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MATHEMATICAL MODELS FOR DETERMINATION OF SPECIFIC ENERGY NEED FOR HEATING USED IN UKRAINE

Introduction

The efficiency of energy use is a relevant issue nowadays due to the exhaustion of fossil energy resources. The main consumer of thermal energy is residential and public buildings. One of the key indicators that characterize efficient energy use for heating purpose is the specific value per unit area and/or volume. Therefore, particular attention is paid to the methods for determining the energy need for heating, on the basis of which the values of specific energy efficiency indicators are calculated, to find out the possible level of energy saving in the building. The lack of building energy need adequate assessment in Ukraine leads to the fact that unlike the EU, it is impossible to determine the basis for comparing the current level of energy efficiency of the real estate sector and to establish realistic goals for its improvement in the long term perspective. Solving these problems, analyzing the actual data and obtaining data for energy consumption adjusted to standard conditions require the use of calculation methods and mathematical models for different purposes. This paper is devoted to the study of various methods application features used to determine energy need for heating, which there are a large number [1].

Determination of energy need for heating based on experimental data has a number of approximations and inaccuracies, so it is advisable to establish the annual energy need for buildings based on the calculated approaches. Addressing these challenges requires the use of calculation methods and mathematical models.

Depending on the tasks being solved, the following calculation methods can be used: stationary, quasi-stationary and dynamic. Stationary calculation methods, which are the most widely used in Ukraine, allow calculating the energy need for heating in building for the entire year and do not take into account thermal inertial features of the building. Quasi-stationary methods are also used to calculate heat balances for a fairly long time interval (usually one month or a whole season); the dynamic processes of utilizing of heat gains and/or losses are taken into account by empirically determined coefficients. Dynamic methods, by which the thermal balance is calculated for short-term time intervals (usually one hour), take into account the amount of heat accumulated in, or released from the building envelope.

Most of the buildings in Ukraine belong to the typical construction of 1960-90s. For these buildings specific heating and ventilation characteristics are determined depending on the purpose, year of construction and the volume of the building [2]. Even nowadays in Ukraine calculations are made according to the aggregated heating characteristics. There are also sectoral norms for energy need for heating depending on the purpose, volume and location of the object [3].

$$Q_o^{year} = Q_o^{max} \frac{\theta_{int} - \theta_{cp.o}}{\theta_{int} - \theta_{p.o}} n_o \cdot 24 \quad (1)$$

where:

Q_o^{year} – annual amount of energy consumption for heating, kWh/year,

Q_o^{max} – maximum heating load, kW,

θ_{int} – normative internal air temperature during the heating season, °C,

$\theta_{cp.o}$ – average outside air temperature during the heating season, °C,

$\theta_{p.o}$ – design outside air temperature, °C,

n_o – duration of heating period, days,

24 – operating time of the heating system during the day, h.

$$Q_o^{max} = \alpha q_0 V_3 \left(\theta_{int} - \theta_{p.o}\right) \cdot 10^{-3} \quad (2)$$

where:

α – coefficient that takes into account the difference between the real and calculated conditions,

q_0 – specific heating characteristics of building at the design outside air temperature $\theta_{p.o} = -30°C$,

V_3 – external volume of the building, m^3.

Till the recent years, the methods for determining energy consumption and energy efficiency assessment in Ukraine took into account only annual energy consumption for heating and did not take into account the need for cooling and hot water supply [4, 5]. According to standard [4], the building energy efficiency should be determined on the basis of calculated or actual annual energy consumption for heating needs, while ensuring appropriate sanitary and hygienic norms in the building spaces.

