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Valeriy DESHKO
Nadia BUYAK
Bilous INNA

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine

DYNAMIC MODELING OF ENERGY NEED FOR HEATING AND THERMAL COMFORT DEPENDENCE ON BUILDING ENVELOPE CHARACTERISTICS

Abstract: *The analysis based on dynamic modeling of the parameters changing effect of the building envelope on the thermal state has been carried out. The influence on the building energy need for heating of the mass building thermal inertia features for various thermal resistances and the different glazing area under the condition of constant room air temperature was investigated. The influence of changes in environmental parameters during the heating period on the parameters of thermal comfort and on average radiant and operating temperature for various variants of building envelope, glazing area of the windows and massiveness of envelope has been also investigated.*

Keywords: *energy need for heating, thermal comfort, predicted mean vote index, mean radiant temperature, operative temperature*

Introduction

The buildings are one of the main consumers of primary energy resources in the world. The climatic conditions of Ukraine are characterized by a long heating period, which causes more than 85% of energy needs for heating. That is why the requirements for energy efficiency are increased, which is reflected in the standards [1-3]. In order to increase the energy efficiency of buildings, the main measures are directed to the envelope and engineering systems. The main indicator of energy efficiency of buildings is the specific energy need for heating, which is calculated provided during the maintenance of the normative room air temperature.

In this case, the issues of thermal comfort are largely neglected, or it is determined by the room air temperature [4]. The estimation of thermal comfort is raised during the energy audit of the premises of the university dormitories in France [5], the design of dwelling houses in China [6], the design of an office air conditioning system in Turkey [7], by the assessing the energy efficiency of public buildings in Ukraine [8, 9] and are regulated by the relevant Ukrainian [10-12] and foreign standards, in addition, it is also introduced the concept of building thermal comfort control [13].

There are two methods for evaluating the thermal comfort in the premises [14]:

1. It is grounded on the stationary heat balance model for the human body, developed by Fanger [15], is based on EN ISO 7730 [12] and ASHRAE 55 [16]. This standard gives examples of recommended building thermal comfort category with mechanical heating and cooling. There are four building thermal comfort category, depending on the value of PMV.
2. The second method is based on the adaptive approach [17], on the basis of which the linear regression equations are obtained, which shows the relationship between the operating room air temperature and the environment temperature. The value of the comfort temperature depending

on the temperature of the outside air is included ASHRAE 554 2004 [18] and EN 152515 [10]. Providing an appropriate level of thermal comfort with an adaptive approach is presented on the example of the Iranian School [19], Japanese Offices [20], residential buildings (domestic buildings) in different countries [21-23].

The development of the exergy approach to thermal comfort, which allows taking into account the human thermoregulation mechanism, and thus lowering the level of comfortable temperatures, thereby providing energy savings, is presented in works by M. Prek [24-26], Shukuya [27-31], Isawa [32], etc.

A great scientific interest in the issue of thermal comfort, makes it necessary to take into account the model of thermal comfort during the design and operation of the building. Incorporation of the human thermal comfort model into a complicated system of "heat source – building envelope" [33, 34] is a significant step towards reducing energy consumption of buildings and ensuring an adequate level of thermal comfort. In addition, the dynamic change in the environmental parameters causes the change of subjective parameters of the microclimate (room air temperature, mean radiant temperature), and therefore the indicators of thermal comfort. Estimation of thermal comfort indicators in the event of a dynamic change in the environmental parameters will show the possibility of adjusting the heating system with the aim of providing an adequate level of thermal comfort and possible reduction of energy consumption. In addition, the development of research in this direction allows us to consider the building as a complex system "heat source – human – building envelope – environment", which in turn will provide the design and operation of new generation buildings and is an important step towards sustainable development.

Purpose and research objectives

The purpose of the work is to analyze using the dynamic BEM modeling of the impact on energy demand, parameters and indicators of thermal comfort for changing the parameters of the heat insulation the outer walls of different massivity and the coefficient of buildings glazing which are the characteristic of the massive building of Ukraine.

The following tasks should be solved, according to the goal:

1. Creation of room dynamic models in the EnergyPlus software with the most common thermal and geometric characteristics for the Ukraine conditions.
2. Analysis of the building energy characteristics for typical thermal and geometric characteristics of the building's shell.
3. Analysis of the change of objective parameters of the microclimate and indicators of thermal comfort during the heating period for typical thermal and geometric characteristics of the buildings envelope.

Research matter and results

Input data. In order to study of the building energy characteristics, there were created dynamic simulation model based on the EnergyPlus software for the room's 50s and 60s of construction thermal properties, glazing coefficients [0.4...0.6], oriented to the northern (N) and southern (S) side. Room dimensions 5.5x6.1 m, height of the room is 3.2 m. The room has one external wall (5.5 m) with a window. The window is a two-chamber metal-plastic double-glazed window with an air filling. The main part of the outer wall is made on the basis of brickwork in: 1) one brick (250 mm); 2) two bricks (500 mm). The main part of the inner walls is made of half brick. The rooms overlappings are 20 cm reinforced concrete. Ventilation is natural with 1 air changes per hour. In the work there are considered three most common insulation materials: mineral wool, basalt wool, polystyrene foam. The layer of insulation is 10 cm. Air heating system is used. In this study where used hourly climatic data of the typical year of the international weather file IWEC for the Kyiv conditions [35], which are presented in the EPW extension, for easy synchronization with the simulation model based on EnergyPlus.

Basic parameters of person, premises and environment are presented in table 1.

Table 1. *The basic parameters of the modelling*

Virtual human model	
Human clothing thermal resistance, $m^2{\cdot}°C/W$	0.155
Metabolism (human activity), W/m^2	70
Mechanical work, W/m^2	0
Air changes per hour n, $hour^{-1}$	1
Virtual premise model	
Internal enclosing constructions area, m^2	56.64
Window thermal resistance R_v, $m^2{\cdot}°C/W$	0.17
Outer wall thermal resistance R_z, $m^2{\cdot}°C/W$	0.8

Model description. Geometry of representative premises was created in the graphic editor GoogleSketchup, which is synchronized through OpenStudio. The sampling rate of the calculation is chosen 1 hour. The dynamic model allows receiving an hourly change in air and radiant temperature in the room area and in heating level. In a model based on EnergyPlus are imposed restrictions that all solar heat inputs entering the room are diffuse and uniformly distributed between all surfaces. To calculate solar activity, the position of the sun relative to the horizon during the year and its changes over the course of the day are taken into account. EnergyPlus calculates solar heat transfer on vertical surfaces, the detailed methodology "Full interior and exterior with reflection" is used in the research.

It is carried out a dynamic modeling of the energy characteristics of the building before insulation and after for the constant temperature of the thermostat for N and S oriented representative premises.

To assess the level of thermal comfort, is used the method, which is presented in ISO Standard 7730 [12], based on the equations of thermal balance for the human body [15].

The influence of thermal protection and dynamic change of environmental parameters on energy demand and load on the heating system

It is investigated the influence on the building heating need of the most common insulators for wall different massiveness with constant internal air temperature of 20°C controled (fig. 1).

