ТЕПЛОЕНЕРГЕТИКА (144)

UDC 697.1

JOINT INFLUENCE OF INTERMITTENT HEATING MODE AND OUTDOOR FACTORS ON APARTMENT HEAT LOAD

D. Sc. (Tech.) V. Deshko, PhD (Tech.) I. Sukhodub, postgraduate student O. Yatsenko

СУМІСНИЙ ВПЛИВ ПЕРЕРИВЧАСТОГО РЕЖИМУ ОПАЛЕННЯ ТА ЗОВНІШНІХ ФАКТОРІВ НА ТЕПЛОВЕ НАВАНТАЖЕННЯ КВАРТИРИ

Д-р техн. наук В. І. Дешко, канд. техн. наук І. О. Суходуб, асп. О. І. Яценко

DOI: https://doi.org/10.18664/1994-7852.191.2020.217286

Abstract. *Qualitative energy efficiency measures calculation should take into account the interaction between various factors influence and building thermal mode. The main direction of this work is the investigation of outdoor and indoor factors influence on the energy performance indicators and heating system operation mode. Using energy simulation program apartment heat load for constant and intermittent heating modes was analyzed.*

Keywords: *energy saving, intermittent heating, apartment, building energy modelling, EnergyPlus.*

Анотація. *Дослідження ефективності роботи системи опалення може проводитися за різними підходами, з урахуванням контрольованих та неконтрольованих факторів. Якісний розрахунок заходів з підвищення енергоефективності повинен враховувати динамічну поведінку будівлі – взаємодію між температурним режимом всередині та факторами, які впливають на нього. Основним напрямом цієї роботи є дослідження зовнішніх та внутрішніх факторів, які впливають на енергетичні показники приміщень і режим роботи системи опалення. Оцінювання впливових факторів проводилось для існуючого приміщення квартири за допомогою спеціалізованого програмного забезпечення для динамічного моделювання EnergyPlus. Програмована модель квартири враховує теплоінерційні властивості будівельних конструкцій та дозволяє оцінити вплив зміни зовнішніх і внутрішніх факторів на енергетичні показники у часі. Зокрема досліджено вплив температури навколишнього середовища та радіаційної складової сонячних теплонадходжень на навантаження системи опалення квартири для заданих режимів постійного та переривчастого опалення. З метою детального оцінювання впливу сонячних теплонадходжень проведено аналіз температур на внутрішніх поверхнях зовнішніх стін і поверхнях внутрішніх стін кімнат при різній орієнтації зовнішніх огороджувальних конструкцій за сторонами світу. Результати, приведені в даній роботі, отримано шляхом погодинної симуляції в програмній моделі квартири та подано у вигляді діаграм і графіків. Також проведено чисельний аналіз річного енергоспоживання квартири за погодними умовами з бази даних IWEC для міста Києва при застосуванні постійного та переривчастого режимів опалення і залежно від орієнтації огороджувальних конструкцій за сторонами світу.*

Наявність енергетичної моделі приміщення в програмному середовищі EnergyPlus дозволяє прийняти оптимізаційні рішення шляхом дослідження впливу внутрішніх і зовнішніх факторів на динамічну поведінку будівлі, а також проаналізувати вплив цих факторів на енергетичні показники будівлі. Наведені результати досліджень доводять, що рекомендації щодо вибору режиму роботи системи опалення доцільно розробляти з урахуванням проаналізованих впливових факторів.

Ключові слова: *енергозбереження, переривчасте опалення, квартира, енергетичне моделювання, EnergyPlus.*

Introduction. The buildings and construction sector has the largest shares of energy and emissions in the world. According to United Nations Environment Programme (2018) buildings construction and operations consumes for 36 % of global final energy use, of which residential buildings accounts for 22 %. Therefore, there is a need to find and implement approaches to improve the energy efficiency of each building. European experience shows that implementation of energy efficiency measures should be carried out comprehensively.

Most residential buildings in Ukraine do not reach the European energy performance indicators. Due to the high payback period, building owners are implementing measures gradually. So they follow strategy that typically include increase of building envelope thermal insulation but they usually neglecting the possibility of weather-dependent heating system regulation. But for the highest effect from implementation of measures it is important to consider interaction between building constructions materials and heating and ventilating systems, under dynamic ambient air conditions indoor and outdoor.

