I, Koroleva T I, Danilin G V, By`zev V V and Averkin A G 2008 *E`konomika e`nergosberezheniya v sistemax otopleniya, ventilyacii i kondicionirovaniya vozduxa* [Energy saving economy in heating systems, ventilation and air conditionings] (Moscow: Izd-vo Associacii stroitel`ny`x vuzov) [In Russian] | 8% |
| Shilkin N V 2007 E`konomicheskie aspekty` vnedreniya individual`ny`x teplovy`x punktov [Economic aspects of introduction of individual thermal points] *E`nergosberezhenie* **3** 12–5 [In Russian] | 15% |
| Gasho E G (general edition) 2016 *Metodicheskie rekomendacii po raschetu e`ffektov ot realizacii meropriyatij po e`nergosberezheniyu i povy`sheniyu e`nergeticheskoj e`ffektivnosti: Spravochno-analiticheskij document* [Methodical recommendations about calculation of effects of realization of actions for energy saving and increase in power efficiency: Help and analytical document] (Moscow: Russian Government Analytical Centre) [In Russian] | 20…30% |
| Vasil`ev G P et al 2015 *Prakticheskoe posobie po povy`sheniyu e`nergeticheskoj e`ffektivnosti mnogokvartirny`x domov (MKD) pri kapital`nom remonte* [Practical grant on increase in power efficiency of apartment houses at major repair.] vol 1 (Moscow: .: GK Fond Sodejstviya Reformirovaniyu ZhKX; OAO «Insolar-invest») [In Russian] | 15% |
| 2004 *E`nergosberezhenie v zhilishhnom fonde: problemy`, praktika i perspektivy* [Energy saving in housing stock: problems, practice and prospects] (Moscow: Dena, Fond «Institut e`konomiki goroda») [In Russian] | 5-10% |
| Prakticheskie rezul`taty` ustanovki ITP v tipovom 9-e`tazhnom 4-pod``ezdnom panel`nom dome [Practical results of the ITP installation in the type 9-storey 4-access apartment house of bearing-wall construction]. URL http://dom-pogoda.ru/automation/primer-ekonomicheskogo-effekta-raboty [In Russian] | 25% |

A number of publications indicate that there is a large difference in the specific energy consumption between different types of schools and pre-school institutions, classified by mode of operation, nature and level [25].

The aim of the work was to assess the actual energy-saving effect after the installation of AICP in educational institutions of the Belgorod region.

The analysis of thermal energy consumption in the spring and autumn seasons [26]. Special attention is paid to the comparison of heat consumption in identical buildings. Awareness of the difference in heat consumption in similar houses can strengthen confidence in energy saving tools and improve the thermal reconstruction of residential and public buildings [27, 28].

## 2. Materials and Methods

The reconstruction of heating systems was carried out in the summer and autumn of 2016 within the framework of energy service contracts. 18 buildings (12 schools and 6 kindergartens) were selected for the analysis, where before the events the heat consumption was taken into account by the instrument method. The buildings had the characteristics shown in the table 2.