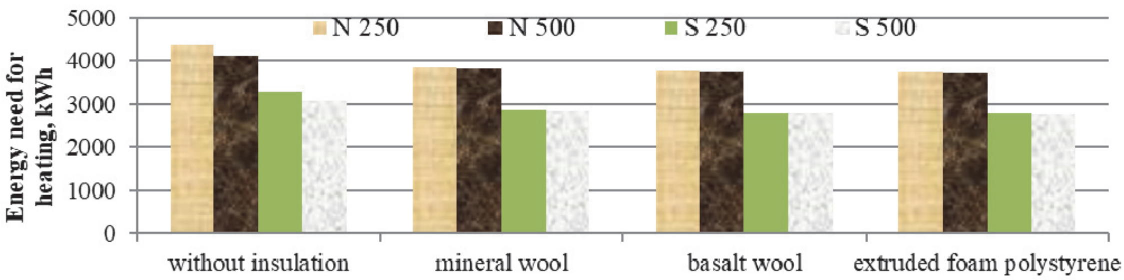
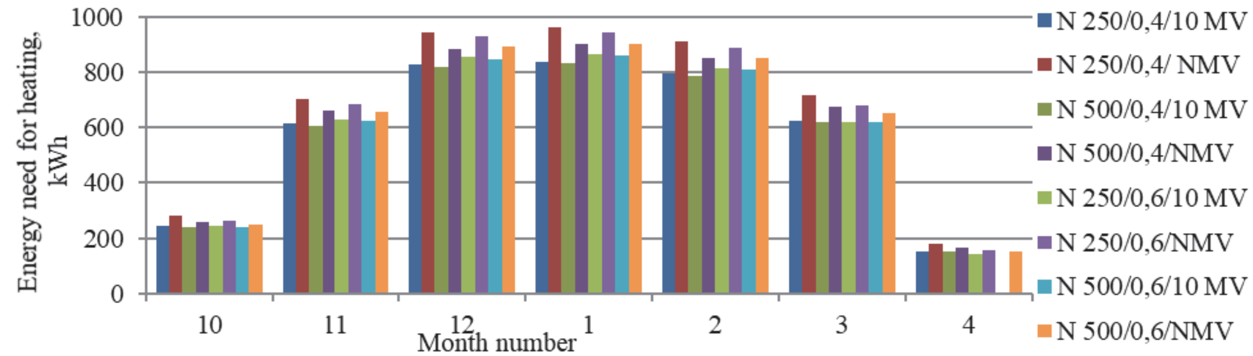


Figure 1. *Energy need for heating for various heat-inertial features of the building envelope. Nomenclature: North (N) and South (S) room orientation; the thickness of the red brick layer 500 mm and 250 mm*

From figure 2 we can see that the mass of the wall 250 mm and 500 mm without heat insulation reduces the energy need for heating by 7% in all orientations. In the presence of the insulator (any of the considered), the results of energy need for heating modeling is almost not affected by the massivity of the wall in one or two bricks for the North and South orientations. The three most commonly used insulators have almost the same effect on the building need for heating. The peculiarity of the use of one or other insulators is related to the cost and features of the application (number of floors, purpose of the building, etc.). A more detailed monthly and hourly analysis of heating energy requirements is made for mineral wool insulation of wall in one and two bricks for the North and South orientation of the representative room.

Figure 2 shows the building energy need for heating for different wall massiveness without (NMV) and with (MV) insulation for the coefficients of glazing 0.4 and 0.6 oriented to N (fig. 2a) and S (fig. 2b).



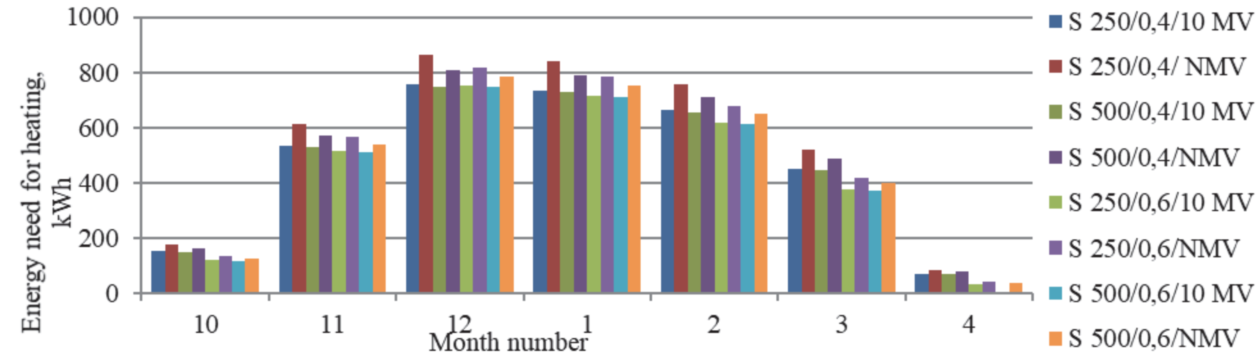


FIGURE 2. *Monthly values of the specific energy need for heating for representative premises oriented for north (a) and south (b)*

For the coefficient of glazing 0.6 and the southern room orientation, the window during the period off-season acts as a passive heating system and leads to the fact that for insulated external walls in the southern orientation it can last for almost a month less for the heating season of the city of Kiev (fig. 2b).

Figure 3 shows the load on the heating system, provided the system maintains an internal temperature of 20°C. During periods of solar peak activity, the heating system can be switched off (typical for the spring and autumn period of the off-season), and the internal air temperature exceeds 20°C.

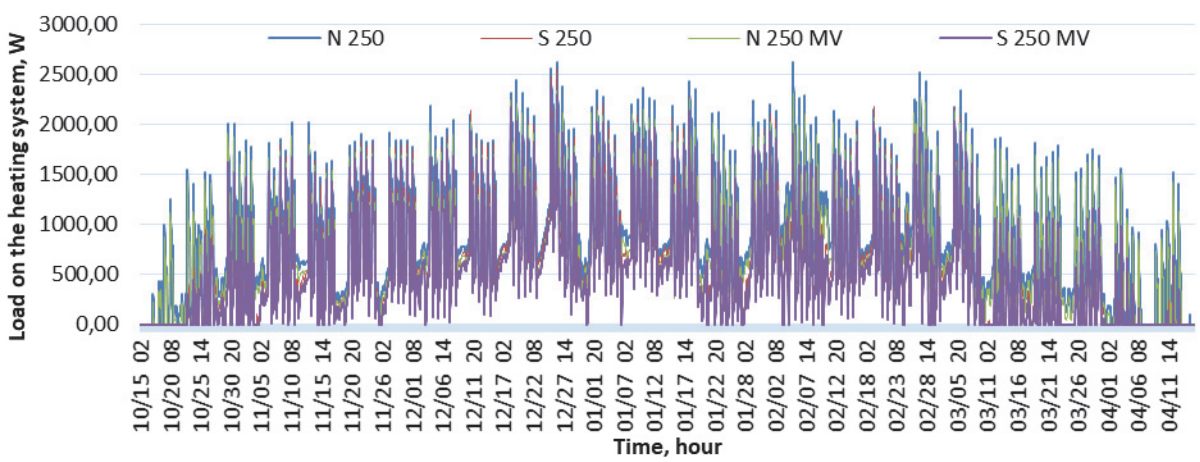


FIGURE 3. *Load on the heating system for different orientation and thermal resistance (without and with insulation) of room wall for the glazing coefficient of 0.4*

In figure 4 it was investigated the walls massiveness and the presence of wall insulation affects on the value of the average per month deviation of the load relative to the average monthly heating load for the coefficient of glazing 0.4. For the cold period of the year, the deviation of the load from the average monthly is almost the same for the N and S room orientation. In addition, it should be noted that the insulation of external walls leads to a decrease in load fluctuations relative to the average monthly value for all orientations.

