UDC 620.91
DOI: 10.15587/1729-4061.2021.243112

DETERMINATION OF FEATURES OF FORMATION OF ENERGY SUPPLY SYSTEMS WITH THE USE OF RENEWABLE ENERGY SOURCES IN THE TRANSITION PERIOD

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An urgent scientific and practical problem is the formation of energy efficient systems for ensuring climatic conditions in premises based on the use of renewable energy sources. The work has improved the technical and methodological approach to the calculations of energy supply and storage systems when using energy-active fences. The special effectiveness of these fences has been shown in the transitional periods of the year, that is, in spring and autumn.

A mathematical model has been developed to reliably predict the process of ensuring temperature comfortable conditions (heat balance) when using nonparametric statistics methods. It will improve the quality of forecasting the effect of external air temperature during the transitional periods of the year. The temperature inside the room is taken into account in the presence of a multilayer energy-active fence.

To determine the approach to the use of heat in energy supply systems during the transition period, thermal parameters from the inner and outer sides of the building structure are considered. This makes it possible to take into account changes in the heat transfer of these structures when designing a power supply system and determining the optimal modes of its functioning in various natural conditions.

The function of energy-active fences associated with the generation of additional heat into the system, obtained through the conversion of solar radiation energy, is considered. To increase this generation, special multilayer designs of energy-active fencing have been proposed. The proposed thermal modernization with the use of energy-active fences allows, on average, over the cold period of the year, to reduce energy consumption by 3.5 times for industrial and residential buildings

Keywords: energetic fences, solar radiation, multilayer structures, energy conversion, thermal modernization, convection

Received date 11.09.2021
Accepted date 21.10.2021
Published date 29.10.2021

***How to Cite:** Nakashidze, L., Gabrinets, V., Mitikov, Y., Aleksejenko, S., Ljashenko, I. (2021). Determination of features of formation of energy supply systems with the use of renewable energy sources in the transition period. Eastern-European Journal of Enterprise Technologies, 5 (8 (113)), 23-29. doi: https://doi.org/10.15587/1729-4061.2021.243112*

1. Introduction

Many issues on the construction of energy supply systems that use renewable energy sources (RES) have already been resolved. At the same time, special attention is paid to the construction of energy supply systems that operate year-round and use various types of energy in a comprehensive manner. However, the features of the use of such systems during transition periods (March-April and October-November) are fully considered. These periods are characterized by daytime temperatures above 5 °C, nighttime temperatures below 0 °C and high humidity. That is, when heating, a changeable temperature regime for the supply of the coolant is required. However, the provision of such a regime is not carried out due to the presence of a number of technical and economic problems. Most often, during these periods, the consumer does not receive heat from the centralized supplier at all. This leads to the emergence of uncomfortable living conditions for consumers in buildings (both multi-storey and low-rise). Therefore, there is a need to solve such a problem – the formation of energy supply systems, taking into account the peculiarities of the shift mode of their functioning during the transition period of the year.

Further development of a methodology that takes into account the peculiarities of the transitional period of the year in the formation of energy efficient systems for ensuring climatic conditions in premises based on the use of renewable energy sources is of great scientific and practical importance for the development of the energy industry in the world. It is an urgent scientific and practical problem that requires further refinement and solution.

2. Literature review and problem statement

The work [1] formulates an approach to the design of energy supply systems that use renewable energy sources (RES). The peculiarity of this approach is that it is complex. In works [2, 3] it is shown that only the complexity will allow to form an efficient power supply system. A clear definition of what the complexity consists of is shown in [4, 5]. It is determined that the complexity lies in the fact that a number of factors are considered. Among them:

– cost and timing of the use of renewable energy sources;

– technical potential of renewable energy sources has been realized in accordance with certain climatic zones;

– technical and institutional issues and costs of introducing various renewable energy technologies into energy systems and markets;

– comprehensive assessment of the socio-economic and environmental aspects of the introduction of renewable energy sources and other energy efficient technologies;

– political, institutional and financial mechanisms to ensure the economically efficient use of renewable energy sources in a wide variety of conditions.

However, the disadvantage of this approach is the large number of factors that must be taken into account.

In works [6, 7] it is shown that only due to taking into account the complex of physical, technical, economic, technological indicators it is possible to objectively choose the optimal composition of the energy supply system that uses RES, which meets the needs of the consumer.

