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# RADIANT HEATING AND COOLING SYSTEM EFFICIENCY OF OFFICE PREMISE BASED ON TABS

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**In this article the specific heating and cooling capacity of the ceiling TABS was determined. The step of tube laying varied and was 10, 15, 20, 25, and 30 cm. Determination of the specific heating capacity was carried out for $t_h$ /$t_c$ = 35/31; 36/32; 34/30 °C. The determination of the specific cooling capacity was carried out for $t_{cold}$ /$t_{heated}$ = 15/18; 16/19; 16/20 °C. The radiant heating system based on ceiling TABS allows providing the necessary heating capacity to fully cover the heat loss of the room. The maximum values of the carrier temperature are $t_h$ /$t_c$ = 34/30 °C. In the warm period, the ceiling TABS does not allow to provide the necessary cooling capacity of the room. Thus, the greatest cooling capacity of TABS is observed at coolant parameters $t_{cold}$ /$t_{heated}$ = 15/18 °C, which allows covering about 70 % of the estimated heat gains of the room. Therefore, during the hours of peak heat gains an additional cooling device should be used in the room.**

**Key words: district heating and cooling system; renewable energy source; radiant heating system; radiant cooling system; thermally activated building system; specific capacity.**

## Introduction

One of the ways to achieve the European Union's goal of achieving zero greenhouse gas emissions by 2050 is the use of district heating and cooling systems. District heating and cooling systems allow to efficiently and safely supply energy for the needs of heating and cooling systems for the buildings of various purposes (Abugabbara, 2023). Such systems are recognized as a key solution for the decarbonization of the energy sector due to the high potential for the integration of renewable energy sources. As energy resources in district heating and cooling systems, such renewable energy sources as biomass, geothermal energy from the depths of the earth and water bodies, waste heat from industrial and public buildings are considered (Savchenko, et al., 2018; Lepiksaar, et al., 2021; Lis & Savchenko, 2022; Pakere, et al., 2021; Yurkevych, Savchenko & Savchenko, 2022). The main problem with the use of renewable energy sources in heating and cooling systems is their low temperature potential, which determines the operating temperature range of coolants in the systems, and, accordingly, the choice of the type of heating and cooling system in houses (Savchenko, et al., 2023). One of the possible types of heating and cooling systems, which are advisable to use in the presence of low-temperature coolants, are radiant heating and cooling systems (Kazanci, Shinoda & Olesen, 2022; Babiak & Vagiannis, 2015; Stojanovi, et al., 2014). Such radiant systems provide thermal comfort in the room and reduce the consumption of energy resources compared to convective heating systems (Seo, et al., 2023; Gallardo & Berardi, 2021). In radiant heating systems air or water coolant or electric cables can be used for heat transfer, and in radiant cooling systems water coolant is used (Shindo, et al., 2023). Therefore, when designing district heating and cooling systems, it is advisable to use combined radiant systems with a water coolant. One of the varieties of radiant heating and cooling systems, which use water as a heat carrier, are thermally activated building systems (TABS). For radiation or release of heat in TABS, building enclosures of the premises are used, in which tubes for water circulation are installed, and the installation of tubes is carried out at the stage of building construction. The tubes in TABS are used alternately in the warm period of the year and in the cold period of the year, respectively, by the cooling and heating systems. At the same time, in the warm season of the year, cold water circulates through the TABS tubes and absorbs excess heat from the room through the ceiling massif, and in the cold season of the year, heated water moves in the tubes and heats the room. In Ukraine, radiant heating systems are used mainly for heating industrial or agricultural buildings, and as heating devices they use mainly electric or gas infrared heaters (Dudkiewicz, Voznyak & Spodyniuk, 2023; Fialko, Zhelykh & Dzeryn, 2013). The use of radiant panel systems is characterized only by isolated cases (Savchenko, Dzeryn & Lis, 2023). However, the future accession of Ukraine to the European Union and the need to comply with the requirements for the introduction of low-temperature centralized heating and cooling systems of the 4th generation will promote the use of radiant heating and cooling systems. Therefore, it is currently relevant to investigate the operation of the radiant heating system in rooms of various purposes.

That is why, the aim of this article is to assess the possibility of using a radiant heating and cooling system to maintain acceptable microclimate parameters of an office premise in Lviv.