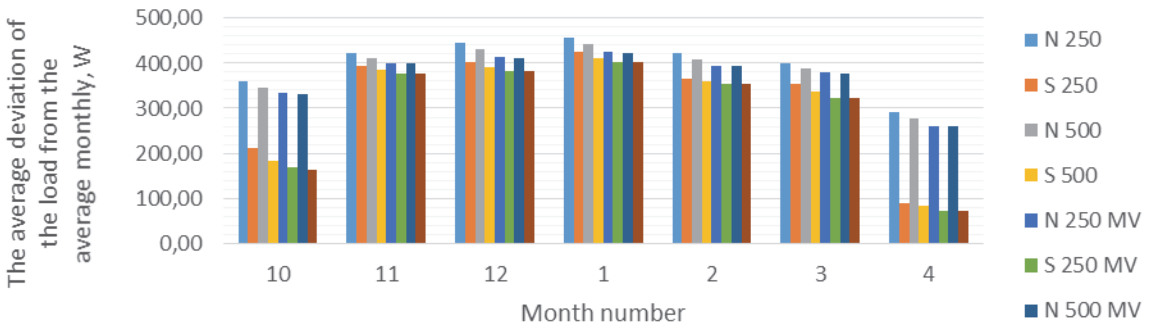


FIGURE 4. *The average month deviation of the load on the heating system relative to the average monthly load for the S and N orientation*

The effect of thermal protection and dynamic change of the environmental parameters on the human thermal comfort sensation

In this model, the main objective thermal comfort parameter of changing is the mean radiant temperature t_r. The change of t_r is due to the room inclosure temperature, the outside air temperature and the flow of solar radiation changes. The value of t_r in EnergPlus is calculated as the surface weighted, considering that the person is in the center of the room. During the study it is considered that the subjective parameters of thermal comfort are constant, namely human activity and type of clothing, so the change in PMV (the basic parameter of thermal comfort) is due to the change in t_r, that is, the dynamic change in environmental parameters.

Figure 5 shows the change in the mean radiant temperature t_r and PMV during the heating period for a building with a outer wall main layer 250 mm, with different orientation (namely, N and S) and the coefficient of glazing (0.4 and 0.6). The range of changes t_r during the heating period is set to 18-28.8°C, and PMV as the main indicator of thermal comfort from -0.5-1.3 for different variants of the inclosure. The highest values of t_r, and consequently PMV are characteristic for the wall with a coefficient of glazing 0.6, insulated with mineral wool 10 cm, and the lowest for the wall with a 0.4 coefficient without insulation. This is due to the fact that the increase in the glazing area and the thermal resistance of the wall due to insulation leads to an increase in t_r, and accordingly to PMV.

For a more detailed analysis of the impact of the outer wall on the t_r and PMV in figure 6 it is shown the variation of these values for different types of glazing and orientation options during 202 observations. It is established that for the data of observations, the difference between the average radiant temperature in the room can reach 8.4°C, while the PMV varies from -0.3 to 1.38. That indicates the significant impact of fencing on the indicators of thermal comfort. There is a higher influence of the orientation of the fences compared with the coefficient of glazing on t_r and PMV. Changing the glazing coefficient from 0.4 to 0.6 for the S orientation wall causes a change in t_r at 3°C and a PMV of 0.69, and a change in orientation for a glazing coefficient of 0.6 changes in t_r at 7°C and a PMV of 1.6. Therefore, the influence of the orientation of the fence has a more significant effect on the objective parameters of thermal comfort compared with the coefficient of glazing.

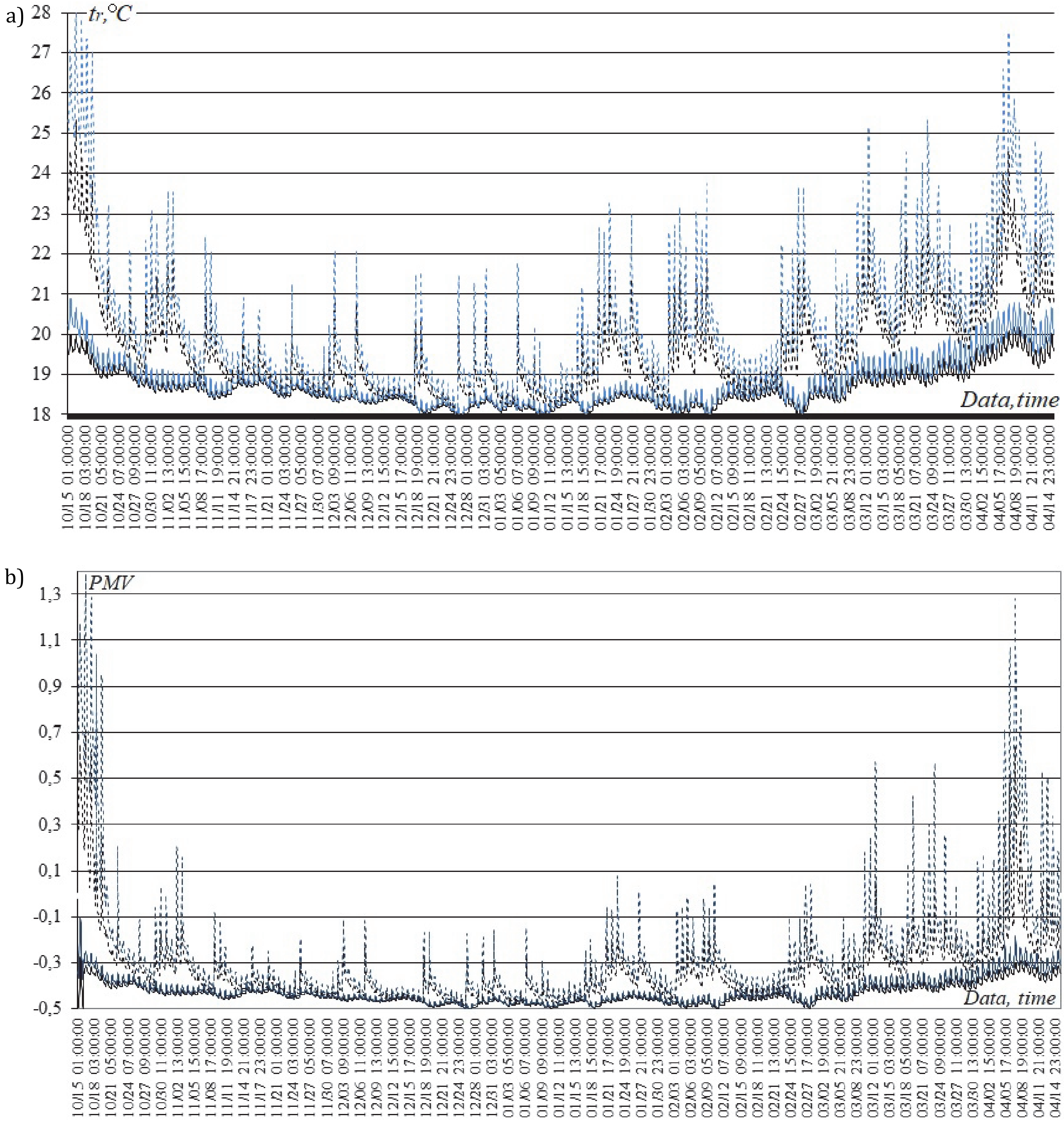


FIGURE 5. *Change of average radiant temperature and PMV: —— – glazing coefficient 0.4 orientation of N; —— – glazing coefficient 0.6 orientation of N; ----- – glazing coefficient 0.4 orientation of S; ----- – glazing coefficient 0,6 orientation of S*

