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IMPROVING THE EFFICIENCY OF THERMAL ENERGY USE WHEN HEATING BUILDINGS THROUGH THE INTRODUCTION OF TECHNOLOGIES «SMART HOME»

Purpose. Investigation of the effectiveness of application in the heating systems of administrative, residential, industrial and other buildings of automated thermal management systems for premises using the «smart home» technology **Methods.** Analysis and synthesis of information, mathematical modeling of the heat supply process of a building, statistical data processing, a computational experiment to assess the effectiveness of the use of «smart home» technologies in heat supply systems. **Results.** A natural object was selected and investigated for the introduction of energy-saving technologies − a 3-storey fragment of the O.M. Beketov National University of Urban Economy in Kharkiv administrative building with a total heated area of 225,3 m^2; investigated: structure, principle of operation, efficiency of the use of an automated control system for thermal conditions of the premises - HERZ Smart Comfort. **Conclusions**. The efficiency of using the HERZ Smart Comfort system was assessed according to the following criteria: the relative and absolute values of the decrease in thermal energy for heating a building - a natural object, the reduction in atmospheric emissions of carbon dioxide - CO_2, and the economic efficiency from saving thermal energy.The heat loss calculation was performed at round-the-clock temperature in premises +18 ° C for average monthly outside air temperatures in Kharkov during the heating seasons 1981-2016. It has been established that the use of «smart home» technologies allows reducing the costs for heating a natural object during the heating season by 16.6%, which is 4709 kWh and leads to a reduction in CO_2 emissions from the production of heat in the amount of 0.95 tons/year; The economic effect in this case is 6430 UAH.

Keywords: power system, heat supply, heating system, thermal regime, “smart home”, natural object, energy efficiency

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВИКОРИСТАННЯ ТЕПЛОВОЇ ЕНЕРГІЇ ПРИ ОПАЛЕННІ БУДІВЕЛЬ ВПРОВАДЖЕННЯМ ТЕХНОЛОГІЙ «РОЗУМНИЙ БУДИНОК»

Мета. Дослідження ефективності застосування в системах опалення адміністративних, житлових, промислових та інших будівель автоматизованих систем управління тепловими режимами приміщень з використанням технології «розумний будинок». **Методи.** Аналіз і синтез інформації, матема-тичне моделювання процесів теплопостачання будівель, статистична обробка результатів спостережень, розрахунковий експеримент для оцінювання ефективності використання smart-технологій «розумний будинок» в системах теплопостачання будівель. **Результати.** Обрано і досліджений натурний об'єкт для впровадження енергозберігаючих технологій теплопостачання будівель – 3-поверховий фрагмент адміністративного корпусу Харківського національного університету міського господарства імені О.М. Бекетова із загальною опалювальною площею 225,3 м^2; досліджені: структура, елементи, принцип дії, ефективність використання автоматизованої системи керування тепловими режимами приміщень - HERZ Smart Comfort. **Висновки.** Проведено комплексну оцінку ефективності використання системи HERZ Smart Comfort за наступними критеріями: відносні і абсолютні значення зниження кількості теплової енергії, що витрачається на опалення будівлі - натурного об'єкта, зниження викидів в атмосферу вуглекислого газу - CO_2, економічна ефективність від скорочення витрат теплової енергії. Розрахунок втрат тепла проводився при середньодобовій температурі в приміщеннях +18 °C для середньомісячних температур атмосферного повітря у м. Харкові в опалювальні сезони 1981-2016 років. Встановлено, що використання технології «розумний будинок» дозволяє знизити витрати на опалення натурного об'єкта за опалювальний період на 16,6%, що становить 4709 кВт·год і призводить до скорочення викидів CO_2 при виробництві теплової енергії в розмірі 0,95 тонни на рік. Економічний ефект при цьому складає 6430 грн.