## Materials and methods

Thermally activated building systems (TABS) are divided depending on the working elements. Currently, they are divided as follows: systems with pipes that are embedded in a massive concrete slab, and systems with capillary tubes embedded in a thin layer that can be thermally bonded to the massive slab. Concrete panels, in which pipelines for the circulation of the heat carrier are installed, are used as enclosing structures of premises, in particular ceilings, walls or floors. The concrete panel provides significant thermal inertia, helping to continue releasing heat after the system is turned off and maintaining a stable indoor temperature. In addition, large areas of thermally activated surfaces provide significant heat flows between the premises and the structure even with relatively small temperature differences. Water is most often used as a heat carrier due to its high heat-accumulating properties.

The intensity of thermal radiation during the operation of thermally activated building systems depends on many parameters, in particular, the location of the enclosing structure, the orientation of the outer wall of the building, the type of pipe laying, the pitch of pipe laying, the diameter and material of the pipes, the temperature and the speed of the liquid circulating in the pipes.

For example, Chandrashekar and Kumar (Chandrashekar & Kumar, 2023) investigated the effect of different types of flooring on the performance of a thermally activated building system. Vinyl and granite flooring were compared for maximum floor cooling. According to the results of experimental research, the authors concluded that with a granite floor covering, the cooling efficiency is higher by 64 %, and the air temperature and heat flow in the granite covering were kept uniform for a significant part of the time.

Other studies have analyzed the effect of location, separation, and pipe spacing in wall-mounted TABS on indoor air temperature. Yes, Jiang et al. (Jiang, et al., 2020) investigated the influence of the coolant velocity and the type of tube arrangement on the water temperature. In a numerical study, they compared two TABS designs: series-connected tubes in a wall and a wall with parallel-connected tubes. The authors found that the inlet water temperature had a more significant effect on the internal temperature than the sol-air temperature. The authors observed that lowering the water temperature below 26 °C in summer and increasing the temperature above 18 °C in winter reduces the heat load for cooling and heating, respectively.

Romani and others (Romaní, Gracia & Cabeza, 2018) made a numerical model of a radiant wall in 2D, verified with an experimental prototype. A parametric study showed that the distance and depth of pipe placement significantly affect the thermal behaviour of the walls. The authors obtained better performance when placing the pipes at a depth of 0.045 and 0.065 m and with a distance of 0.0125 and 0.0150 m, because heat flows and temperature inside were minimized.

Leo Samuel and others (Samuel, Nagendra &Maiya, 2018) analyzed the effect of three parameters on the thermal behaviour of TABS. The following indicators were changed: the step between the pipes, the vertical position and the location of the pipes embedded in the roof and floor. They found that reducing the pitch between the pipes from 0.3 to 0.1 m and moving the pipes towards the inner surface from 0.135 to

0.015 m reduced the indoor air temperature by 1.6 and 2.7 °C, respectively. Meanwhile, changing the arrangement of pipes from a coil to a parallel arrangement reduced the indoor air temperature to 32.1 °C. The authors achieved such reductions at a distance of 0.1 m and a vertical position of 0.015 m, and the parallel arrangement of the pipes reduced the indoor air temperature by 6.8 °C, reaching a comfortable indoor temperature of 29 °C.

The main advantages of TABS are the shift of the peak load, a comfortable thermal environment, and the integration of low-quality renewable energy sources and the storage of energy in the thermal mass of the building (Romaní, Gracia & Cabeza, 2016; Chandrashekar & Kumar, 2023). Recent studies show the feasibility of using such structures in combined heating and cooling systems (Villar-Ramos, et al., 2022).

In Ukraine, some requirements for the design of radiant heating systems are given in DBN B.2.5-67:2013 “Heating, ventilation and air conditioning”, as well as in DBN B.2.2-43:2021 “Basic provisions on infrared gas heaters”. The implementation of radiant heating and cooling systems in Ukraine is carried out by companies producing the corresponding products. So, in 2021, REHAU published a manual that contains technical information on the equipment of radiant heating and cooling systems, their design and installation features, and testing requirements.

## Results and discussions

Analytical studies were carried out for the heating and cooling system of an office building built in the city of Lviv, with dimensions of 15×12 m. The temperature of the internal air in the cold period of the year is 20 °C, in the warm period is 26 °C. Heat gains in the warm period of the year were assumed to be 31 W/m$^2$. The heat transfer resistance of external enclosures meets the requirements of DBN V.2.6-31:2021 “Thermal insulation and energy efficiency of buildings”. In the heating and cooling system, a thermally activated ceiling structure was used, the design of which is presented in Fig. 1. REHAU RAUTHERM S polymer pipes measuring 20×x2.0 mm are located in the middle of the 270 mm thick concrete ceiling.