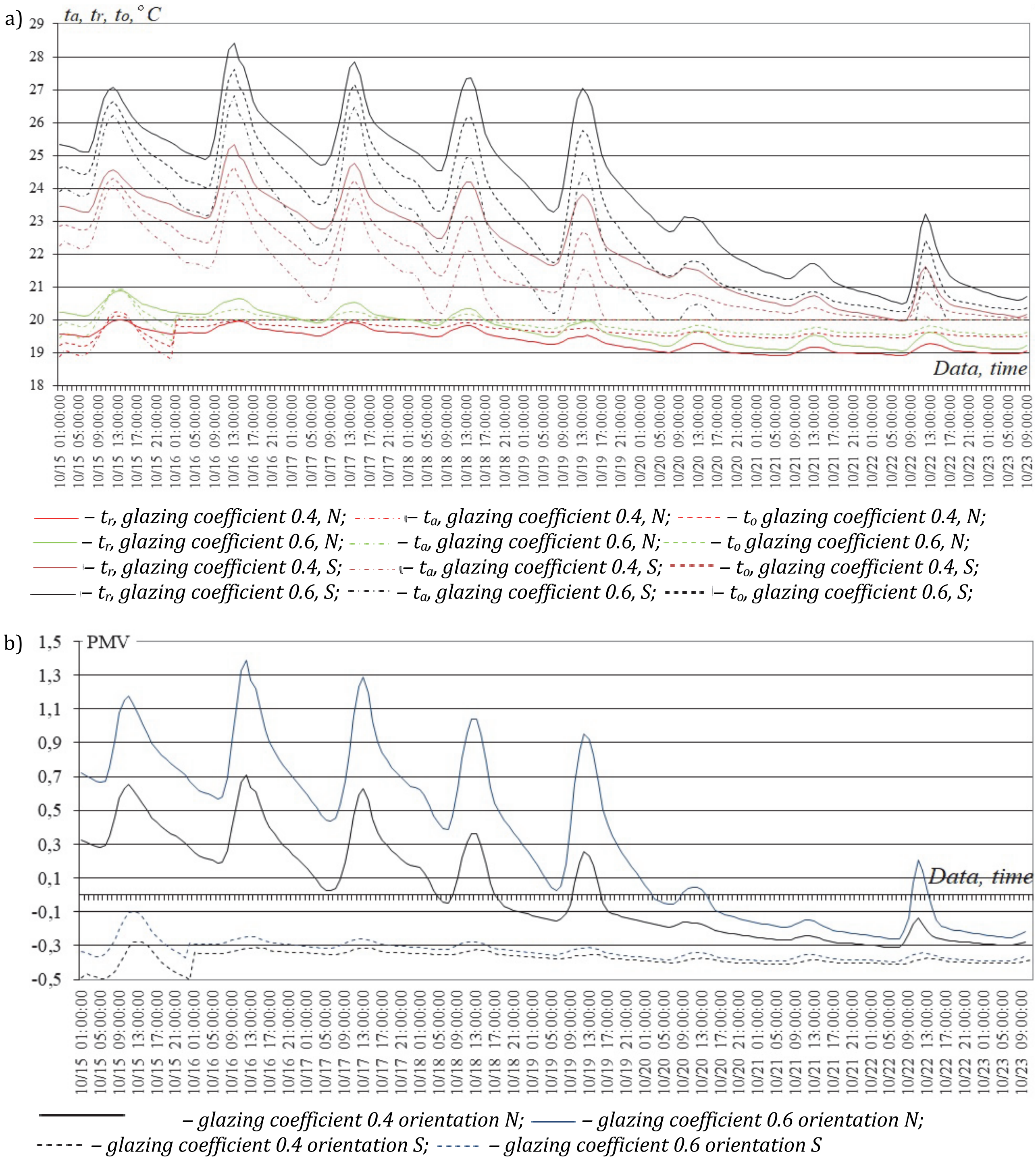


FIGURE 6. *Changing the objective thermal comfort parameters and PMV during 8 days of the heating period*

The dynamic modeling of the massiveness and thermal insulation influence on the indicators and parameters of thermal comfort during the heating period has been carried out. It has been shown that the change in the massivity from 200 mm to 500 mm and the establishment of thermal insulation can increase the average radiation temperature by 0.6°C, and PMV 0 in 0.83.

Consequently, the change in the orientation of the building from N to S and the increase in the coefficient of glazing significantly affect the increase in thermal comfort due to the growth of solar inputs and an increase in average radiant temperature. Increasing the massivity and the growth of building envelope thermal resistance due to thermal insulation in a less increases the t_r, and hence PMV.

There are distinguished four recommended buildings thermal comfort categories according to standard [10], depending on the value of PMV for the design of buildings with mechanical heating and cooling. The first category is for sensitive and sick people where -0.2 < PMV < +0.2; second, corresponds to the normal expectations level, should be used for new buildings and renovations and -0.5 < PMV < +0.5. Consequently, for an insulated and non-insulated building, it is possible to reduce indoor air temperature to provide PMV = -0.5, which in turn will reduce energy consumption and provide the appropriate level of thermal comfort expectations.

Providing an appropriate level of thermal comfort is an important and topical task, changing the comfort conditions under the dynamic changes in the environment parameters, and therefore the objective parameters of thermal comfort has not previously been investigated. It is established, the range of change in average radiant temperature for the heating period for various variants of the fences is within the range of 18-28.8°C, and PMV, as the main indicator of thermal comfort, from -0.6 to 1.2. This analysis shows a wide range of changes in objective parameters and indicators of thermal comfort, and the possibility of reducing energy consumption by reducing the air temperature in the room during the period of high values of the mean radiant temperature

Conclusions

In this research, it was carried out energy need for heating and building comfort conditions for various thermal and inertial features of fencing based on dynamic models created in the EnergyPlus software product. The following results are obtained:

1. In the presence of insulation, the building energy need for heating data of modeling is almost not affected by the initial massivity of the wall in one or two bricks for the N and S orientations. The three most commonly used insulators have almost the same effect on the building need for heating.
2. For the glazing coefficient of 0.6 and the southern orientation of the premises during the off-season, the window acts as a passive heating system and leads to the fact that for warmed external walls in the southern orientation southern heating can last for almost a month less for the city of Kyiv.
3. For the cold period of the year, for hourly intervals, the deviation of the load from the average monthly is almost the same for the North and South orientation of the room. It is noted that the insulation of external walls leads to a decrease in load fluctuations relative to the average monthly value for all orientations.
4. It is analyzed the changes in mean radiant temperature and PMV (thermal comfort index) for dynamic changes of environmental parameters and various variants of building envelope. The range of t_r temperature variations during the heating period for different building envelope options is set at 18-28.8°C, and PMV as the main indicator of thermal comfort from -0.6 to 1.2. This analysis shows a wide range of changes in objective parameters and indicators of thermal comfort, and the possibility of reducing energy consumption by reducing the room air temperature in the during the period of high values of the mean radiant temperature.
5. It was also analyzed the influence of fencing on the change of PMV, it was established that by changing the parameters of the building envelope it is possible to change PMV almost twice, which indicates the need for an integrated approach to the assessment of thermal comfort. Namely, the importance of taking into account the dynamic changes in environmental parameters and possible thermo-modernization.

Limitations: The EnergyPlus model introduces a limitation that all solar heat inputs entering the room are diffused and evenly distributed across all surfaces. The model of thermal comfort does not take into account the mechanism of human thermoregulation. The consideration of which will reduce the comfort temperature, and hence the energy consumption of buildings.

Future work will be devoted to a more detailed analysis of energy need for heating and thermal comfort combination on the basis of dynamic modeling. Namely: for conditions of intermittent heating, and for restrictions only on the air temperature in hours of unemployment.

References

[1] EN 13790:2008, 2008, *Energy performance of buildings – Calculation of energy use for space heating and cooling*, CEN: European Committee for Standardization, 53p.

[2] EN 15217:2007 2007, *Energy performance of buildings – Methods for expressing energy performance and for energy certification of buildings*, CEN: European Committee for Standardization, 31p.

[3] EN 15603:2008, 2008, *Energy performance of buildings – overall energy use and definition of energy ratings*, CEN: European Committee for Standardization, 43p.

