ENGINEERING

IMPLEMENTATION OF A HYBRID INTERMITTENT HEAT SUPPLY SYSTEM FOR EDUCATIONAL INSTITUTIONS

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Abstract: The experience of introducing a hybrid intermittent heating system for educational institutions is presented. The analysis of theoretical and experimental research, modern energy technologies for the integration of renewable energy sources into innovative and existing heat supply systems for buildings. The adaptation of modern developments of hybrid systems to buildings operating both in permanent and intermittent operation mode (administrative institutions, educational institutions and other public buildings) has been carried out. The conditions for increasing the efficiency of using heterogeneous renewable energy sources in combined heat supply systems have been established. For the proposed combined heat supply system, a hybrid heat generation is provided using low-potential renewable heat sources in the heat pump cycle and high-potential traditional heat sources in a pellet boiler. A mathematical model of the operating modes of a combined heat supply system using renewable heat sources is proposed, which can be used for numerical modeling of thermal processes in a variable heat supply mode for public buildings. The study of the dynamics of heating the premises when changing the climatic conditions of different regions of Ukraine, including the southern regions, is done. This makes it possible to analyze the efficiency of using alternative energy sources for heat supply and substantiate the conditions for including heat accumulators in the circuit. The research results are relevant because allow to achieve significant energy savings for heat supply of public buildings, characterized by a low level of energy efficiency. The proposed solutions indicate that the combined use of the capabilities of heterogeneous renewable energy sources can be effective only with a hybrid method of heat generation using a heat pump and a pellet boiler, taking into account the operating mode of buildings. As a result of theoretical and experimental studies, it was established: the dynamics of heating and cooling of premises with a high accumulation capacity; the share of replacement of the consumed thermal power in the hybrid use of heat generators. The conditions for the most effective use of heat accumulators in a combined heat supply system have been established. The results obtained make it possible to increase the efficiency of the use of renewable energy sources for public buildings, taking into account the mode of their operation, in which the heat supply system operates in an intermittent mode.

Keywords: renewable energy sources, combined heat supply systems, heat pump, intermittent heat supply, hybrid generation, building operation mode.

1. Introduction

Analysis of theoretical and experimental studies shows that when only 10 % of consumers in the southern regions of Ukraine switch to alternative heat supply, an annual fuel saving of 0.170 million tons of fuel equivalent can be achieved. [1]. When using the substituting possibilities of insolation with an average annual capacity of 4300 MJ/m^2, approximately 25 % of consumers' needs for heating and 50 % for hot water supply can be met [2]. The practical implementation of combined energy supply systems based on a heat pump cycle is of considerable interest for energy-saving technologies [3]. Therefore, theoretical and practical studies aimed at increasing the efficiency of these systems by adapting them to changing modes of energy consumption is of considerable interest [4].

To speed up the process of practical implementation of combined heat supply systems based on alternative fuels, it is necessary to reduce the payback period by increasing the replacement ratio of traditional primary energy resources [5]. However, for combined heat supply systems operating in a permanent mode of operation, it is quite problematic to solve this problem even due to the hybrid use of the replacement capabilities of several heterogeneous renewable energy sources (RES) [6].

Energy saving, taking into account the principles of energy-saving technologies, can be obtained by introducing a combined autonomous heating system (CAHS), which operates in intermittent heat supply mode. These systems make it possible to rationally use traditional, renewable energy sources and alternatives of energy on alternative fuels.

The relevance of the work lies in the fact that the theoretical and practical substantiation of the conditions for the implementation of the proposed intermittent heat supply system allows achieving significant energy savings. In addition, CAHS is a rational way to improve the operating conditions of the system by removing pulsations during heat generation.

2. Methods of research

Modeling of processes in a heat supply system using renewable heat sources (heat pump, pellet boiler) on the example of an educational building is based on the use of intermittent heating.

Intermittent heating mode is determined by the work schedule of the educational building and consists of the following modes:
– mode of forced heating of the room;
– mode of maintaining the parameters required by the norms in the room;
– mode of switching off heat sources;
– standby mode.

The operating mode is determined based on the operating conditions of the building from 8:00 to 16:00.

Modeling the dynamic properties of a building and heating system is based on a system of differential equations and the corresponding boundary conditions [7].

The criterion for optimizing the load modes of a combined heat supply system [8], which operates in an intermittent heating mode, where a given temperature mode is maintained, is the total heat consumption from a pellet boiler and a heat pump $\sum_{i=0}^{23} Q_i$ per day.

The equation for determining the optimal daily load mode of the heat source, when the target function is minimal, has the form:

$$\sum_{i=0}^{23} Q_i = = \sum_{i=0}^{23} \left(Q_i^{PK} + Q_i^{HP} \right), \qquad (1)$$

where i – the time of day, h; Q_i^{PK} – average hourly thermal power of the pellet boiler, kW; Q_i^{HP} – average hourly heat power of the heat pump, kW.

From a mathematical point of view, the optimization problem can be considered as the problem of finding the extremum of a function of 24 variables. Accordingly, the average hourly heat loads $\left(Q_i^{PK}, Q_i^{PK} \xleftrightarrow{} i = \overline{0,...,23} \right)$ taking into account the constraints and boundary conditions imposed on the optimized system.