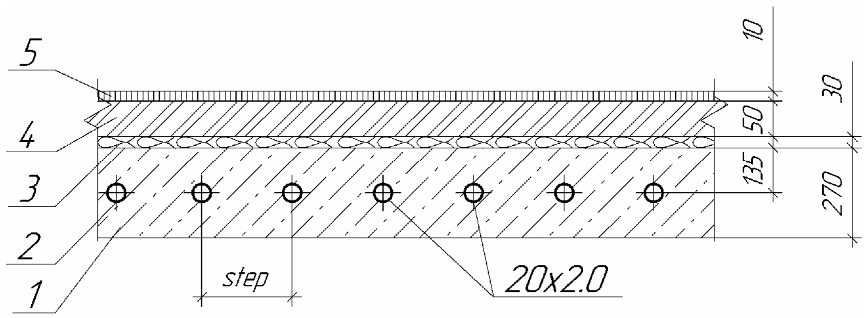


*Fig. 1. Construction of a thermally activated ceiling structure:*
*1 – concrete ceiling; 2 – tubes; 3 – noise isolation; 4 – screed; 5 – covering of the floor*

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In these studies, the simplest case of engineering systems for maintaining microclimate parameters in the room was considered. In particular, to cover heat gains in the warm period of the year and heat loss in the cold period of the year, a combined radiant heating and cooling system was designed, and fresh air is supplied to the premises when needed by natural ventilation, namely when windows and doors are opened (Fig. 2).

The determination of the specific heating capacity of the combined radiant system was carried out separately for the heating and cooling systems for different steps of laying tubes, in particular 10 cm, 15 cm, 20 cm, 25 cm and 30 cm. The simulation was carried out using the REHAU computer program. The operation of the thermally activated building system in the cold period of the year was investigated to cover the heat loss of the room with three groups of heat carrier parameters, namely $t_h / t_c$ = 35/31; 36/32; 34/30 $^{o}$C, and the calculated air temperature in the premise was 20 $^{o}$C. The values of the specific heating capacity of the thermally activated ceiling during its operation in the radiant panel heating system are shown in Fig. 3.

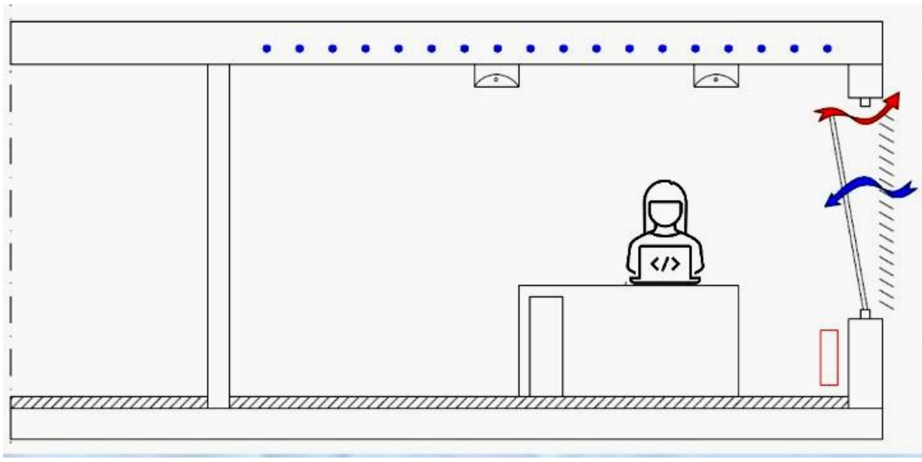


*Fig. 2. Scheme of an office space with a combined radiant heating and cooling system and natural ventilation*