[4] Ghita S.A., Catalina, T., 2015, Energy efficiency versus indoor environmental quality in different Romanian countryside schools, *Energy and Buildings,* 92, pp. 140-154. doi:10.1016/j.enbuild.2015.01.049.

[5] Allab Y., Pellegrino M., Guo X., Nefzaoui E., Kindinis A., 2017, Energy and comfort assessment in educational building: Case study in a French university campus, *Energy and Buildings*, 143, pp. 202-219. doi:10.1016/j.enbuild.2016.11.028.

[6] Gou S., Nik V.M., Scartezzini J.-L., Zhao Q. & Li Z., 2018, Passive design optimization of newly-built residential buildings in Shanghai for improving indoor thermal comfort while reducing building energy demand, *Energy and Buildings*, 169, pp. 484-506. doi:10.1016/j.enbuild.2017.09.095.

[7] Zhao Z., Houchati M., & Beitelmal A., 2017, An Energy Efficiency Assessment of the Thermal Comfort in an Office building, *Energy Procedia,* 134, pp. 885-893. doi:10.1016/j.egypro.2017.09.550.

[8] Fareniuk H.H., Filonenko O.I., Tymofieiev M.V, 2017, Enerhoefektyvnist hromadskykh budynkiv z vrakhuvanniam erhonomiky teplovoho seredovyshcha, *Komunalne hospodarstvo mist. Seriia: Tekhnichni nauky ta arkhitektura*, 135, pp. 119-124.

[9] Deshko V.I., Buyak N.A., 2017, Heating building need and exergy thermal comfort model, *Industrial Heat Engineering*, *39*, 5, pp. 103-107.

[10] DSTU B EN 152515: 2011, 2012, *Rozrakhunkovi parametry mikroklimatu prymishchen dlia proektuvannia ta otsinky enerhetychnykh kharakterystyk budivel po vidnoshenniu do yakosti povitria, teplovoho komfortu, osvitlennia ta akustyky budivel*. [Chynnyi vid 2013-07-01], Kyiv, Minrehion Ukrainy, 71 s.

[11] DSTU B EN 15261: 2012, 2012, *Rozrakhunok parametriv mikroklimatu*. [Chynnyi vid 2013-01-01], Kyiv, Minrehion Ukrainy, 81 s.

[12] DSTU B EN ISO 7730: 2011, 2012, *Erhonomika teplovoho seredovyshcha. Analitychne vyznachennia ta interpretatsiia teplovoho komfortu na osnovi rozrakhunkiv pokaznykiv PMV i PPD i kryteriiv lokalnoho teplovoho komfortu*, [Chynnyi vid 2013-01-01]. Kyiv, Minrehion Ukrainy, 74 s.

[13] Esmaeilzadeh A., Zakerzadeh M.R., & Yousefi Koma A., 2018, The Comparison of Some Advanced Control Methods for Energy Optimization and Comfort Management in Buildings, *Sustainable Cities and Society,* 43, pp. 601-623. doi:10.1016/j.scs.2018.08.038.

[14] Rupp, R.F., Vásquez, N.G., & Lamberts, R., 2015, A review of human thermal comfort in the built environment*. Energy and Buildings,* 105, pp. 178-205. doi:10.1016/j.enbuild.2015.07.047.

[15] Fanger P.O., 1970, *Thermal comfort: analysis and applications in environmental engineering*, New York, McGraw-Hill Inc.

[16] ASHRAE 55-2017, 2017, *Thermal environmental conditions for human occupancy*, Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

[17] Humphreys M., Nicol F., Roaf S., 2015, Adaptive Thermal Comfort, Foundations and Analysis, Routledge, Earthscan, London.

[18] ASHRAE 554 2004., 2004, *Thermal Environmental Conditions for Human Occupancy*.

[19] Haddad S., Osmond P., King S., 2019, Application of adaptive thermal comfort methods for Iranian schoolchildren, *Building Research and Information*, 47, 2, pp. 173-189.

[20] Hom B. Rijal, Michael A. Humphreys & J. Fergus Nicol, 2017, Towards an adaptive model for thermal comfort in Japanese offices, *Building Research & Information*, 45,7, pp. 717-729. doi: 10.1080/09613218.2017.1288450.

[21] Song Y., Sun Y., Luo S., Tian Z., Hou J., Kim J., Dear R., 2018, Residential adaptive comfort in a humid continental climate – Tianjin China, *Energy and Buildings,* 170, pp. 115-121. doi: 10.1016/j.enbuild.2018.03.083.

[22] Attia, S., & Carlucci, S., 2015, Impact of different thermal comfort models on zero energy residential buildings in hot climate, *Energy and Buildings,* 102, pp. 117-128. doi: 10.1016/j.enbuild.2015.05.017.

[23] Albatayneh A., Alterman D., Page A., & Moghtaderi B., 2017, Thermal Assessment of Buildings Based on Occupants Behavior and the Adaptive Thermal Comfort Approach*, Energy Procedia, 115*, pp. 265-271. doi: 10.1016/j.egypro.2017.05.024.

[24] Prek M., 2004, Exergy analysis of thermal comfort, *International Journal of Exergy,* 1, pp. 303-315, part. 2.

[25] Prek M., 2006, Thermodynamical analysis of human thermal comfort, *Energy*, 31, 5, pp. 732-43.

[26] Prek M., Butala V., 2010, Principles of exergy analysis of human heat and mass exchange with the indoor environment, *Int J Heat Mass Transf*, 53, 25-26:5806-14.

[27] Shukuya M., Saito M., Isawa K., Iwamatsu T., Asada H., 2009, *Human-body Exergy Balance and Thermal Comfort*. Draft Report for IEA/ECBCS/Annex49.

[28] Shukuya M., 2013, *Exergy: Theory and Applications in the Built Environment*, Berlin, Springer, 374 p.

[29] Shukuya, M, 2018, *Exergetic Aspect of Human Thermal Comfort and Adaptation. Sustainable Houses and Living in the Hot-Humid Climates of Asia,* Springer, Singapore, pp. 123-129.

[30] Juusela M.A., Shukuya M., 2014, Human body exergy consumption and thermal comfort of an office worker in typical and extreme weather conditions in Finland, *Energy and Buildings*, 76, pp. 249-257.

[31] Schweiker M., et al., 2017, Challenging the assumptions for thermal sensation scales, *Building Research & Information*, 45,5, pp. 572-589.

[32] Isawa, K., 2015, Human body exergy balance: numerical analysis of an indoor thermal environment of a passive wooden room in summer, *Buildings*, 5, pp. 1055-1069.

[33] Buyak N.A., Deshko V.I., Sukhodub I.O., 2017, Buildings energy use and human thermal comfort according to energy and exergy approach, *Energy and buildings*, 146, pp. 172-181.

[34] Deshko V.I., Buyak N.A., Sukhodub I.O., 2018, Influence of Subjective and Objective Thermal Comfort Parameters on Building Primary Fuel Energy Consumption, *International Journal of Engineering & Technology*, 7, 4.3, pp. 383-386.

[35] *EnergyPlus Energy Simulation Software*. http://apps1.eere.ener-gy.gov/buildings/energyplus.

[36] *International Weather for Energy Calculations*: https://energy-plus.net/weather-location/europe_wmo_region_6/UKR.