**Table 2.** Characteristics of buildings

| Building number | Name of institution | Floors | Area, $m^2$ | Volume, $m^3$ | Wall material* | Start date ESK |
|---|---|---|---|---|---|---|
| 1 | Nursery school # 20 (Razumnoye area) | 2 | 999 | 3702 | P | 01.12.2016 |
| 2 | Nursery school # 7 (Belovskoye area) | 2 | 1334 | 3787 | P | 20.12.2016 |
| 3 | Nursery school # 14 (Golovchino area) | 2 | 1658 | 5706 | SB | 14.10.2016 |
| 4 | Nursery school # 13 (Politotdel'skii area) | 2 | 1984 | 3806 | P | 01.10.2016 |
| 5 | Nursery school # 29 (Krasnyy oktyabr) | 3 | 2700 | 12231 | SB | 20.12.2016 |
| 6 | School of Streletskoye | 2 | 1755 | 5266 | SB | 01.10.2016 |
| 7 | School Pushkarnoe area | 2 | 2150 | 6542 | SB | 16.10.2016 |
| 8 | School Belovskoye area | 2 | 2615 | 8783 | P | 11.11.2016 |
| 9 | School Zhuravlevka area | 2 | 2676 | 6560 | SB | 01.10.2016 |
| 10 | School of Khokhlovo | 2 | 3036 | 7275 | SB | 01.12.2016 |
| 11 | School of Myasoedovo | 2 | 3121 | 9524 | SB | 26.11.2016 |
| 12 | School of Red October | 3 | 4163 | 15654 | P | 01.10.2016 |
| 13 | School # 1 of Razumnoye area | 3 | 5420 | 16285 | P | 15.10.2016 |
| 14 | School of Bessonovka area | 3 | 4780 | 15175 | SB | 20.12.2016 |
| 15 | Otradnenskaya school | 2 | 4854 | 14564 | SB | 20.12.2016 |
| 16 | School #2 of Razumnoe area | 3 | 4389 | 18489 | P | 20.12.2016 |
| 17 | School of Schetinovka area | 3 | 5614 | 22370 | SB | 20.12.2016 |

* P – reinforced concrete panels; SB – silicate brick

The heating season 2015/2016 is adopted as the base period, the estimated periods are the heating seasons 2016/2017 and 2017/2018.

The actual climatic data of the weather station of Belgorod received from the site were used for the calculation of the DDHP https://rp5.ru. The considered periods were characterized by a significant difference in climatic conditions (figure 1).

Therefore, the calculation of savings was given with the reduction of data to comparable conditions using the value of the parameter degree-day heating period $Dd$, °C·day:

$$Dd = D(t_{\text{in}} - t_{out}), \tag{1}$$

where $D$ – the number of days( days) in the period; $t_{\text{in}}$ – the average temperature inside the building, °C; $t_{out}$ – the average ambient temperature in the period, °C.

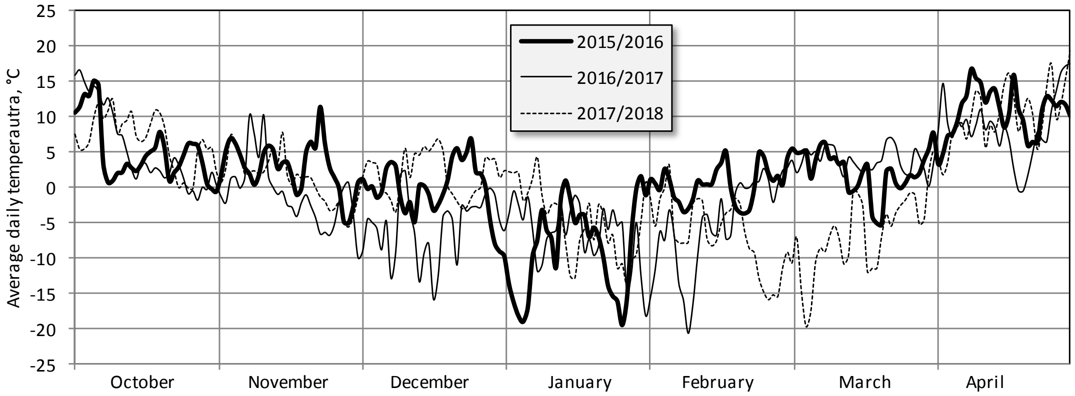


**Figure 1.** Temperature changes during heating periods $t_{out}$

If the period consists of several parts (for example, several heating seasons, or with interruptions in heating or data storage), the total value of the degree-day can be found as the sum of the values for each part of the period:

$$Dd = \Sigma\, Dd_j.$$

If to recalculate the regulatory conditions, the relative thermal energy saving $\Delta q$, %, it will have a look

$$\Delta q = \frac{\frac{Q_b}{Dd_b}Dd_n - \frac{Q_i}{Dd_i}Dd_n}{\frac{Q_b}{Dd_b}Dd_n}100\% \,, \qquad (2)$$

Where $Q_b$ and $Q_i$ – heat consumption in the base and estimated period; $Dd_b$, $Dd_i$ and $Dd_n$ – degree-day of the base period, the estimated period and the normative value for the city of Belgorod 4807 °C•day for preschool and 4183 °C •day for school.
After conversion expression (2) will look like:

$$\Delta q = \left(1 - \frac{Q_i}{Q_б}\frac{Dd_b}{Dd_i}\right)100\%. \qquad (3)$$

The expression (3) will not change if instead of normative conditions recalculation is made on conditions of the base or estimated period, or other conditions.