Ключові слова: теплоенергетика, теплопостачання, система опалення, тепловий режим, «розумний будинок», натурний об'єкт, енергоефективність

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ИСПОЛЬЗОВАНИЯ ТЕПЛОВОЙ ЭНЕРГИИ ПРИ ОТОПЛЕНИИ ЗДАНИЙ ВНЕДРЕНИЕМ ТЕХНОЛОГИЙ «УМНЫЙ ДОМ»

Цель. Исследование эффективности применения в системах отопления административных, жилых, промышленных и других зданий автоматизированных систем управления тепловыми режимами помещений с использованием технологии «умный дом». **Методы.** Анализ и синтез информации, математическое моделирование процессов теплоснабжения зданий, статистическая обработка результатов наблюдений, расчетный эксперимент для оценки эффективности использования smart-технологий «умный дом» в системах теплоснабжения зданий. **Результаты.** Выбран и исследован натурный объект для внедрения энергосберегающих технологий теплоснабжения зданий − 3-этажный фрагмент административного корпуса Харьковского национального университета городского хозяйства имени А.Н. Бекетова с общей отапливаемой площадью 225,3 м^2; исследованы: структура, элементы, принцип действия, эффективность использования автоматизированной системы управления тепловыми режимами помещений - HERZ Smart Comfort. **Выводы.** Проведена комплексная оценка эффективности использования системы HERZ Smart Comfort по следующим критериям: относительные и абсолютные значения снижения количества тепловой энергии, затрачиваемой на отопления здания - натурного объекта, снижение выбросов в атмосферу углекислого газа - CO_2, экономическая эффективность от сокращения затрат тепловой энергии. Расчет потерь тепла проводился при среднесуточной температуре в помещениях +18 °С для среднемесячных температур атмосферного воздуха в г. Харькове в отопительные сезоны 1981-2016 годов. Установлено, что использование технологии «умный дом» позволяет снизить затраты на отопление натурного объекта за отопительный период на 16,6%, что составляет 4709 кВт·ч и приводит к сокращению выбросов CO_2 при производстве тепловой энергии в размере 0,95 тонны в год. Экономический эффект при этом составляет 6430 грн.

Ключевые слова: теплоэнергетика, теплоснабжение, система отопления, тепловой режим, «умный дом», натурный объект, энергоэффективность

Introduction

In recent years, a significant number cities of Ukrainian, in particular, Kyiv, Kharkiv, Lviv, Ternopil, Chernivtsi and others, joined the "Covenant of Mayors on Climate and Energy" [1], which provides carrying out measures by the municipal authorities on a significant reduction of greenhouse gas emissions by 30% by 2030. Achieving this result requires a new strategy for the use and development of municipal power system, which envisages increasing the ecological safety of boiler plants and heat-energy centers through the introduction of innovative highly effective energy and environmental technologies [2, 3]. It should take into account such problems homeland heat energy as: outdated technology of production and equipment, high energy intensity and material capacity, which exceeds 2-3 times the corresponding indicators of developed countries; the lack of proper environmental protection systems, the lack of proper legal and economic mechanisms which would stimulate development of environ-mentally sound technologies and environmental protection systems, etc. [4,5]. At the same time, stimulation of effective consumption of heat energy by the population will reduce the resource-intensive of urban heat networks, which will reduce the pollution of the environment and emission reductions into the atmosphere of greenhouse gases [6].

The price increase of the energy resources stimulates the development and improvement of energy saving technologies. In Ukraine, there is a significant potential for energy saving due to the reduction of heat loss through the walls, ceiling, windows, and other enclosing structures of residential and public buildings. Unlike residential buildings, where in accordance with the requirements of public health regulations the temperature must be maintained continuously throughout the heating period, in administrative buildings it is possible to reduce the temperature during the absence of staff and visitors. According to the authors of this publication, a temporary decrease in temperature is advisable if premises are not occupied for at least 10–12 hours at a time, which takes place in administrative buildings and classrooms at night, on weekends, and during holidays. In order to avoid the disruption of the desirable humidity levels and thermal movement a temporary decrease in temperature should not exceed 3 °C. The purpose of this work was to develop technical proposals for optimizing the heat supply schedule of the administrative building with further evaluation of the ecological impact.

