ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

ENERGETICS

ЕНЕРГЕТИКА

UDC 621.577

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SIMULATION OF INTERMITTENT HEATING MODE OF THE EDUCATIONAL BUILDING

Г.А. Баласанян, О.А. Климчук, А.А Семеній, Є.С Бабаєв, Л.В. Саченко. **Моделювання режиму переривчастого опалення будівлі навчального корпусу.** Запропоновано алгоритм роботи системи теплопостачання в режимі переривчастого опалення, який враховує особливості експлуатації будівлі. Мета роботи – оцінка ефективності використання режиму переривчастого опалення для навчального корпусу теплотехнічної лабораторії Державного університету «Одеська політехніка». В даний час реалізується проект з відключення теплопостачання від котельні Університету та переведення корпусу теплотехнічної лабораторії Університету на автономне теплопостачання на базі конденсаційного настінного газового котла. Комбінована система опалення з використанням різних опалювальних приладів (радіатори, фенкойли, кліматична панель, система «тепла підлога») дозволяє проводити дослідження динаміки нагріву приміщень лабораторії при різних варіантах теплової ізоляції та екранування зовнішніх та внутрішніх стін. В роботі проаналізовано фактори, щодо зниження енергозатрат в режимі програмного теплопостачання. Виконано моделювання режимів роботи генератора теплоти системи теплозабезпечення, що працює в режимі переривчастого опалення. Запропоновано математичну модель динаміки нагріву повітря в приміщеннях з урахуванням особливостей режимів роботи та різних типів опалювальних пристроїв у складі системи теплопостачання. Для різних кліматичних умов проведено математичне моделювання режимів експлуатації системи опалення та отримано показники ефективності роботи системи. Досліджено потенціал економії енергоресурсів для адміністративних, навчальних, офісних будівель в залежності від теплоакумулюючих властивостей конструкцій зовнішніх та внутрішніх стін. Підтверджено доцільність використання принципу максимуму Понтрягіна щодо підвищення ефективності ранкового натопу будівель з різними . постійними часу акумулювання.
Ключові слова: система теплопостачання, переривчасте опалення, режим експлуатації будівлі, ранковий натоп

G. Balasanian, O. Klymchuk, A. Semenii, Ye. Babaiev, L. Sachenko. **Simulation of intermittent heating mode of the educational building.** The algorithm of operation of the heat supply system in the mode of intermittent heating which considers features of operation of the building is offered. The purpose of the work is to assess the effectiveness of the use of intermittent heating for the educational building of the thermal laboratory of the Odessa Polytechnic State University. Currently, a project is being implemented to disconnect heat supply from the University boiler room and transfer the building of the University's heating laboratory to autonomous heat supply based on a condensing wall-mounted gas boiler. The combined heating system with the use of different heating devices (radiators, fan coils, climate panel, “underfloor heating” system) allows to study the dynamics of heating the laboratory premises with different thermal insulation and shielding of external and internal walls. The factors of reduction of energy consumption in the mode of program heat supply are analyzed in the work. Modeling of modes of operation of the heat generator of the heat supply system operating in the mode of intermittent heating is executed. The mathematical model of dynamics of heating of air in rooms taking into account features of operating modes and various types of heating devices as a part of system of heat supply is offered. For different climatic conditions the mathematical modeling of operating modes of the heating system is carried out and indicators of efficiency of work of system are received. The potential of energy saving for administrative, educational, office buildings depending on the heat-accumulating properties of external and internal wall structures has been studied. The expediency of using the Pontryagin maximum principle to increase the efficiency of morning flooding of buildings with different ones has been confirmed. accumulation time constants.
Keywords: heat supply system, intermittent heating, building operation mode, morning flood

Introduction

For administrative, educational institutions, as well as office buildings, one of the ways to reduce energy consumption for heating is to use the mode of intermittent heating of the building. It is based on lowering the indoor temperature during the absence of people. Then, at a certain point, the heating

DOI: 10.15276/opu.2.64.2021.03

system is turned on to heat the air to a comfortable temperature until people arrive in the room. Daily regulation of room temperature is the least expensive. But the wide application of this regime requires the definition of the main directions for saving energy for heating.

Analysis of recent research and publications

A number of scientific works have been devoted to the study of intermittent heating for energy saving [1, 2, 3]. Thus, in [1] the author considers a room of 34 m^2 as an object of study and concludes that the potential for saving 2…9 % of thermal energy, which raises some doubts about the possibility of generalizing the results of the study for the whole building. [2] Considers the problem of optimal control of space heating, the volume of which does not exceed 50 m^3, which also imposes certain restrictions on the generalization of results. The analysis of other researches [3] testifies that the question of complex application of the specified heating mode taking into account thermophysical properties of heating systems, inertial properties of building constructions and modes of operation of buildings is insufficiently studied.