In works [8, 9], it is shown that solar heating and cooling technologies used in residential and commercial buildings are currently an established market. The features of its formation in different countries of the world are shown. A positive trend of growth rates of about 16 % per year is shown. In Europe, the corresponding market size has more than tripled in recent years. A significant proportion are complex helium water heating systems. In the works, it is outlined that competition in this direction is to increase the energy efficiency of energy supply systems through the use of a passive component. But in these works, the market for the use of energy efficient technologies in energy saving was not considered.

In works [9, 10], it is proposed to use an approach that consists in passive thermal insulation to stabilize heat loss when heating is turned off. The positive factor indicated in these works is that new materials are used to effectively store heat. It has been shown that the main criteria for the selection of such materials are their readiness, the possibility of using them for heat accumulation (materials in which the heat of phase transformations is used, for example, paraffin), etc. [11, 12].

In [13], one more direction of passive design was formulated, which consists in adding internal mass to the structure of a building. The positive features of this approach are confirmed in [14]. However, there is a significant drawback in using this approach – the impossibility of its application in functioning objects.

The use of a passive approach increases the economic performance of the energy supply system (including from renewable energy sources). The disadvantage of such systems is the impossibility of rapid additional implementation of innovations in accordance with the needs for energy services.

Solar water heating systems are usually more competitive in regions with high levels of solar radiation. However, in other regions, the introduction of such systems is also advisable.

3. The aim and objectives of research

The aim of research is to determine the features of the formation of energy supply systems that use renewable energy sources during the transition period of the year. This will improve the technical and methodological approach to the formation of energy supply systems in the accumulation and use of heat during the transitional period of the year, which is provided with the help of energy-active fences.

To achieve the aim, the following objectives were set:

– to develop a mathematical model that allows calculating heat transfer processes in multilayer structures of energy-active fences under variable boundary conditions;

– to outline the directions for the large-scale introduction of energy-active devices;

– to determine the qualitative and quantitative indicators of the work of energy-active multi-layer fences;

– to determine the qualitative and quantitative indicators of the work of energy-active multi-layer fences.

4. Materials and methods of research

It is proposed to consider the thermal parameters from the inner and outer sides of the building structure to determine the approach to the preservation/use of heat, which is provided with the help of energy-active fences, during the transition period.

This will allow taking into account changes in the heat transfer of these structures when designing a power supply system and determining the optimal modes of its functioning in various natural conditions, including during the transition period.

This approach is based on works [12, 13], which propose to consider the process of heat transfer, according to which fluctuations in heat fluxes and temperatures on the outer and inner surfaces of fences follow a "harmonious" law. It was shown in [14] that the approach from the point of view of this theory has many assumptions.

For example, this approach does not take into account a number of boundary conditions. This is especially true of the outer side of the structure, where influential factors such as air temperature, intensity of solar radiation, wind speed, etc. are constantly changing. These indicators are difficult to predict clearly.

Therefore, in accordance with the methodology presented in [15], it is necessary to consider internal and external factors.

To achieve this goal, it is proposed to use the methods of nonparametric statistics. This direction is now actively developing, due to its simplicity, accuracy and versatility of nonparametric hypotheses. Nonparametric tests for distributions that are far from normal are more efficient and accurate than parametric ones.

5. Results of the study of the influence of the physical and technical features of multilayer energy-active energy supply systems

5. 1. Mathematical model of heat transfer processes in multilayer energy-active fences under variable boundary conditions

When considering external factors in this technique, it is proposed to refer to external factors as:

a) premise temperature $T_p(t)$.

It is known that, for example, in residential premises, the air temperature should be 18–22 °C with a possible fluctuation of ±1.5 °C. However, in the absence of heating during the transition period, such a value can be achieved only with the help of other energy sources, for example, electric;

b) the emissivity of the surface is internal (convective flows).

It is recommended to calculate the radiant heat transfer coefficient in accordance with the mathematical relationship:

$$\alpha_l = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}-\frac{1}{C_b}} \cdot \frac{\left(\frac{T_1+273}{100}\right)^4 - \left(\frac{T_2+273}{100}\right)^4}{T_1 - T_2}, \quad (1)$$

where C_1, C_2 – surface emissivity;

C_b – emissivity of an absolutely black body

T_1, T_2 – surface temperatures interact.

