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INFLUENCE OF THE BUILDING'S THERMAL INSULATION ON INTERMITTENT HEATING MODE EFFICIENCY

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Abstract:
The results of mathematical modeling of a building's thermal insulation influence on the efficiency of intermittent heating mode are presented. This work aim is to assess the influence of thermal insulation on the efficiency of using the intermittent heating mode for the educational building of the Odessa National Polytechnic University's Heat Engineering Laboratory. The paper analyzes the factors related to improving the efficiency of the programmed heat supply mode. Modeling of the operating modes for heat supply system operated in intermittent heating mode is carried out. There was performed the mathematical modeling of the heating system operation modes for the most unfavorable climatic conditions at low outdoor temperatures, with respective system efficiency indicators obtaining. The potential of energy saving level for administrative, educational, and office buildings depending on the thickness of thermal insulation of external and internal walls is studied. Recommendations have been elaborated for the use of buildings thermal insulation to improve the efficiency of intermittent heating.

Key words: energy efficiency, intermittent heating, thermal insulation, mathematical modeling

INTRODUCTION

The use of buildings intermittent heating is a fairly effective energy-saving method, which is now relatively widespread [1, 2, 3, 4]. The intermittent heating provides the greatest energy-saving effect for administrative and office buildings, educational institutions, etc., whose working hours usually last 8-9 hours a day and 5 days a week [5]. During non-working hours, the heating may be turned off or significantly reduced in power consumption. Reducing the room temperature after working hours provides appropriate energy saving.

The efficiency of intermittent heating depends on many factors, the most influential among which are [6]:

1. thermal inertia of buildings;
2. maximum power of the heating system during heating "on" period;
3. inertia of heating devices;
4. availability of a digital control system for building heating mode, etc.

Thermal insulation of buildings is a fairly effective means of saving the energy resources. There exists a number of works devoted to the study of thermal insulation effect on the efficiency of buildings heating according to the intermittent mode. Thus, in [7], the authors analyzed changes in energy demand and thermal comfort indicators for representative rooms with different thermal protection level, varied orientation, and under intermittent heating modes. The authors concluded that when arranging an additional layer of thermal insulation, the comfort conditions increase in terms of PMV indicator, especially for walls North-ward oriented. However, the study does not highlight the effect of thermal insulation on the heating system load mode.

LITERATURE REVIEW

Authors in the paper [8] analyze the heat energy consumption and the premises' temperature regime in the conditions when the internal air temperature control used. The obtained research results allow to assess the economic effect of applying such control for various options of building insulation. However, it remains unclear how the economic effect is related to the heating system operating mode.

In the work [9] a description of the thermal regime for an individual building operated in intermittent heating mode is presented. The authors have developed a method for determining the required thickness of double-layer external walls that ensure the compliance with sanitary-and-hygienic requirements and comfortable living conditions, as well as the minimum heating time during the room heating process "on". The obtained results never allow to link the room heating process dynamics with the heating system parameters. This indicates that much attention is paid to the study of the thermal insulation influence on the heat supply system's intermittent heating mode, but those known studies do not solve the problem of optimizing the heat supply mode depending on the level of heat supply facilities' thermal modernization.

The aim of this work refers to studying the effect of thermal insulation on the efficiency and optimization of intermittent heating mode for the Heat Engineering Laboratory educational building of the Odessa National Polytechnic University.

RESEARCH METHODOLOGY

The heat engineering laboratory building is specific with the following parameters:

- 4-storey red brick building built in the 1950 s;
- wall thickness – 0.6 m; external wall area – 1500 m^2, building volume – 4800 m^3, heated area – 1200 m^2;
- water-tube heating system with individual Danfoss heat point, water temperature control with internal air temperature correction;
- the heating system heat output at the estimated outdoor temperature is 70 kW.

The mode of intermittent heating is calculated for the following conditions:

- the indoor air temperature is maintained at 20°C during the working period from 8.00 to 15.00 (class time 1...4 pairs);
- average daily outdoor temperature $t_{o.a}$ = -15°C, it changes during the day according to the harmonic law with an amplitude of 5°C;
- during the heating period and working hours, the heat supply is provided from a Viessmann gas boiler producing a maximum heat out-put of 115 kW, during the non-working period (from 15.00 to the start of heating period in the next day) – the heat supply is completely turned off;
- the boiler operating parameters were determined according to the corresponding Viessmann equipment passport characteristics in variable modes;
- ducted or wall-mounted fan coils are installed in order to arrange the low-inertia heating devices.

The dynamic properties of the building and heating system have been calculated on the basis of a system of differential equations at corresponding boundary conditions [10, 11, 12, 13].

To calculate the dynamic modes of indoor air heating/cooling, the authors proposed a mathematical model that takes into account the additional consideration of the low-inertia process of heat exchange be-tween the air and internal surfaces of the room and provides increased accuracy of calculations and identification of the heating process acceleration path [14, 15, 16].