Analysis of recent research and publications. In modern buildings with high electrical energy consumption and intermittent heating mode, impact of different factors on thermal building behavior investigated by many authors. In general, highlighted the following main factors that affect building thermal mode [1]:

– outdoor – outside air temperature, solar radiation and wind speed;

– indoor – heating capacity of a building and internal heat gains.

Data-based building energy models were utilized to calculate energy saving, which is then compared to the actual data. Outside dry air temperature was the only energy consumption influence factor. So the impact of other parameters, especially solar gains, on energy consumption needs further consideration [2].

An exploration of the intermittent heating system operation modes efficiency is carried out in different approaches taking into account controlled and uncontrolled factors. The article [3] compares the two approaches: quasi-stationary and dynamic. According to [3] quasi-stationary approach can only provide an approximate energy efficiency estimation because it doesn't take into account the duration of real transient processes in the heating system. At the same time dynamic approach allows to achieve higher quality results taking into account dynamic characteristics of the building constructions. The importance of dynamic characteristics consideration in conditions of intermittent heating mode is investigated in paper [4]. The paper [4] presents calculation results of various single-layer walls dynamic characteristics done by an exact and an approximate methods of no stationary thermal conductivity. The results indicate that reducing the building massiveness reduce heat losses and time spent on heating of building.

Comparison of standard and new approaches of intermittent thermal energy need calculation is made in article [5]. The proposed in [5] new approach improves transparency of the current ISO 13790 method and provides more accurate results. To validate the proposed calculation of intermittent energy need, the article [5] presents the results of modeling in EnergyPlus. Review of occupant-centric building controls [6] shows the feasibility of studying and practical consideration of the influence of solar radiation on intermittent heating modes.

The article [7] includes analysis of outdoor and indoor factors influence on building energy performance indicators. In this work the daily average heating load forecast using non-linear multivariate regression models is based on daily average factors history data.

The dynamic behavior of buildings in response to environment factors is extremely complex and difficult to analyze. Dynamic simulation software is a powerful tool that allows to take into account different thermal storage capacities of the building constructions as well as different climates for thermal state investigation [8]. Such programs allow to get high-quality results for decision making to enhance energy efficiency during the building design and operation phases [9, 10].

In article [11] results of intermittent heating mode simulation was compared with available practical data of indoor temperature profile. Created in dynamic simulation program apartment energy model accurately describes the heat-inertial properties of building envelope and allows to take into account outdoor temperature changes over time.

Purpose and objectives of the study. The main purpose of this study is to present selected results of the analyzes of the way exterior walls cardinal direction impact on heating system mode during the day in case of constant and intermittent heating schedule. Studies were conducted on the example of an existing apartment with individual heating source.

According to the purpose the following tasks are solved:

– apartment dynamic energy model was created;

– hourly heat load for chosen day in case of constant and intermittent heating mode determined;

– investigated outdoor temperature and solar radiation impact on the thermal mode during the chosen day;

– analyzed solar radiation impact on the walls inner surface temperature;

– annual apartment energy consumption was determined.

Main Body of Paper

Dynamic energy modelling of the apartment. The 3d apartment model was created in DesignBuilder software. Calculations have been carried out by means of simulation program EnergyPlus. So DesignBuilder uses EnergyPlus engine to perform dynamic building energy simulation. Programmed apartment model describes the heat-inertial properties of building constructions and allows to take into account outdoor and indoor factors changes over time. Thus EnergyPlus dynamic approaches take into account the building enclosing structures accumulation ability. At the same time, point and linear heat-conducting inclusions are not considered by the program.

The apartment enclosing structures reported in tabl. 1.

Fig. 1 presents the apartment plan as well as rooms area data.

Table 1

Enclosing structures description

Construction type	Construction layers	U-value, W/m2·K
Exterior walls	- gypsum plastering 10 mm - brick 400 mm - mineral fibre 50 mm - external rendering 10 mm	0,488

Exterior windows and glazed door	double-chamber glazing with internal Low-E glass and two chambers with argon	1,058
Internal partitions	- gypsum plastering 10 mm - brick 125 mm - gypsum plastering 10 mm	-
Ceiling	- cast concrete 200 mm	-
Floor	- cast concrete 200 mm	-