When determining the coefficient of radiant heat transfer for the interior, a number of boundary conditions are taken:

– T_1 is equal to the internal air temperature T_a;

– T_2 is equal to the temperature of the inner surface T_0 of the fence.

According to the methodology considered [13], it is necessary to take into account one more factor – the convective component. It is known that the convective component of heat transfer depends on:

– air temperature T_a;

– surface temperature T_0;

– thermophysical properties of air;

– direction of air movement.

This list is supplemented by two more important factors that are obvious to the heating engineer:

– air speed;

– surface roughness.

The latter factor characterizes the turbulization of the laminar layer of air flow on the wall of the room, the narrowest point of heat transfer. Applying certain finishing materials of varying degrees of roughness, it is possible to regulate convective heat fluxes in the direction of the desired direction.

To calculate the coefficient of the convective component, it is advisable to use the empirical dependence proposed in [14]. This dependence allows to consider the parameters of vertical walls in heated premises.

$$\alpha_{\mathrm{a,c}} = 1{,}43\sqrt[3]{T_a - T_0}. \quad (2)$$

According to [15], for horizontal surfaces the value of the convective component coefficient is recommended to be increased by 30 % for ceilings, reduced by 30 % for floors, or left unchanged.

According to the methods proposed in [13, 14] for calculating the density of heat fluxes acting on the inner surface of fences, it is advisable to use mathematical relationships:

$$q_{a,c} = \alpha_{a,c} \cdot (T_a - T_0),$$

$$q_{a,l} = C_{a,0}^{p}\left[\left(\frac{T_a+273}{100}\right)^4 - \left(\frac{T_0+273}{100}\right)^4\right], \quad (3)$$

$$q_a = q_{a,c} + q_{a,l}.$$

The heat flux is directed towards the outer surface of the fence.

According to [15], to take into account the radiation component in the form of the radiation heat transfer coefficient, it is advisable to use the mathematical dependence:

$$\alpha_l = \frac{1.163}{\frac{1}{C_{5,6}}+\frac{1}{C_{6,7}}+\frac{1}{C_b}} \cdot \frac{\left(\frac{T_{5,6}+273}{100}\right)^4 - \left(\frac{T_{6,7}+273}{100}\right)^4}{T_{5,6} - T_{6,7}}, \quad (4)$$

where the numeric indexes indicate the corresponding surfaces at the boundaries between the layers.

When carrying out the analysis, it is advisable to take into account natural convection. According to [15, 16], it is taken into account by taking into account the convection coefficient ε_c. This coefficient is determined by the following relationship:

$$\varepsilon_c = \frac{\lambda_{eq}}{\lambda_{air}} = 0.105\left(Gr_{sur}\,\mathrm{Pr}_{sur}\right)^{0.3}, \quad (5)$$

at $10^3 < Gr_{sur}$, $\mathrm{Pr}_{sur} < 10^6$,

$$Gr_{sur} = \frac{\gamma g \delta_6^3 \left(T_{5,6} - T_{6,7}\right)}{\upsilon^2}, \quad \mathrm{Pr}_{sur} = \left(\frac{\nu}{a}\right)_{sur}, \quad (6)$$

where λ_{eq} – equivalent coefficient of thermal conductivity, which takes into account the convective and molecular components of heat transfer.

Thermophysical characteristics of air are determined at a temperature

$$T_{sur} = (T_{5,6} + T_{6,7})/2.$$

It should be especially noted that the thermophysical properties of air should be taken taking into account the average statistical humidity for a particular region in a given period of the year.

It is possible to determine the total heat transfer in the air gap according to the mathematical relationship:

$$q_6 = -\left(\lambda_{eq} + a_l \delta_6\right) \cdot \frac{T_{6,7} - T_{5,6}}{\delta_6}.$$

According to the chosen methodology, the following factors that are considered are external factors. The main external factors that have a direct impact on heat transfer through fences are:

– air temperature T_{air};

– wind speed v_{air};

– intensity of the solar radiation flux q_S.