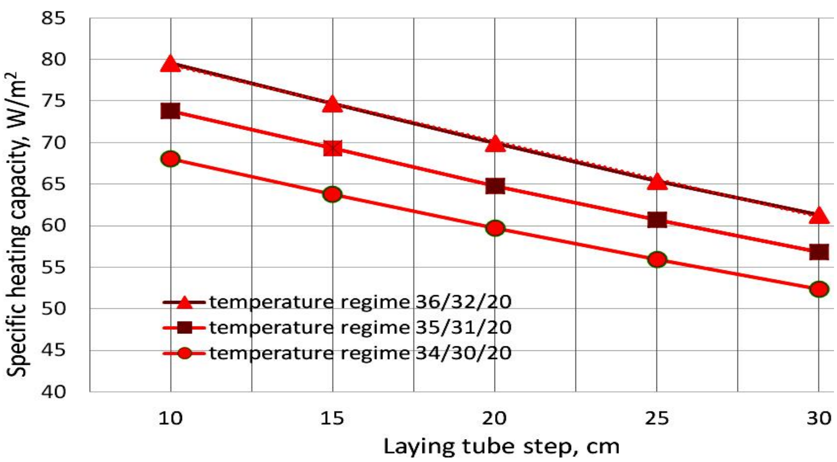


*Fig. 3. TABS specific heating capacity of the office premise in the cold period of the year*

As can be seen from Fig. 3, the highest values of the specific heating capacity of the studied TABS are observed at the temperature of the hot water $t_h$ = 36 °C and the temperature of the cooled water $t_c$ = 32 °C, therefore, the higher the temperature of the hot water, the higher the specific heating capacity of the TABS will be. In addition, the specific heating capacity of the studied TABS is also directly affected by the step of laying tubes. The smaller the tube installation step, the greater the specific heating capacity of TABS. For the studied conditions, the highest specific heating capacity was observed at a tubes installation step of 10 cm.

The operation of the thermally activated building system in the warm period of the year was carried out to assimilate the heat entering the premises. For this purpose, the value of the specific cooling capacity of the studied TABS was calculated for three groups of coolant parameters, namely $t_{cool}$ / $t_{heated}$ = 15/18; 16/19; 16/20°C, the calculated air temperature in the room was 26 °C. The values of the specific cooling capacity of the thermally activated ceiling during its operation in the radiant cooling system are shown in Fig. 4.

As can be seen from Fig. 4, the highest values of the specific cooling capacity of the studied TABS are observed at the temperature of cold water $t_{cold}$ = 15 °C and the temperature of heated water $t_{heated}$ = 18 °C. Therefore, the lower the temperature of cold water, the higher the specific cooling capacity of TABS will be. In addition, the highest value of the specific cooling capacity of the studied TABS was observed at a tubes installation step of 10 cm.

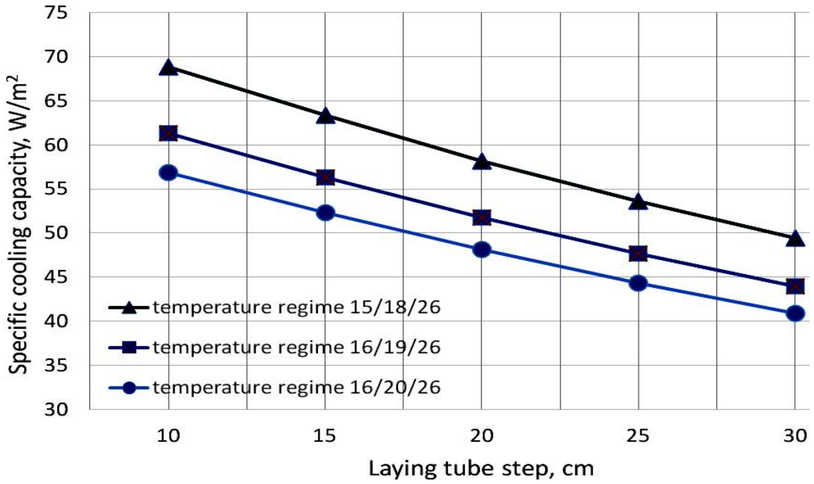


*Fig. 4. TABS specific cooling capacity of the office premise in the warm period of the year*

Analytical studies were also conducted for the investigated office premise to ensure acceptable microclimate parameters with the help of TABS in cold and warm periods of the year, in particular, whether they will be able to fully cover the heat loss and heat gain of the office premise. To do this, with the help of the REHAU computer program, the share of coverage of heat losses and the share of coverage of heat gains when changing the step of laying tubes heat carrier parameters was determined. Thus, Fig. 5 shows the graphs of coverage of heat loss in an office premise using radiant heating, namely ceiling TABS.