The potential for reducing the energy consumption of intermittent heating is a debatable issue, as it depends on many factors, the main of which are:

– thermal inertia of the building;

– the duration of working time indoors;

– maximum thermal productivity of the heating system;

– type of system and heating devices;

– outside air temperature, etc.

Analysis of the efficiency of the heating system is based on the creation of an adequate mathematical model.

The purpose. Evaluation of the effectiveness of the use of intermittent heating for the educational building of the Heat Engineering Laboratory of the Odessa Polytechnic State University.

Presenting main material

Currently, a project is underway to disconnect heat supply from the University boiler room and transfer the building of the University Heating Laboratory to autonomous heat supply based on a condensing wall gas boiler Viessmann with a capacity of 105 kW.

Parameters of the building of the thermal laboratory:

– 4-storey red brick building of the 50 s;

– wall thickness – 0.6 m, area of external walls – 1500 m^2, volume of the building – 4800 m^3, heating area – 1200 m^2;

– water pipe heating system with individual heating station of Danfoss; regulation of water temperature with correction for indoor air temperature;

– thermal power of the heating system at the design temperature of the outside air – 70 kW.

Intermittent heating mode was calculated for the following conditions:

– the temperature in the room is maintained at 18°°C during the working period from 8:00 to 15:00 (classroom hours from 1 to 4 pairs);

– relative heat loss of the building was determined according to experimental data and amounted to 1.74 kW/°C;

– amplitude of daily fluctuations of outdoor air temperature $\Delta t_{outdoor} = \pm 5$ °C.

– mode parameters of the gas boiler were determined by the passport characteristics in variable modes.

The calculation of the dynamic properties of the building and the heating system was performed based on a system of differential equations and the corresponding boundary conditions [4].

The task of controlling intermittent heating is the task of optimal control. The result of its solution is a daily schedule of thermal average hourly loads of the gas boiler, providing a minimum of heat consumption, as well as a daily schedule of changes in room temperature.

Given the nature of the relationship between variables, the optimization problem belongs to the class of nonlinear programming problems and in general can be written:

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

$$\begin{cases} \sum_{i=0}^{23} Q_i^{\mathrm{GB}} \to \min; \\ Q_i^{\min} \le Q_i^{\mathrm{GB}} \le Q_i^{\max}; \\ i = \overline{0,\ 23}, \end{cases}$$

where the first element is the objective function, the second is the constraint, and i is the time of day, h; Q_i^{GB} – average hourly heat capacity of a gas boiler, kW.

As a tool for solving the problem, the MS Excel package was used which allowed performing multidimensional optimization taking into account the limitations and boundary conditions in the system under the option "Solution Search".

The calculations varied the outside air temperature within $t_{\mathrm{outdoor}} = 5 - (-11)$ C and the accumulation time constant of the building $T = 30...100$ h, calculated according to the method [5]. For the building of the Heat Engineering Laboratory, the time constant was $T = 50$ h, which corresponds to the moderate thermal storage capacity of the building.

Figures 1 and 2 show, respectively, the daily load schedules of the heating system and the temperature in the room at the rated power of the gas boiler ($Q_{\mathrm{GB}}^{\max} = 70$ kW) and the average daily outside air temperature $t_{\mathrm{outdoor}} = 0$°C. This maximum power of the gas boiler corresponds to the calculated outside air temperature (for Odessa: −18°C) at the round-the-clock heating mode. A further decrease in temperature t_{outdoor} leads to a corresponding increase in the immersion time and its beginning earlier than 00:00 hours of the day, which will already exceed the working period and is not appropriate.

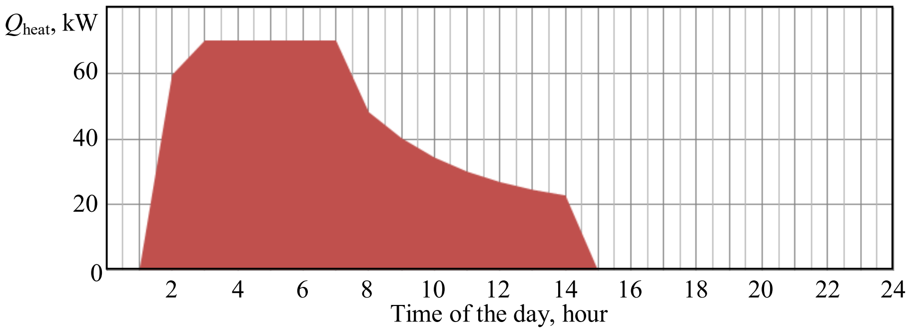

Fig. 1. Daily schedule of heating the building at a constant time $T = 50$ hours, $Q_{\mathrm{GB}}^{\max} = 70$ kW, $t_{\mathrm{outdoor}} = 0$ °C