According to [12, 13], to calculate the components of heat transfer, it is advisable to use the following mathematical relationships:

– the influence of the wind flow:

$$\alpha_{air,c} = 6.31v^{0.656} + 3.25e^{-1.91v},$$

where v – wind speed;

– convective component:

$$q_{out,c} = \alpha_{out,c}\left(T_0 - T_{out}\right);$$

– the radiant capacity of the outer surface of the fence of the structure:

$$q_{out,l} = \frac{1}{\dfrac{1}{C_\delta}+\dfrac{1}{C_n}-\dfrac{1}{C_b}}\left[\left(\frac{T_\delta+273}{100}\right)^4-\left(\frac{T_{out}+273}{100}\right)^4\right];$$

– total heat flux:

$$q_{out} = q_{out,c} + q_{out,l}.$$

Since the ambient temperature, wind speed, and the intensity of the solar radiation flux are not constant values and change constantly and unpredictably, statistical patterns are unknown. But there is a correlation dependence between some parameters, which are both stochastic and deterministic (season, air temperature on the previous day, state of the atmosphere, last year's air temperature indicators). For a more reliable prediction of the process of ensuring temperature comfortable conditions (heat balance), it would be advisable to develop mathematical algorithms to improve the quality of forecasting the conditional outside air temperature during the transition period.

5. 2. Directions for the development of technologies for the creation and large-scale implementation of energy-active devices

According to a certain approach, a comparison was made between two options for fencing a structure:

– Option 1 – a traditional building structure made of bricks (δ=0.51 m, λ=0.67 W/(m·K), ρ=1.6·10^3 kg/m^3, c=0.84·10^3 J/(kg·K) The inner surface of the structure has a layer of plaster, on the outer surface there are no additional layers;

– Option 2 – a multi-layer energy-active fencing is integrated to the outer brick surface, shown in Fig. 1.

According to [17], heat-receiving elements 3 are made in the form of rotary blinds. On the side of the wall 6, the blinds have a surface that reflects heat radiation well, and on the side of solar radiation – a surface that absorbs it well. All sections of the louvers of the heat-absorbing element 3 can be rotated around their axis by 90°. This makes it possible, on the one hand, to regulate the amount of absorbed solar energy, and, on the other hand, to switch from the thermal insulation mode to the heat capture mode (Fig. 1).

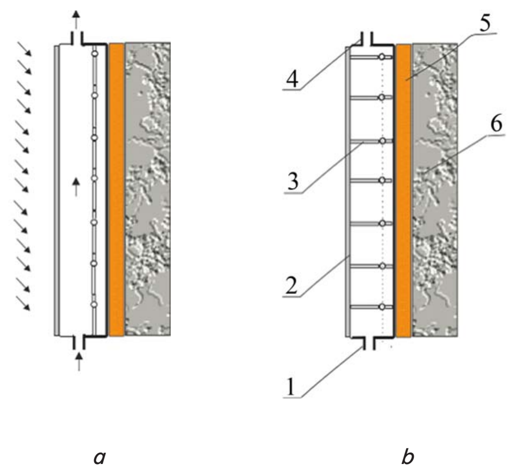

Fig. 1. Schematic design of energy-active coatings: *a* — thermal insulation mode; *b* — heat shooting mode; (1 — air inlet, 2 — transparent coating, 3 — movable blinds, 4 — air outlet, 5 — thermal insulation, 6 — building wall)

In both cases, the orientation of the walls is considered to be south. The temperature in the living room, according to the regulations, is 20 °C and is kept almost constant.

To obtain such conditions, it is assumed that there is a heat flow directed into the room (traditional heating systems).

Also, when calculating, it is necessary to take into account the layers from which the basic structure of the structure is built. Such layers, for example, are the inner surface of the wall plastered.

The air gaps in the energy-active fence are closed, therefore they serve as a heat insulator. At the same time, natural air circulation and heat transfer by convection, molecular thermal conductivity and radiation bounding the surface take place in the air gap.

5. 3. Qualitative and quantitative indicators of the work of energy-active multi-layer fences

Fig. 2–9 show the temperature distribution in the section of the supporting structure of the structure made of brick and with an additionally installed energy-active fence. The calculated results on the daily distribution of heat flows are presented for mid-winter, spring, summer and autumn. The analysis of the calculated results was carried out. As a result, the positive thermal insulation properties of energy-active fences were confirmed.