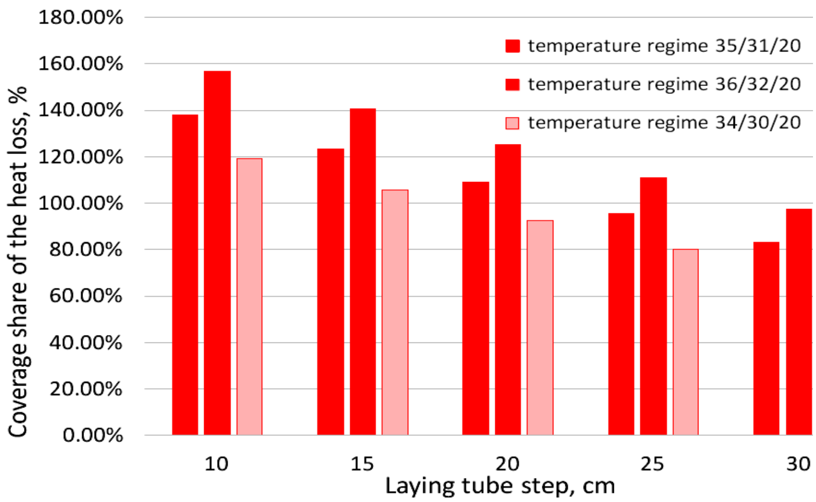


*Fig. 5. The share of heat loss coverage of the office premise by TABS depending on the step of laying the tubes and the heat carrier parameters*

As can be seen from Fig. 5, at the same specific heating capacity of TABS, the temperature of the hot water of the carrier circulating in the tubes has the greatest influence on the efficiency of the radiant heating system. Thus, the heat carrier with the parameters $t_h$ /$t_c$ = 36/32 °C completely covers the heat loss of the office premise at all investigated steps of laying the tube. The heat carrier with the parameters $t_h$ / $t_c$ = 34/30 °C has the worst performance, it allows to cover the heat loss of the room only at a step of 10 cm and 15 cm.

Thus, Fig. 6 shows the graphs of coverage of the heat gains of the office premise with the help of radiant cooling, namely ceiling TABS.

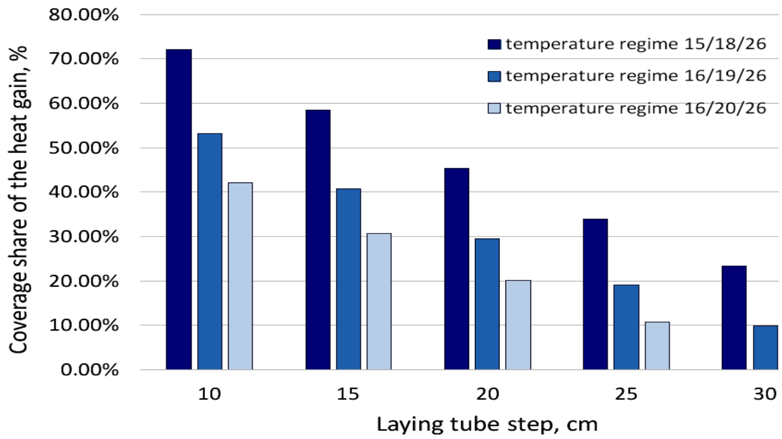


*Fig.6. The share of coverage of the heat gain of the office premise by TABS depending on the step of laying the tubes and the coolant parameters*

As can be seen from Fig. 6, at the same value of TABS heat inputs, the temperature of the cold water of the coolant circulating in the tubes has the greatest influence on the efficiency of the radiant cooling system. Thus, the coolant with the parameters $t_{cold} / t_{heated}$ = 15/18 °C has the highest coverage of heat gains to the room for all investigated steps of tube laying, and the coolant parameters $t_{cold} / t_{heated}$ = 16/20 °C has the worst indicators. In addition, the results of the analytical studies showed that none of the investigated TABS options for different steps of tube laying and coolant parameters allow to completely cover all the heat gains of the investigated office premise. The highest value reaches 72 % with a tube step of 10 cm and coolant parameters $t_{cold} / t_{heated}$ = 15/18 °C. Therefore, to ensure acceptable parameters of the microclimate in the office premise and to cover all heat gains, it is necessary to provide additional devices for air cooling, for example, a wall-mounted TABS or an air conditioner.