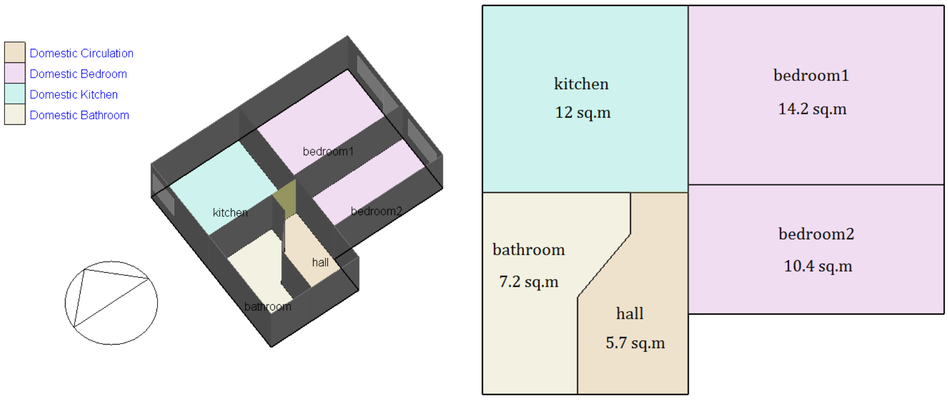

Fig. 1. Apartment plan

In fact, the exterior walls and windows of the apartment are oriented to the east («bedroom1» and «bedroom2») and west (kitchen). The exterior glass area in «bedroom1» – 3,26 m², in «bedroom2» – 1,8 m², in “kitchen” – 1,32 m².

The apartment has individual water-based heating system with automated gas-fired boiler. Boiler operates to maintain specified temperature mode for all hours. Each room in apartment is heated during the heating period. Such heating system allows setting individual heating schedules using a thermostat.

Assumed heating schedule is maintained an internal temperature at 16-22 °C for weekdays and at 20-22 °C for weekends. In fact, heating mode for the apartment corresponds to the occupancy schedule. The programmed daily heating schedules for weekday and weekend are shown in histograms in fig. 2.

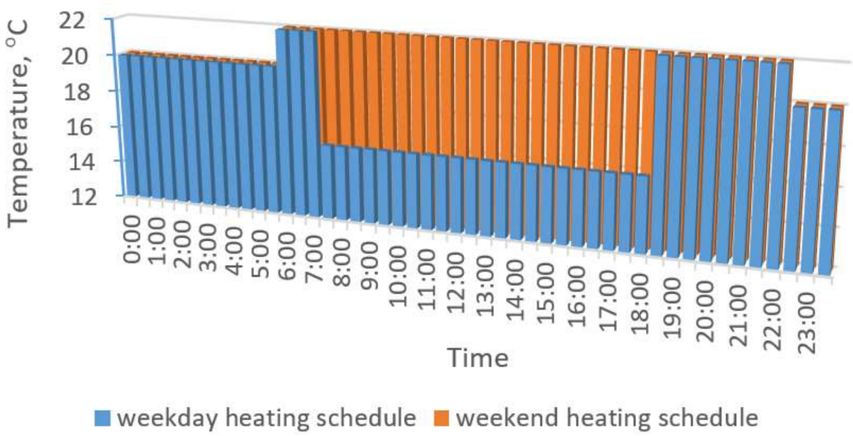

Fig. 2. Weekday and weekend heating schedules

Air exchange rate in the apartment was assumed to be 0,6 h^{-1}.

The energy model of the apartment also takes into account occupancy schedule and internal heat gains (people, lighting and electric equipment). To consider heat gains from people next histograms are presented in fig. 3.