The total heat consumption from a gas boiler, was chosen as a criterion for optimizing the heating system load modes that provides a set temperature regime of the building and are given for a certain time interval (to a 24-hour period). Given the nature of relationship between variables, the optimization problem belongs to the class of nonlinear programming problems [17, 18, 19, 20, 21] and can be written in general form as:

$$\begin{Bmatrix} \sum_{i=1}^{23} Q_i \rightarrow min \\ Q_{imin} \leq Q_i \leq Q_{imax} \\ i = 0.23 \end{Bmatrix} \quad (1)$$

where:

i is the time of day, *h*;

Q_i – average hourly heat output of the gas boiler, kW.

The result of solving the optimization problem is embodied with daily graphs of the gas boiler heat loads, providing a minimum heat consumption, as well as daily graphs of changes in indoor air temperature.

RESULTS

This paper considers options for using external thermal insulation of enclosing structures, thermal insulation of internal walls and partitions, and the joint use of external and internal thermal insulation.

The thermal insulation material's thermal conductivity is assumed to be λ = 0.05 W/(M·K), the external thermal insulation thickness is varied from 0 to 0.2 m, the internal one – from 0 to 0.05 m. The model is simulated for the outdoor air temperature $t_{o.a.}$ = -15°C.

In Fig. 1 respectively, are given the heat supply system heat load daily graphs and changes in the room temperature in the mode intermittent heating in the absence of thermal insulation.

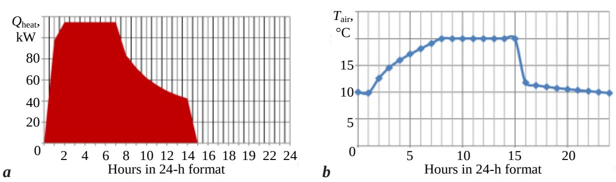

Fig. 1 Daily graphs of the heat load on heating system: a) and changes in room temperature b) in the absence of thermal insulation: $t_{o.a.}$ = -15°C; Q_{max} = 115 kW

Analysis of the daily schedule (Fig. 1) shows that according to these conditions, the room heating time is quite long (from 0.00 to 8.00 hours), the system operates at the maximum thermal load for this time. The room temperature during the non-working period decreases from 20 to 10°C, respectively, the heat consumption for heating per day is very significant.

In Fig. 2 respectively, are given daily graphs of heat load and temperature changes in the room under the mode of intermittent heating in the presence of external thermal insulation with a thickness of δ_{ext} = 0.1 m.

Analysis of the daily schedule (Fig. 2) shows that due to the presence of external thermal insulation with a thickness of 0.1 m, the room heating time has significantly decreased (lasting from 5.00 to 8.00 hours), the system operates at a maximum load only 1 hour. The room temperature during non-working hours decreases from 20 to 16°C, respectively, the heat consumption for heating during the day has significantly decreased.

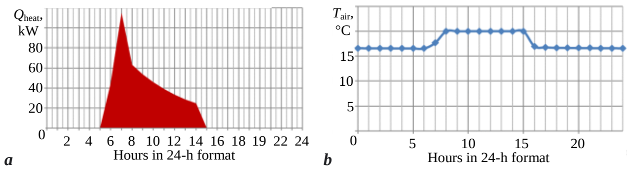

Fig. 2 Daily graphs of the heat load for heating system:
a) and changes in room temperature
b) with external thermal insulation thickness: δ_{ext} = 0.1 m; $t_{o.a.}$ = -15°C, Q_{max} = 115 kW

In Fig. 3 respectively, are given daily graphs of heat load and temperature changes in the room in the mode of intermittent heating in the presence of external thermal insulation with a thickness of δ_{ext} = 0.1 m, and internal thermal insulation thickness δ_{int} = 0.02 m.

Analysis of the daily schedule (Fig. 3) shows that due to the presence of external and internal thermal insulation, the room heating time has decreased by another 1 hour (lasts from 6.00 to 8.00 hours), the system load during heating does not exceed 75 kW. The room temperature during non-working hours decreases from 20 to 12°C, respectively, the heat consumption for heating per day decreased.

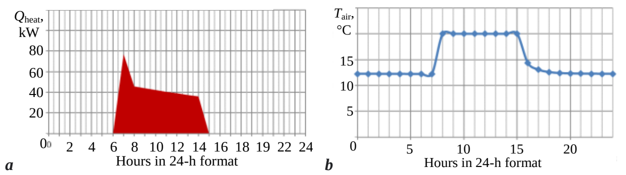

Fig. 3 Daily graphs of the heat load for heating system:
a) and changes in room temperature
b) with external thermal insulation thickness: δ_{ext} = 0.1 m and internal thermal insulation δ_{int} = 0.02 m; $t_{o.a.}$ = -15°C; Q_{max} = 115 kW

In Fig. 4 respectively, are given the daily graphs of heat load and temperature changes in the room in the mode of intermittent heating only if there is only internal thermal insulation δ_{int} = 0.02 m.

Analysis of the daily schedule (Fig. 4) shows that due to the presence of only internal thermal insulation with a thickness of 0.02 m, the heating progress time increased by 1hour compared to the previous version (lasts from 5.00 to 8.00 hours), the system load during heating progress reaches a maximum value of 115 kW. The room temperature during non-working hours is significantly reduced from 20 to 4°C, which is due to the low average temperature of the walls in the presence of only internal thermal insulation. This option of using thermal insulation is never admissible. The heating system heat consumption during the day increased significantly.

