sciendo

LATVIAN JOURNAL OF PHYSICS
AND TECHNICAL SCIENCES
2024, N 2

DOI: 10.2478/lpts-2024-0012

ENERGY PERFORMANCE OF HIGHER EDUCATION INSTITUTIONS BUILDINGS OPERATING DURING QUARANTINE RESTRICTIONS AND/OR MARTIAL LAW IN UKRAINE

V. Deshko[1], I. Bilous[1]*, T. Boiko[1], O. Shevchenko[1], A. Borodinecs[2], J. Zemitis[2]

[1] National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute",
Institute of Engineering Thermophysics,
37 Peremohy Ave, Kyiv, 03056, UKRAINE
[2] Riga Technical University,
Department of Heat Engineering and Technology
6A Kipsalas Str., Riga, LV-1048, LATVIA
* e-mail: biloys_inna@ukr.net

During the pandemic and periods of martial law, educational institutions in Ukraine implemented various forms of organising the educational process, combining in-person and remote classes. As a result, there has been a decrease in the level of use of building premises. The analysis of the characteristics of energy consumption in these conditions requires additional attention. In this study, a dynamic energy model of the building was created using the educational building of Igor Sikorsky Kyiv Polytechnic Institute as an example. Energy consumption for heating needs was determined for normal operating conditions and quarantine conditions in Ukraine (only a specific part of the premises is being operated, ensuring that the standard temperature value is maintained while people are present). Based on the results of the study, the features of the energy consumption of the building during quarantine/martial law restrictions, subject to the partial use of the building, were analysed, and the main disadvantages of such a mode were identified. For the educational building of the university, the total energy consumption for heating needs depends on the number of rooms that are actively used, and the modes of regulation of heating and ventilation; the consumption can decrease depending on the chosen scenario by 61 %, 56 %, and 34 % in quarantine mode. The findings indicate that the efficiency of regulation modes can decrease by more than four times when compared to normal mode due to internal heat exchange with unoccupied rooms.

Keywords: *Air exchange, building operation during quarantine and/or martial law, educational institutions, energy consumption, energy saving, hourly infiltration rate, indoor air temperature.*

1. INTRODUCTION

1.1. Overview

At the end of 2019, humanity faced the challenges of the global COVID-19 pandemic, which impacted all spheres of economic and social development worldwide. The most significant challenge was the need for a radical change in approaches to organising and conducting business/work activities. Many organisations implemented remote work arrangements, either fully or partially, wherein employees worked from home or adopted a hybrid model, combining remote work with occasional visits to their workplace. The sphere of education was no exception, including in Ukraine. Therefore, to prevent the spread of COVID-19 and ensure the continuity of learning, educational institutions introduced remote or blended learning formats. In addition to the challenges of the pandemic, in 2022 Ukraine faced full-scale military operations on its territory. Educational institutions have switched to remote mode of operation. The consumption of electricity and water in educational institutions has decreased, but the issue of heating educational institutions remains unresolved. In the conditions of the energy crisis in Ukraine caused by targeted and regular missile attacks on critical energy infrastructure, the energy-efficient use of energy is an urgent issue.

In most educational institutions in Ukraine, operational control of the centralised heating system occurs simultaneously at the system's entry point for the entire building. Therefore, to reduce the use of energy resources, the feasibility of maintaining normative temperature conditions in rooms that are not involved in face-to-face learning during quarantine/war restrictions becomes an additional factor that will alleviate the deficit of generating capacities in the energy system. Currently, the possibilities of such an approach can be explored using dynamic simulation modelling of heat distribution in the premises of the educational building with the construction of a corresponding energy model of the building. Such a model consists of energy characteristics during the partial use of the building. It allows analysing the characteristics of heat consumption during distance learning for different operating modes of heating and ventilation systems, as well as conducting simulations and evaluating the heat exchange between rooms with different operating modes. This will enable making informed decisions regarding the more compact placement of certain departments within the educational institution, which will operate during distance learning and will require adequate temperature regulation. Energy saving and enhancement of energy efficiency are priority areas of political activity in Ukraine as well as globally. These measures are crucial requirements for the European integration of the national energy system. Buildings deserve special attention in the field of energy saving because they account for more than a third of the world's energy consumption [1]. At the same time, during the evaluation and formulation of an energy-saving action plan, it is imperative to consider various parameters that characterise the building. In particular, these parameters include a set of operational factors. Such factors include the work schedule, indoor air temperature, duration, and frequency of occupancy, lighting operation, equipment usage, and more. Occupants differ in their

requirements for comfort, which are also influenced by their behaviour. The efficient use of energy resources in buildings is influenced by operational and behavioural factors [2], [3].

Understanding occupant behaviour has been emphasised as an important factor in occupancy modelling to achieve energy efficiency improvements, especially in building heating, ventilation and air conditioning systems [4]. To this end, the authors of [4] conducted an experiment to monitor indoor environmental variables such as temperature, lighting, relative humidity, and CO_2 levels in the living room of a residential building. The residential building consists of five separate rooms, in Taman Teratai Johor, Malaysia, which has a tropical climate with typical temperatures ranging from 25 °C to 30 °C all year round. Five different occupancy prediction models were used to predict occupancy. According to this study, occupancy detection can reduce energy costs by up to 30 % while boosting indoor air quality. Educational institutions are interesting from an operational perspective, as they are characterised by intensive occupancy during regular classes [5], [6], which in turn largely affects the integral characteristics of heat gains into the premises and energy consumption depending on the level of awareness of potential consumers (whether the light is turned off, the faucet is closed towards the end, windows are opened / closed, etc.) [7]–[9].

1.2. Energy Performance of Educational Institutions during the Pandemic Period

Research [10] shows the effect of 15 architectural building design parameters (ABDPs) on energy consumption and students' thermal comfort for a single-storey education building at the University of Newcastle, Australia. Sensitivity and uncertainty analyses were used to assess the most important ABDPs. According to the authors' recommendation, these results can be useful for building designers, but they do not take into account the dynamics of operational factors.

A comprehensive effectiveness analysis of the deep retrofitting process of an educational building located in north-eastern Poland is presented [11]. Planned and actual energy effects were compared, as well as the associated reductions in pollutant emissions. The analysis of the reasons for the change in the final Heating Energy Indicator within four years after retrofitting did not take into account possible changes in the schedule of use of the building.

An overview of thermal comfort and indoor air quality (IAQ) of educational buildings closely related to ventilation energy consumption was conducted [12]. This paper critically reviewed the interaction of thermal comfort, IAQ and ventilation energy consumption at different educational levels under different climates. It was noted that more studies were required for investigating thermal comfort in educational buildings during the heating period. University buildings require increased attention. The number of publications concerning Central European countries is relatively limited, particularly regarding university premises where the level of ventilation control is comparatively low. The review overlooked the issues related to energy consumption during the dissipation and reduced use of premises, which are particularly prominent under quarantine conditions and the prevalent combination of in-person and online forms of classes during

the war period in Ukraine.

The COVID-19 pandemic significantly affected the energy consumption of government institutions, including higher education establishments, due to the implementation of social distancing, ensuring adequate indoor ventilation, and personal hygiene measures [13].

Consequently, there are now stricter needs for maintaining high standards of in-door air quality in order to prevent airborne virus transmission [14]. The developed strategy for the optimal control of the HVAC system allows reducing energy consumption by an estimated 30 % for the case study of an educational building of the University of Pisa. Schedules of the building use are taken into account. It is acknowledged that addressing the issue of COVID-19 necessitates a higher ventilation rate to achieve improved air quality levels. Simultaneously, when analysing the challenge of balancing occupants' comfort with energy consumption in buildings, it is crucial to consider reduced schedules for use of premises under quarantine restrictions.