The distribution of energy parameters (Fig. 2–9) is closely related to the influence of solar radiation, the temperature of the outer surface $T(t, \delta)$ and the heat flux on it $q(t, \delta)$. The quantity $q(t, \delta)$ begins to decrease starting from sunset. In winter, it reaches zero in the period of 24–6 hours, then at other times of the year it reverses sign for a longer period. During this period, solar energy accumulation takes place with the help of energy-active fences. The temperature $T(t, \delta)$ changes rapidly when exposed to solar radiation, and the internal parameters $T(t, 0)$, $q(t, 0)$ practically do not change during the day. This correlates with the data for the layers of energetic barriers (Fig. 6–9).

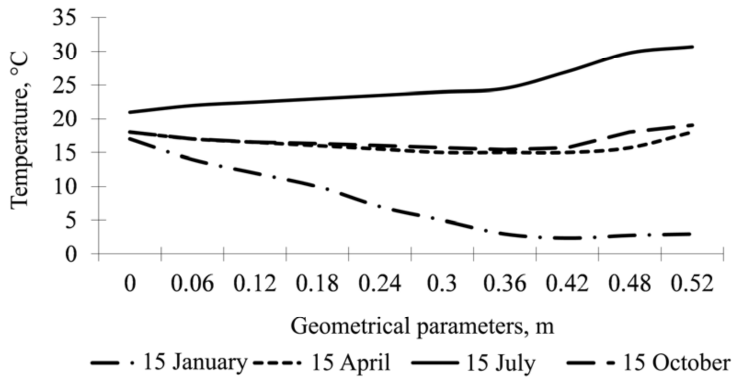

Fig. 2. Distribution of temperatures in a brick basic fence with a southern orientation relative to the day, which corresponds to the middle of each season of the year at 6 hour of a day

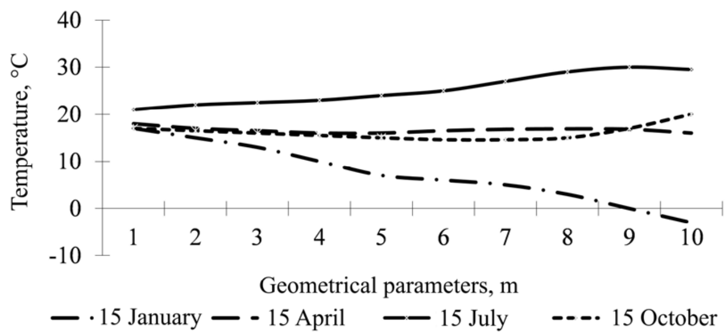

Fig. 3. Distribution of temperatures in a brick basic fence with a southern orientation relative to the day, which corresponds to the middle of each season of the year at 12 hour of a day

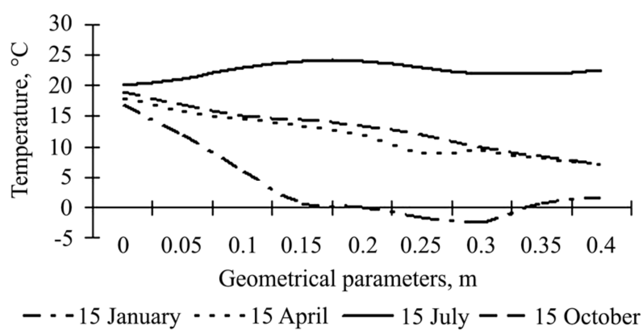

Fig. 4. Distribution of temperatures in a brick basic fence with a southern orientation relative to the day, which corresponds to the middle of each season of the year at 18 hour of a day

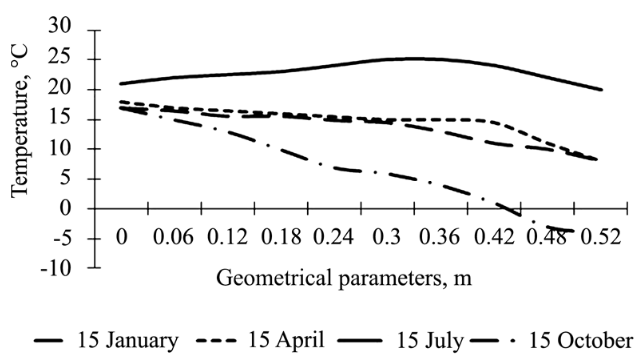

Fig. 5. Distribution of temperatures in a brick basic fence with a southern orientation relative to the day, which corresponds to the middle of each season of the year at 24 hour of a day