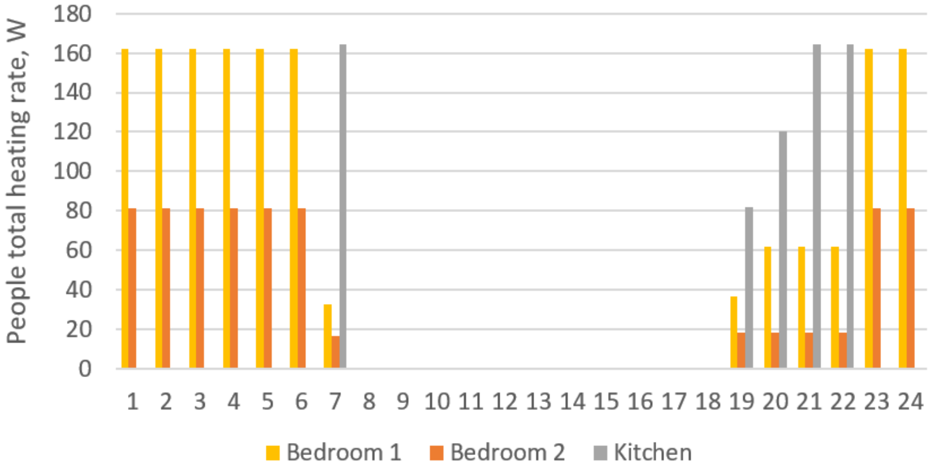

Fig. 3. Weekday people heat gains

The calculations have been performed for the climatology of the sunny winter day (10 February, weekday) taken from the IWEC weather database for Kyiv [12]. The outside air temperature minimum (-15 °C) appears at 5 AM at morning, and maximum (-7,7°C) at 2 PM at afternoon.

Fig. 4 presents the graph of outside air temperature as well as histograms of windows transmitted solar radiation rate depending on cardinal direction (IWEC solar radiation data).

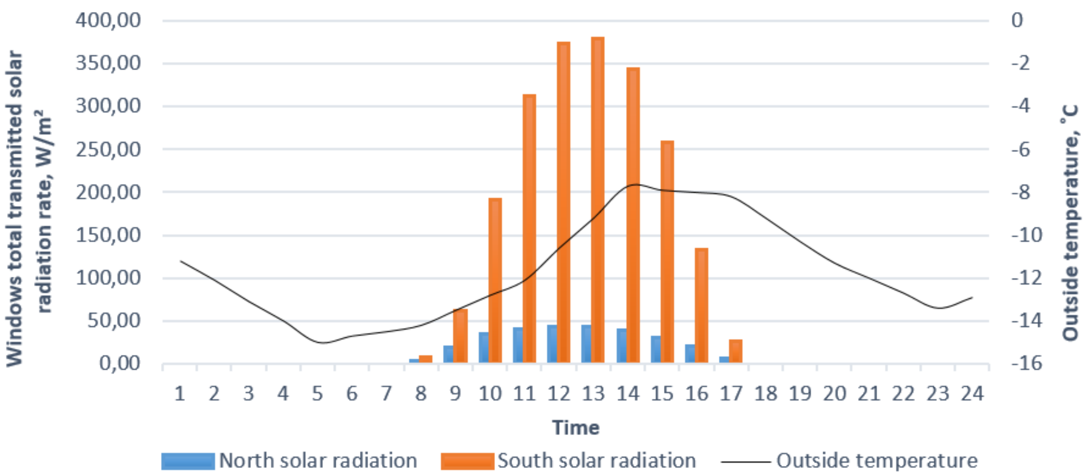

Fig. 4. Daily outside air temperature and windows solar radiation rate

IWEC weather database was also used to determine annual apartment heat consumption.

Apartment heating load hourly investigation. Apartment heating system load during the day is investigated using constant mode, as well as intermittent mode. The first study was conducted when bedrooms exterior walls correspond to the north cardinal direction. The solar radiation effect on the heating load in constant (22 ˚C) and intermittent (16-22 ˚C) modes was investigated and shown in fig. 5 and 6.

It was also analyzed heating load when the bedrooms exterior walls correspond to the southern orientation (fig. 7 and 8).