1.3. Educational Institutions in Ukraine during the Pandemic/Wartime Conditions

With the aim of increasing social distancing and limiting contact between people, a significant number of countries implemented partial or full transition to remote learning for educational institutions, commercial establishments, and industrial enterprises [15]. These measures resulted in significant changes in energy usage schedules and patterns [16]. At the beginning of the pandemic in Ukraine, most educational institutions at all levels of education also shifted to blended or remote working modes. This was determined by the epidemiological situation in the area where the educational institution was located. In 2023, when most countries worldwide had overcome the threat of COVID-19 spread and returned to in-person learning, Ukraine was facing a new challenge related to military threats. This situation requires the ongoing implementation of alternative learning methods to prioritize safety and protect the lives of students and educators. Under such circumstances, to avoid excessive use of energy and ensure the smooth operation of buildings, a very important issue arises – the establishment of schedules for the rational use of energy for heating needs, while considering the occupancy patterns of the premises. At the same time, the regulation of heating, ventilation, and air conditioning systems according to these schedules requires the availability of appropriate energy monitoring systems and the optimal configuration of equipment, which will ensure economic viability of such regulation. Currently, an increasing body of evidence suggests that the performance of a building is affected by the dynamics of occupant behaviour [17]. In particular, the results of a study by the World Business Council for Sustainable Development [18] estimate that inefficient user behaviour can contribute to a one-third increase in a building's energy consumption, whereas energy-saving behaviour can lead to a one-third reduction in energy costs.

Considerable attention in the study of energy consumption during the COVID-19 pandemic is devoted to the increase in consumption of electricity [12], [19], [20] and water [21] in residential buildings, provided that employees work from home. For Ukraine with a sharply continental climate, the issue of the use of heat energy is the most urgent, because its level can

make up to 85 % of the total energy balance of the building [22]. Energy-efficient modes of heating energy use in buildings are associated with the use of intermittent modes of heating and ventilation [23]. In the article [24], a study of the natural level of air exchange in educational institutions of Ukraine was conducted. The obtained results are used to adjust the energy model of the building under study.

A thorough analysis of implementing short-term and energy-saving modes of operation for the heating and ventilation systems of educational premises not used during remote learning is relevant and aligns with the approaches outlined in the Law of Ukraine "On Energy Efficiency of Buildings" [25]. Furthermore, it serves to justify the viability and importance of implementing monitoring capabilities for energy and operational parameters in buildings, as a fundamental requirement to enable effective energy resource conservation in cases of excessive usage. The results of the study [17] represent the possibilities of using data from the energy monitoring system, using the example of a set of three residential buildings, including a total of 305 student apartments located at the main campus of the Royal Institute of Technology (KTH) in Stockholm. An additional analysis is required, which would take into account the schedules and distribution of the use of premises when determining energy consumption in the conditions of quarantine restrictions and martial law for Ukrainian universities. Such an analysis can deepen the understanding of the distribution of energy consumption and of how comfort can be ensured under changing conditions of use of educational institution buildings.

Pandemic restrictions in Europe and worldwide were somewhat eased in 2022, but due to the enforcement of martial law in Ukraine, the implementation of blended learning was not possible due to the constant threat of rocket attacks. Educational institutions continued to operate in a remote mode, and the requirements for educational institutions remained unchanged.

1.4. Objectives

The subject of this study is Building No. 17 of the Radio Engineering Faculty at Igor Sikorsky Kyiv Polytechnic Institute. The research focuses on the heating energy consumption patterns of the building during both remote and in-person learning modes.

The objectives of the study are as follows:

1. To create a dynamic model of the building using the DesignBuilder software environment, based on the investigated object.
2. To conduct simulations of the building's energy consumption patterns using three proposed scenarios: No. 1 – at a constant temperature and steady air exchange (indoor air temperature t = const, hourly infiltration rate n = const); No. 2 – with intermittent heating mode (lowering the temperature during non-working hours and weekends) and steady air exchange (t = var, n = const); No. 3 – with intermittent heating and intermittent air exchange (t = var, n = var).
3. To simulate the energy consumption of the building under quarantine, considering the schedules for using the premises and the permissible levels of temperature drop in them when implementing the three proposed scenarios (No. 1, No. 2, No. 3 – similarly).
4. To evaluate the indicators of building energy consumption in the case of implementing distance learning.

2. MATERIALS AND METHODS

Building Energy Modelling (BEM) involves predicting a building's energy consumption and its corresponding energy-saving level compared to a standard baseline. BEM approaches are implemented through software products, with EnergyPlus and TRNSYS being the most commonly used ones [26]. Unlike TRNSYS, which is a paid software product, EnergyPlus is more appealing for usage due to its free availability. EnergyPlus does not have its own graphical editor, so the building geometry is created using the DesignBuilder software environment, which is synchronized with EnergyPlus. The software allows for conducting energy simulations for the entire building or individual zones with a time step of 10 minutes. It includes defining the thermal properties of the building envelope, window constructions with optical glazing properties, engineering systems, energy sources, equipment operating schedules, lighting and temperature regimes, occupancy schedules, human activity, clothing insulation properties, and more. The software considers the inertial characteristics of the building envelope and systems, as well as the dynamics of climate data variability. The output provides information on air temperature, surface radiant temperature, loads on heating/cooling and ventilation (HVAC) systems, comfort levels, and more. EnergyPlus incorporates codes from DOE-2, ASHRAE, and BLAST, which are aligned with European standards, making it a viable choice for use [27].

The model takes into account heat transfer between building zones. The thermal balance of the building/zone is calculated dynamically with respect to the indoor air temperature, considering variable conditions at zone boundaries and heat gains inside the zone, zone air heat balance, internal and solar heat gains, and transmission links with adjacent zones and the external environment through zone boundaries (envelope). A detailed description of dynamic energy simulation is presented in EnergyPlus "Input Output Reference" [28].

In order to study the energy performance of the building, energy models of one of the educational buildings of Igor Sikorsky Kyiv Polytechnic Institute (Kyiv, Ukraine) were created based on the software product EnergyPlus [26]. 3-D model of the building geometry was created in the graphic editor DesignBuilder; thermal properties of the multi-layer enclosure, window structures with optical features of glazing, engineering systems, operation schedule and temperature regimes, etc. were specified [9]. The software product takes into account the inertial characteristics of the building envelope and systems, the dynamics of climatic data variability. At the output, the software product allows obtaining air temperature, surface radiation temperature, heating/cooling and ventilation system (HVAC-system) load, and others [22].

The results presented in this article are a continuation of the research presented in the article [9]. Below are the initial data of the research object used to create the building energy model.

Initial data. Building and model [9]: For creating a building model in the DesignBuilder software, educational building No. 17 of Igor Sikorsky Kyiv Polytechnic Institute was used. It was built in 1969. The building is located in Kyiv. Geometrically, the building is of a regular extended rectangular shape. The main part of the facades is oriented to the north and south. The building comprises five floors, as along with a heated basement and an unheated

attic. The heating volume of the building is 42371 m^3, the area is 12185 m^2. All windows of the building were replaced with metal-plastic single-chamber double-glazed windows with air-filled chambers, with the exception of the technical floor, where glass blocks were installed. At the same time, the share of the area of translucent structures is 36.7, 12.0, 35.4 and 12.0 % in the northern, eastern, southern and western orientations, respectively. The bearing layer of the outer walls of the building is made of expanded clay concrete. For external walls U-Factor with Film – 1.02 W/m^2·K. Covering of the building – flat roof, rolled: U-Factor with Film – 0.80 W/m^2·K; one part of the coverage is the coverage of the 5th floor, another part is the coverage of the technical floor. Foundation – concrete blocks (floor U-Factor with Film – 0.75 W/m^2·K). Glass U-Factor for windows – 2.38 W/m^2·K. The building is supplied with heat through the networks of a centralized heating system, the model of which allows for the introduction of intermittent heating modes. The building has a water central heating system with regulation at the system's entrance. Zone temperature control for office spaces according to the occupancy schedule is achieved through electric heating. The building's heating system is two-pipe with shut-off valves. In addition, it is provided that the heating devices installed on the premises are M140 cast-iron radiators with thermostatic heads, which allow for adjustment by building zones. The ventilation system is natural – it is provided at the level of 0.7 ac/h by opening the windows and doors; another 0.3 ac/h is provided by the infiltration component (due to the looseness of the enclosed structures). Thus, the total air exchange is 1 ac/h, aligning with the standard requirement for educational buildings. The number of people in the building during normal operation is 2763.

