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DETERMINATION OF PRIMARY ENERGY CONSUMPTION FOR RESIDENTIAL PREMISES HEATING NEED

Abstract: *In this article, the calculation of energy characteristics of residential premises and the results of calculations and experiment considered the expediency of installing a controller in the individual heating system of residential premises.*

Keywords: *energy demand for heating, energy saving, individual heating system, controller, energy efficiency.*

Introduction

Heating of buildings consumes about 70% of the total energy consumption in Ukraine with specific characteristics of annual consumption of 100 kW·h/m^2 per year. The construction of multi-apartment houses with individual heat supply systems has become widespread. When newly built and modernized, meeting the issues of current energy efficiency standards faces the problems of a general low level of financing and cheapening the cost of housing [1, 2].

Energy saving and energy efficiency today are the most important issues. In general, the energy efficiency of buildings is aimed at achieving comfortable conditions using less energy [3]. It should be noted that today in Ukraine there is limited practice of providing an individual heating system by controllers from the developer, and therefore specialists and residents do not know enough about such an opportunity of energy saving. Today in Ukraine the regulatory base has become active to provide energy efficiency of buildings [2, 4], implemented method for determining the power consumption calculation which is based on European standards, namely, "Method for calculating energy consumption in heating, cooling, ventilation, lighting and hot water supply" [5].

The purpose and objectives of the study

The main objective are to determine the energy requirement for heating the living space and compare the calculation results with the actual data provided by the heating needs in the system with and without the controller installed during one heating period and to analyze the feasibility of installing the controller.

Research material and results

The object of the study was a residential space, namely a one-room apartment, with a total area of 48 m^2. The apartment is located in the city of Kiev and has an east-west orientation.

The main characteristics of the layers of the outer wall structure agreed with [6]:

- internal plaster with thickness δ = 0.015 m and thermal conductivity λ = 0.93 W/(m·K);
- brick laying on a cement-sand solution with a thickness δ = 0.38 m and thermal conductivity λ = 0.81 W/(m·K);

- heater extruded polystyrene foam with thickness δ = 0.1 m and thermal conductivity λ = 0.037 W/(m·K);
- external facade plaster thickness δ = 0.01 m and thermal conductivity λ = 0.6 W/(m·K).

The area of the walls in the study apartment is 85 m^2, and the area of the windows 7.36 m^2.

The heating system of this apartment is an individual heating system with a two-circuit gas boiler (capacity 24 kW and efficiency of 0.9) and the installed controller.

This controller allows you to regulate the operation of the boiler, namely the mode of switching on/off, depending on the internal temperature in the room and the specified temperature mode in the controller. This system allows reducing the actual demand for heating and natural gas consumption by reducing the number (period) of switching on the boiler, and also allows the consumer to control the indoor temperature in the room and achieve comfortable conditions.

Also in this article the results of the same heating system are considered, for a similar object of research, but without a controller. In this system, the regulation of comfortable conditions in the room is carried out by the consumer mechanically directly in the boiler, namely the regulation of the temperature of the coolant in the heating circuit. The mode of boiler activation is carried out in the normal mode of the boiler, namely approximately every 3 minutes after the shutdown (when the coolant temperature has decreased by the set value in the boiler).

According to [7] we will calculate the energy demand for heating for this apartment.

The calculation is made for each month of the heating period.

The energy demand for heating the room is calculated by the formula:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \cdot Q_{H,gn} \tag{1}$$

where:

$Q_{H,ht}$ – total heat transfer in heating mode, W·h;

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$\eta_{H,gn}$ – is the dimensionless revenues use rate.

Total heat transfer in heating mode is determined by:

$$Q_{H,ht} = Q_{tr} + Q_{ve} \tag{2}$$

where:

Q_{tr} – total heat transfer by transmission, W·h;

Q_{ve} – total heat transfer by ventilation, W·h.