Standard DSTU N B A.2.2.5: 2007 [4] uses a more detailed method for energy consumption calculation on the basis of heating degree-days (HDD), that is based on the stationary approach. The fixed heating period duration is necessary for calculating the total heat losses and gains during the heating period [4].

$$Q_o^{year} = Q_{tr} - \left(Q_{int} + Q_s\right) \quad (3)$$

where:

Q_{tr} – total heat losses through building envelope, kWh/year,

Q_{int} – internal heat gains during the heating period, kWh/year,

Q_s – heat gains through windows from solar radiation during the heating period, kWh/year.

$$Q_{tr} = \chi_1 k_b D_d F_\Sigma \quad (4)$$

where:

χ_1 – dimensional coefficient,

k_b – total heat transfer coefficient of the building envelope, W/(m^2·K),

D_d – number of heating period degrees, days,

F_Σ – internal total area of the enclosing structures with consideration of exterior roof and floor, m^2.

$$k_b = k_{tr} + k_{ve} \tag{5}$$

where:

k_{tr} – total heat transfer coefficient of the building enclosing structures, W/(m²·K),

k_{ve} – conditional coefficient of heat transfer of the building enclosing structures, taking into account heat losses due to infiltration and ventilation, W/(m²·K).

This method allows adjusting the heating energy consumption according to the actual outside air temperature and average temperatures in building spaces [6]. However, when considering the building as a complex energy system the needs for heating and cooling should be considered in order to maintain the set inside air temperature, also energy need for hot water supply, as well as energy sources should be taken into account.

To replace the DSTU N B A.2.2.5: 2007 [4], national method of calculation is introduced on the basis of DSTU B A.2.2-12: 2015 [7], which includes the estimation of energy need for heating, cooling, hot water supply and is based on definition of monthly indicators (quasi-stationary calculation method). In this regard, standard [5] was further developed and standard [8] was introduced. Normative values of specific building energy consumption indicators are also revised, including the need for heating, cooling and hot water supply [8].

The annual building energy need for heating is determined by:

$$Q_o^{year} = \sum_{i=1}^{n} Q_{H.nd.i} \tag{6}$$

where:

i – serial number of the heating month,

n – number of heating months,

$Q_{H.nd}$ – monthly energy need for heating, kWh.

$$Q_{H.nd} = Q_{H.tr} + \eta_{H.gn} Q_{H.gn} \tag{7}$$

where:

$Q_{H.tr}$ – monthly total heat transfer by transmission and ventilation, kWh,

$Q_{H.gn}$ – monthly total heat gains in heating mode, kWh,

$\eta_{H.gn}$ – dimensionless monthly heat gains utilization factor.

$$Q_{H.hr} = Q_{tr} + Q_{ve} \tag{8}$$

where:

Q_{tr} – heat transfer by transmission, kWh,

Q_{ve} – heat transfer by ventilation, kWh.

$$Q_{H.gn} = Q_{int} + Q_{sol} \tag{9}$$

where:

Q_{int} – amount of internal heat gains, kWh,

Q_{sol} – amount of solar heat gains, kWh.

$$Q_{tr} = H_{hr} \left(\theta_{int} - \theta_e \right) t \quad (10)$$

where:

H_{hr} – total zone heat transfer coefficient by transmission, W/K,

θ_{int} – the set building zone temperature for heating, °C,

θ_e – average monthly outside air temperature, °C,

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

$$Q_{ve} = H_{ve} \left(\theta_{int} - \theta_e \right) t \quad (11)$$

where:

H_{ve} – total heat transfer coefficient by ventilation, W/K.

Dynamic models for energy consumption calculation are advisable to use for the detailed analysis of energy performance indicators. A large number of papers are devoted to the system analysis mathematical methods application for the study of buildings energy performance [9-11]. The approach of European standard [12] accepted in Ukraine is based on a simplified hourly method for calculating building energy consumption. The standard [12] proposes five resistances, one capacity (5R1C) model, which allows implementing the model in a simplified three-node method. This approach requires the creating or use of existing programs for this method realization. The figure 1 shows a simplified scheme for implementing the method.