The 3-D model of the educational building No. 17, created in the DesignBuilder software environment, is shown in Fig. 1.

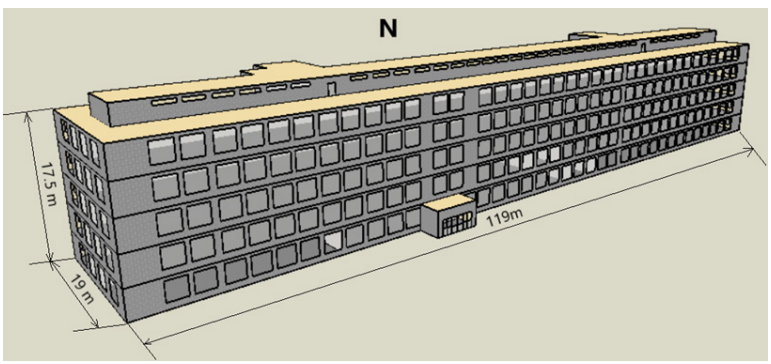


Fig. 1. 3-D-model of educational building No. 17 of Igor Sikorsky Kyiv Polytechnic Institute (N – North).

During the quarantine and especially during the period of martial law, the number of occupants and room occupancy schedules changed. Apart from remote learning, mixed forms of education were sometimes used, and safety conditions were maintained during air raids. Therefore, the model applied both the normal mode of operation and the quarantine mode, where only administrative and office spaces were utilized during remote learning. In the applied occupancy schedules, heat gains from occupants and office equipment were considered according to the standards [29], [30].

For the building model under normal operation mode (in-person learning period),

rooms with similar functional purposes were merged into a single zone in the building model, including:

- Educational spaces (lecture halls, computer labs, methodological rooms, etc.);
- Common areas (corridors, restrooms);
- Utility rooms (basement, attic, vestibules).

Such merging is justified as the operational parameters of the combined zone (internal temperature, air exchange, occupancy per unit area) remain unchanged. However, during the period of distance learning, significant differences in operational parameters, as well as thermal and mass flows at the boundaries between the utilized and unutilized spaces, led to the addition of thermal zones for individual rooms in the model with designated parameters based on the simulated scenario. Figure 2 illustrates the zoning of a typical floor of the building.

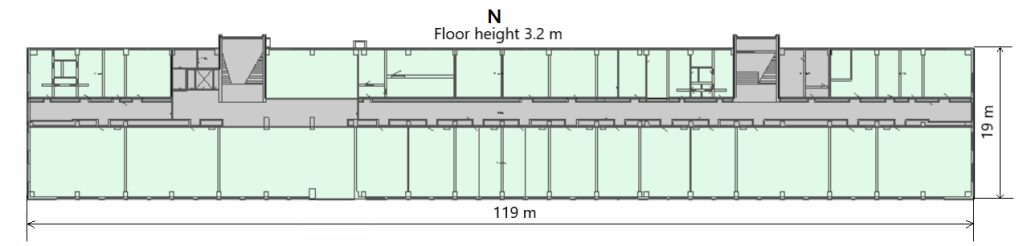


Fig. 2. Zoning of a building, using a typical floor as an example (N – North).

Initial data. Schedules of operation of the building and engineering systems. The hourly climate data used for the simulation is an IWEC hourly file for a typical year for Kyiv conditions [31]. The analysis of weather data, namely, the hourly variations in outdoor temperature and the amount of solar heat gains received by the room through window structures per unit of heated area of the room, is presented in [9]. Specific indicators of solar heat gains are determined taking into account the area and location of window structures using DesignBuilder on the basis of typical hourly data on the direct and diffuse component of solar radiation for the conditions of Kyiv, taken from IWEC.

For the normal operation mode of the premises, the number of occupants in the building was determined according to the requirements of standard [30], and for educational institutions, the average value of this parameter per building is 5 m^2/person. Before the pandemic, the total number of staff and students in the educational building corresponded to the specified number of individuals according to the requirements of regulatory documents. Under the conditions of the pandemic, the Ministry of Health of Ukraine demanded compliance with the requirements of not less than 4 m^2/person for the yellow level of danger [32], which corresponded to the accepted normative number of people for normal working conditions. For the pandemic mode, the occupancy density in administrative premises remained unchanged compared to the normal working mode. However, since the educational process was switched to remote mode, the model assumed the absence of people in classrooms and laboratories. For the simulated operating modes of the investigated building, the occupancy density throughout the day was set according to the schedule presented in Table 1.

Table 1. Occupancy Profile during Working Days

Time	Normal mode	Quarantine mode
	Educational and administrative premises	Administrative premises
	Load (%)	
7:00–8:00	25	
8:00–9:00	50	
9:00–12:00	100	
12:00–14:00	75	
14:00–17:00	100	
17:00–18:00	50	
18:00–19:00	25	
19:00–7:00	0	

Visitors are absent in educational premises for quarantine mode and in all premises on weekends, public holidays, vacations for all time.

In DesignBuilder, metabolism is considered a constant value, representing the amount of heat generated by an average adult with a typical body surface area of 1.8 m^2. The model of the investigated building assumes an equal number of men and women, so the metabolic factor is set at 0.9, which corresponds to 0.85 for women and 1.0 for men. The metabolic rate M and the thermal insulation of clothing I_{clo} are adopted at the level of typical office work, which is 140 W (taking into account the metabolic factor – 126 W) and 1, respectively.

Artificial lighting was set at a level of 300 lux on the work surface, and the lighting system's power consumption was 2.1 W/m^2. On weekends, holidays, and vacations, artificial lighting was not used. The power consumption of office equipment was 4.74 W/m^2, and its usage schedule coincided with the visitors' activity schedule in the building.

A 3D model of the building was created in the DesignBuilder software, taking into account the efficiency of the building engineering systems. The calculation of the building energy characteristics was carried out using the detailed method, which allows considering the efficiency of engineering systems. EnergyPlus software allows taking into account the thermal inertia of the building envelope. In the adopted calculation scheme, the inertia of the engineering systems was not considered, resulting in losses in the systems amounting to 15 %.

Several scenarios were developed for the investigated building model: for normal building operation mode (in-person learning) and partial utilization of the building premises (remote learning): Scenario No. 1 provided for maintaining the temperature and air exchange at stable values throughout the entire time; when implementing Scenario No. 2 – during non-working hours and weekends the temperature was lowered to 17 °C; under Scenario No. 3 – temperature was decreased to 17°C during non-working hours and weekends and the standard air exchange was decreased to the level of 0.3 ac/h during non-working hours and weekends (during non-working hours, the windows were not open and only the infiltration component remained). Detailed parameters of the proposed modes and premise schedules are given in Table 2.

Table 2. Parameters of the Proposed Modes

Scenario No.	Normal mode of operation	Quarantine mode	
		Used premises (separate premises and toilets on the 1st and 2nd floors)	All other unused premises
1	t = 20 °C [24 hours & 7 days] n = 1 ac/h [24 hours & 7 days]	t = 14 °C 24 hours & 7 days n = 0.3 ac/h 24 hours & 7 days	
2	$t_{heating}$ = 20 °C [from 7:00 until 18:00] $t_{heating\ set\ back}$=17°C [the rest of the working hours + weekends]		
3	$t_{heating}$ = 20 °C [from 7:00 until 18:00] $t_{heating\ set\ back}$=17°C [the rest of the working hours + weekends] n = 1 ac/h [from 7:00 until 18:00] n = 0.3 ac/h [the rest of the working hours + weekends]		

* Air exchange (ac/h); t: Given indoor air temperature without the regulation (°C); $t_{heating}$: During working hours in premises occupied by people (°C), $t_{heating\ set\ back}$: When it is lowered during non-working hours (°C)

3. RESULTS

Output parameters. Based on the input data presented in Section 2, a series of energy dynamic simulations were conducted for different modes of operation of engineering systems and building operation schedules. The results yielded hourly data, including thermal heating loads, indoor air temperatures, and mean radiant temperatures within the premises. Additionally, annual heating energy demand data were obtained for a subsequent analysis.