Taking into account the nature of the dependence between the variables, the optimization problem belongs to the class

of nonlinear programming problems and can be written in general form:

$$\begin{cases} \sum_{i=0}^{23} Q_i = \sum_{i=0}^{23}\left(Q_i^{PK} + Q_i^{HP}\right) \to \min, \\ \begin{cases} Q_{i\min} \le Q_i^{PK} \le Q_{i\max}, \\ Q_{i\min}^{HP} \le Q_i^{HP} \le Q_{i\max}^{HP}, \\ i = \overline{0.23}. \end{cases} \end{cases} \qquad (2)$$

As a result of solving the problem of optimizing the load mode of the heat supply system, it is possible to obtain daily graphs of the heat loads of the boiler and the heat pump, which provide a minimum of heat consumption, as well as the daily graph of changes in the air temperature in the room, for this it is necessary to perform numerical modeling.

3. Research results

Modeling of heat supply processes using intermittent operation is carried out in relation to an object with a high accumulation capacity (HAC).

The HAC objects of heat supply include buildings with massive external and internal walls, which have a high accumulation capacity and a low glazing coefficient and, as a consequence, a large time constant T.

For numerical modeling of the high-inertia CAHS heat supply facility, the characteristics of the building are used. The educational building has 4 floors; wall thickness – 0.6 m; internal wall area – 1,500 m^2; volume of premises – 4,800 m^3; heated area – 1,200 m^2. Thermal power of the heating system at the design temperature of the outside air (minus 18 °C) is 74 kW.

In numerical modeling, the features of the modes of heat consumers are considered [9, 10], for four characteristic values of the outside air temperatures: +5 °C; 0 °C; –5 °C; –10 °C (**Fig. 1–3**). The time constant for accumulating the building is equal to T=200 hours.
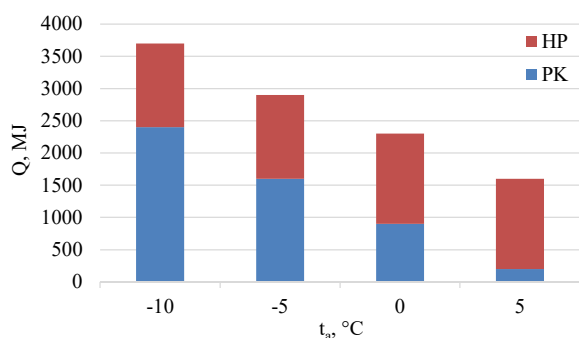

Fig. 1. General daily load of the educational building CAHS in intermittent mode at differrent t_a; T=200 h

As seen from **Fig. 1–3**, the efficiency of using heat accumulators has limitations associated with the outside air temperature. This circumstance can be used in recommendations for the introduction of a hybrid heating system.
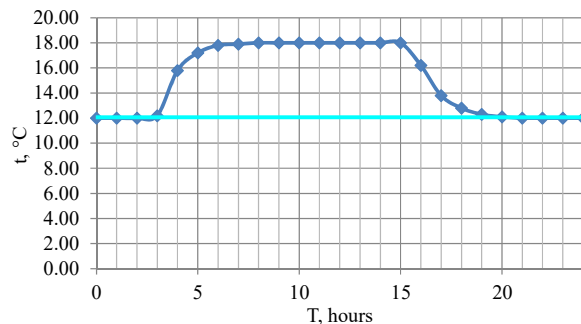

Fig. 2. Graph of temperature changes in the room during the day in intermittent heating mode at t_a=−10 °C, T=200 h
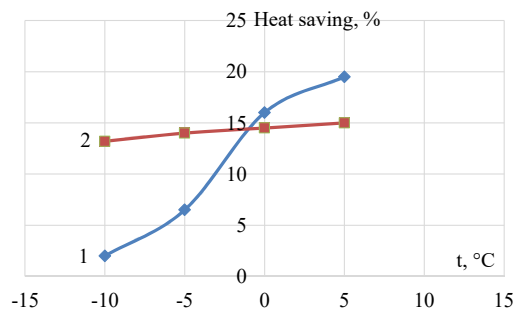

Fig. 3. Graph of changes in fuel economy during operation of the pellet boiler as a function of external temperature:
1 – without heat accumulator; 2 – with heat accumulator

4. Discussion of results

These studies were carried out for a specific group of buildings, and require further research for buildings with a more uniform operating regime, as well as for buildings with a low accumulation capacity.

The results obtained can be applied to existing HAC-type buildings with variable operation during the modernization of the heat supply system.

Further research will be aimed at studying the influence of internal factors of buildings on intermittent heat supply modes in order to increase the efficiency of the RES use.

5. Conclusions

The obtained simulation results allow to estimate the share of participation of each of the heat sources in the hybrid generation of CAHS energy. At the same time, as can be seen from the results (**Fig. 1**), the share of the heat pump at temperatures below – 5 °C is significantly reduced, which allows to speak about the lower limit of its effective use.

At the same time, the dynamics of heating and cooling of the premises (**Fig. 2**) of the HAC-type building makes it possible to judge the reserve – CAHS "latent" heat capacity during the cooling periods of the building and the standby mode. The reserve "latent" heat capacity can be accumulated during the non-working period to reduce the forced heating mode of the premises. However, in this case, it is necessary to take into account the heat losses of the battery itself and the area of its effective use (**Fig. 3**).

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