Information and consumption of thermal energy in buildings for each month of the base period and the duration of the heating period, common to all institutions, were obtained in the district heat supply organization (beginning of the heating season 07.10.2015, ending 11.04.2016, actual $Dd_b$ = 3676 °C•day).

Daily consumption of thermal energy for the estimated periods was obtained using the energy management System of the Belgorod region, which carries out the accumulation and processing of remotely obtained data from heat metering devices. According to the daily consumption, the beginning and the end of heating periods were determined individually for each building. Since the launch of the AICP in different institutions was carried out at different times in the period from October 1, 2016 to December 20, 2016, and for individual metering devices there were interruptions in operation, lasting up to a month, the estimated periods included only those days in which the metering devices worked, so the consumption of thermal energy and DDHP used to calculate the savings could be less than these indicators in the heating season. In the calculations, the air temperature in tin buildings was assumed to be constant and equal to 20°C.

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## 3. Results

The estimated (taken into account in the calculation of savings) heat consumption for the three heating seasons and the resulting specific actual savings per year after the installation of the AICP compared to the base heating season is shown in table 3. The average value of the economy was 14%, the maximum-31%. Savings were not available for individual agencies.

**Table 3.** Thermal energy consumption and the value of saving

| Building number | Volume, $m^3$ | The consumption for the billing period, Gcal (Dd, °C·day) | | | Specific savings Δq |
|---|---|---|---|---|---|
| | | 2015/2016 | 2016/2017 | 2017/2018 | |
| 1 | 3702,2 | 164,8 (3676) | 143,5 (3168) | 163,0 (4145) | 5,6% |
| 2 | 3786,6 | 242,0 (3676) | 139,3 (2656) | 200,0 (3820) | 20,4% |
| 3 | 5705,6 | 277,7 (3676) | 288,2 (4129) | 255,2 (3995) | 11,4% |
| 4 | 3806,3 | 214,8 (3676) | 227,0 (4171) | 195,5 (3864) | 10,1% |
| 5 | 12231,0 | 350,7 (3676) | 243,9 (2656) | 404,0 (4102) | 0,3% |
| 6 | 5266,2 | 299,9 (3676) | 215,0 (4094) | 259,3 (3728) | 25,2% |
| 7 | 6542,4 | 253,1 (3676) | 267,5 (3987) | 268,6 (4133) | 4,1% |
| 8 | 8783,0 | 352,7 (3676) | 276,5 (3628) | 307,7 (3832) | 18,4% |
| 9 | 6559,8 | 280,8 (3676) | 300,9 (4242) | 275,1 (4087) | 9,4% |
| 10 | 7275,0 | 586,8 (3676) | 372,1 (3175) | 320,7 (3188) | 31,8% |
| 11 | 9523,9 | 348,6 (3676) | 296,3 (3290) | 354,3 (4066) | 6,6% |
| 12 | 15653,6 | 675,4 (3676) | 483,3 (3208) | 573,7 (4151) | 21,4% |
| 13 | 18489,3 | 616,3 (3676) | 381,9 (2656) | 599,9 (4119) | 13,7% |
| 14 | 15175,4 | 522,9 (3676) | 360,5 (2666) | 437,7 (4104) | 15,0% |
| 15 | 14564,4 | 357,6 (3676) | 185,8 (2656) | 321,0 (4133) | 24,1% |
| 16 | 16284,8 | 617,3 (3676) | 695,9 (3987) | 690,1 (4073) | -2,4% |
| 17 | 22370,4 | 707,9 (3676) | 405,6 (2656) | 617,4 (3987) | 20,1% |