Below are the first results of the research on the impact of heating and ventilation system operations in educational institutions on energy consumption during the period of military state and pandemic for the conditions of Ukraine.

The calculation of the basic level of energy consumption was carried out in accordance with the comfort parameters outlined in the standards of Ukraine [29], [30], [33], [34], taking into account the typical climatic conditions for Kyiv. It is worth noting that since 2016, Ukraine has fully transitioned to European and international standards for assessing the energy efficiency of buildings. The temperature regulations for different types of buildings are uniformly specified both in modern Ukrainian standards and in the EN series standards. However, there are differences in the requirements for air exchange in the standards of various EU countries and Ukraine.

It is worth noting that during the pandemic, specific requirements are imposed on the level of air exchange. In the case of adaptive mechanical ventilation systems, it is recommended to reduce the CO_2 level almost by half and maintain it at 400 ppm, whereas in normal conditions, this parameter should not exceed 1000 ppm, depending on the building purpose [24]. In the context of the pandemic, ensuring an increase in air quality/air exchange requirements is challenging for the majority of educational institutions in Ukraine due to limitations in the existing engineering systems. This is one of the reasons for the transition to distance learning. In office and administrative premises, the distance between occupants and the level of air exchange (occupant density, lighting density, device heat density, and schedule) are assumed to be the same for normal and quarantine conditions. A possible reduction in occupant density does not significantly affect energy consump-

tion for maintaining comfort conditions in working areas.

The primary measure to limit the spread of the COVID-19 virus was to transfer students to distance learning. After the full-scale military invasion and the introduction of martial law in Ukraine, the Ukrainian educational institutions (particularly in northern, southern, and eastern regions) continued to operate in a remote mode.

The created 3-D energy model of the educational building at Igor Sikorsky Kyiv Polytechnic Institute was validated using actual energy consumption data, considering the real indoor air temperature, room occupancy schedules, equipment usage, etc., under normal operating conditions before the implementation of quarantine restrictions. The difference between the actual energy consumption recorded by the heat energy meter and the energy model of the building in the EnergyPlus software environment is approximately 10 %. Additionally, a comparison was made between the results of energy modelling of the building heating requirements using the quasi-stationary method DSTU B A.2.2-12:2015 [30], a national calculation method for establishing the baseline energy consumption and assessing the energy efficiency level of buildings, and the dynamic energy model of the building created in the EnergyPlus software environment, showing a discrepancy of about 18 %.

Total area of used premises for normal and quarantine mode is presented in Table 2. Tables 3 and 4 present the results of building energy consumption modelling. The first number in the designation shows the mode of operation X/X: 1/X – normal mode, 2/X – quarantine; the second number corresponds to the scenario number (for example, X/3 is Scenario No. 3). Similar designations will be maintained here and below. For example: "1/1" – normal mode, with stable temperature and air exchange values throughout the entire time; "2/1" – quarantine mode, with stable temperature and air exchange values throughout the entire time. Different temperature levels are maintained for the used and unused rooms. "Δ%" – the percentage deviation of energy consumption in the quarantine mode compared to the normal mode under a given scenario.

Table 3. Need for Heating by the Created Models

1	Mode / scenario, X/X	1/1	2/1	Δ (%)
2	Heating area of the building (m^2)	12184.8		-
3	Area of used premises (m^2)	12184.8	992.1	-91.9
4	The need for heating, used premises (kWh/season)	-	219483.0	-
5	Energy consumption for the heating season (kWh/season)	1596335.8	617532.9	-61.3
6	Specific energy consumption (kWh/m^2)	131.0	50.7	-61.3
7	Specific energy consumption of used premises (kWh/m^2)		221.2	68.9
8	Specific energy consumption of the used representative premises, north orientation (kWh/m^2)	131.9	241.7	83.2
9	Specific energy consumption of the used representative premises, south orientation (kWh/m^2)	115.1	215.1	86.8
Δ: Deviation of calculation results 2/1 from 1/1 (%).				

Table 4. Heat Consumption by the Created Models

1	Mode / scenario, X/X	1/2	2/2	Δ (%)
2	Heating area of the building (m^2)	12184.8	12184.8	-
3	Area of used premises (m^2)	12184.8	992.1	-91.9
4	The need for heating, used premises (kWh/season)	-	169745.7	-
5	Energy consumption for the heating season (kWh/season)	1363925.1	592826.0	-56.5
6	Specific energy consumption (kWh/m^2)	111.9	48.7	-56.5
7	Specific energy consumption of used premises (kWh/m^2)		171.1	52.9
8	Specific energy consumption of the used representative premises, north orientation (kWh/m^2)	110.8	185.2	67.1
9	Specific energy consumption of the used representative premises, south orientation (kWh/m^2)	94.4	162.0	71.6
Δ: Deviation of calculation results 2/2 from 1/2 (%)				

In addition to the aforementioned information, the comparison of heat consumption is presented in Table 5.

Table 5. Heat Consumption by the Created Models

1	Mode / scenario, X/X	1/3	2/3	Δ (%)
2	Heating area of the building (m^2)	12184.8	12184.8	-
3	Area of used premises (m^2)	12184.8	992.1	-91.9
4	The need for heating, used premises (kWh/season)	-	120678.3	-
5	Energy consumption for the heating season (kWh/season)	829736.1	546852.8	-34.1
6	Specific energy consumption (kWh/m^2)	68.1	44.9	-34.1
7	Specific energy consumption of used premises (kWh/m^2)		121.6	78.6
8	Specific energy consumption of the used representative premises, north orientation (kWh/m^2)	66.9	134.3	100.8
9	Specific energy consumption of the used representative premises, south orientation (kWh/m^2)	53.0	112.2	111.6
Δ: Deviation of calculation results 2/3 from 1/3 (%)				

Therefore, according to the modelling results for Scenario No. 1, partial utilization of the building during remote learning will reduce heating energy consumption by 61.3 % [9], No. 2 – 56 %, No. 3 – 34 % in quarantine mode. At the same time, the specific consumption to the total heating area is reduced by the equivalent value. However, if we compare the specific consumption of heat energy in heated rooms to the appropriate level, this value increases by 68.9 % compared to the usual mode. If we consider a single room, which is zonally separated in both models for analysis, its

specific consumption increased by 83.2 % and 86.9 % for the northern and southern orientation compared to the usual mode, respectively. Similar observations can be made for scenarios No. 2 and No. 3. If we compare Scenario No. 1 and Scenario No. 2, we see that the use of intermittent heating mode reduces energy consumption both in normal operation (by 14.6 %) and in quarantine (by 4 %, savings are reduced due to the flow to adjacent premises). The reduction in heat energy consumption during quarantine is not particularly significant since only a small part of the premises is operational. Consequently, there will be a decrease in temperature during non-working hours. Scenario No. 3 is the most energy efficient as evidenced by the obtained results. Energy savings, compared to Scenario No. 2 for the normal mode, are 39.2 % and for the quarantine – 7.8 %. Thus, the total energy savings for scenarios No. 1 and No. 3 for normal/steady state are 48 % and for quarantine – 11.5 % [9]. The hourly heating load for in-person (normal) and remote learning conditions is shown in Fig. 3. The illustration of the heating load on the heating system for Scenario No. 1 is presented in the paper [9]. It follows from Figs. 4 and 5 that when the proposed operating modes are implemented under quarantine restrictions, the load on the heating system is generally reduced, and Scenario No. 3 is the most energy efficient for both operating modes.