The analysis of Fig. 5 and Fig. 6 allows us to establish that to ensure acceptable parameters of the microclimate of the office premises, it is possible to use a combined system of radiant heating and cooling based on the ceiling TABS, with tubes measuring 20.0×2.0 mm and a step of 10 cm, which are located in the middle of the concrete floor. At the same time, in the cold period of the year, the temperature of the coolant should not be higher than the value $t_h / t_c$ = 34/30 °C, and in the warm period of the year – not higher than $t_{cold} / t_{heated}$ = 15/18 °C. In addition, an additional cooling device should be used during the hours of peak heat gains in the office premise.

## Conclusions

1. As the research data showed, the radiant heating and cooling system based on the ceiling TABS allows you to partially maintain the acceptable parameters of the microclimate in the office premises, and its effectiveness depends on the step of tubes laying and parameters of the coolant in the TABS. Thus, for the climatic conditions of Lviv, the highest values of specific capacity were observed for the smallest value of the step of tube laying, namely 10 cm.

2. Determination of the specific heating capacity of the radiant heating system for the cold period of the year was carried out for three groups of carrier parameters: $t_h / t_c$ = 35/31; 36/32; 34/30 °C, and the determination of the specific cooling capacity of the radiant cooling system for the warm period of the year was carried out for the following groups of coolant parameters: $t_{cold} / t_{heated}$ = 15/18; 16/19; 16/20 °C. It has been established that the radiant heating system based on the ceiling TABS provides the necessary heating capacity to fully cover the heat loss of the room. At the same time, the maximum values of the carrier temperature are $t_h / t_c$ = 34/30 °C.

3. In the warm period of the year, the ceiling TABS does not allow to provide the necessary cooling capacity of the room. The greatest cooling capacity of TABS is observed at coolant parameters $t_{cold} / t_{heated}$ = 15/18 °C, which allows covering about 70 % of the estimated heat gains of the room.

4. During the hours of peak heat gains in the warm period of the year, an additional cooling device should be used in the room.

5. In further research, it is advisable to establish the amount of primary energy that was saved when using radiant heating and cooling systems to ensure microclimate parameters in the office premises.

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## ЕФЕКТИВНІСТЬ СИСТЕМ ПРОМЕНЕВОГО ОПАЛЕННЯ ТА ОХОЛОДЖЕННЯ ОФІСНОГО ПРИМІЩЕННЯ НА ОСНОВІ ТАБС



Централізовані системи тепло- і холодопостачання є ключовим рішенням щодо декарбонізації енергетичного сектору через високий потенціал інтеграції відновлюваних джерел енергії. Проте низький температурний потенціал відновлюваних джерел енергії зумовлює відповідні діапазони робочих температур теплоносіїв у системах опалення та охолодження. За наявності низькотемпературних теплоносіїв доцільно використовувати системи променевого опалення та охолодження, які забезпечують тепловий комфорт у приміщенні та зменшують споживання енергетичних ресурсів. У статті визначено питому потужність стельової ТАБС із вмонтованими трубами розмірами 20×2,0 мм, що розташовані в середині бетонного перекриття завтовшки 270 мм. Крок укладання трубопроводів змінювався та становив 10, 15, 20, 25 та 30 см. Визначення питомої теплової потужності променевої системи опалення виконано для параметрів теплоносія: $t_г$ / $t_о$ = 35/31; 36/32; 34/30 °C. Визначення питомої холодильної потужності променевої системи охолодження здійснено для параметрів теплоносія: $t_х$ / $t_н$ = 15/18; 16/19; 16/20 °C. Результати аналітичних досліджень показують, що система променистого опалення на основі стельового ТАБС дає змогу забезпечити необхідну теплову потужність для повного покриття тепловтрат приміщення, а максимальні значення температури теплоносія становлять $t_г$ / $t_о$ = 34/30 °C. У теплий період року стельова ТАБС не дає змоги забезпечити необхідну холодильну потужність приміщення. Найбільша холодильна потужність ТАБС спостерігається за параметрів холодоносія $t_х$ / $t_н$ = 15/18 °C, що дає змогу покрити близько 70 % розрахункових теплонадходжень приміщення. Тому в години пікових теплонадходжень у теплий період року у приміщенні необхідно використовувати додатковий охолоджувальний прилад.

**Ключові слова: система централізованого опалення та охолодження; відновлюване джерело енергії; система променевого опалення; система променевого охолодження; термічно активована будівельна система; питома потужність.**