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EFFICIENCY OF AUTONOMOUS HEATING SYSTEM IN INTERMITTENT MODE WITH HEAT ACCUMULATOR

Г. Баласанян, А. Семеній. **Ефективність автономної системи опалення в переривчатому режимі з акумулятором тепла.** Досліджено ефективність автономної системи опалення в переривчатому режимі з акумулятором тепла будівлі навчального корпусу національного університету «Одеська політехніка». Сформульовано основні вимоги щодо розв'язання завдання оптимізації процесу обігріву приміщення. Розглянуто шляхи щодо підвищення ефективності ранкового обігріву приміщення. На підставі розробленої математичної моделі динаміки теплових процесів елементів автономної системи опалення досліджено режими теплового навантаження системи опалення при зміні температури зовнішнього повітря. Запропоновано основні напрями удосконалення теплозабезпечення будівель в режимі переривчастого опалення та враховано їх практичне застосування при моделюванні та дослідженні системи. Наведено результати оптимізації добових графіків навантаження основних елементів автономної системи опалення при змінних зовнішніх умовах. Наведено оптимальні добові графіки динаміки температури повітря у приміщенні та температури мережної води системи опалення. Досліджено залежність коефіцієнта заповнення графіка навантаження системи опалення та генератора тепла від температури зовнішнього повітря в межах від 5 до –15 °C. Досліджено вплив добового акумулювання тепла на зниження номінальної теплової потужності генератора тепла. Виконано оцінку економії тепла за результатами оптимізації режимів навантаження запропонованої системи в режимі переривчастого опалення в порівнянні з цілодобовим режимом опалення, що склала відповідно 25,2 %. На підставі результатів дослідження зроблено висновок, що добове акумулювання тепла для систем опалення, що працюють у переривчастому режимі, є дієвим заходом щодо підвищення ефективності ранкового обігріву приміщення, досягнення максимально можливої теплової потужності системи опалення під час обігріву та скорочення його тривалості до 1 год.
Ключові слова: режим переривчастого опалення, математичне моделювання, акумулювання тепла, ранковий обігрів приміщення, коефіцієнта заповнення графіка навантаження, оптимізація режимів навантаження

H. Balasanian, A. Semenyii. **Efficiency of an autonomous heating system in intermittent mode with a heat accumulator.** The effectiveness of the autonomous heating system in intermittent mode with a heat accumulator of the building of the educational building of the Odessa National Polytechnic University was studied. The main requirements for solving the task of optimizing the room heating process are formulated. Ways to increase the efficiency of morning room heating are considered. On the basis of the developed mathematical model of the dynamics of thermal processes of the elements of the autonomous heating system, the regimes of the thermal load of the heating system when the temperature of the outside air changes are investigated. The main directions for improving the heat supply of buildings in the mode of intermittent-frequent heating are proposed and their practical application in modeling and research of the system is taken into account. The results of optimizing the daily load schedules of the main elements of the autonomous heating system under variable external conditions are presented. The optimal daily schedules of the dynamics of indoor air temperature and network water temperature of the heating system are given. The dependence of the filling factor of the load schedule of the heating system and the heat generator on the outside air temperature in the range from 5 to –15 °C was studied. The effect of daily heat accumulation on the reduction of the nominal thermal power of the heat generator was studied. Heat savings were evaluated based on the results of optimization of load modes of the proposed system in the intermittent heating mode compared to the 24-hour heating mode, which amounted to 25.2%, respectively. Based on the results of the study, it was concluded that daily heat accumulation for heating systems operating in intermittent mode is an effective measure for increasing the efficiency of morning room heating, achieving the maximum possible thermal power of the heating system during heating and reducing its duration to 1 hour.
Keywords: intermittent heating mode, mathematical modeling, heat accumulation, morning heating of the room, load schedule filling factor, optimization of load modes

Introduction

For office, administrative, educational, industrial buildings, etc., in order to save heat costs during the day and on weekends, some reduction of the room temperature below the normative value will be used by turning off or significantly reducing the power of the heating system. This mode of "intermittent" heating allows you to save costs. To implement the intermittent heating mode, it is necessary to control the power of the heating system, which limits the range of application of this mode. Thus, when the building is supplied with heat from a thermal power plant, the implementation of the intermittent heating mode is impossible due to the use of qualitative regulation at the source, which does not provide a reserve of thermal power for the functioning of the system. Therefore, the most favorable conditions for the implementation of the intermittent heating regime exist for buildings with autonomous heat supply systems [1].