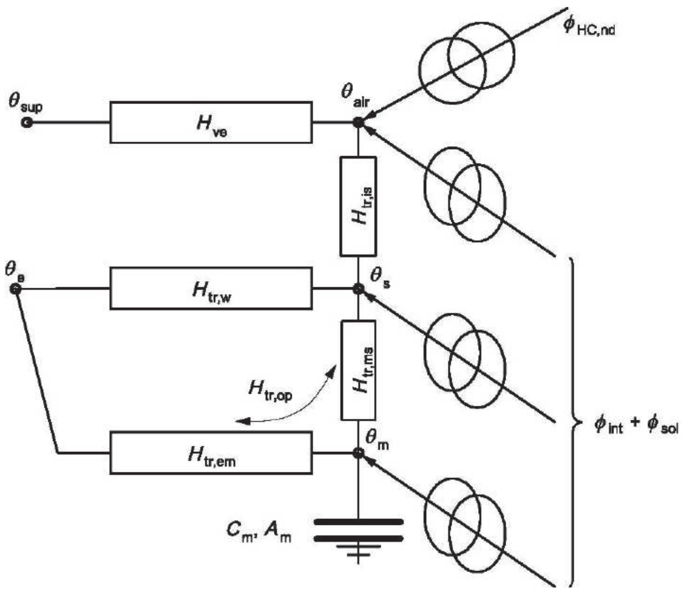

***FIGURE 1.** Model of five resistances and one capacity (5R1C) [12]*

The energy need for heating is based on the calculation of the heating level, $\Phi_{HC.nd}$, for each hour to be delivered to the internal air temperature node, θ_{air}, to maintain a certain set-point temperature. The set-point temperature is an average weighted value of internal air temperature and radiant temperature.

Heat transfer by ventilation, H_{ve}, is directly connected with internal air temperature node, θ_{air}, and the node that corresponds to supply air temperature, θ_{sup}. Heat transfer by transmission is divided into two parts: the first one is through fenestration surfaces, like windows, $H_{tr.w}$, that do not have thermal mass, the second one is through opaque surfaces H_{op}, that have thermal mass, and, in its turn, is divided into two parts: $H_{tr.em}$ that $H_{tr.ms}$. Solar (Φ_{sol}) and internal heat gains (Φ_{int}) are distributed between the internal air temperature node, θ_{air}, the central node, θ_s (mixture of θ_{air} and mean radiant temperature θ_r) and the node representing the building mass, θ_m. The thermal mass is reflected by the specific heat, C_m, located between $H_{tr.ms}$ that $H_{tr.em}$. The coupling by conductivity is determined between the internal air temperature and the central node. This scheme is implemented on the basis of standards EN 13790 and EN 13786 [12, 13].

$$H_{tr.is} = h_{is} A_{tot} \tag{12}$$

$$H_{tr.ms} = h_{ms} A_m \tag{13}$$

$$H_{tr.em} = \frac{1}{\frac{1}{H_{op}} - \frac{1}{H_{tr.ms}}} \tag{14}$$

$$H_{tr.1} = \frac{1}{\frac{1}{H_{ve}} + \frac{1}{H_{tr.is}}} \tag{15}$$

$$H_{tr.2} = H_{tr.1} + H_{tr.w} \tag{16}$$

$$H_{tr.3} = \frac{1}{\frac{1}{H_{tr.2}} + \frac{1}{H_{tr.ms}}} \tag{17}$$

$$C_m = \sum k_j A_j \tag{18}$$

$$\Phi_{m.tot} = \Phi_m + H_{tr.em}\theta_e + \frac{H_{tr.3}(\Phi_{st} + H_{tr.w}\theta_e + H_{tr.1}\left(\frac{\Phi_{ia} + \Phi_{HC.nd}}{H_{ve}} + \theta_{sup}\right)}{H_{tr.2}} \tag{19}$$

$$\theta_m = \frac{\theta_{m,t} + \theta_{m,t-1}}{2} \tag{20}$$

$$\theta_{m,t} = \frac{\theta_{m,t-1}\frac{C_m}{3600} - 0.5\left(H_{tr.3} + H_{tr.em}\right) + \Phi_{m.tot}}{\frac{C_m}{3600} + 0.5\left(H_{tr.3} + H_{tr.em}\right)} \tag{21}$$

$$\theta_s = \frac{H_{tr.ms}\theta_m + \Phi_{st} + H_{tr.w}\theta_e + H_{tr.1}\left(\frac{\Phi_{ia} + \Phi_{HC.nd}}{H_{ve}} + \theta_{sup}\right)}{H_{tr.ms} + H_{tr.w} + H_{tr.1}} \tag{22}$$

$$\theta_{air} = \frac{H_{tr.is}\theta_s + H_{ve}\theta_{sup} + \Phi_{ia} + \Phi_{HC.nd}}{H_{tr.is} + H_{ve}} \tag{23}$$

where:

θ_{air} – internal air temperature, °C,

θ_s – temperature of central node *s*, °C,

θ_m – temperature of node *m*, °C,

θ_{sup} – temperature of supply air in ventilation systems, °C,

Φ_{int} – internal heat gains, W,

Φ_{sol} – solar radiation heat gains, W,

$\Phi_{ia}, \Phi_m, \Phi_{st}$ – internal and solar radiation heat gains are distributed between the 3 nodes, $\theta_{air}, \theta_s, \theta_m$,

$\Phi_{m.tot}$ – total heat flow, W,

$\Phi_{HC.nd}$ – heat flow from heating or cooling, W,

h_{is} – heat transfer coefficient between the internal air temperature node, θ_{air}, and central node, θ_s, has a fixed value $h_{is} = 3.45$ W/m^{2}K,

h_{ms} – heat transfer coefficient between the nodes *m* and *s*, has a fixed value $h_{ms} = 9.1$ W/m^{2}K,

A_m – effective mass area, m^2,

A_j – area of the *j*-element, m^2,

A_{tot} – the area of all external enclosures of the building, m^2,

C_m – internal heat capacity, J/K,

k_j – internal heat capacity per unit area of the *j*-element of the building, J/(m^2·K),

$H_{tr.ms}$ – coupling by conductivity between nodes *m* and *s*, W/K,

$H_{tr.em}$ – coupling by conductivity between node *m* and outside air temperature, W/K,

$H_{tr.is}$ – coupling by conductivity between node *s* and inside air temperature, W/K,

H_{op} – total heat transfer coefficient of building opaque elements, W/K,

$H_{tr.w}$ – heat transfer coefficient of building fenestration elements, W/K,

$H_{tr.1}, H_{tr.2}, H_{tr.3}$ – conductivity of conditional nodes 1, 2, 3, W/K,

H_{ve} – total heat transfer coefficient by ventilation, W/K.

An alternative option is to use existing software products, such as EnergyPlus, eQUEST, TRNSYS, ANSYS/FLUENT, SolidWorks, Modelica and so on [14-16]. Depending on the tasks being solved, the corresponding programs are used based on the modeling or physical calculations methodology. The EnergyPlus, eQUEST, and TRNSYS software products are based on dynamic methods and approaches. Non-stationary or transient approaches are used in software products ANSYS/FLUENT, SolidWorks, Modelica that allow to analyze the uneven distribution of the studied parameters.

The EnergyPlus software product (E+) is one of the most comprehensive open-access programs for building energy performance modeling [17]. This program uses the best approaches of the two well-known programs DOE-2 and BLAST, the calculation methods of which are close to European standards [17]. In contrast to the above mentioned method, E+ separately takes into account the heat capacity of external and internal enclosures. In the simulation of heat fluxes through fenestration surfaces E+ uses a subroutine of Window 5 calculation [18], a Slab pre-processor program [19] is used for calculating the heat losses through the slab on grade, OpenStudio plug-in can be used for creating geometry.

The E+ software uses climatic data from the International Weather for Energy Calculation (IWEC) file as a typical year for the considered city [20]. For Ukraine territory two climatic IWEC files for Kiev and Odessa are created, which are averaged characteristics of each of two temperature zones. IWEC 2 database has weather files for the 41 city of Ukraine, but this is a fee-based resource that restricts their use.