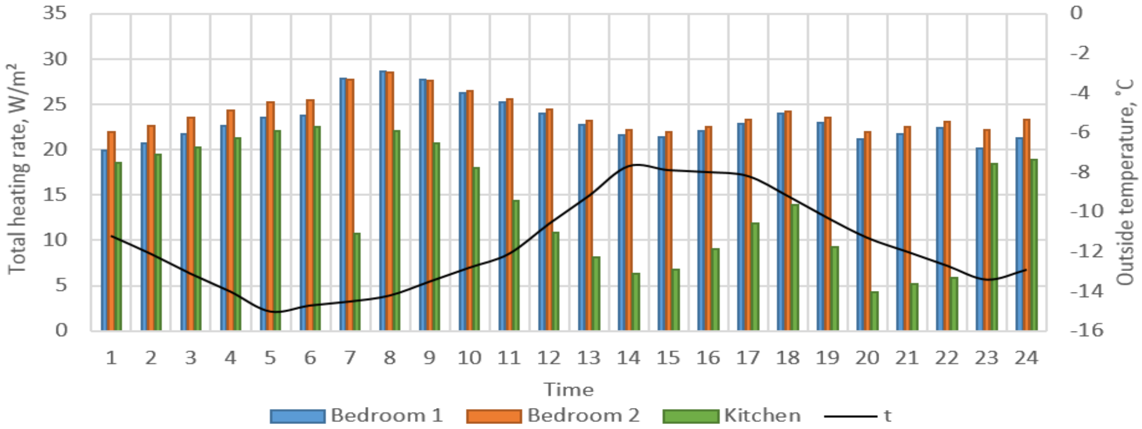

Fig. 5. Total heating load during the chosen day with constant heating mode (Bedrooms – N, kitchen – S)

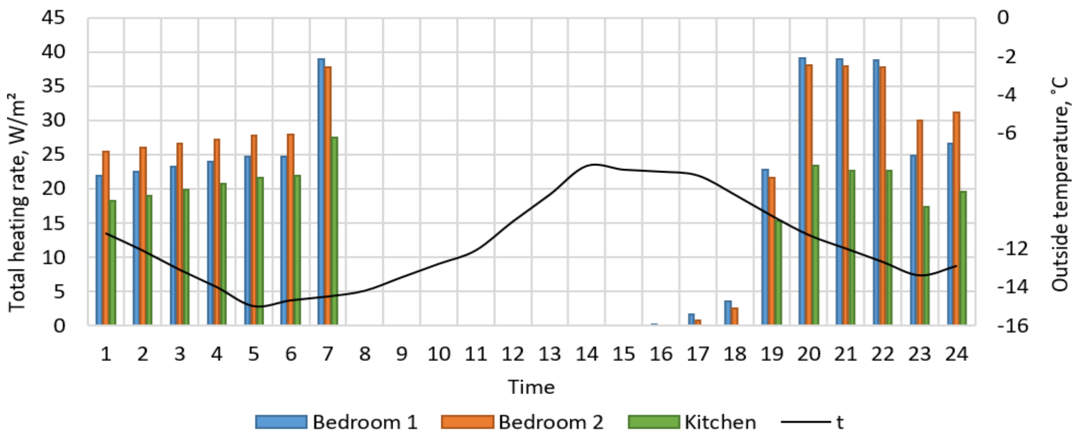

Fig. 6. Total heating load during the chosen day with intermittent heating mode (Bedrooms – N, kitchen – S)

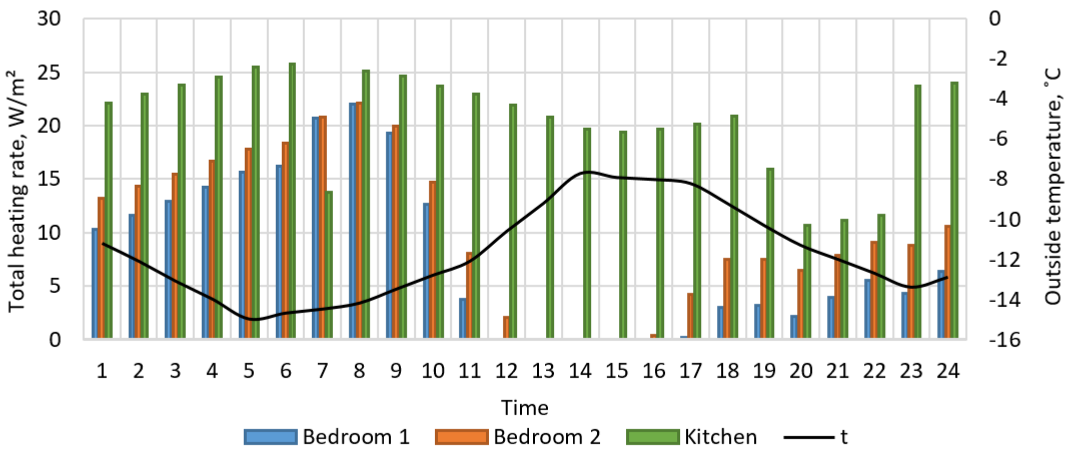

Fig. 7. Total heating load during the chosen day with constant heating mode (Bedrooms – S, kitchen – N)