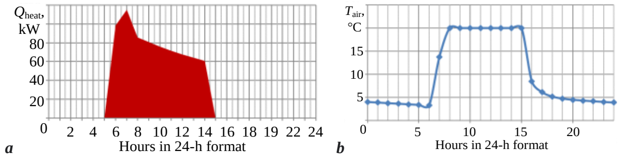

Fig. 4 Daily graphs of the heat load for heating system:
a) and changes in room temperature
b) when internal thermal insulation arranged: δ_{int} = 0.02 m; $t_{o.a.}$ = -15°C; Q_{max} = 115 kW

To summarize the results obtained and determine the most effective parameters of thermal insulation for intermittent heating, model's simulation has been performed for various variants of its thickness and the corresponding energy saving has been estimated in comparison with a building without thermal insulation (Fig. 5).

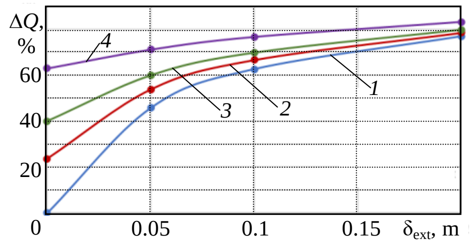

Fig. 5 Efficiency of using thermal insulation in intermittent heating mode, daily heat saving for heating: 1 – δin = 0 m; 2 – δ_{int} = 0.01 m; 3 – δ_{int} = 0.02 m; 4 – δ_{int} = 0.05 m

Based on the results obtained, it can be concluded that the use of external thermal insulation provides significant heat saving when heating process. The internal thermal insulation significantly enhances this effect, while its thickness is several times less than the external one.

The resulting effect is very significant, but it does not show separately the effect of using thermal insulation on the efficiency of intermittent heating mode, i.e., the thermal insulation use in any mode provides an energy-saving effect [22, 23, 24, 25]. In Fig. 6 shown are the simulation results for various variants of thermal insulation thickness and determined is the corresponding energy saving level in comparison with the round-the-clock heating mode.

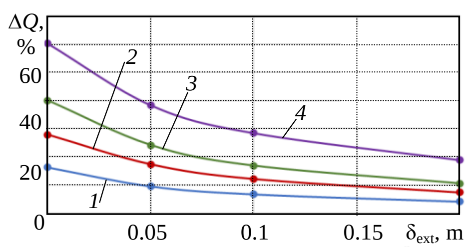

Fig. 6 Efficiency of using thermal insulation in intermittent heating mode compared to round-the-clock heating, daily heat saving for heating: 1 – δ_{int} = 0 m; 2 – δ_{int} = 0.01 m; 3 – δ_{int} = 0.02 m; 4 – δ_{int} = 0.05 m

Analysis of Fig. 6 shows that in comparison with round-the-clock heating, thermal insulation significantly increases the efficiency of intermittent heating. A more significant relative energy effect is characteristic for a small thickness thermal insulation. Internal thermal insulation has a more significant impact on heating efficiency [26, 27].

This study also investigated the effect of thermal insulation on the maximum heat output of the heating system during heating process (Fig. 7).

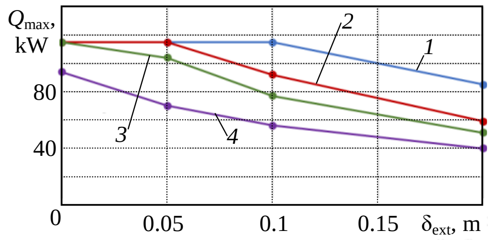

Fig. 7 Dependence of the heating system's maximum heat output during heating on the thermal insulation parameters: 1 – δ_{int} = 0 m; 2 – δ_{int} = 0.01 m; 3 – δ_{int} = 0.02 m; 4 – δ_{int} = 0.05 m

If the thickness of the external thermal insulation is more than 0.1 m, the maximum heat output of the system decreases during heating. The presence of internal thermal insulation more significantly affects the maximum heat output and allows it to be reduced by almost 2 times.

CONCLUSIONS

In this article the following results were observed. The arrangement of thermal insulation of buildings with intermittent heating significantly increases the energy efficiency of the heat supply system. The most appropriate combination is external thermal insulation of enclosing structures and internal thermal insulation of walls, partitions, ceilings.

Internal thermal insulation provides greater energy efficiency of the intermittent heating mode, but its separate use significantly reduces the room temperature during non-working hours, which can lead to condensation on the enclosing structures.

Daily heat saving in intermittent heating mode in comparison with 24-hour mode with external thermal insulation thickness δ_{ext} = 0.1 m and internal δ_{int} = 0.02 m (implemented in the building of the Heat Engineering Laboratory of Odessa National Polytechnic University) is 18%.

The combined use of external and internal thermal insulation reduces the maximum thermal power of heating systems during heating by 1,5...2 times.

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