There is no dependence of the saving value $\Delta q$ on the area, volume or heat consumption (correlation coefficients, respectively, 0,04; 0,08; 0,25), but the saving depends on the specific heating characteristics $q_{sp}$, Вт/($m^3$·K), figure 2, which for the building should be a constant value:

$$q_{sp} = \frac{4{,}186 \cdot 10^9}{24 \cdot 60 \cdot 60} \frac{Q}{V\ Dd} = 48449 \frac{Q}{V\ Dd}, \quad (4)$$

where $Q$ – heat consumption for heating, Gkal; $V$ – volume, $m^3$.

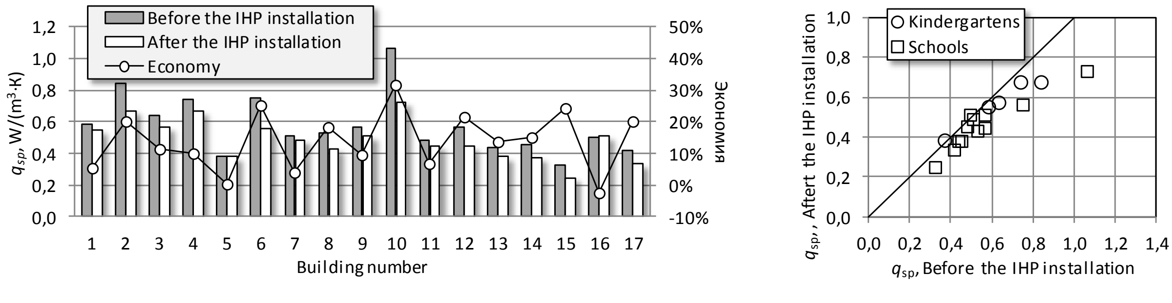


**Figure 2.** The change of the specific heat characteristics of buildings (taken at a constant temperature of the internal air 20°C)

The correlation coefficient between economy and specific heat characteristic is 0, 93 for kindergartens and 0,45 for schools (figure 3).

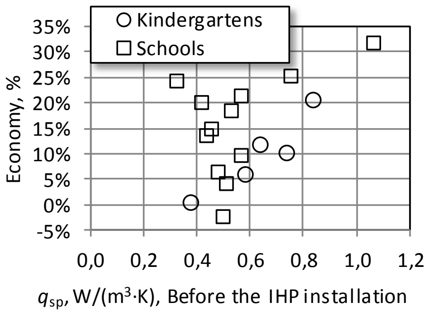


**Figure 3.** The relationship between savings and specific heat characteristics

## 4. Discussion

Analyzing the changes in characteristics before and after the installation of AICP, three cases can be distinguished.

1. The heating load of the building (the dependence of the heating consumption on the outside temperature) is regulated both in the base period and in the estimated period, but the heat energy consumption for heating is reduced (figures 4, 5), which is typical for buildings # 2 (economy is 20 %); 6 (25%); 8 (18%); 10 (32%); 15 (24%).