Object and methods of research

Description of natural object for realization of researches. As an object of research, a section of the administrative building at the Kharkiv National University of Urban Economy has been selected, which houses a lecture hall, laboratory, conference room, and offices of the university administration (fig. 1). It is a three-story building with two exterior walls and two interior walls adjacent to heated rooms. As a result of a full-scale building survey, the constructive parameters of enclosing structures necessary for carrying out thermal calculations were obtained. According to the indications of meters, the average actual value of specific heat consumption for the entire administrative building in the 2017 heating season was $\boldsymbol{q}_{\boldsymbol{averag}}$ = 97,5 kWh /m^2. The selected section of the building has two external walls and window openings facing north. The ratio of the window opening area to the exterior wall area is substantially larger than the average value of the entire building. Therefore, it can be assumed that the value of specific heat consumption in the selected section of the building will exceed the average value of specific heat consumption for the entire building according to the indications of meters. The average temperature inside the building during the heating season 2017 is t_{ex} = +18 °C.

Method for calculating heat consumption management efficiency natural object. The technique is designed to assess the effectiveness of the use of a remote control system for thermal conditions of an object's premises - HERZ Smart Comfort, which automatically reduces the temperature in rooms that are not currently used, by an average of 3 °C. The restrictions of the temperature schedule were adopted in accordance with the requirements of the current regulatory acts, considering the temperature should remain between 17–23 °C during classes in classrooms and auditoriums. The maximum permissible value of the specific annual energy demand for the University campus buildings was used in order to assess the energy efficiency class of the building, which

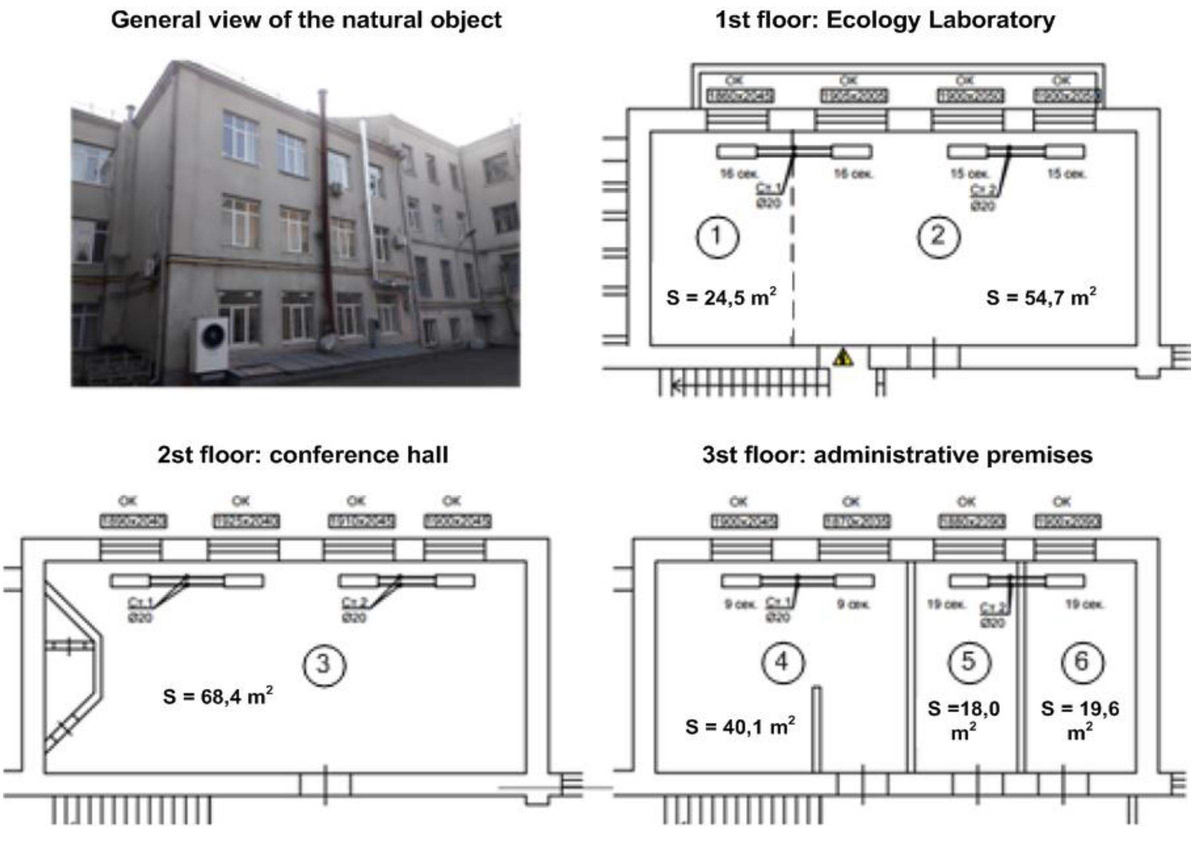

Fig. 1 − Natural object for research on the efficiency of heat consumption with total heated area 225.3 m^2