Analysis of literary data and statement of the problem

To a large extent, the effectiveness of using the intermittent heating regime is determined by one of its main stages – morning heating of the room. Theoretical and experimental studies of the heating

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mode [2, 3] show that the main requirement for its efficiency is to achieve a comfortable temperature in the room t_{ro} in a minimum time with a minimum heat consumption. The solution of such a task is carried out using the theory of optimal control – Pontryagin's maximum principle [4]. The result of the solution is the optimal time for the start of morning heating and the maximum possible thermal power of the heating system Q_{op}^{max} during this period.

The fulfillment of this requirement has certain limitations, which are primarily determined by:

– nominal installed heat capacity Q_{hg}^{nom} of the heat generator in the heating system;

– the maximum operating value of the temperature of the network water of the heating system t_{op}^{max};

– type and characteristics of heating devices.

There are many options for technical solutions to overcome these limitations, the most common of them are:

– increasing the nominal thermal power of the heat generator with "reserve" by 1.5...2 times;

– installation of an additional separate heating system of the appropriate capacity to provide only morning heating;

– use of daily heat accumulation for morning heating, etc.

The implementation of the specified technical solutions usually requires significant additional capital costs, however, the use of heat storage is a fairly effective and relatively low-cost means of increasing heating efficiency. The use of heat accumulators is a fairly common solution in autonomous systems of energy supply and on-time work [5]. However, the author of the paper suggests using heat accumulation only to compensate for the system's generation capacity deficit in certain periods of the day. Based on the results of research in [6], the author makes an objective conclusion about the need to increase the power of the intermittent heating system during the heating period, but does not propose the use of heat storage itself. The main conclusion of the authors based on the results of research in work [7] is that the thermal energy accumulator can be used to regulate the load of the heating system, to equalize the load on the energy generation source to ensure peak heat needs with a high utilization factor of the equipment capacity. But the effect of heat accumulation on the efficiency of the intermittent heating mode was not investigated in the work.

The given analysis of the problem indicates the lack of specific studies on the impact of daily heat accumulation on the efficiency of morning heating of premises with intermittent heating mode, as an effective and relatively low-cost means.

The purpose and objectives of the research

The purpose of this work is to optimize the load modes of an autonomous intermittent heating system (AIHS) with a heat accumulator in order to determine the optimal energy efficiency operating modes of the main elements of the AIHS and the system as a whole. To achieve this goal, the following tasks must be solved:

– to determine the criteria for optimizing the load modes of the main elements of the heating system in intermittent mode during mathematical modeling;

– to investigate the influence of daily heat accumulation on the load regimes of the heating system;

– to determine the dependence of the nominal power of the heat generator of the heating system under variable external conditions, taking into account the daily accumulation of heat.

Research materials and methods

The object of the study is the heating system operating on the principle of intermittent heating of the building of the educational building of the Odessa National Polytechnic University. The parameters of the building of the heat engineering laboratory of Odessa National Polytechnic University are given in [8].

Mathematical models of the system elements, given in [9], were used for the simulation of AIHS modes.

In order to achieve the maximum efficiency of the intermittent heating mode, the main directions for improving the heat supply of buildings in the intermittent heating mode were also applied in the simulation of AIHS, namely:

– thermal modernization of the building with an external layer of thermal insulation of 0.1 m, and internal thermal insulation with a thickness of 0.02 m;

– heat accumulation, both for effective heating of the room and for a significant reduction of the maximum power of the heat generator in the system;

– use of low-inertia heating devices – fan coils.

The configuration of the studied system is given in Fig. 1.

The heat accumulator at AIHS works around the clock: during heating and during working hours – in discharge mode, during non-working hours – in charging mode. Such use requires a significant volume of it, which according to calculations is 8 m^3. The maximum battery charging temperature is 75 °C.