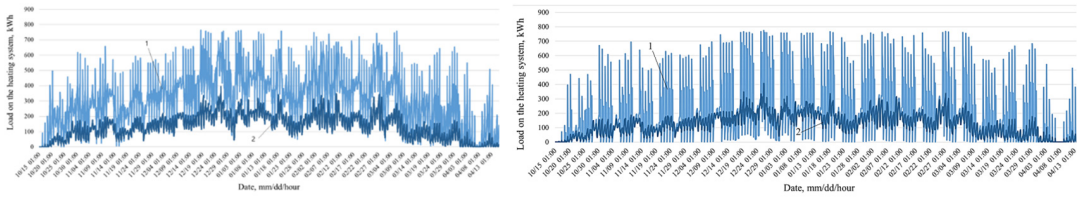


Fig. 3. Hourly need for heating by the building.
(a – Scenario No. 2; b – Scenario No. 3;
1 – normal mode; 2 – quarantine mode).

However, as noted, the specific energy consumption per unit of heating area (up to the appropriate temperature level) has increased. Figure 3 shows the graphical hourly specific consumption of heat energy for the heating of a separate room, which is operated under quarantine and normal conditions. To compare the consumption of heat energy at different orientations, the azimuth of the building model was rotated in the program by 180° (the results obtained are given in Table 2) and one room was considered for two cases. The room under consideration has an area of 37.4 m^2 and two windows (5.4 m^2), the glazing factor is 0.52. The increase in specific consumption indicates that in rooms where the proper temperature is maintained during working hours, the heat flow intensifies through the inner walls to neighbouring rooms, where the level of heating is reduced. The southern orientation is characterised by more frequent shutdowns / reductions in the load on the heating system compared to the northern orientation, due to the intensity of solar revenues.

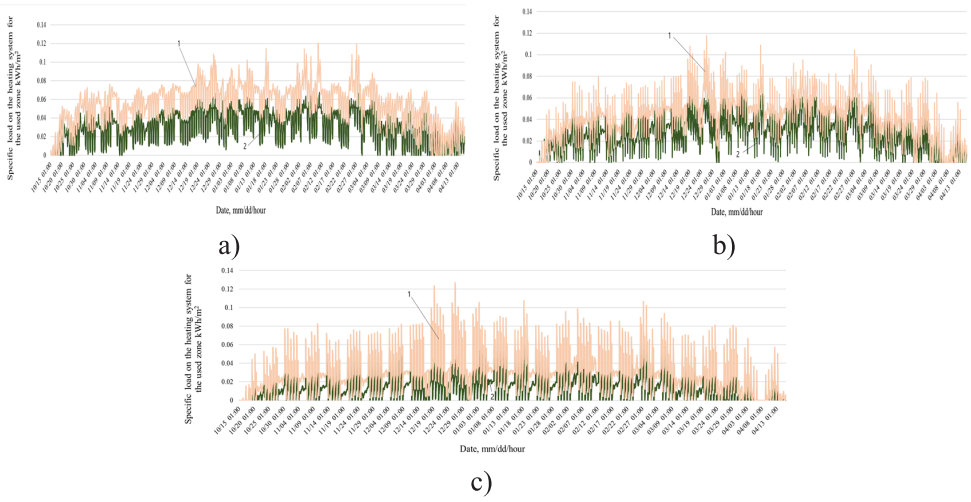


Fig. 4. Hourly heat consumption by representative premises of north orientation. (a – Scenario No. 1; b – Scenario No. 2; c – Scenario No. 3; 1 – quarantine mode; 2 – normal mode).

Figure 5 shows hourly graphs of air temperature fluctuations, average radiation temperature and air exchange during normal operation and quarantine in the considered representative room of northern orientation.

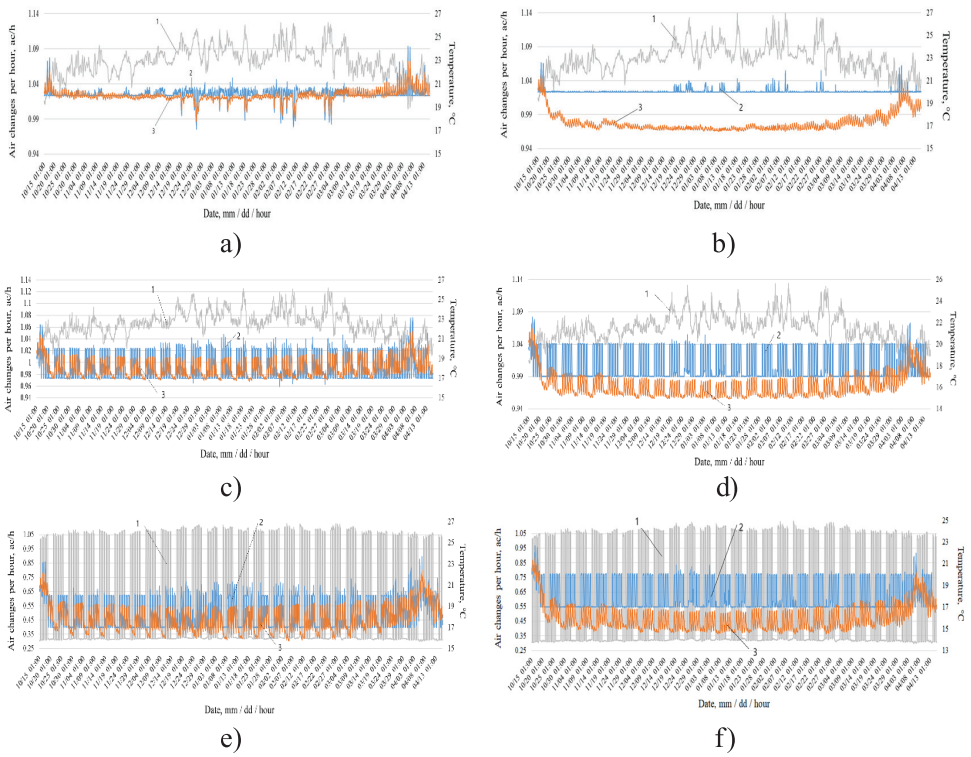


Fig. 5. Fluctuation of air temperature, average radiation temperature, air exchange level during the heating period for representative premises of north orientation. (a – 1/1; b – 2/1; c – 1/2; d – 2/2; e – 1/3; f – 2/3; where: 1/X – normal mode, 2/X – quarantine mode, X/1 – Scenario No. 1; X/2 – Scenario No. 2; X/3 – Scenario No. 3; 1 – air exchange; 2 – deviation of indoor air temperature; 3 – deviation of the average radiation temperature).

The same analysis was carried out for the south orientation. The general trend for south orientation is similar, but the values of indoor temperature and mean radiation temperature are higher. The average difference between the room temperature and the average radiation temperature for the calculation period are presented in Table 6, where X/X_S – south and X/X_N – north orientation.

Table 6. Indoor Air Temperature and Average Radiation Temperature for the Obtained Models

Scenario	t_{air_in} (°C)	t_{mean_rad} (°C)	Δ(°C)	Scenario	t_{air_in} (°C)	t_{mean_rad} (°C)	Δ(°C)
1/1_S	20.1	20.0	0.1	2/2_S	18.1	16.7	1.4
1/1_N	20.3	20.6	-0.3	2/2_N	18.2	16.9	1.3
2/1_S	20.1	17.3	2.8	1/3_S	18.3	17.9	0.4
2/1_N	20.2	17.9	2.3	1/3_N	18.6	18.6	0.0
1/2_S	18.1	18.1	0.0	2/3_S	18.1	16.0	2.1
1/2_N	18.3	18.7	-0.4	2/3_N	18.3	16.8	1.5

* North orientation, S: South, tair_in: Indoor air temperature, (°C), tmean_rad:
Average radiant temperature (°C), Δ: Temperature difference between tair_in and tmean_rad (°C)

From the given results, it follows that the parameters of comfort in the premises used under quarantine restrictions are deteriorating (the average radiation temperature decreases).