constitutes 30 kWh / m3 for the Kharkov climate zone.To create a mathematical model for calculating the heat loss of the facility traditional methods of thermal engineering calculations were used as well as standard values of the heat engineering characteristics of the walls, ceiling, windows, and other enclosing structures [7].

Heat flow (heat loss) Q, W through the enclosing structures (exterior walls, windows, floors, ceilings) is determined in accordance with the expression:

$$Q = k \cdot F \cdot \Delta t$$

where k – heat transfer coefficient, W/м^2 К;

F – is the surface area, m^2;

Δt – the difference between the exterior and interior temperatures, ^oC;

Heat transfer coefficient could be calculated according to the formula:

$$k = \frac{1}{\frac{1}{\alpha_{in}} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \ldots + \frac{d_3}{\lambda_n} + \frac{1}{\alpha_{ex}}}$$

where α_{in} – heat transfer coefficient from indoor air to the wall, W/м^2· К;

d_1 – thickness of the first layer of the building envelope, m;

λ_1 – thermal conductivity coefficient of the first layer of the enclosing structure, W/(m·K);

d_2 ,…, d_n – thickness of the second and subsequent layers of the enclosing structure, m;

λ_2 ,…,λ_n – thermal conductivity coefficient of the second layer and subsequent layers of the enclosing structure, W/(m·K);

α_{ex} – heat transfer coefficient from the wall to the outside air, W/м^2· К.

According to [7] assume α_{in} = 8,7 W/м^2· К; α_{ex} = 23 W/м^2· К.

Infiltration heat loss is defined as:

$$Q_{\inf} = c \cdot m \cdot \Delta t$$

where c is the average heat capacity of humid air, determined in accordance with [7], kJ / kg ^oC;

m - normative air permeability of enclosing structures of buildings, kg / m^2 hour;

Δt – the difference between interior and exterior temperature, ^oC.

In Kharkov during the heating season of 2017 the average monthly air temperature used in the calculation is shown in table 1.

Table 1

Average monthly air temperature in Kharkov during the heating season of 2017

№	**Month**	**Average monthly air temperature, ^oC**	**Notes**
1	January	− 6.07	
2	February	− 3.88	
3	March	+ 5.6	
4	April	+ 9,99	between 04.01.17 - 04. 15.17
5	October	+ 6,39	between 10.15.17 - 10. 31.17
6	November	+1,8	
7	December	+2.38	

The results of the heat loss calculations with Kharkov average monthly outdoor temperatures during the 2017 heating season and at +18 °C room temperature are listed in table 2.

The calculated average value of specific heat consumption of the section of the building in the heating season of 2017 was obtained $q_{average}$ = 115 kWh/m^2, which is 17% higher than the average value of specific heat consumption according to meter readings for the entire building.

The comparative analysis of the average monthly air temperatures in Kharkov in the heating season of 2017 showed that it is not representative of the average temperatures of the heating season taken over a long-term period [9], presented in table 3.

For example, the average outdoor temperature in December 2017 differed from the average air temperature in December for a thirty-five year period by more than 5 °C.

The heat loss calculation was performed at round-the-clock temperature in premises +18 ° C for average monthly outside air temperatures in Kharkov during the heating seasons 1981-2016. Its results are presented in table 4.