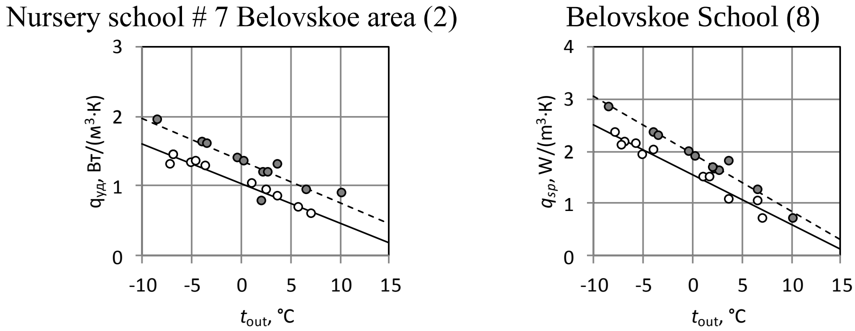


**Figure 4.** The heating feature: •, --- – before installing AICP; ◦, — – after installing AICP

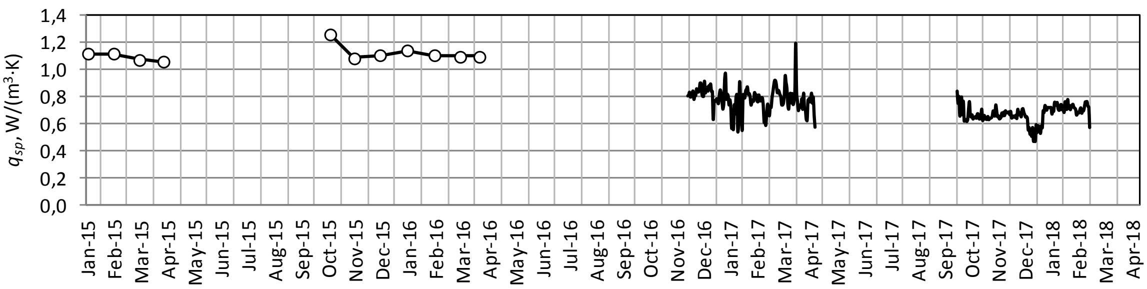


**Figure 5.** Change in specific heating characteristics for Khokhlovskaya secondary schools (# 10)

In this case, the savings achieved by the elimination of the constant "overheating" and reduce the temperature in the building increased to the optimum. For the conditions of the city of Belgorod the average outdoor temperature during the heating season close to 0°C, so the change of temperature inside the building 1 °C with leads to a change in consumption for heating by approximately 5%. There-

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fore, we can assume that prior to the installation AICP the temperature in the buildings was about 24 °C.

2. The heating load of the building was not adjusted before the events (Fig. 6, 7), which is typical for buildings # 3 (economy 11%); 4 (10%); 5 (0%); 7 (4%); 9 (9%); 11 (7%); 12 (21%); 13 (14%); 17 (20%)

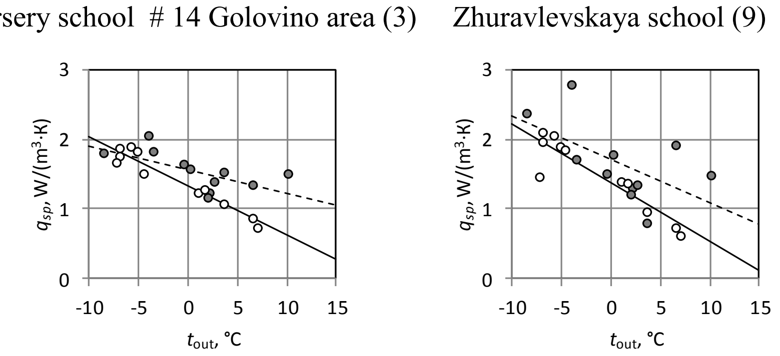


**Figure 6.** Heating characteristic:
• , --- – before installing AICP; ◦, — – after installing AICP

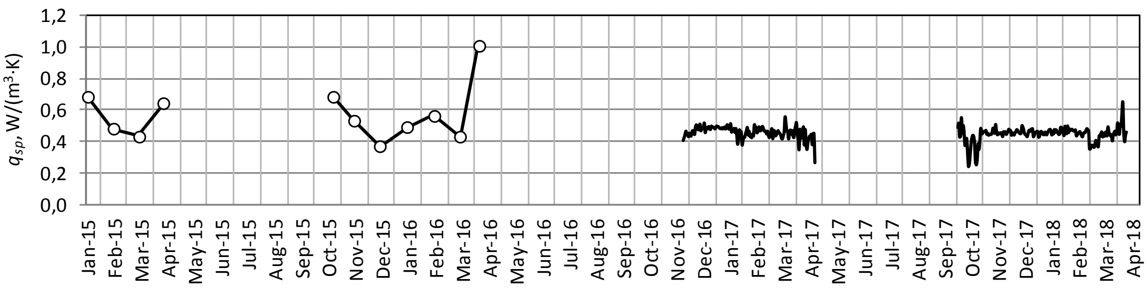


**Figure 7.** Change of specific heating characteristic for Myasoyedov Secondary School (# 11)

In this case, the savings achieved by the elimination of periodic "overheating" at the beginning and end of the heating season. On parts of buildings additional savings is also determined by the reduction of the constantly high temperature in the building to the optimum.