Consequently, due to the fact that above-mentioned dynamic methods are only becoming widespread in Ukraine, the aim of the work is to compare the approaches for calculating the building energy need for heating when determining buildings energy efficiency indicators. Objectives:

1. Analysis of the features of using the meteorological data of the typical year and normative climatic data and other output data when applying different methods of determining the annual energy need for heating.
2. Determination of the annual energy need for heating by the aggregated, detailed quasi-stationary and non-stationary methods.
3. Creation of a quasi-stationary model using monthly approach according to the national calculation method of DSTU B.A.2.2-12: 2015 and determination of energy need for heating.
4. Creation of a dynamic simplified hourly model based on EN 13790, EN 13786 and calculation of energy need for heating.
5. Calculation of energy need for heating in dynamic mode on the basis of the created model in E+ software.
6. Comparison of the obtained results.

Input data

The research object is a room in the building of the 1970s typical construction. Room dimensions are 5.5×6.1 m, floor-to-ceiling height is 3.2 m. It has one exterior wall (5.5×3.2 m) with exterior window (5×2.5 m). The exterior wall has the thermal resistance R = 0.8 (m^2·K)/W (one-brick wall). The outer window is a double glazed system with wooden frame. Interior walls are built with half-brick (δ = 0.125 m). Ceiling and floor construction is reinforced concrete slab (δ = 0.2 m). Ventilation is natural; air exchange rate is 1 h^{-1}. The building is located in the city of Kiev. The design internal air temperature is 18°C. The heating system is ideal load air system. Solar heat gain coefficient of fenestration surfaces in the room is 0.56. This coefficient was calculated in the E+ program according to the type of glazing.

Analysis of the climatic characteristics used in calculating energy need for heating at different bases of climatology

The normative climatic data in Ukraine include the average monthly values of the external air temperature and solar heat radiation falling on the vertical and horizontal surfaces, which is sufficient in the stationary and quasi-stationary methods of calculation [21]. When calculating the building energy need for heating and/or cooling by dynamic methods, hourly climatic values are needed. The paper analyzes and compares the normative climatic data in Ukraine and the international weather file IWEC for use during energy need for heating determination.

Hourly climatic data from IWEC file was used in the calculations, which include dry-bulb temperature, relative humidity, atmospheric pressure, wind speed and direction, direct and diffuse solar radiation etc. [17]. The weather file was developed as a part of the research project RP-1015. The procedure for obtaining data was based on the choice of a typical year for the 18-year sequence of hourly weather data. To analyze normative climatology used in Ukraine and international weather file IWEC calculations should be made. To calculate solar heat gains on vertical surfaces, the sun position to the horizon during the year and change during the day has to be determined; the hourly values of solar heat gain per unit of surface for each orientation of building surfaces are averaged monthly.

Software products that use climatic data of the typical year IWEC (for example, EnergyPlus) contain built-in conversion techniques from simplified to advanced ones. In the created model on E+ base the detailed method of calculation "Full interior and exterior with reflection" is used.

Current approaches applied in Ukraine for energy need for heating determination use climatic data from building climatology standard [7, 21]. The use of IWEC file in other approaches, other than the E+ software, has difficulties with information presentation format.

In Ukraine, the simplified hourly dynamic method of calculation based on the European standard EN 13790 [12] has come into force, which takes into account in its calculations the total solar heat transfer to the room area. While using dynamic models based on the simplified hourly calculation method 5R1C the classical technique of converting solar heat gains to vertical surfaces of different orientations which is given in Duffy's papers can be used [22]. In this technique it is assumed that the diffuse component of solar radiation equally falls on all surfaces and it does not take into account reflected solar radiation from the ground surface. Therefore, while using a simplified hourly method, this feature of converting IWEC file data can make the difference between the results of energy consumption for heating purpose.

The software product E+ was used to compare the methods for converting solar heat gains to the vertical surfaces of the IWEC climatic file. The average monthly values derived from the classical hourly Duffy calculation method [22] and the calculation results in the EnergyPlus software product are quite close, the average difference is 5%, the maximum difference in the results in the winter period was 8%, in the summer – up to 15%.