Table 2

The results of the heat loss calculations with Kharkov average monthly outdoor temperatures during the 2017 heating season and at +18 ° C room temperature

№	Period	Heat loss during the period kWh
1	January	6127
2	February	4741
3	March	3092
4	April	1343
5	October	1547
6	November	4355
7	December	5563
8	Heating season	26768

Table 3

The average air temperature in Kharkov during the heating seasons 1981-2016

№	Month	Average monthly temperature, ^{o}C	Notes
1	January	− 4,6	
2	February	− 4,5	
3	March	+ 0,7	
4	April	+ 7,4	between 04.01. - 04. 15.
5	October	+ 5,6	between 10.15. - 10. 31.
6	November	+0,9	
7	December	− 3,5	

Table 4

The results of the heat loss calculations at round-the-clock indoor temperature +18 ° C and average monthly air temperatures in Kharkov during the heating seasons 1981-2016

№	Period	Heat loss during the period, kWh
1	January	5800
2	February	5217
3	March	4531
4	April	1337
5	October	1569
6	November	4338
7	December	5542
8	Heating season	28334

The need for heat supply of the premises was established as a result of the research:

- the ground floor is used on average 30 hours per week: 6 days for 5 hours;
- the second floor is used on average 2 hours a week: 2 days for 1 hour;
- the third floor is used on average 45 hours per week: 5 days for 9 hours.

It is proposed to apply The remote temperature control system that uses elements from HERZ Smart Comfort system, which will ensure the automatic temperature reduction in unoccupied premises by an average of 3 °C.

System of remote-control by the thermal mode of apartments with the use of technology «clever house» - HERZ Smart Comfort. HERZ Smart Comfort is a set of components for controlling heating on a smartphone. The kit includes (fig. 2):

– electronic thermal heads ETKF +;

– window open sensor;

– room wall thermostat;

– switching module Cube +;

– Eco SWITCH + wall heating switch.

All radiators in the house are equipped with electronic thermal heads ETKF +. In each room, a room programmable thermostat is installed, which measures the temperature in the room and gives commands to the thermal heads for opening and closing. It is possible to control directly the electronic thermal head according to the air temperature in the room, however, the savings are reduced, since the thermal head is installed directly on the radiator, its operation can be affected by curtains, direct sunlight. The room thermostat can be installed at an optimum height where external factors will not affect it. Each window must have a window opening sensor installed. To control thermostats via a smartphone, the system must be equipped with a Cube + module, which is located next to the router and provides connection to the Internet. The Eco SWITCH + heating switch is purchased one for the whole house, installed in the hallway and turned on when the last tenant leaves the house.

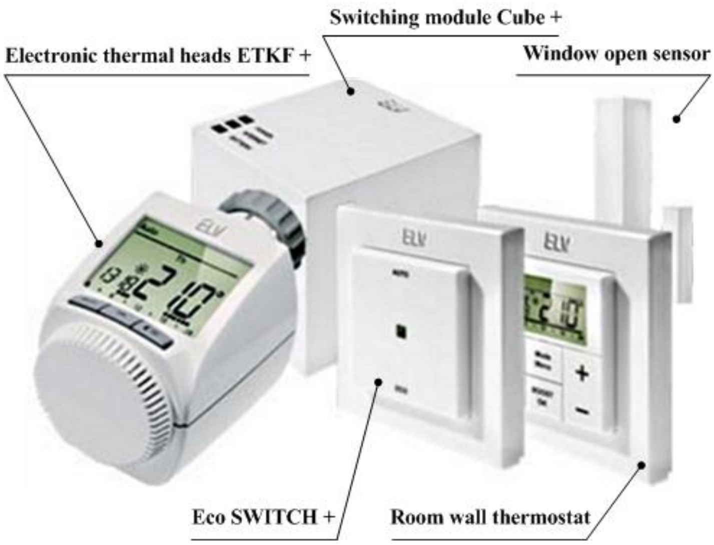

Fig. 2 – The main elements of the automated system HERZ Smart Comfort

The whole system HERZ Smart Comfort works as follows. The room thermostat measures the temperature in the room and through the thermal head changes the amount of heat-transfer fluid passed through the radiator. When you open the window, the sensor is triggered and the room temperature is automatically maintained at 17 °C (factory setting) or other user defined. With the help of a wall-mounted room thermostat, depending on the mode of homeowners, an hourly temperature change is configured. For example, in the afternoon from 8-00 to 17-00, when no one is home, you can set the temperature to 16 °C, and to return from 17-00 22 °C. A total of 6 hours periods can be set for a day with different temperatures. When changing the set schedule, the owner of the house through the smartphone with the pre-installed application can change.