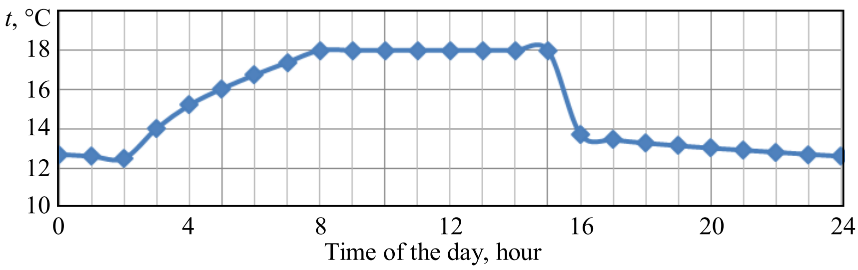

Fig. 2. Daily schedule of room temperature at a constant time $T = 50$ hours, $Q_{\mathrm{GB}}^{\max} = 70$ kW, $t_{\mathrm{outdoor}} = 0$ °C

The optimization algorithm allows to determine the optimal time of the beginning of heating at the set initial data (in the 2nd time of day) and average hourly loading of heating system, both in the period of heating, and in working hours. At a given maximum power of the gas boiler Q_{GB}^{max}, the duration of heating is proportional to the difference between the outdoor temperature $t_{outdoor}$ and the operating temperature in the room 18 °C. This allows you to conveniently program the time of onset of heating depending on the temperature $t_{outdoor}$.

According to the Pontryagin maximum principle [6], the optimal load of a gas boiler during heating hours should be equal to its maximum power Q_{GB}^{max}.

It is determined that the heating efficiency, according to the principle of maximum, increases with increasing maximum heat output of the heating system Q_{GB}^{max}. In Fig. 3, 4 presents daily graphs of the load of the heating system and the temperature in the room at $Q_{GB}^{max} = 115$ kW. At the same time, the optimal time of the beginning of heating was significantly reduced (the beginning of heating at 4:00 o'clock), and the total daily heat consumption for heating was reduced from 637 to 615 kWh. Further increase in the capacity of the heating system is limited by the increase in the temperature of direct mains water above 85°C.

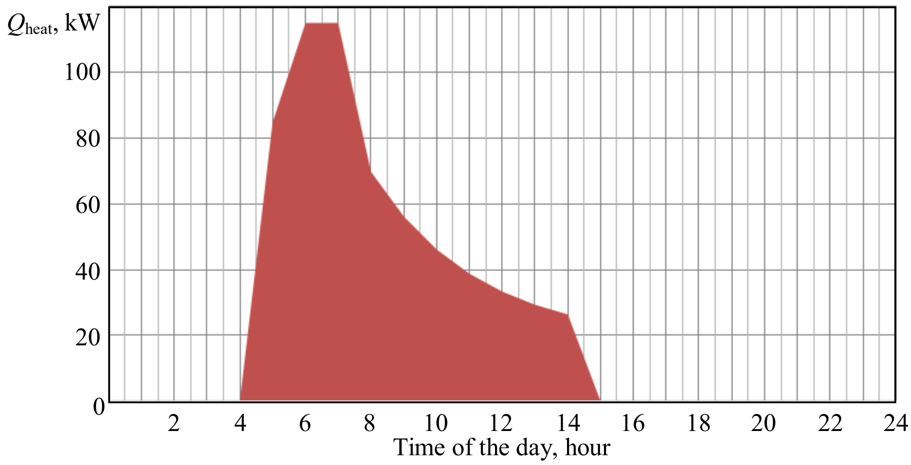

Fig. 3. Daily schedule of heating the building at a constant time $T = 50$ hours, $Q_{GB}^{max} = 115$ kW, $t_{outdoor}$=0 °C

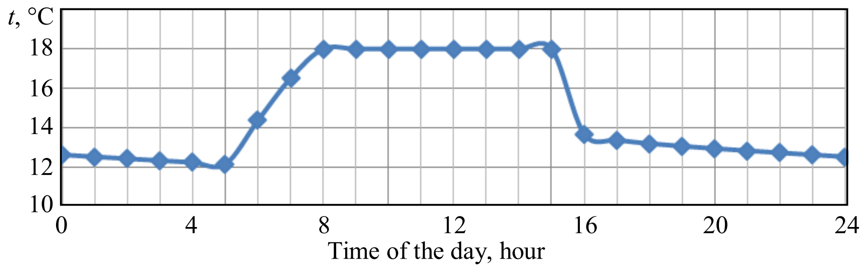

Fig. 4. Daily schedule of room temperature at a constant time $T = 50$ hours, $Q_{GB}^{max} = 115$ kW