Figure 2 shows a graph of changes in the average monthly values of external air temperature and solar radiation on vertical surfaces, calculated on the basis of IWEC values by Duffy's technique [20] (marking: IWEC S, IWEC N) and the national calculating methodology DSTU B A.2.2-12: 2015 [6] (marking: S Normative climate data, N Normative climate data), also the values calculated by the E+ program on the IWEC database (marking: E+ S, E+ N) are given.

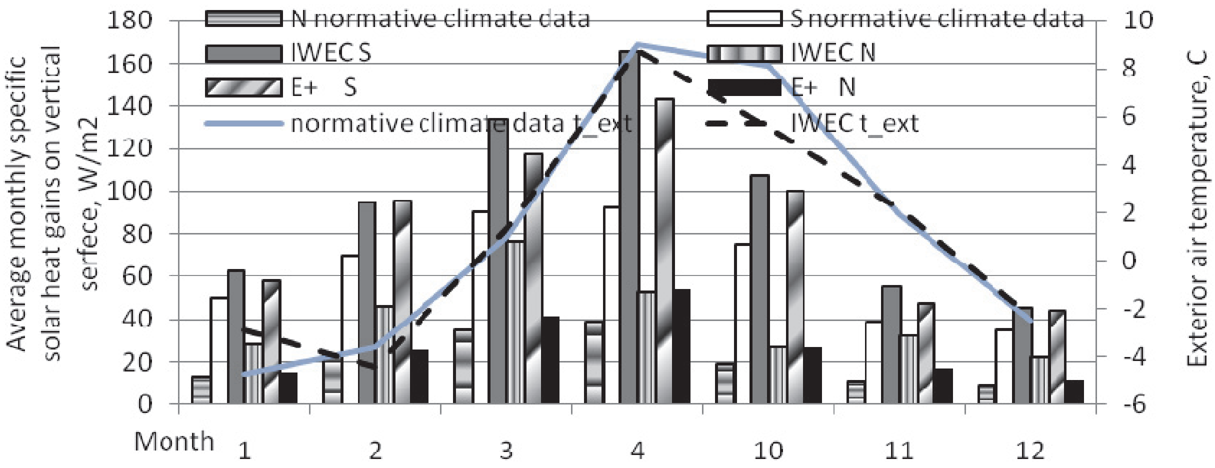

***FIGURE 2.** Average monthly external air temperature and solar heat gains*

The external air temperature is almost the same for the two climatological bases. Solar heat gains are significantly different from those used in norms of Ukraine. The difference for Kyiv for the vertical surfaces is about 40% in the winter and 30% in the summer and 10% gor the horizontal surface. E+ uses IWEC file for a particular city during the calculations. The difference between regulatory documents climatic data in Ukraine and IWEC file can make a difference in results of calculating buildings energy efficiency indicators.

Application of different methods for calculation of energy need for heating

The space energy need for heating was calculated according to the IWEC and normative climatic data and included transmission heat losses, ventilation heat losses and solar heat gains to the zone (in all methods for determining energy need, solar heat gains to the space was determined using the same technique proposed in E+ Full interior and exterior with reflection"). Two extreme cases of determining the energy need for heating are considered: for southern (S) and northern (N) orientation, because the difference in climatic values of solar radiation for the southern and northern orientations significantly changes the value of the energy need for heating, which is derived from the energy balance of the space with the appropriate orientation of the exterior walls and translucent elements of building envelope.

Calculation models using aggregate indicators (KTM-204) [2], detailed annual calculation using DSTU N B A.2.2.5: 2007 (HDD method) [4] and monthly calculation method according to DSTU B.A.2.2-12: 2015 [6] are implemented in the Microsoft Excel, the model based on EN 13790 and EN 13786 [12, 13] is implemented on the basis of Mathcad. E+ is a software product for calculating building energy performance without its own graphic interface. E+ uses the Google Sketch-up graphic editor that is synchronized through OpenStudio Plug-in.

The calculation of annual energy need (KTM-204, method GD), monthly energy need (according to DSTU B.A.2.2-12: 2015) and hourly energy need for heating (E+ and 5R1C) is carried out. In the context of the annual energy consumption calculated values using different methods are shown in figure 3. Considered calculation methods take into account solar heat gains to the building zone, depending on the orientation, except for KTM-204 which considers the average value of solar heat gains during the heating period.