Benefits HERZ Smart Comfort. The main factor that ensures the efficiency of the heating system and lower gas costs is flexibility in management. The temperature in the room should be exactly what is needed at the current moment and not a degree more. This functionality and provides HERZ Smart Comfort.

HERZ Smart Comfort features:

– control and temperature control in each room;

– heating control from a smartphone, laptop via the Internet;

– automatic temperature change in the room by periods (6 periods per day);

– the ability to remotely set the room temperature when changing the schedule;

– minimization of heat loss when airing rooms.

When managing heating from a smartphone via the HERZ Smart Comfort system, according to the manufacturer, it is possible to save up to 60% of energy resources.

Results and discussion

The results of the heat loss calculations while using the remote temperature control system are presented in table 5. In the calculations of thermal losses the average monthly temperatures of air are stopped up in Kharkiv in a heating season, got for thirtyfive-year period 1981-2016.

As follows from the comparison of the calculation results, the use of the remote temperature control system provides 4 700 kWh of heat savings for the heating season, reducing the cost of heating the building by 16.6%. As a result of switching to the optimal heat supply schedule the ecological efficiency was estimated by determining the potential fuel economy required to obtain the saved thermal energy (taking into account the averaged losses inevitable at each stage of the technological chain during energy transmission) and the corresponding environmental impact due to the fuel extraction, transportation, and combustion.

It is necessary to review the various ways of fuel production, transportation, combustion, transmission, and use of thermal energy in order to perform the precise assessment of the environmental impact. The major point for assessing the environmental performance is the reduction of greenhouse gas emissions, primarily CO_2 [9], as a result of burning natural gas. Given that in Ukraine there is no established national carbon emission factors for natural gas combustion, the potential reduction in CO_2 emissions was estimated based on recommendations of the International Expert Group.

Table 5

Results of the heat loss calculations while using the remote temperature control system at average monthly air temperatures in Kharkov during the heating seasons 1981-2016

№	Period	Heat loss during the period kWh
1	January	5159
2	February	4638
3	March	3390
4	April	1009
5	October	1238
6	November	3317
7	December	4874
8	Heating season	23625

As a result of a reduction in thermal energy consumption, the reduction of the greenhouse gas (CO_2) emissions that were generated as a result of fuel combustion are:

$$M_{CO_2} = K_{CO_2} \cdot \Delta Q$$

where K_{CO2} = 0,202 T/MW/h − CO_2 emission factor for thermal energy;

ΔQ − heat savings for the heating season.

As a result, the potential reduction in carbon emissions will be 0.95 tons / year.

Based on current tariffs for budget institutions of the utility company «Kharkov heat networks» [10], the heat energy savings during the heating season as a result of the use of the remote temperature control system with elements from HERZ Smart Comfort in the chosen section of the administrative building amounts to 6430 UAH.

Conclusions

1. The efficiency of application of automated systems for controlling thermal conditions of premises using the «smart home» technology in heating systems of administrative, residential, industrial and other buildings has been investigated. A natural object was selected and investigated for the introduction of energy-saving technologies − a 3-storey fragment of the O.M. Beketov National University of Urban Economy in Kharkiv adminis-

trative building with a total heated area of 225.3 m^2; investigated: structure, principle of operation, efficiency of the use of an automated control system for thermal conditions of the premises - HERZ Smart Comfort.

2. The efficiency of using the HERZ Smart Comfort system was assessed according to the following criteria: the relative and absolute values of the decrease in thermal energy for heating a building − a natural object, the reduction in atmospheric emissions of carbon dioxide − CO2, and the economic efficiency from saving thermal energy.The heat loss calculation was performed at round-the-clock temperature in premises +18 °C for average monthly outside air temperatures in Kharkov during the heating seasons 1981−2016. It has been established that the use of “smart home” technologies allows reducing the costs for heating a natural object during the heating season by 16.6%, which is 4709 kWh and leads to a reduction in CO_2 emissions from the production of heat in the amount of 0.95 tons/year; The economic effect in this case is 6430 UAH.

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