This is caused by the contact of these spaces with cold zones, where the temperature is tair_in= 14 °C. Due to the existence of internal heat flows between these zones, there is a reduction in the average radiant temperature (tmean_rad) in the occupied spaces. For Scenario No. 1, the lowest average radiation temperature is typical of the northern orientation room used in quarantine. The highest average radiation temperature – for the southern orientation in normal operation (in this case, the average radiation temperature even exceeds the air temperature by 0.3 °C). A characteristic feature of south-facing rooms, in addition to the general increase in average radiation temperature, is the increase in the amplitude of fluctuations in both average radiation temperature and indoor air temperature during the day and night, due to additional heat from the sun on the south side. Similar analogies are observed for scenarios No. 2 and No. 3. For Scenario No. 2, there is a decrease in the average radiant temperature and indoor air temperature during the heating period. Additionally, the difference between the indoor and average radiant temperatures is also reduced. Scenario No. 3 compared to No. 2 is characterised by an increase in indoor air temperature, as the air exchange in the premises during non-working hours decreases. However, this slightly reduces the average radiation temperature. As a result, in the implementation of Scenario No. 3, the moisture in the air condenses to a greater extent than in No. 2 and diffuses into the enclosing structures, removing heat from them and, as a result, reducing the average radiation temperature. However, the reduction is very small compared to the savings of heat energy in Scenario No. 3, so the most appropriate scenario to be used for both modes of operation is Scenario No. 3.

4. DISCUSSION

The conditions of the COVID-19 pandemic have led to a significant transformation of teaching methods adopted in higher educational institutions, shifting towards a reliance on online learning systems. Considerable attention from researchers has been directed towards studying electricity consumption issues [35]–[37]. Overall, the analysis shows that the total electricity consumption in 2020 was significantly lower for educational institutions compared to 2019 [35], [36]. For instance, in the buildings of the University of Jordan campus, electricity consumption decreased by 20.8 % [36]. Similar studies on electricity consumption reduction have been conducted for universities in Michoacan, Mexico [35]. The article [37] explores how the COVID-19 pandemic has affected the demand and changes in electricity consumption in the energy system of the USA. However, the issue of thermal energy consumption for heating needs in educational institutions during the pandemic period has not been studied sufficiently.

The article [38] presents results regarding the increased energy consumption for heating and cooling purposes in residential buildings of the sleeping districts in Geneva, Switzerland. The obtained results indicate that the energy demand for heating and cooling of the premises tended to increase by 8 % and 17 %, respectively, during partial lockdown, while these figures grew to 13 % and 28 % in the case of a full lockdown. In the present article, the assessment of the change in energy consumption for heating in university buildings has been conducted for the conditions of Kyiv, Ukraine, for the first time.

During the pandemic and periods of martial law, a decrease of classes and classrooms has been observed in educational institutions of Ukraine and, consequently, a decrease in the number and area of rooms in which the comfort conditions necessary for classes are maintained. For the academic building of the university, the total energy consumption for heating needs depends on the number of rooms that are actively used and the heating and ventilation control modes. Simulation of dynamic modelling was conducted to analyse the energy consumption of the educational building, specifically focusing on heating requirements. The simulation was performed using the educational building of Igor Sikorsky Kyiv Polytechnic Institute as a representative example.

The conducted studies consider the unique characteristics of energy processes within the multi-component structure of the building, specifically when determining energy consumption for heating purposes. These characteristics include the influence of the dynamics of solar heat gains, the building orientation in relation to cardinal directions, heat accumulation and internal heat flow. Special attention is dedicated to investigating the impact of various modes of operation of the heating and ventilation system.

The article presents data on the impact of decentralization and occupancy schedules of the utilised premises on energy consumption reduction. The results were obtained using dynamic modelling of a multi-zone three-dimensional model of energy processes in the building. The magnitude of potential savings for different scenarios and the justification for the placement of the occupied premises were the main objectives of this study.

If we consider the utilization of the

building according to Scenario No. 1, the reduction of the utilized areas during the quarantine mode by 92 % (Table 3) leads to an 83 % decrease in energy consumption for heating in simplified proportional estimations without considering interzone airflows based on average outside temperatures during the heating period. In Table 4, we observe a 61 % decrease, meaning that the percentage reduction in the utilization of building spaces does not lead to a proportionate decrease in energy consumption due to inter-zone heat flows between neighbouring spaces.

During dynamic simulations, the reduction in energy consumption relative to the base calculation for normal building operation (mode 1, Scenario No. 1) is as follows:

1) In the case of implementing pandemic-specific mode 2/1 (with constant temperature levels throughout the day for working spaces not in use) – 61.3 %; 2/2 (with intermittent operation modes for heating systems) – 62.7 %; 2/3 (intermittent heating and ventilation modes) – 65.7 %;

2) for normal operating mode, with the implementation of intermittent heating system operation 1/2 – 14.6 %, and with intermittent heating and ventilation operation 1/3 – 48 %.

The articles [22], [38], [39] present potential energy savings when implementing temperature level regulation throughout the day for residential [38]–[40] and administrative buildings [22], but not for conditions of martial law and pandemic. In [22], it is indicated that implementing a reduction of indoor air temperature by 3 °C from the set level allows for a 18 % reduction in thermal energy consumption. Introducing variable temperature regimes in residential buildings [38] can lead to a 16 % reduction in thermal energy consumption. The implementation of variable operation modes for ventilation systems and temperature regimes in residential buildings [39] can reduce heating energy demand by 25 % compared to a model with constant air exchange. It is worth noting that the obtained results in [22], [38] correspond to different usage patterns of residential building spaces, which significantly differ from the occupancy schedules of educational institutions. The effects of heat transfer between zones were not investigated in the results of [22], [39], as the temperature regime was uniform across all building zones. This underscores the necessity of conducting studies that allow for the assessment of thermal transfer between building zones under different temperature schedules and variations in the conditions of use for different spaces.

The increase in the specific consumption of heat energy by the premises used during quarantine is attributed to their proximity to colder zones. This proximity also results in a decrease in the average radiation temperature, impacting the comfort parameters, particularly for premises with a northern orientation. This observation is supported by the collected hourly data on fluctuations in air temperature, average radiation temperature, and their overall averages throughout the heating season.

The conducted research indicates that the difference between indoor air temperature and average radiant temperature can reach up to 14 %, depending on the orientation of the spaces and the temperature regimes in the considered and adjacent rooms. Temperature studies conducted for educational institutions in Ukraine show that the difference between indoor air temperature and average radiant temperature can reach up to 21 % [41].

Therefore, when choosing separate working areas during quarantine, preference should be given to south-facing rooms. Based on the analysis of various param-

eters, it can be concluded that Scenario No. 3 represents the most energy saving mode. The disadvantage of this mode is a decrease in the intensity of mass transfer processes as a result of a decrease in the level of air exchange. This leads to moisture retention on the enclosing structures, which leads to a decrease in the average radiation temperature compared to Scenario No. 2. However, this decrease is very small and imperceptible for the human body. Therefore, this mode can be recommended for implementation in quarantine / martial law mode and normal mode.

Therefore, it is demonstrated that the spatial arrangement of the premises and different modes of their use need to be taken into account when determining energy consumption for heating in each specific case. In order to address these challenges, the use of multi-zone dynamic energy models for buildings is recommended.

5. CONCLUSIONS

A dynamic model of a typical educational building for the conditions of Ukraine of Igor Sikorsky Kyiv Polytechnic Institute with centralized heating and natural ventilation was chosen as the object of research. Dynamic modelling of the energy state of the building was performed using EnergyPlus software, which takes into account the improvement of heating and air exchange modes.

The paper presents the first results of research on the impact of the peculiarities of heating and ventilation systems operation in educational institutions on energy consumption during the period of military state and pandemic conditions in Ukraine.