As a heat generator, you can use a gas boiler, an electric boiler, a powerful heat pump, and others that provide charging of a heat accumulator up to a temperature of 75 °C. For this AIHS, due to reaching the maximum value of the filling factor of the load schedule of the heat generator (round-the-clock operation at the minimum temperature of the outside air t_{out} = –15 °C), its maximum power does not exceed Q_{op}^{max} = 17 kW.

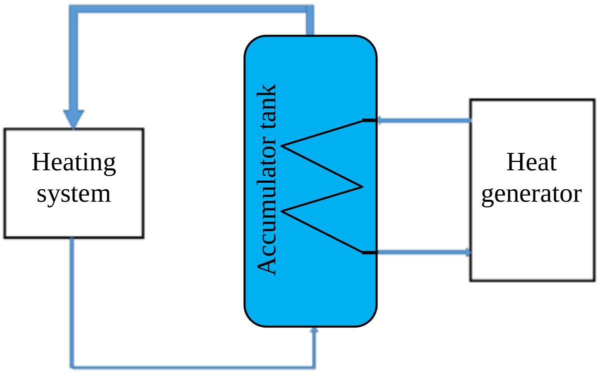

Fig. 1. The structure of AIHS regarding the optimization of load modes

The study was conducted in the range of changes in the average daily outdoor air temperature from –15 to +5 °C.

The problem of optimization of the heating duration was solved by searching for the conditional extremum of the function of many variables using the mathematical apparatus embedded in the Excel spreadsheets in the "Search for a solution" option.

The task of optimizing the heating duration is part of a more complex task of daily optimization of the heating system load [10], which as the following general form:

$$\begin{cases} \sum_{i=0}^{23} Q_i^{op} \to \min \text{ (TF)}; \\ \dfrac{dy_1}{dt} = f_1(x_1, ..., x_n) \text{ (DE)}; \\ \vdots \\ \dfrac{dy_j}{dt} = f_1(x_1, ..., x_n); \\ F(x_1, ..., x_n) \text{ (MD)}; \\ x_{i_{\min}} \le x_i \le x_{i_{\max}} \text{ (Constraints)}; \\ i = \overline{0, 23}, \end{cases}$$

where TF – the target function is the total consumption of heat for heating per day;

DE – differential equations describing the dynamics of processes in system elements [9];

MD – the corresponding mathematical description that connects the variables in the mathematical model;

Constraints – the upper and lower limits of variables in a mathematical model;

i – time of day number.

Research results

The solution to the optimization problem is provided in the form of daily schedules of the heat load of the heating system.

Fig. 2 shows the optimal daily schedule of the AIHS load at t_{out} = –15 °C.

Thanks to the implementation of measures to increase the efficiency of the intermittent heating regime, even at t_{out} = –15 °C, the heating time does not exceed 1 hour, and the thermal power of the heating system during working hours is Q_{op} = 25...48 kW.

Fig. 3 shows the daily load schedule of the heat generator.

Optimization of the load schedule of the heat generator made it possible to reduce its maximum power to 17 kW and reach the value of the schedule filling factor K_{fil} = 0.78. At the same time, the heat generator works at minimum power only from 4:00 a.m. to 7:00 a.m. in order to compensate for heat loss in the battery due to its self-discharge.

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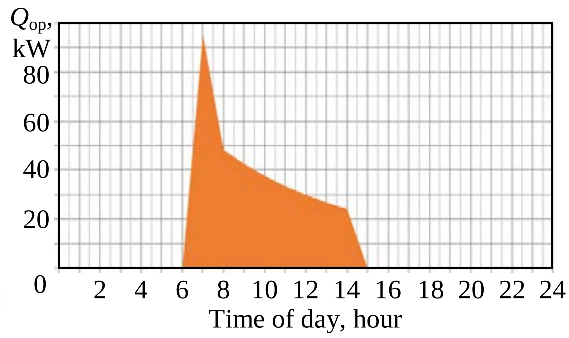