As an indicator of the efficiency of the intermittent heating mode, heat savings for heating ΔQ are proposed in comparison with the round-the-clock heating mode, which is defined as:

$$\Delta Q = \int_0^{23} (Q_i^{DA}(t) - Q_i^{IHM}(t))\mathrm{d}t,$$

where Q_i^{DA}, Q_i^{IHM} – respectively, the thermal capacity of the heating system in the round-the-clock mode and in the intermittent heating mode, kW.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

Results

In Fig. 5 presents the relative (percentage) daily heat savings for heating in the mode of intermittent heating in comparison with the round-the-clock mode depending on the heat capacity of the system. The increase of Q_{GB}^{max} from 70 to 115 kW (1.64 times), respectively, provides an increase in heat savings from 15.2 to 18.2 %, which is consistent with the principles of optimal management.

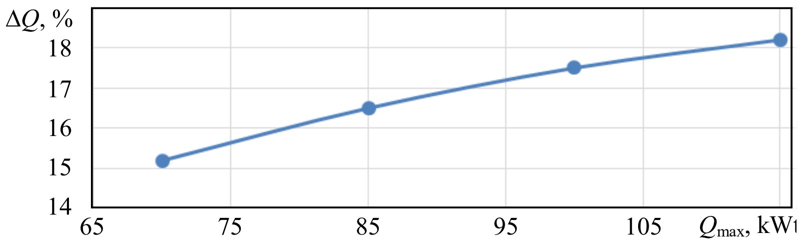

Fig. 5. Daily heat savings for heating at $T = 50$ hours, $t_{outdoor} = 0$ °C

Fig. 6 presents heat savings in the mode of intermittent heating depending on the outside air temperature $t_{outdoor}$ and the time of accumulation of the building T at $Q_{GB}^{max} = 115\,kW$. Reducing the time constant T (for example, lightweight frame buildings) significantly increases the heat savings in the mode of intermittent heating. More efficient use of this mode is also observed with increasing outside air temperature $t_{outdoor}$.

The lowest daily average value of $t_{outdoor}$ on the graph is –11 °C. With a further decrease in the temperature of the gas boiler is not enough to ensure the temperature in the room 18 °C from the beginning of heating at 00:00 hours to 8:00 (beginning of working hours). Then it is recommended to switch to round-the-clock heating. But the number of such days per year, according to statistics, does not exceed 7.

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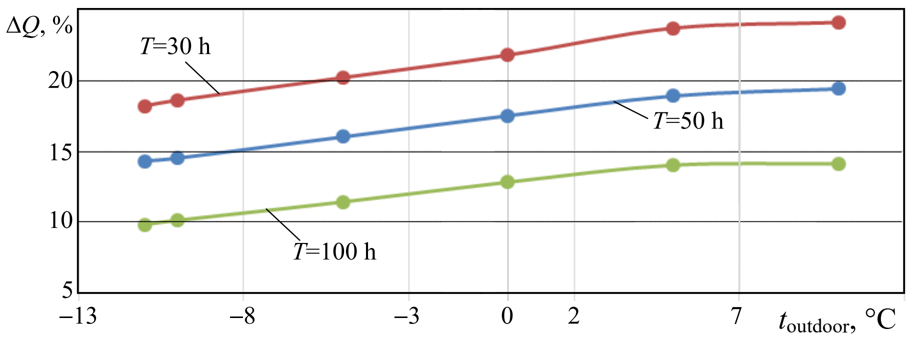

Fig. 6. Daily heat savings for heating when changing the time constant T

Conclusions

Based on the results of the work, the following conclusions can be made:

1. The use of intermittent heating for administrative, educational, office buildings opens additional opportunities for energy savings within 10…25 %, which is determined by the relatively short working hours (7…9 hours per day).

2. The use of intermittent heating is more effective for buildings with low storage capacity (modern frame lightweight buildings, etc.).

3. In the mode of intermittent heating, for the period of morning heating, it is necessary to provide the maximum possible heating load to reduce the time to reach the required air temperature in the building (when designing to set increased capacity of the heating system or possible installation of additional capacity for existing systems).

4. The use of low-inertia heaters (fan coils, modern steel radiators) increases the efficiency of intermittent heating mode.

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Received October 07, 2021

Accepted November 30, 2021