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Taras DYKUN, Lubov HAIEVA
Fedir KOZAK, Yaroslav DEMIANCHUK
IFNTUOG, Ivano-Frankivsk, Ukraina

THE ANALYSIS OF CERTAIN FEATURES OF WORKING PROCESS OF INTERNAL COMBUSTION ENGINE THAT WORKS ON BIOGAS FROM DISPOSAL SITES

Abstract: *The importance of providing humankind with cheap energy through alternative ways has significantly increased in recent years. One of the areas is the production and usage of biogas. Nowadays, the potential of LCV gases is poorly implemented. These gases are produced in large quantities by agriculture and industry. The number of existing domestic installations for the disposal of this gas is insignificant, although in most developed countries there are hundreds and thousands of such units.*

One of the most promising sources of energy is the biogas from disposal sites, which is now polluting the atmosphere or is burned in flares. Another direction of biogas usage as a fuel in internal combustion automobile engines is also lowly developed. Because of the instability of the biogas composition, the working process of the engines has certain features that should be taken into account. In particular, an important criterion that affects the composition and, accordingly, the toxicity of the exhaust gases of the engines, is the excess air ratio for the fuel mixture.

Keywords: *biogas, disposal sites, efficiency, waste gases, combustion products, excess air ratio, methane content*

General information

Biogas is a gas produced from organic waste (food waste, dumps) with the help of bacteria and has a composition similar to natural gas: it is methane, hydrogen sulfide, carbon dioxide, water vapor, and the like. Biogas has a number of advantages over natural gas, namely:

- biogas is produced from raw materials, therefore, its production and incineration are part of the natural cycle of carbon, which does not lead to the accumulation of natural gas in the atmosphere and the greenhouse effect;
- biogas is a renewable energy source, which will never exhaust. While natural oil and gas according to the calculations will last no more than 50 years;
- biogas is produced close to the consumer, the raw material for its production is also located close to the factories. No need for long distance gas transportation.

The very process of gas formation is the so-called *methane fermentation*. Its essence lies in anaerobic fermentation (no air access), which occurs because of the life of microorganisms and is accompanied by a number of biochemical reactions. The actual process of biogas formation itself consists of two stages: the first is microorganisms splitting biopolymers into monomers; the second is the processing of monomeric biomolecules by microorganisms. At present, the share of renewable energy sources (RES) in the world energy balance is small – about 14%, and the contribution of biomass – about 1.8%. However, as practice shows, even small fluctuations in energy markets cause large price changes. This suggests that the role of alternative energy in the markets will only grow. In the structure of alternative energy in the world, the biomass energy contains up to 13%. According to scientists' predictions, the share of renewable energy sources will reach 47.7% by 2040 and the contribution of biomass will be 23.8%.

The ecological effect of biogas production is the ecologically safe processing of organic waste with the development of integrated technologies for biomass utilization due to methane fermentation. In biogas plants, primarily, animal excrements and reproducible raw materials, primarily, are various organic waste of the agro-industrial complex, which are rich in cellulose and other polysaccharides. However, biogenic waste from the food industry and household waste are becoming increasingly important. In biogas production, primary raw materials are used, which was not used before and only contributed to the contamination of the environment. Such organic substances are used either alone or in combination (substrates) with other organic substances. Thus, you can create programs for a specific location that allows the rational production and usage of biogas.

The aim of the research

The aim of the research to determine the advantages and disadvantages of biogas usage from disposal sites as vehicles fuel; to analyze the characteristics of the waste gases' compound of internal combustion engines (ICE), based on biogas; investigate its impact on the environment.

Foreign experiences

In most developed countries, recycling of waste dumps in biogas plants is more often used for the thermal and electric energy production. The energy produced in this way, on average, makes about 3-4% of the total energy consumption in the countries of the European Union (EU). For example, Finland, Sweden and Austria legislatively promote the use of biomass energy at the state level. The share of energy produced from biomass in these countries reaches 15-20% of the energy consumed in general.

Today, the European biogas plants market remains about $ 2 billion; it is predicted to grow up to 25 billion by the year of 2020. The use of electricity and heat from biomass anaerobic digestion is most common in Austria, Finland, Germany, Denmark and the UK.

In Germany today there are more than 9,000 anaerobic digestion plants, of which about 2000 large and about 7,000 averages. In the future, 10-20% of the natural gas used in the country can be replaced by biogas. By 2020, an increase in the number of installations is expected to reach 20,000.

In Austria, there are more than 120 installations with reactor volumes of over 2000 m^3 each; about 25 plants are under construction and planning.

Denmark is leading the way in using biogas, where this kind of fuel provides nearly 20% of the energy consumption of the country at present.

The biogas market in the USA is developing much slower than in Europe. For example, despite the presence of a large number of farms, there are only about 200 biogas plants processing agricultural waste on the territory of the country. Since 2002, the Chinese government has allocated about 200 million dollars annually to support the construction of biogas plants. The state subsidy for each installation is approximately 50% of the average cost. Thus, the government has achieved an annual increase in the number of biogas plants to 1 million per year.

In Europe, there are more than 500 bio-stations for receiving gas from landfills, but they provide for only 40% of biogas production in general. The main obstacle of biogas usage as an alternative fuel for transport vehicles is the high cost of its refinement. This makes its small-scale production economically unprofitable. Sweden is one of the most advanced countries in the use of biogas as automotive fuel. In Gothenburg, more than 4,000 cars are functioning on biogas.

Components of biogas

Biogas more than by half (about 50-65%) consists of methane (CH_4). It also contains carbon dioxide (CO_2), about 25-30%, as well as other gases such as water vapor, hydrogen sulfide, carbon monoxide, nitrogen and others. Depending on the conditions in which biogas is obtained its compound may vary (tab. 1).

TABLE 1. *Components of biogas*

Component	Amount, %
methane	50-60
carbon dioxide	25-30
hydrogen	1.0
hydrogen sulfide	3.0
nitrogen	10.0
oxygen	2.0

Refinement of biogas

In order to use biogas as a fuel for internal combustion engines, it is necessary to pre-clean biogas from moisture, hydrogen sulfide and carbon dioxide. Cleaning biogas from moisture lays in reducing its temperature. This is achieved by passing biogas through a cooled tube to condense the moisture at lower temperatures. When the gas is reheated, the moisture content in it is significantly reduced. Such drying of biogas is especially useful for used dry gas meters, since they are necessarily filled with moisture over time. Hydrogen sulfide, mixed in biogas with water, forms an acid that causes corrosion of the metal. This is a serious limitation of the use of biogas in engines. The most simple and economical way to clean biogas from hydrogen sulfide is dry cleaning in special filters. The metal "sponge" is used as an adsorbent; it consists of a mixture of iron oxide and wood shavings.

The impact of exhaust gases on the environment

The working fluid from the ICE is a product of oxidation and incomplete combustion of hydrocarbon fuel. The waste gases contain a certain amount of toxic and harmful components. Emissions of waste gases – the main reason for exceeding the maximum permissible concentrations of toxic substances and carcinogens in the atmosphere of large cities, the formation of smog, which is a frequent cause of poisoning in the closed space.

The composition and volumes of waste gases emissions determine the amount of pollutants emitted into the atmosphere with them.

When working on a biogas engine with the coefficient of excess air $\alpha < 1$ form the following main combustion products: carbon dioxide (CO_2), carbon monoxide (CO), water vapor (H_2O), hydrogen (H2), nitrogen compounds (N_xO_y), and sulfur dioxide.

Carbon dioxide (CO_2), non-lethal gas, colorless and odorless, and is a natural component of the atmosphere. It has greenhouse properties, that is, it promotes heat retention on the Earth's surface and makes a major contribution to global warming.

Carbon monoxide (CO) is a toxic substance. When it enters the lungs and blood, "binds" the blood cells, which leads to oxygen starvation of the tissues of the body and to death. The share of toxicity of aldehydes is relatively small and is 4-5% of the total toxicity of waste gases. The toxicity of various hydrocarbons varies greatly, but the feature is that unsaturated hydrocarbons in the presence of nitrogen dioxide are photochemically oxidized by exposure to sunlight, forming poisonous oxygencontaining compounds – the components of the smog. The quality of toxic carbon monoxide burning on modern catalytic converters is such that the CO content after the neutralizer is usually reduced to less than 0.1%.