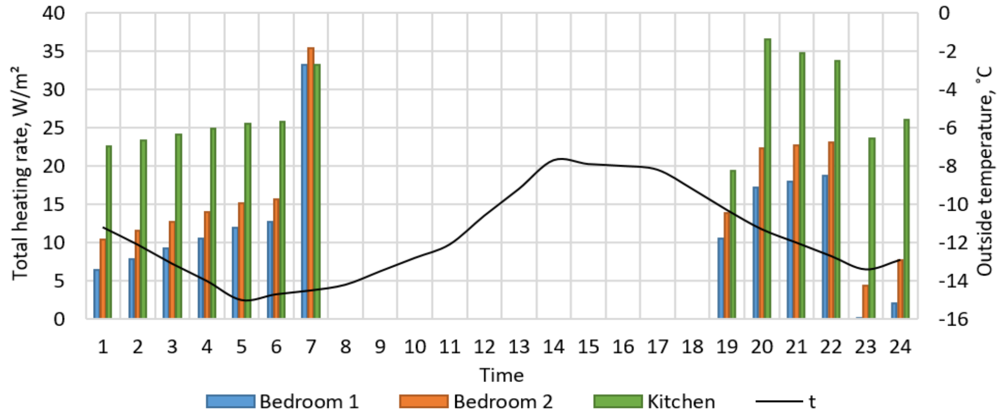

Fig. 8. Total heating load during the chosen day with intermittent heating mode (Bedrooms – S, kitchen – N)

In case when bedrooms exterior walls correspond to the southern orientation the apartment consumes 17,2 % less energy in constant heating mode and 17,6 % less energy in intermittent heating mode than in the previous case. Results of building energy consumption calculations are given in table below (tabl. 2).

Table 2

Energy consumption calculations

Cardinal direction	Specific energy consumption, kWh/m²	
	Constant heating mode	Intermittent heating mode
Bedrooms – N, kitchen – S	48,89	40,7
Bedrooms – S, kitchen – N	40,49	33,52

Inside surfaces temperature analysis. To analyze the effect of solar radiation on the thermal state of the premises, the temperature on the inner surfaces of exterior walls and interior partitions was investigated on different cardinal directions (fig. 9 and 10).

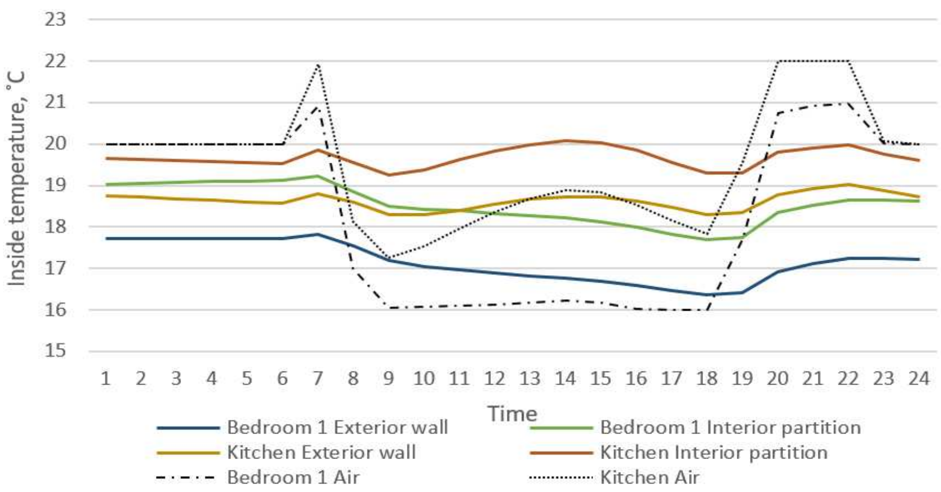

Fig. 9. Temperature on the inner surfaces of exterior walls and interior partitions with intermittent heating mode (Bedrooms – N, kitchen – S)