3. There were no savings in buildings 5 and 16 (Figure 6).

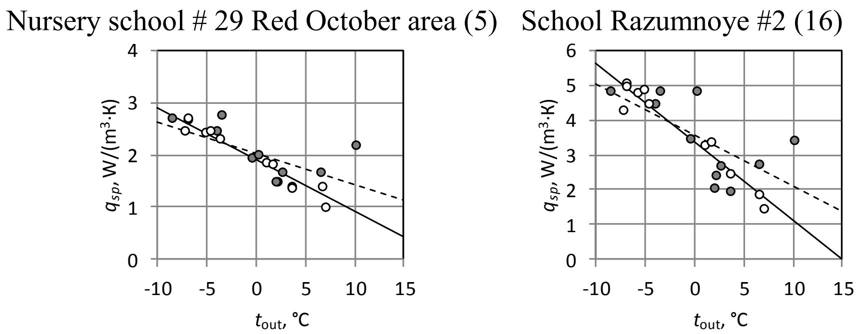


**Figure 8.** The heating feature: • , --- – before installing AICP;
◦, — – after installing AICP

In this case, it can be assumed that before the events in the buildings was below the standard temperature.

Setting the AICP involves reducing the temperature on holidays and weekends. For each building for the period of two years, the average value of the specific heating characteristics was calculated separately for non-working and working days, as well as the specific heating characteristics on the first non-working day after the working day and on the first working day following the non-working day (table 4).

**Table 4.** Average specific heating characteristics (calculation periods 2016/2017 and 2017/2018)

| Building number | The specific heating characteristics $q_{sp}$, W/(m$^3$·K) | | | | | Relation to the average heating characteristic | | | |
|---|---|---|---|---|---|---|---|---|---|
| | average | working days | on non-working days | on the first non-working day | on the first working day | working days | on non-working days | on the first non-working day | on the first working day |
| 1 | 0,542 | 0,556 | 0,551 | 0,560 | 0,547 | 103% | 102% | 103% | 101% |
| 2 | 0,668 | 0,662 | 0,679 | 0,667 | 0,670 | 99% | 102% | 100% | 100% |
| 3 | 0,568 | 0,575 | 0,553 | 0,589 | 0,554 | 101% | 97% | 104% | 98% |
| 4 | 0,672 | 0,669 | 0,679 | 0,701 | 0,664 | 100% | 101% | 104% | 99% |
| 5 | 0,384 | 0,388 | 0,376 | 0,386 | 0,383 | 101% | 98% | 101% | 100% |
| 6 | 0,557 | 0,558 | 0,555 | 0,564 | 0,548 | 100% | 100% | 101% | 98% |
| 7 | 0,484 | 0,486 | 0,479 | 0,499 | 0,472 | 100% | 99% | 103% | 98% |
| 8 | 0,423 | 0,430 | 0,411 | 0,428 | 0,407 | 101% | 97% | 101% | 96% |
| 9 | 0,499 | 0,508 | 0,498 | 0,531 | 0,490 | 102% | 100% | 106% | 98% |
| 10 | 0,719 | 0,726 | 0,706 | 0,731 | 0,711 | 101% | 98% | 102% | 99% |
| 11 | 0,449 | 0,450 | 0,448 | 0,460 | 0,442 | 100% | 100% | 102% | 98% |
| 12 | 0,448 | 0,446 | 0,453 | 0,451 | 0,446 | 99% | 101% | 101% | 100% |
| 13 | 0,374 | 0,382 | 0,360 | 0,387 | 0,355 | 102% | 96% | 103% | 95% |
| 14 | 0,375 | 0,390 | 0,362 | 0,400 | 0,358 | 104% | 97% | 107% | 95% |
| 15 | 0,248 | 0,251 | 0,243 | 0,250 | 0,243 | 101% | 98% | 101% | 98% |
| 16 | 0,497 | 0,501 | 0,489 | 0,507 | 0,478 | 101% | 98% | 102% | 96% |
| 17 | 0,332 | 0,344 | 0,319 | 0,333 | 0,308 | 103% | 96% | 100% | 93% |
| Average | 0,485 | 0,489 | 0,480 | 0,497 | 0,475 | 101% | 99% | 102% | 98% |