The total heat transfer by the transmission is determined by:

$$Q_{tr} = H_{tr,adj} \cdot \left(\Theta_{\text{int},set,H} - \Theta_e\right) \cdot t \tag{3}$$

where:

$H_{tr,adj}$ – the total heat transfer coefficient of the zone transmission, W/K;

$\Theta_{\text{int},set,H}$ – the temperature of the building zone for heating, °C;

Θ_e – average monthly temperature of the environment, °C;

t – duration of the month for which the calculation is made, h.

The total heat transfer coefficient of transmission is calculated by the formula:

$$H_{tr,adj} = b_{tr} \cdot \left[\sum (A_i \cdot U_i) + \sum (l_i \cdot \psi_i) + \sum (n_i \cdot x_i) \right] \tag{4}$$

where:

b_{tr} – the correction factor, we accept equal to 1;

A_i – area of the *i*-th element of the shell of the room, m^2;

U_i – the reduced heat transfer coefficient of the *i*-th shell element of the building, $W/(m^2 \cdot K)$, which is $U_i = 1/R_{\sum пр i}$;

$R_{\sum пр i}$ – the resistance of the heat transfer of the *i*-th element of the shell of the building is reduced, $m^2 \cdot K/W$.

We calculate the transmission costs by formula (3) for each month and enter the results in table 1.

Calculation of total heat transfer by ventilation.

$$Q_{ve} = H_{ve,adj} \cdot \left(\Theta_{\text{int},set,H,z} - \Theta_e \right) \cdot t \tag{5}$$

where:

$H_{ve,adj}$ – total heat transfer coefficient by ventilation, W/K;

$\Theta_{\text{int},set,H,z}$ – the temperature of the zone of the building for heating, °C;

Θ_e – average monthly temperature of the environment, °C;

t – duration of the month for which the calculation is made, h.

Finding the total heat transfer coefficient by ventilation:

$$H_{ve,adj} = \rho_a \cdot c_a \cdot \left(\sum b_{ve,k} \cdot q_{ve,k,nm} \right) \tag{6}$$

where:

$\rho_a \cdot c_a$ – he heat capacity of the air unit of volume, is equal to 0.33 $W \cdot h/(m^3 \cdot K)$;

$q_{ve,k,nm}$ – average and sometimes air flow from *k*-th element, m^3/h;

$b_{ve,k}$ – temperature correction factor for *k*-th element of air flow, we assume equal to 1.

Averaged over time, the air flow rate of the *k* element of the air flow $q_{ve,k,nm}$, m^3/h, is calculated by the formula:

$$q_{ve,k,nm} = n_{\text{inf},mn} \cdot V \tag{7}$$

where:

$n_{\text{inf},mn}$ – multiplicity of air exchange (we accept 0.7 h^{-1}, since multiplicity of air exchange is provided by natural ventilation);

V – building volume, m^3.

We calculate the ventilation costs according to formula (5) for each month and enter the results to table 1.

TABLE 1. Total transmission and ventilation heat losses of premises.

Month	Θ_e, °C	t, h	$\Theta_{int,set,H}$, °C	$H_{tr,adj}$, W/K	$H_{ve,adj}$, W/K	Q_{tr}, kW·h	Q_{ve}, kW·h
October	8.1	372	20	33.54	29.94	148.48	132.53
November	1.9	720				437.10	390.15
December	-2.5	744				561.46	501.16
January	-4.7	744				616.36	550.16
February	-3.6	672				531.92	474.79
March	1	744				474.12	423.20
					∑	2769.44	2471.97

Consequently, the total heat loss for the heating period is 5241.41 kW·h

The heat from internal heat sources in the area of the considered building, Q_{int}, W·h, for a given month is calculated by the formula:

$$Q_{\text{int}} = \left(\sum \Phi_{\text{int},mn,k} \cdot A_f\right) \cdot t \tag{8}$$

where:

$\Phi_{\text{int},mn,k}$ – the time averaged flux from the k-th internal source, W/m, is determined according to table 6 of [7];

A_f – conditioned area of the building, m²;

t – the duration of the use period, expressed in hours per month.