Fig. 2. Daily schedule of AIHS load at t_{out} = –15 °C

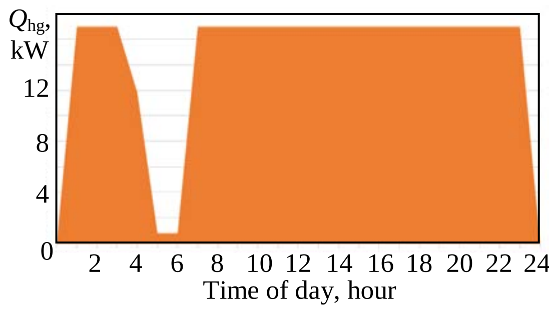

Fig. 3. Daily load schedule of the heat generator at t_{out} = –15 °C

Fig. 4 shows the daily temperature schedule of the heat carrier in the heat accumulator at t_{out} = –15 °C.

Analysis of Fig. 4 shows that the charging of the heat accumulator continues from non-working hours from 3 p.m. to 4 a.m. to a temperature of 75 °C, then from 4 a.m. to 7 a.m. the battery does not work, it maintains a charging temperature of 75 °C, and from 7 a.m. it begins intensive discharge during heating and further discharge during working hours. The minimum temperature in the accumulator tank is 53 °C at 15.00. During the discharge of the accumulator tank, the heat generator works, which slows down this process.

Fig. 5 shows the daily schedule of indoor air temperature changes. The minimum temperature t_{ro} =8 °C is observed before the start of heating at 7:00 a.m., the working temperature in the room, thanks to the measures regarding heating efficiency, t_{ro} = 20 °C is reached in 1 hour of heating.

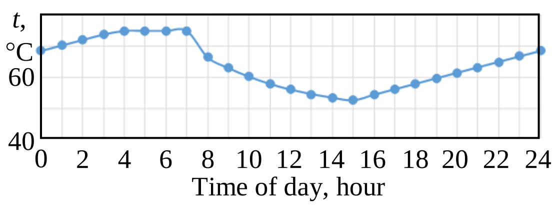

Fig. 4. Daily temperature graph of the heat accumulator at t_{out} = –15 °C

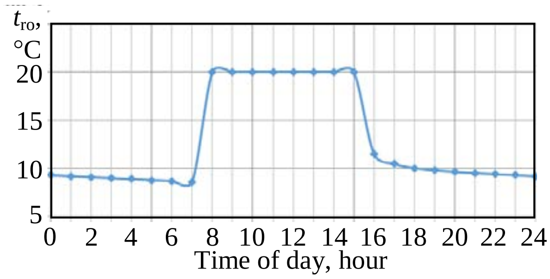

Fig. 5. Daily schedule of indoor air temperature changes

Fig. 6 shows the daily schedule of changes in the temperature of the mains water in the heating system. The maximum value of the direct network water temperature t_{mw} = 72 °C is observed at the moment of the start of heating, at the end of the working time the temperature of the direct network water is t_{mw} = 37 °C.

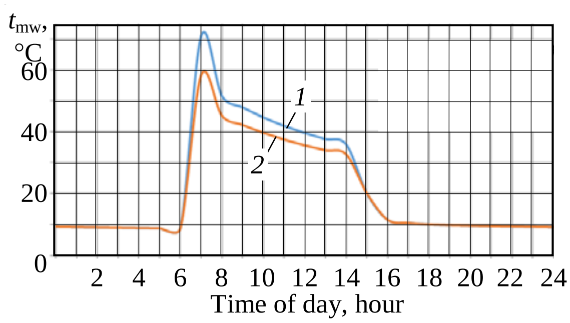

Fig. 6. Daily schedule of changes in the temperature of mains water in the heating system: *1* – Direct mains water; *2* – Return mains water

Regulation t_{mw} is carried out by a three-way valve by mixing return water with hot water from the storage tank.

Modeling of AIHS load modes was also carried out accordingly at different average daily outdoor air temperatures t_{out} = –10; –5; 0 and +5 °C.

Fig. 7 shows the daily schedule of the AIHS load at t_{out}= +5 °C, as an option at the maximum value of the outside air temperature.

Under such favorable external conditions, the maximum thermal power of the AIHS during heating is 40 kW, and during working hours, respectively, 10...20 kW.