The main results of the research include the following:

1. Modelling of thermal energy consumption by the building under normal operation conditions (in-person learning) was performed for three developed scenarios: No. 1 – modelling of the operation of engineering systems at preset constant temperature and steady air exchange (indoor air temperature 20 °C, hourly infiltration rate 1 ac/h, t = const, n = const); No. 2 – with intermittent heating mode (lowering the temperature during non-working hours and weekends to 17 °C) and steady air exchange (t = var, n = const); No. 3 – with intermittent heating and intermittent air exchange (during non-working hours and weekends lowering the temperature to 14 °C and hourly infiltration rate to 0.3 ac/h, t = var, n = var). For the premises under quarantine mode that are utilized (distributed, 12 % of the total area), the same scenarios were employed. For unused premises t = 14 °C and n = 0.3 ac/h, t = const, n = const. According to the results of modelling of the three proposed modes of operation for the heating system and natural ventilation, the most substantial influence on reducing energy consumption for heating is attributed primarily to the reduction of air exchange rate and temperature in the unutilized premises during quarantine periods (for scenarios No. 1, No. 2, and No. 3, these values are 61.3 %, 62.7 %, and 65.7 %, respectively). It has been determined that the most energy saving result corresponds to Scenario No. 3. The total energy savings between scenarios No. 1 and No. 3 for the normal mode are 48 % and

for quarantine – 11.5 %. The analysis reveals that the efficiency of regulation modes during the quarantine period can decrease by more than four times compared to the normal mode. This decrease is primarily attributed to a reduction in the number of actively utilised rooms subject to control, as well as internal heat exchange with unoccupied spaces.

2. It has been determined that in the case of partial use of the building during quarantine, with the implementation of zone regulation, the total energy consumption of the building decreases by 61.3 %, 56.5 %, and 34 % for scenarios No. 1, No. 2, and No. 3, respectively. When the building is partially used under distance learning conditions, the specific thermal energy consumption for heating per unit of heated area increases compared to the conditions of in-person learning (normal mode). Specifically, for scenarios No. 1, No. 2, and No. 3, the increase is by 68.9, 52.9, and 78.6 %, respectively. Additionally, when considering a separate research room with north and south orientations, the difference in specific consumption is more prominent in the southern orientation (+86.8 %) compared to the northern orientation (+83.2 %), primarily due to uneven heat distribution from the sun. If it is possible to change the choice of premises used, it is advisable to try to place them next to each other and on the south side to reduce energy consumption for heating.
3. The introduction of intermittent heating allows reducing energy consumption in normal mode of operation by 14.6 %, in quarantine – by 4 % (internal heat flows between warm and cold zones of the building result in a decrease of the average radiant temperature in the occupied rooms and reduce the expected thermal energy savings). The introduction of intermittent ventilation allows increasing energy savings by 39.2 % for normal operation and by 7.8 % for quarantine / martial law. Thus, the total energy savings from the introduction of intermittent heating and ventilation for the normal mode is 48 % and for quarantine – 11.5 %. When considering the permissible typical control values, the reduction of preset indoor air temperature and ventilation has a greater impact on heating energy consumption. Decreasing the air exchange rate, both under normal operating conditions and during partial occupancy, has a greater impact on heating energy consumption for both normal and partial use conditions.

The modelling results provide a basis for determining the efficiency and feasibility of implementing zonal heating regulation in the university building under Ukrainian conditions. It is recommended to employ the suggested approaches to reduce energy consumption when planning schedules for the use of educational facilities with partial loading outside the pandemic period or martial law. This can be the subject of further studies.

Research limitation. The article conducts modelling of the energy characteristics of buildings aimed at maintaining the indoor air temperature at a specified level without considering comfort parameters, which can be assessed using the Predicted Mean Vote method (PMV). To ensure comfort within the premises during partial operation under quarantine restrictions, it is advisable to investigate the impact of increasing the air temperature in the operated premises to a level that aligns with the PMV comfort parameter within the acceptable range of ±0.5.

ACKNOWLEDGEMENTS

This research has been funded with support of European Regional Development Fund project "Optimal Control of Indoor Air Quality and Thermal Comfort Based on Room Real-time 3D Motion Scanning Data", Grant Agreement No 1.1.1.1/21/A/010.20:23

REFERENCES

1. Yoshino, H., Hong, T., & Nord, N. (2017). IEA EBC Annex 53: Total Energy Use in Buildings—Analysis and Evaluation Methods. *Energy Build*, 152. DOI: 10.1016/j.enbuild.2017.07.038.
2. Deshko, V., Bilous, I., Buyak, N., & Shevchenko, O. (2020). The impact of energy-efficient heating modes on human body exergy consumption in public buildings. In *ESS 2020 – Proceedings*. 12–14 May 2020, Kyiv, Ukraine. DOI: 10.1109/ESS50319.2020.9160270.
3. Upitis, M., Amolina, I., Geipele, I., & Zeltins, N. (2020). Measures to Achieve the Energy Efficiency Improvement Targets in the Multi-Apartment Residential Sector. *Latvian Journal of Physics and Technical Sciences*, *57* (6), 41–52. DOI: 10.2478/lpts-2020-0032.
4. Aliero, M. S., Pasha, M. F., Smith, D. T., Ghani, I., Asif, M., Jeong, S. R., & Samuel, M. (2022). Non-Intrusive Room Occupancy Prediction Performance Analysis Using Different Machine Learning Techniques. *Energies (Basel)*, *15* (23), 9231. DOI: 10.3390/en15239231.
5. Saraiva, T. S., de Almeida, M., Bragança, L., & Barbosa, M. T. (2018). Environmental Comfort Indicators for School Buildings in Sustainability Assessment Tools. *Sustainability (Switzerland)*, *10* (6), 1849. DOI: 10.3390/su10061849.
6. Katić, D., Krstić, H., & Marenjak, S. (2021). Energy Performance of School Buildings by Construction Periods in Federation of Bosnia and Herzegovina. *Buildings*, *11* (2), 42. DOI: 10.3390/buildings11020042.
7. He, Z., Hong, T., & Chou, S. K. (2021). A Framework for Estimating the Energy-Saving Potential of Occupant Behaviour Improvement. *Appl. Energy*, *287* (1), 116591. DOI: 10.1016/j.apenergy.2021.116591.
8. Laaroussi, Y., Bahrar, M. Elmankibi, M., Draoui, A., & Si-Larbi, A. (2019). Occupant behaviour: A major issue for building energy performance. In *IOP Conference Series: Materials Science and Engineering*, *609*, 072050. DOI: 10.1088/1757-899X/609/7/072050.
9. Deshko, V., Bilous, I., & Boiko, T. (2022). Influence of Heating and Ventilation Modes on the Energy Consumption of University Educational Buildings under Quarantine Conditions in Ukraine. *Journal of New Technologies in Environmental Science*, *6* (1), 36–40.
10. Alghamdi, S., Tang, W., Kanjanabootra, S., & Alterman, D. (2022). Effect of Architectural Building Design Parameters on Thermal Comfort and Energy Consumption in Higher Education Buildings. *Buildings*, *12* (3), 329. DOI: 10.3390/buildings12030329.
11. Sadowska, B., Piotrowska-Woroniak, J., Woroniak, G., & Sarosiek, W. (2022). Energy and Economic Efficiency of the Thermomodernization of an Educational Building and Reduction of Pollutant Emissions—A Case Study. *Energies (Basel)*, *15* (8), 2886. DOI: 10.3390/en15082886.
12. Jia, L. R., Han, J., Chen, X., Li, Q. Y., Lee, C. C., & Fung, Y. H. (2021). Interaction between Thermal Comfort, Indoor Air Quality and Ventilation Energy Consumption of Educational Buildings: A Comprehensive Review. *Buildings*, *11* (12), 591. DOI: 10.3390/buildings11120591.