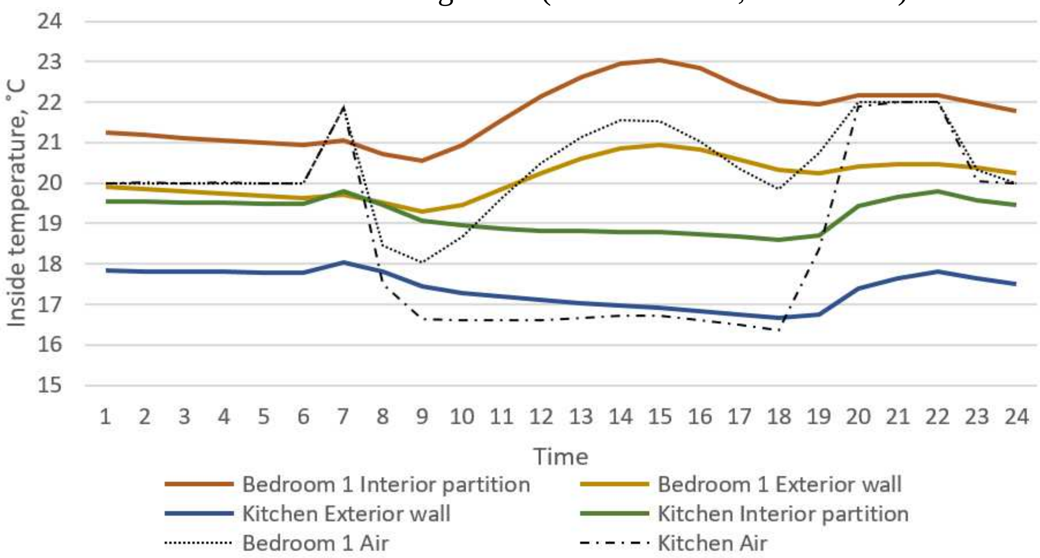

Fig. 10. Temperature on the inner surfaces of exterior walls and interior partitions with intermittent heating mode (Bedrooms – S, kitchen – N)

The schedules in fig. 9 and 10 show that temperature change on the inner surfaces of exterior walls is parallel to the interior partitions. The analysis of the above graphs reveals that during the periods without solar activity the inner surfaces temperature of exterior walls of southern orientation is lower than inside air temperature. This is largely affected by dynamic characteristics of building construction materials. It is also important to note that inside air temperature in the studied premises doesn't reach the programmed 16 ˚C during intermittent heating mode shutdown periods.

To check the massiveness influence the apartment energy consumption was investigated at different brick layer thicknesses of the exterior walls. The brick layer has been chosen as analyzed because it affects the massiveness to a greater extent and has a less impact on U-value. The effect was studied during intermittent heating mode when the bedrooms exterior walls correspond to the northern orientation. It established, that reducing exterior walls brick layer thickness by 20 cm resulted in apartment energy consumption increase by 5,4 %. In the same conditions exterior walls brick layer thickness increase by 20 cm resulted in consumption decrease by 4,3 %. The results of the intermittent heating schedule analysis show that reducing the exterior walls massiveness by 2 times causes the internal temperature decrease by 0,5 ˚C during the shutdown periods. Thus, because of change in building construction massiveness, the heating mode schedule changes.

Conclusions. According to the modeling results in EnergyPlus the use of intermittent heating mode for apartment saves approximately 17 % of thermal energy compared to the constant mode. At different external enclosure structures orientation, the impact of solar radiation on the hourly heat load and total energy consumption of the apartment was evaluated. Thus, the difference in heat consumption of the same premises oriented in opposite cardinal directions could be as high as 17,2 % in constant heating mode. This value depends on windows and exterior walls area as well as solar activity during the heating period.

The analysis of the temperatures on the inner surfaces of the exterior walls and partitions has proved the importance of enclosing structures storage capacity in the context of the dynamics of solar radiation and comfort conditions changes. This context should be taken into account when analyzing the modes of intermittent heating and the development of their hourly forecast.

It established, that recommendations for intermittent heating can be developed depending on the outside air temperature, solar radiation impact and internal heat gains. To improve the quality of future research it is also important to take into account the influence of comfort conditions [13] on energy consumption and the dynamics of its interaction under the conditions of changing external factors.

References

1. Valančius Kęstutis, Stankevičius Vytautas. Influence of active heat capacity on indoor climate and energy demand of a building. Proceedings of the 8th Nordic symposium on building physics in the Nordic countries (NSB 2008), Copenhagen, June 16-18, 2008. Department of Civil Engineering Technical University of Denmark, The Danish Society of Engineers Society for Building Physics, Danish Building Research Institute Aalborg University. Lyngby: Technical University of Denmark. ISBN 9788778772657. Vol. 1 (2008). P. 65-70. [M.kr.:T 002; T 006] [Aut.lankų sk.: 0.429]

2. Kevin Eaton, Nabil Nassif, Pyrian Rai and Alexander Rodrigues. Energy Consumption and Saving Calculations Using Nearest Neighbor and Artificial Neural Network Models. *Energy Management Research Journal*. 2019. Vol. 2. No. 1. P. 1-11.