However, the most dangerous ones are nitrogen oxides, which are about 10 times more dangerous than carbon monoxide. Getting to the mucous membranes and into the blood, nitrogen oxides form nitrogen and nitrous acids and other compounds that are hazardous to health and life. Nitrogen oxides are formed in the engine under the high temperature. The higher the temperature in the combustion chambers, the more nitrogen oxides are formed. The return of the exhaust gases to the inlet manifold allows lowering the combustion temperature of the fuel-air mixture, and thus reducing the formation of nitrogen oxides. In this case, the ratio of components in the fuel-air mixture remains unchanged, and the characteristics of the engine power vary slightly.

Sulfur, which is one of the components of the fuels, also reacts with oxygen and hydrogen and can form toxic sulfur dioxide and hydrogen sulfide gases. Carbon dioxide, although it is not toxic for living organisms, increases concentration while increasing the expansion of building materials (limestone, concrete, etc.), accelerates the "aging" of stone buildings and causes corrosion of metals. Thus, the exhaust gases of engines in addition to direct negative effects on the human body bring material damage.

The volatility of biogas from disposal sites leads to a change in the amount of combustion heat and the volume of components of combustion products. This leads to a change in the combustion rate due to changes in the speed of diffusion and the rate of oxidation of intermediate products. Therefore, when working on biogas the obligatory correction of fuel supply and the angle of advance of ignition is necessary. In order to optimize the combustion process, it should be 30-40°C.

Calculation of individual components in combustion products when working with ICEs on biogas from waste products

Proceeding from the elemental composition of fuel, determine the theoretically necessary amount of air for the complete combustion of 1 m^3 of gaseous fuel

$$L_0^{'} = \frac{1}{0.208}\sum\left(n + \frac{m}{4} - \frac{r}{2}\right)\cdot C_nH_mO_r \quad \left(\frac{\text{m}^3\ \text{air}}{\text{m}^3\ \text{fuel}}\right)\left(\frac{\text{kmol of air}}{\text{kmol of fuel}}\right) \tag{1}$$

where C_n, H_m i O_r are carbon, hydrogen and oxygen contents per unit of fuel (1 m^3 or 1 kmol).

The value of the fresh charge that entered the inner cavity of the engine cylinder is determined in this way. For gas fuels in the shown way below:

$$M_1^{'} = \alpha L_0^{'} \quad \left(\frac{\text{m}^3\ \text{fule mixtures}}{\text{m}^3\ \text{fuel}}\right) \tag{2}$$

where α is coefficient of excess air.

The quantitative content of individual components in the combustion products depends on the composition of the combustible mixture, since at $\alpha > 1$ there is complete combustion, and at $\alpha < 1$ – incomplete combustion.

When combustion of the mixture at $\alpha > 1$ carbon and fuel hydrogen are completely oxidized. Quantitative composition of combustion products for gas fuels

$$M_2^{'} = \sum_{1}^{i=4} M_i^{'} = M_{CO_2}^{'} + M_{H_2O}^{'} + M_{O_2}^{'} + M_{N_2}^{'} \quad \left(\frac{\text{m}^3\ \text{comb. prod.}}{\text{m}^3\ \text{fuel}}\right) \tag{3}$$

where:

M'_{CO_2} – the amount of carbon dioxide in the combustion products;

M'_{H_2O} – quantity of water vapor in products of combustion;

M'_{O_2} – the amount of oxygen in the products of combustion;

M'_{N_2} – the amount of nitrogen in the products of combustion.

Number of individual components of combustion products, $\left(\frac{\text{m}^3\ \text{component}}{\text{m}^3\ \text{fuel}}\right)$

$$M'_{CO_2} = \sum n\left(C_nH_mO_r\right) \tag{4}$$

$$M'_{H_2O} = \sum \frac{m}{2}\left(C_nH_mO_r\right) \tag{5}$$

$$M'_{O_2} = 0{,}208(\alpha - 1)L'_0 \tag{6}$$

$$M'_{N_2} = 0.792\alpha L'_0 + N_2 \tag{7}$$

Values of C, H and O are taken from combustion for one m^3 of fuel. The sum of the accepted values of C, H and O should be equal to one, that is (C + H +O) · 10^{-2} = 1.

For the case of $\alpha < 1$ $\left(\frac{\text{m}^3\ \text{comb. prod.}}{\text{m}^3\ \text{fuel}}\right)$

$$M'_2 = \sum_{1}^{i=5} M'_i = M'_{CO_2} + M'_{CO} + M'_{H_2O} + M'_{H_2} + M'_{N_2} \tag{8}$$

The number of individual components of combustion products:

$$M'_{CO_2} = \sum n\left(C_nH_mO_r\right) - 0.42\frac{1-\alpha}{1+K}L'_0 \tag{9}$$

$$M'_{CO} = 0.42\frac{1-\alpha}{1+K}L'_0 \tag{10}$$

$$M'_{H_2O} = \sum \frac{m}{2}\left(C_nH_mO_r\right) - 0.42\frac{1-\alpha}{1+K}L'_0 \tag{11}$$

$$M'_{H_2} = 0.42K\frac{1-\alpha}{1+K}L'_0 \tag{12}$$

$$M'_{N_2} = 0.79\alpha L'_0 \tag{13}$$

The ratio of the amount of free H_2 and CO in the waste gases is characterized by the K coefficient, which value for biogas

$$K = \frac{H_2}{CO} = 0.45...0.50 \tag{14}$$

The results of calculating the amount of combustion products when using biogas from the landfill are shown in the form of graphs in figures 1-10 at various values of the excess air ratio α and different values of methane content in biogas.