Solar heat revenues are determined by the formula:

$$Q_{sol} = \left(\sum \Phi_{sol,mn,k}\right) \cdot t \tag{9}$$

where:

$\Phi_{sol,mn,k}$ – the time-averaged heat flux from the k source of solar radiation, W, includes the thermal flux of translucent (windows) and opaque (wall) elements of the building;

t – the length of the month under consideration is expressed in hours.

We calculate the internal and solar heat transfer according to formulas (8), (9) and enter the results to table 2 and table 3, respectively.

TABLE 2. Total internal heat revenues

Month	t, h	A, m²	Φ_{int}, W/m	Q_{int}, kW·h
October	372	48	3.91	69.88
November	720			135.24
December	744			139.75
January	744			139.75
February	672			126.23
March	744			139.75
			∑	750.6

TABLE 3. Total solar heat consumption

Month	I_{sol}, m², (east)	I_{sol}, m², (west)	A_{sol}, W/m² (window)	A_{sol}, W/m² (wall)	Φ_{sol}, W/m (window)	Φ_{sol}, W/m (wall)	Q_{sol}, kW·h
October	38	37	0.45	0.03	37.26	9.06	17.23
November	17	17			16.89	1.81	13.46
December	14	15			14.41	0.92	11.40
January	21	22			21.36	3.40	18.42
February	36	38			36.76	8.88	30.68
March	58	61			59.12	16.85	56.52
						∑	147.72

Consequently, the total heat consumption for the heating period is 898.3 kW·h.

We calculate the energy demand for heating for normative conditions by the formula (1), the coefficient of utilization of heat revenues for this apartment was calculated in accordance with the standard [5]:

$$Q_{H,nd} = 5241.41 - 0.2 \cdot 898.3 = 5061.75 \text{ kW·h}$$

It should be noted that the value of actual gas consumption is expressed without taking into account the cost of GWP, since there are installed counters for water consumption in the GPU circuit. The corresponding consumed energy for heating is determined taking into account the general consumption of gas and water temperature for hot water supply, and taking into account the efficiency of the boiler. The gas consumed for hot water supply is subtracted from the total consumption of a boiler counter per month.

To bring actual consumption of natural gas to regulatory normative/standard conditions, it is necessary to use the following formulas:

$$Q_{awer} = Q_{gas} \cdot k_{awer} \tag{10}$$

$$k_{\text{пр}} = \frac{DD^{norm}}{DD^{act}} = \frac{t_{in}^{norm} - t_{aver}^{norm}}{t_{in}^{act} - t_{aver}^{act}} \tag{11}$$

where:

Q_{gas} – actual heat consumption for heating purposes of the building, kW·h;

DD^{norm}, DD^{act} – the normative and actual number of degrees-days of the heating period.

Bringing heat consumption to regulatory conditions is to use when calculating the actual number of GD OPs not normative, but the actual temperature inside the premises and outside air [8].

We calculate the actual energy demand for the heating of the premises in the system with and without the controller by the formulas (10), (11), and let us calculate the table 4. Normative internal and external average monthly temperatures are determined according to [9]. The actual average monthly temperatures for the heating period 2017/2018 are determined according to [5].

The consumption of natural gas for heating needs is determined by the formula:

$$B_{gas} = \frac{Q_H \cdot 3.6}{\eta \cdot Q_H^P} \tag{12}$$

where:

Q_H – energy consumption for heating, kW·h;

η – total efficiency of heating system and boiler;

Q_H^P – the calorific value of natural gas, which according to [10] is 31.8 MJ/m³.

TABLE 4. *The actual energy consumption of premises brought to regulatory terms*

Month	DD^{norm}	DD^{act}	System with controller			System without a controller		
			B_{gas}, m³	Q_{gas}, kW·h	Q_{awer}, kW·h	B_{gas}, m³	Q_{gas}, kW·h	Q_{awer}, kW·h
October	11.9	14	68	540.60	459.38	93	739.35	628.27
November	18.1	19.1	122	969.90	918.86	167	1327.65	1257.79
December	22.5	20.5	140	1113.00	1221.24	208	1653.60	1814.42
January	24.7	24.4	169	1343.55	1359.69	216	1717.20	1737.83
February	23.6	25.9	168	1335.60	1216.65	228	1812,59	1651.17
March	19	24.1	129	1025.55	808.30	171	1359.45	1071.47
				∑	5985.63		∑	8160.94

As can be seen from the calculations, the system with the controller provides less natural gas consumption and reduces actual energy demand for heating the premises to the level of the calculated one. In figure 1 shows how different the actual gas consumption for heating with and without the controller from the calculated.