Economy is characterized by the relation of heating characteristic in the non-working days (weekends) $q_{sp\ nw}$ and in the working days $q_{sp\ w}$. This ratio makes from 0.93 to 1. The value 0.93 corresponds to saving 7%. The value 1 shows lack of economy. For objects number 1, 7, 10 a ratio more than 1 (respectively 1.03; 1.02; 1.01).

Economy was in standard conditions as a difference the difference of expenses without decrease in a heating load to the actual costs of heating:

$$\Delta q = \frac{q_{sp\ w}(n_w + n_{nw}) - (q_{sp\ w}n_w + q_{sp\ nw}n_{nw})}{q_{sp\ w}(n_w + n_{nw})}100\% = \left(1 - \frac{q_{sp\ w}n_w + q_{sp\ nw}n_{nw}}{q_{sp\ w}(n_w + n_{nw})}\right)100\%,$$

where $n_w$ – number of the working days; $n_{nw}$ – number of the non-working days (weekends).

Results of definition of economy are presented on Figure 9.

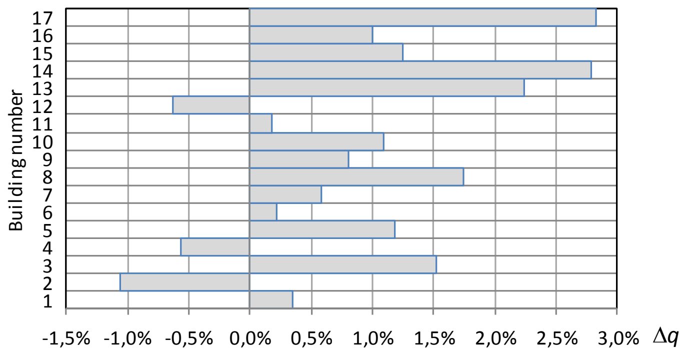


**Figure 9.** Economy at decrease in a heating load on the non-working days (weekends)

Average economy at decrease in temperature in buildings in down time has made 0.9%.

The expense of heat raised in the first working day in comparison with average (Figure 10). The over expenditure has made 6-7% for the most part of buildings. The over expenditure did not depend on economy size.

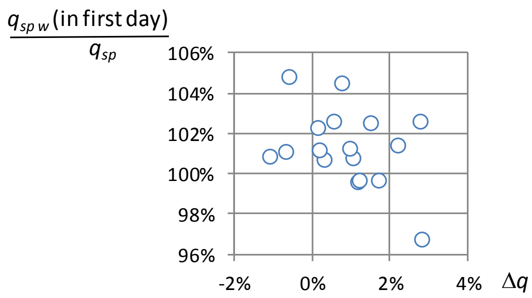


**Figure 10.** The relation of economy of thermal energy of $\Delta q$ to an over expenditure of thermal energy in the first working day after weekends

The average decrease in heating heat consumption on the first non-working day was accompanied by an increase in heating consumption on the first working day after non-working days. That is, the resulting savings were subsequently offset by increased heating costs to warm up the building after non-working days.

## 5. Conclusion

In work for 18 educational institutions of the Belgorod region on the basis of the actual data of metering devices the analysis of economy of thermal energy after installation in organizations of the automated individual calorific points performing weather regulation of heating loading is made. The average unit savings for all institutions was 14 per cent. It is established that the greatest value of economy, 20-30%, provides temperature reduction in buildings to an optimum level. Elimination of" overflows " in the autumn-spring period allows to save 5-10% of thermal energy. The decrease in temperature on non-working days is characterized by a small amount of savings, not more than 3%, or its absence.

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