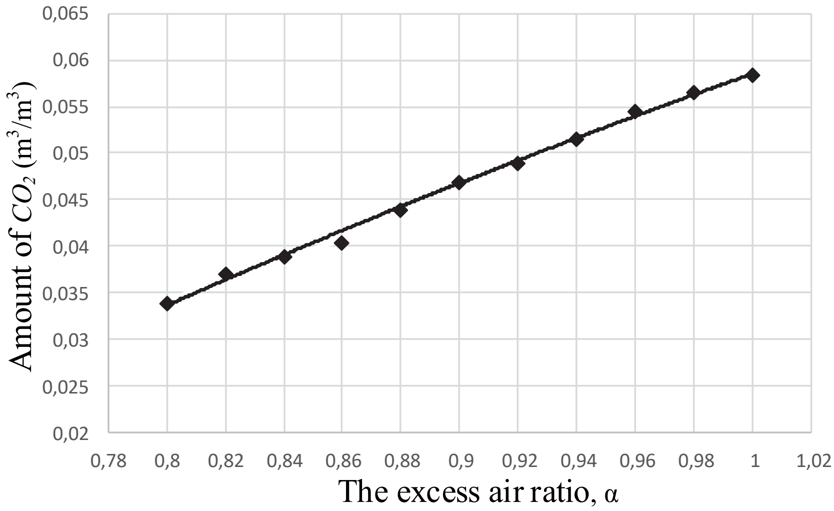

***FIGURE 1**. Dependence of the amount of CO_2 in waste gases on the excess air ratio*

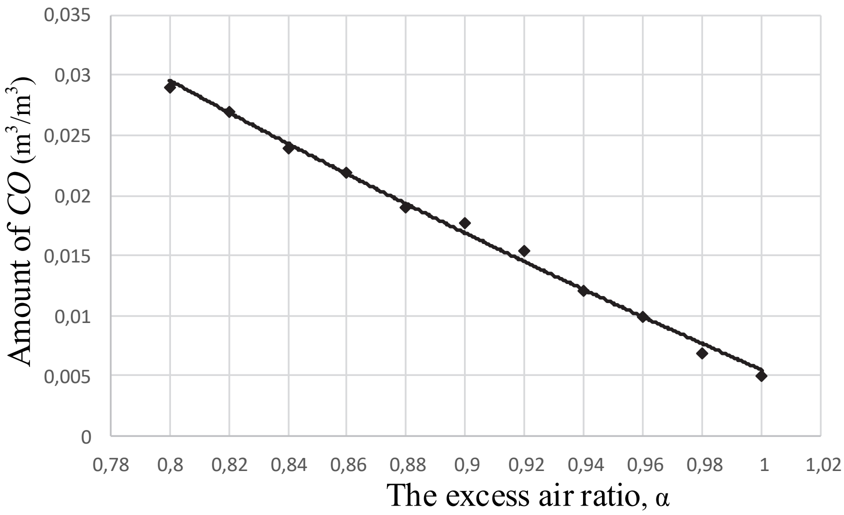

***FIGURE 2**. Dependence of the amount of CO in waste gases on the excess air ratio*

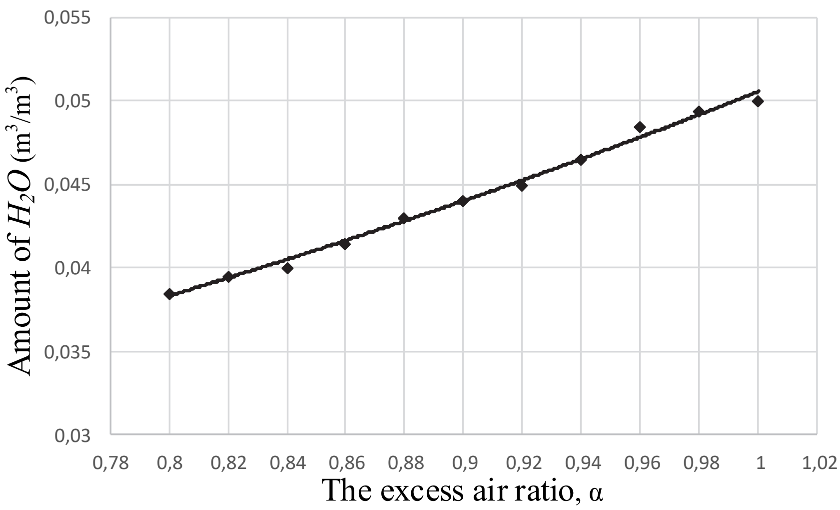

***FIGURE 3**. Dependence of the amount of H_2O in waste gases on the excess air ratio*

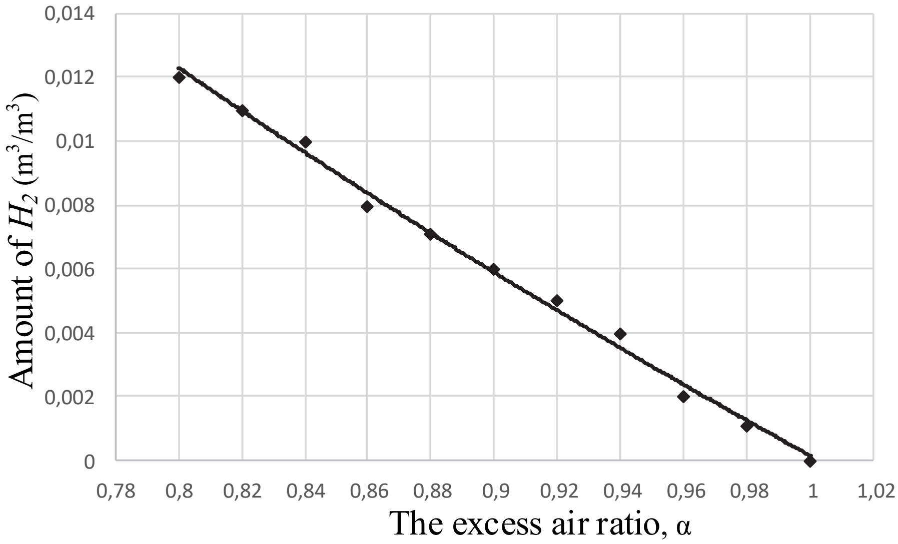

FIGURE 4*. Dependence of the amount of H_2 in waste gases on the excess air ratio*

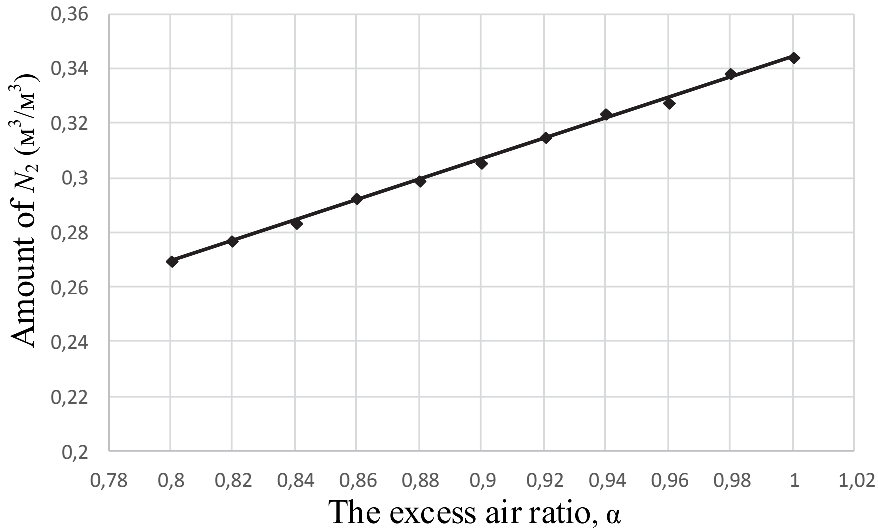

FIGURE 5. *Dependence of the amount of N_2 in the exhaust gases on the excess air ratio*

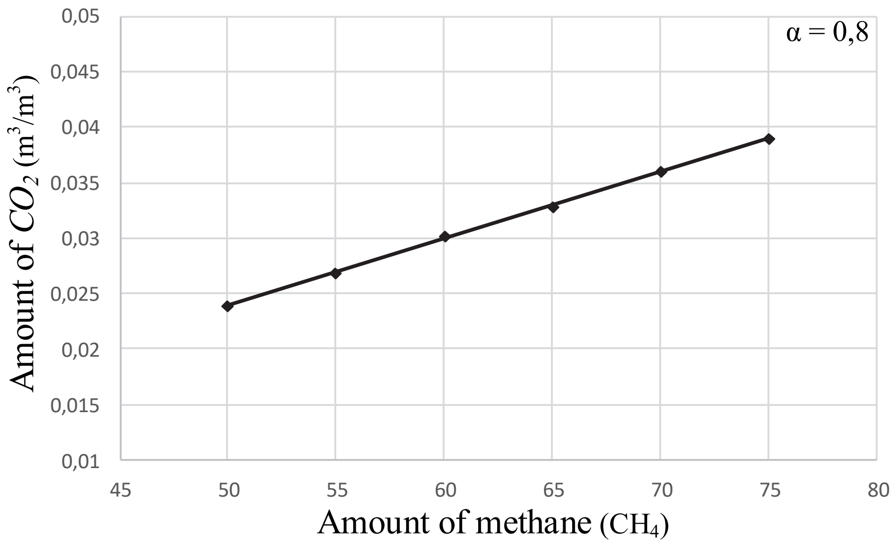

FIGURE 6*. Dependence of the amount of CO_2 in waste gases on the amount of methane in biogas*