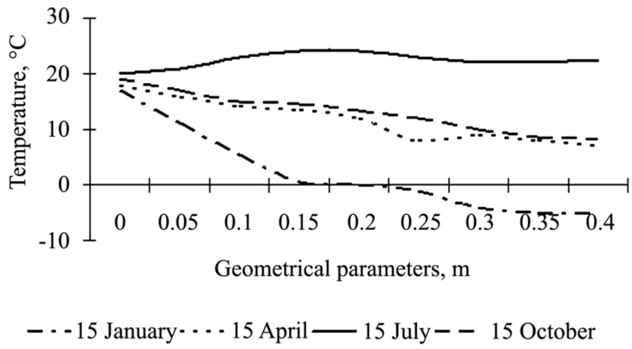

Fig. 6. Temperature distribution in the basic fence with the system "brick layer – energy-active fences" of southern orientation relative to the day, which corresponds to the middle of each season of the year at 6 hour of a day

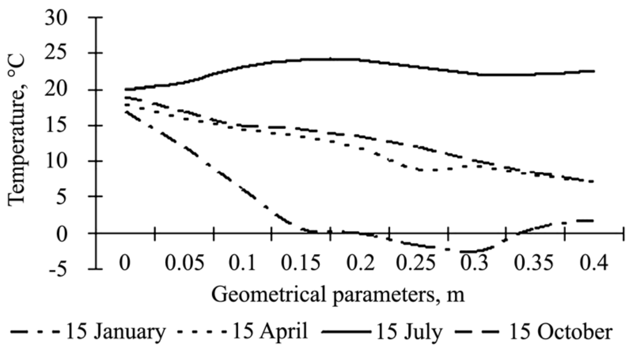

Fig. 7. Temperature distribution in the basic fence with the system "brick layer – energy-active fences" of southern orientation relative to the day, which corresponds to the middle of each season of the year at 12 hour of a day

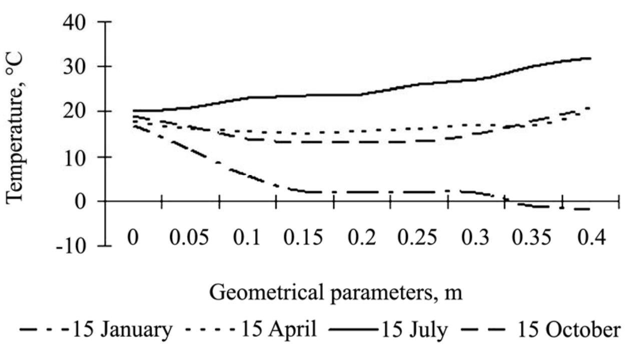

Fig. 8. Temperature distribution in the basic fence with the system "brick layer – energy-active fences" of southern orientation relative to the day, which corresponds to the middle of each season of the year at 18 hour of a day

It has been determined that the operational characteristics of energy-active fences significantly depend on the degree of emissivity, roughness, speed (vortices) of the air flow, thermophysical properties of the material of the corresponding surface. On the other hand, an important advantage of energy-active fences is their versatility. This is primarily due to their thermal insulation properties, which require further research. The proliferation of energy-active fences will also be facilitated by their ability to decorate the exterior of the buildings where they are installed. Combinations of energy-active fences with photovoltaic converters have not been investigated.

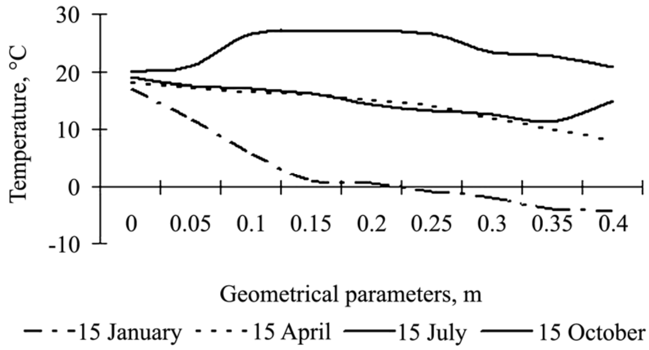

Fig. 9. Temperature distribution in the basic fence with the system "brick layer – energy-active fences" of southern orientation relative to the day, which corresponds to the middle of each season of the year at 24 hour of a day