Fig. 8 shows the daily schedule of air temperature changes in the room at t_{out} = +5 °C. The minimum temperature in the room t_{ro} = 15 °C is observed before the start of heating at 7.00, the working temperature in the room t_{ro} = 20 °C is also reached after 1 hour of heating.

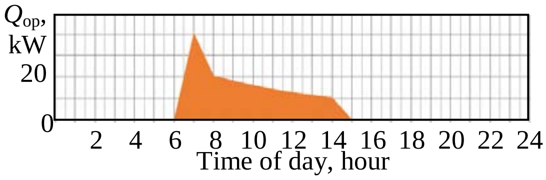

Fig. 7. Daily schedule of AIHS load at t_{out} = +5 °C

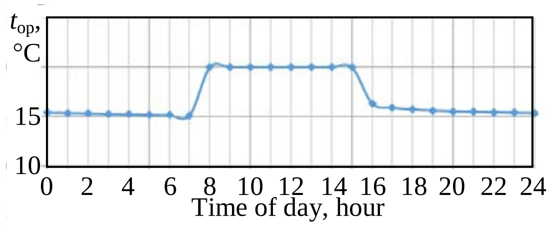

Fig. 8. Daily schedule of air temperature changes in the room at t_{out} = +5 °C

Fig. 9 shows the dependence of the filling factor K_{fi1} of the load schedule of the heating system and the heat generator on the outside air temperature t_{out}. The value of the filling factor of the load schedule of the heating system is in the range of 0.09...0.2, which is very low and leads to irrational use of the power of the heat generator and significant capital costs for it. But thanks to the daily accumulation of heat and the optimization of the power of the heat generator, it was possible to achieve the value of the filling factor of the load schedule of the heat generator in the range of 0.4...0.78 and reduce the maximum power of the heat generator in comparison with the maximum power of the heating system by 2.4...5.6 times (Fig. 10).

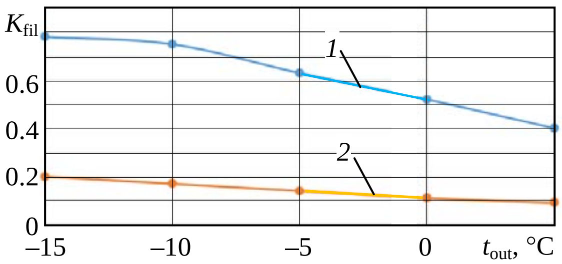

Fig. 9. Dependence of the filling factor of the load schedule of the heating system and the heat generator on the outside air temperature: *1* – heat generator; *2* – heating system

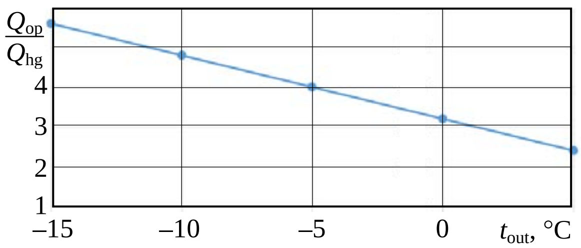

Fig. 10. Dependence of the ratio of the maximum load of the heating system Q_{op}^{max} to the maximum load of the heat generator Q_{hg}^{max} on the outside air temperature

According to the results of the optimization of AIHS in the intermittent heating mode, the daily heat saving compared to the 24-hour heating mode was ΔE = 25.2%.

Conclusions

1. Daily accumulation of heat for heating systems operating in intermittent mode is an effective measure to increase the efficiency of morning room heating, achieve the maximum possible thermal power of the heating system during heating and reduce its duration to 1 hour;

2. Accumulation of heat makes it possible to significantly increase the filling factor of the schedule of the daily load of the K_{fil} heat generator to values of 0.4...0.8, which is quite a significant result for intermittent heating mode;

3. Due to the daily accumulation of heat, the ratio of the maximum load of the heating system Q_{op}^{max} to the maximum load of the heat generator Q_{hg}^{max} can reach 2.5...5.5 times, which, accordingly, significantly reduces the nominal thermal power of the heat generator and, accordingly, the capital costs of the system heating.

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