3. Куценко А. С., Коваленко С. В., Товажнянский В. И. Анализ энергоэффективности прерывистого режима отопления здания. *Ползуновский вестник*. 2014. № 4-1. С. 247-253.

4. Vychtikov Yu., Saparev M., Chulkov A. Analyzing energy consumption while heating one-layer building envelopes in conditions of intermittent heating. MATEC Web of Conferences 106. 06013 (2017).

5. Lee Sang-Hoon. Intermittent Heating and Cooling Load Calculation Method - Comparing with ISO 13790. *Architectural Research*. 2012. 14 (1). P. 11-18.

6. June Young Park, Mohamed M. Ouf, Burak Gunay, Yuzhen Peng, William O'Brien, Mikkel Baun Kjærgaard, Zoltan Nagy. A critical review of field implementations of occupant-centric building controls. Building and Environment. 165 (2019). 15 p.

7. Bilous, I., Deshko, V., Sukhodub, I. Parametric analysis of external and internal factors influence on building energy performance using non-linear multivariate regression models. *Journal of Building Engineering*. 2018. Vol. 20. P. 327-336.

8. Deshko V., Sukhodub I., Yatsenko O. Comparison of building energy consumption by instrumental and calculation approaches. *Journal of New Technologies in Environmental Science*. 2017. Vol. 2. P. 74-80.

9. Abdullah A., Cross B., Aksamija A. Whole Building Energy Analysis: A Comparative Study of Different Simulation Tools and Applications in Architectural Design. 2014 ACEEE Summer Study on Energy Efficiency in Buildings. 2014. P. 11-1, 11-12.

10. Attia S., Hensen J.L.M., Bertran L. & De Herde A. Selection criteria for building performance simulation tools: contrasting architects' and engineers' needs. *Journal of Building Performance Simulation*. 2012. Vol. 5. no 3. P. 155-169.

11. Deshko V., Sukhodub I., Yatsenko O. Intermittent heating system operation modes for residential spaces. *Journal of New Technologies in Environmental Science*. 2019. Vol. 3. P. 139-148.

12. International Weather for Energy Calculations. URL: https://energyplus.net/weather-region/europe_wmo_region_6/UKR%20%20.

13. Deshko V., Buyak N., Bilous I., Voloshchuk V. Reference state and exergy based dynamics analysis of energy performance of the «heat source - human - building envelope» system. *Energy*. 2020. Vol. 200.

Дешко Валерій Іванович, д-р техн. наук, професор, завідувач кафедри теплотехніки та енергозбереження КПІ ім. Ігоря Сікорського. ORCID iD: 0000-0002-8218-3933. Тел.: (050) 386-88-23. E-mail: te@kpi.ua.
Суходуб Ірина Олегівна, канд. техн. наук, доцент кафедри теплотехніки та енергозбереження КПІ ім. Ігоря Сікорського. ORCID iD: 0000-0002-5895-1306. Тел.: (050) 068-38-90. E-mail: ira_krot@ukr.net.
Яценко Олена Ігорівна, аспірант, асистент кафедри теплотехніки та енергозбереження КПІ ім. Ігоря Сікорського. ORCID iD: 0000-0002-8001-5987. Тел.: (050) 086-96-77. E-mail: loco-motion@ukr.net.

Deshko Valerii, D. Sc. (Tech), Professor, Head of Department of Heat Engineering and Energy Saving at Igor Sikorsky Kyiv Polytechnic Institute. ORCID iD: 0000-0002-8218-3933. Tel. (050) 386-88-23. E-mail: te@kpi.ua.
Sukhodub Iryna, PhD (Tech.), Associate prof., Department of Heat Engineering and Energy Saving at Igor Sikorsky Kyiv Polytechnic Institute. ORCID iD: 0000-0002-5895-1306. Tel. (050) 068-38-90. E-mail: ira_krot@ukr.net.
Yatsenko Olena, postgraduate student, Assistant lecturer, Department of Heat Engineering and Energy Saving at Igor Sikorsky Kyiv Polytechnic Institute. ORCID iD: 0000-0002-8001-5987. Tel. (050) 086-96-77. E-mail: loco-motion@ukr.net.

Статтю прийнято 12.08.2020 р.