13. Sun, C., & Zhai, Z. (2020). The Efficacy of Social Distance and Ventilation Effectiveness in Preventing COVID-19 Transmission. *Sustain Cities Soc.*, *62*. doi: 10.1016/j.scs.2020.102390.
14. Franco, A., Bartoli, C., Conti, P., Miserocchi, L., & Testi, D. (2021). Multi-Objective Optimization of HVAC Operation for Balancing Energy Use and Occupant Comfort in Educational Buildings. *Energies (Basel)*, *14* (10), 2847. DOI: 10.3390/en14102847.
15. Ivanko, D., Ding, Y., & Nord, N. (2021). Analysis of Heat Use Profiles in Norwegian Educational Institutions in Conditions of COVID-Lockdown. *Journal of Building Engineering*, 43. DOI: 10.1016/j.jobe.2021.102576.
16. Bahmanyar, A., Estebsari, A., & Ernst, D. (2020). The Impact of Different COVID-19 Containment Measures on Electricity Consumption in Europe. *Energy Res Soc Sci*, *68*, 101683. DOI: 10.1016/j.erss.2020.101683.
17. Rolando, D., Pallard, W. M., & Molinari, M. (2022). Long-Term Evaluation of Comfort, Indoor Air Quality and Energy Performance in Buildings: The Case of the KTH Live-In Lab Testbeds. *Energies (Basel)*, *15* (14), 4955. DOI: 10.3390/en15144955.
18. World Business Council for Sustainable Development. (2019). *Transforming the Market: Energy Efficiency in Buildings*. Survey Report. Geneva.
19. Chattopadhyay, K., Garg, V., Paruchuri, P., Mathur, J., & Valluri, S. (2022). Impact of COVID-19 on Energy Consumption in a Residential Complex in Hyderabad, India. *Energy Informatics*, *5*. DOI: 10.1186/s42162-022-00240-5.
20. Todeschi, V., Javanroodi, K., Castello, R., Mohajeri, N., Mutani, G., & Scartezzini, J. L. (2022). Impact of the COVID-19 Pandemic on the Energy Performance of Residential Neighborhoods and their Occupancy Behaviour. *Sustain Cities Soc.*, *82*. DOI: 10.1016/j.scs.2022.103896.
21. Tleuken, A., Tokazhanov, G., Serikbay, A.-B., Zhalgasbayev, K., Guney, M., Turkyilmaz, A., & Karaca, F. (2021). Household Water and Energy Consumption Changes during COVID-19 Pandemic Lockdowns: Cases of the Kazakhstani Cities of Almaty, Shymkent, and Atyrau. *Buildings*, *11* (12), 663. DOI: 10.3390/buildings11120663.
22. Deshko, V., Bilous, I., Sukhodub, I., & Yatsenko, O. (2021). Evaluation of Energy Use for Heating in Residential Building under the Influence of Air Exchange Modes. *Journal of Building Engineering*, *42*. DOI: 10.1016/j.jobe.2021.103020.
23. Deshko, V., Bilous, I., Biriukov, D., & Yatsenko, O. (2021). Transient Energy Models of Housing Facilities Operation. *Rocznik Ochrona Srodowiska*, *23*. DOI: 10.54740/ros.2021.038.
24. Deshko, V., Bilous, I., Vynogradov-Saltykov, V., Shovkaliuk, M., & Hetmanchuk, H. (2020). Integrated Approaches to Determination of CO2 Concentration and Air Rate Exchange in Educational Institution. *Rocznik Ochrona Srodowiska*, *22* (1), 82–104.
25. Verhovna Rada of Ukraine. (2017). *Law of Ukraine On Energy Efficiency of Buildings*. The Official Bulletin of the Verkhovna Rada, 33, Article 359. Available at https://zakon.rada.gov.ua/laws/show/2118-19?lang=en#Text.
26. Hong, T., Chen, Y., Belafi, Z., & D'Oca, S. (2018). Occupant Behavior Models: A Critical Review of Implementation and representation approaches in Building Performance Simulation Programs. *Building Simulation*, *11* (1). DOI: 10.1007/s12273-017-0396-6.
27. Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., Buhl, W. F., Huang, Y. J., Pedersen, C. O., … & Glazer, J. (2001). EnergyPlus: Creating a New-Generation Building Energy Simulation Program. *Energy Build*, *33* (4), 319–333. DOI: 10.1016/S0378-7788(00)00114-6.
28. U.S. Department of Energy's (DOE) Building Technologies Office (BTO). (n.d.). *EnergyPlus*. Available at https://energyplus.net/
29. Minbud Ukrainy. (2021). *Teplova izoliatsiia ta enerhoefektyvnist budivel, chynnyi vid 2022-09-01, na zaminu DBN V.2.6–31:2016. Vyd. ofits*. (pp. 1–27). Ukraine.

30. Minrehionbud Ukrainy. (2015). *Enerhetychna efektyvnist budivel. Metod rozrakhunku enerhospozhyvannia pry opalenni, okholodzhenni, ventyliatsii, osvitlenni ta hariachomu vodopostachanni; chynnyi vid 2016-01-01. Vyd. ofits*. (pp. 1–145). Ukraine.
31. International Weather for Energy Calculations. (n.d.). Available at https://energyplus.net/weather-location/europe_wmo_region_6/UKR.
32. Ministry of Health of Ukraine. (n.d.). Available at https://covid19.gov.ua/karantynni-zakhody.
33. Minbud Ukrainy. (2013). *DBN V.2.5-67:2013. Opalennia, ventyliatsiia ta kondytsiiuvannia; chynnyi vid 2014–01–01*, (pp. 1–149).
34. Minrehionbud Ukrainy. (2013). *DSTU-N B V.1.1–27:2010. Budivelna klimatolohiia; chynnyi vid 2011-11-01*, (pp. 1–123).
35. López-Sosa, L. B., Alvarado-Flores, J. J., del Niño Jesús Marín-Aguilar, T., Corral-Huacuz, J. C., Aguilera-Mandujano, A., Rodríguez-Torres, G. M., … & Ávalos-Rodríguez, M. L. (2021). COVID-19 Pandemic Effect on Energy Consumption in State Universities: Michoacan, Mexico Case Study. *Energies*, *14* (22), 7642. https://doi.org/10.3390/en14227642.
36. Ayadi, O., Alnaser, S., Haj-ahmed, M., Khasawneh, H., Althaher, S., Alrbai, M., & Arabiat, M. (2023). Impacts of COVID-19 on Educational Buildings Energy Consumption: Case Study of the University of Jordan. *Front Built Environ*, *9*. DOI: 10.3389/fbuil.2023.1212423.
37. Agdas, D., & Barooah, P. (2020). Impact of the COVID-19 Pandemic on the U.S. Electricity Demand and Supply: An Early View from Data. *IEEE Access*, *8*, 205034-205050 DOI: 10.1109/ACCESS.2020.3016912.
38. Valeriy, D., Inna, B., Maryna, S., & Maksym, H. (2020). Evaluation of Differentiated Impact of Apartment Building Occupants' Behavior on Energy Consumption. *2020 IEEE 7th International Conference on Energy Smart Systems, ESS 2020 – Proceedings,* (pp. 196–200). Kyiv, Ukraine, 2020. DOI: 10.1109/ESS50319.2020.9160046.
39. Deshko, V., Sukhodub, I., & Yatsenko, O. (2018). Building Thermal State and Technical Systems Dynamic Modeling. *Journal of New Technologies in Environmental Science*, *2*, 36–46.
40. Lebedeva, K., Borodinecs, A., Krumins, A., Tamane, A., & Dzelzitis, E. (2021). Potential of End-User Electricity Peak Load Shift in Latvia. *Latvian Journal of Physics and Technical Sciences*, *58* (2), 32–44. DOI: 10.2478/lpts-2021-0010.
41. Savchenko-Pererva, M., Radchuk, O., Rozhkova, L., Barsukova, H., & Savoiskyi, O. (2021). Determining Heat Losses in University Educational Premises and Developing an Algorithm for Implementing Energy-Saving Measures. *Eastern-European Journal of Enterprise Technologies*, *6* (8(114)), 48–59. DOI: 10.15587/1729-4061.2021.245794.