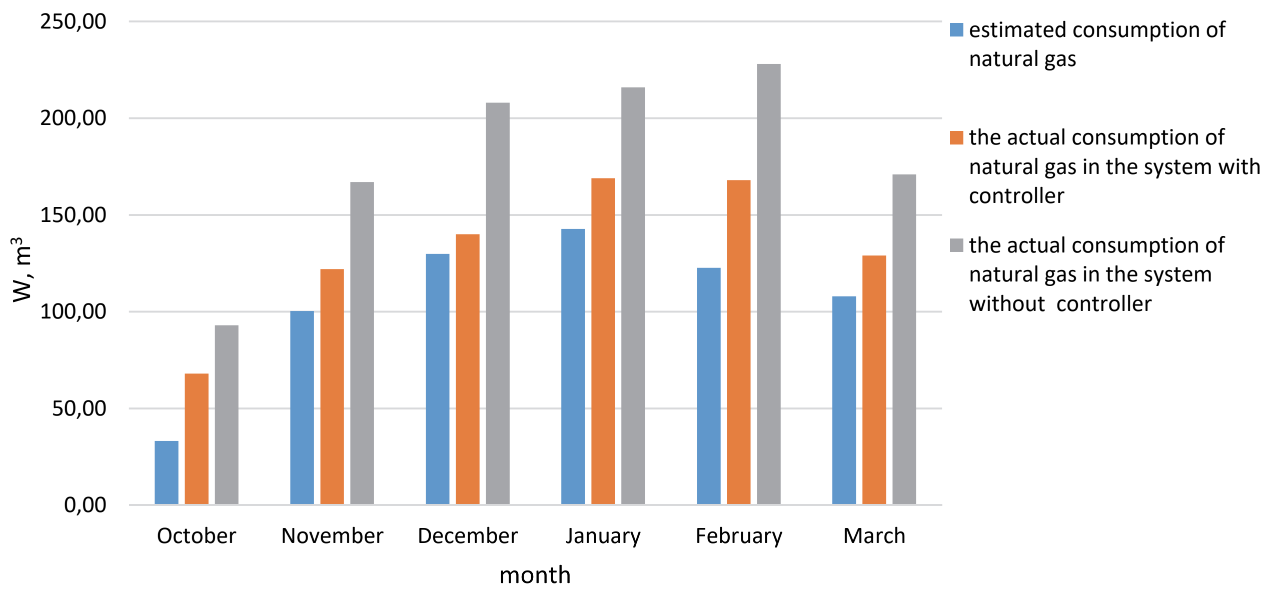

FIGURE 1. *Comparison of the monthly calculated and actual gas consumption W.*

Conclusion

According to the results of the study, the energy demand for heating for a residential area of 48 m² was determined in accordance with [5], which is 5061.75 kW·h. Much of the needs are total heat loss by transmission and ventilation. To reduce the latter, it is possible to install a recuperator that will reduce heat loss through natural ventilation and will allow maintaining comfortable microclimate conditions, such as humidity and indoor temperature. Also, the actual value of the energy demand for heating was brought to the comfortable normative values in accordance with [6]. These calculations have shown that the heat consumption in the system with the controller is 26% lower than in the heating system without it and is close to the calculated value of energy demand. This is explained by the fact that the system without a controller operates in the normal mode of manual adjustment of the provision of comfort conditions and has a frequent activation of the boiler, namely the start of the boiler is carried out approximately every 3 minutes after the shutdown, which results in more natural gas consumption and increases the actual energy demand for heating the premises. Therefore, according to the results of the study, installing the controller into an individual heating system has received quantitative performance indicators.

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