6. Discussion of the research results on the features of the use of energy-active fences during the transition period of the year

The greatest impact (Fig. 2–9) of energy-active fences is manifested in transition periods (spring, autumn). During these periods, without an additional source of energy, which is located in the room, the temperature of the building structure is stabilized during the day. At the same time, the temperature at 12:00 is higher than the temperature at 18:00. The minimum temperatures are in the dark, but this decline in spring and autumn is slow. According to the data presented in Fig. 6–9, it is possible to clearly define the heat absorption of the outer layers of a building structure with energy-active fencing ($\partial T/\partial x>0$) in spring, summer and autumn. The use of such data makes it possible to predict and regulate the thermal characteristics of the basic building fences. This will help regulate the heat. It has been determined that thermal stability during the day is characteristic of the inner layers of a building structure with energy-active fencing, shown in Fig. 2–9, has a positive effect on operational properties. In this case, the temperature difference between the room and the inner surface of the walls comfortably fluctuates within 7 degrees.

According to calculations, in the case of a brick fence, heat loss through such a structure mainly passes from October to April (this coincides with the heated season). In the presence of energy-active fences in April and October, the rate of heat loss is significantly reduced. At certain times, heat gains can exceed heat losses and can be used for accumulation. According to calculations, in the presence of energy-active fences, heat losses are reduced by 2–2.5 times.

The warmth of the period of the year is characterized by the accumulation of heat in the building structure. In the presence of energy-active barriers, it is advisable to determine it by the difference between $e(t, \delta)$ and $e(t, 0)$. In the warm season, the heat flow into the room is perceived by the power supply system and sent to hot water supply and heating.

As a result of the study, it was outlined that the use of energy-active fences in power supply systems is limited by physical, technical, economic and other factors. The efficiency of using energy supply systems with energy-active fences should be considered separately for each facility.

The disadvantage of this study is the complexity of experimental verification of the results obtained.

Further improvement of energy supply systems is possible by improving the designs of energy-active fences and elements of their integration to structures.

7. Conclusions

1. A mathematical model has been developed for calculating the thermal modes of operation of the proposed design. Energy-active fencing qualitatively shows an improvement in the temperature regime of buildings and quantitatively allows to calculate this improvement, especially for transitional (spring-autumn) periods of the year. Preliminary calculations show that passive thermal modernization of the structure will reduce energy consumption in the cold season by an average of 1.5 times. At the same time, thermal modernization using energy-active fences allows, on average, during the cold season, to reduce energy consumption by 3.5 times.

In the warm period of the year, the use of an innovative power supply system with energy-active fences allows to reduce the load on the air conditioning system by 3 times. Additional energy obtained from renewable sources can be used to replace energy costs for hot water supply. The excess energy is used for storage in the seasonal heat accumulator.

2. The research results obtained in this work make it possible to qualitatively propose in the future a number of new designs of energy-active fences. All of them have a common feature – they are multilayer objects and have the ability to regulate the redistribution of heat flows, leading to significant energy savings.

The task of energy-active fences is to minimize heat losses while simultaneously generating additional heat into the system, obtained through the conversion of solar radiation energy. This result is achieved thanks to specially selected for the thermal properties of multilayer structures of energy-active fences. These are such layers as power elements, thermal insulation, energy-saving/energy-transforming elements, decorative protective elements.

3. The qualitative and quantitative indicators of the work of energy-active, multilayer fences have been investigated, which make it possible to develop a methodology for systematic scientific regulation of technical measures for air conditioning and power supply systems in structures for various purposes. The thermal insulation properties of energy-active fences contribute to protection against condensation, regulate the level of steam and moisture penetration, etc. Regulation of the level of heat flow is facilitated by the ability of energy-active fences to regulate the thermal resistance of the basic structure elements. Such a complex of physical and technical positive features of the design of energy-active fencing contributes to the preservation of the temperature balance of the object during the transitional periods of the year. This saves energy resources for the maintenance of the heating system.

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