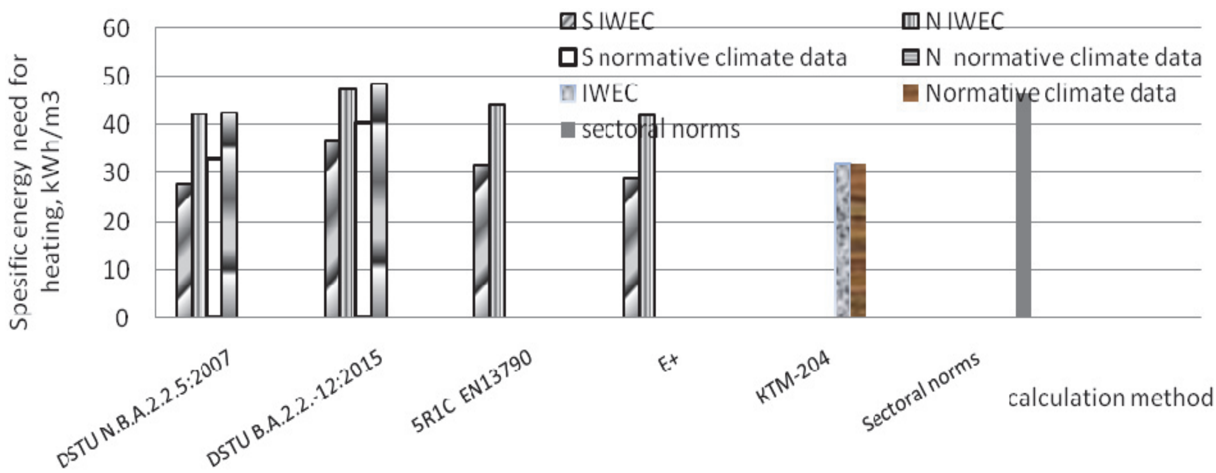

FIGURE 3. *Annual energy need for heating calculated by different methods and weather data bases*

Figure 3 not only shows a comparison of different methods for calculating the annual heating energy need using the same input climatic parameters (IWEC data by the recalculation method given in E+), but also differences in the case of using normative climatic data.

Calculation for KTM-204 takes into account solar heat gains in the specific characteristics of heating level. These characteristics are selected based on indicators such as volume, building purpose and year of construction, and do not take into account the object geographic location, which leads to overestimating the calculated energy need for the southern regions and underestimating for the northern regions.

Energy need for heating calculated based on E+ is chosen as a reference value for calculating differences in the results of calculations according to given approaches. The difference in energy heed for heating values is higher for southern oriented zone than for northern oriented zone. KTM-204 uses in calculations building energy characteristics that take into account average value of solar heat gains for southern and northern orientations. Sectoral norms are given for large cities and regional centers of Ukraine. Among the methods presented, sectoral norms give the greatest value of specific characteristic.

Stationary methods (using sectoral norms and aggregated method) and quasi-stationary method of calculation (monthly calculation method according to DSTU B.A.2.2-12: 2015) have the largest differences compared with E+ results. The calculated heating energy need for southern orientation according to the aggregate indicators (KTM-204) gives a difference of about 40%, sectoral norms – up to 60%, the detailed method of the HDD (DSTU N B A.2.2.5: 2007) has the lowest difference which is about 5% for southern orientation and 10% for northern orientation, for DBN B.A.2.2-12: 2015 is 12% for northern and 28% for southern orientation. The dynamic methods E+ and 5R1C give almost the same value of energy need for heating difference up to 7% for all orientations.

If the method of converting solar heat gains to the vertical surface according to [19] is used, the annual energy need for heating for 5R1C model differs by 4% compared with the energy consumption for 5R1C model, calculated for solar heat gains by the E+ method "Full interior and exterior with reflection".

Figure 4 shows the heating energy consumption diagram depending on the heating period month.

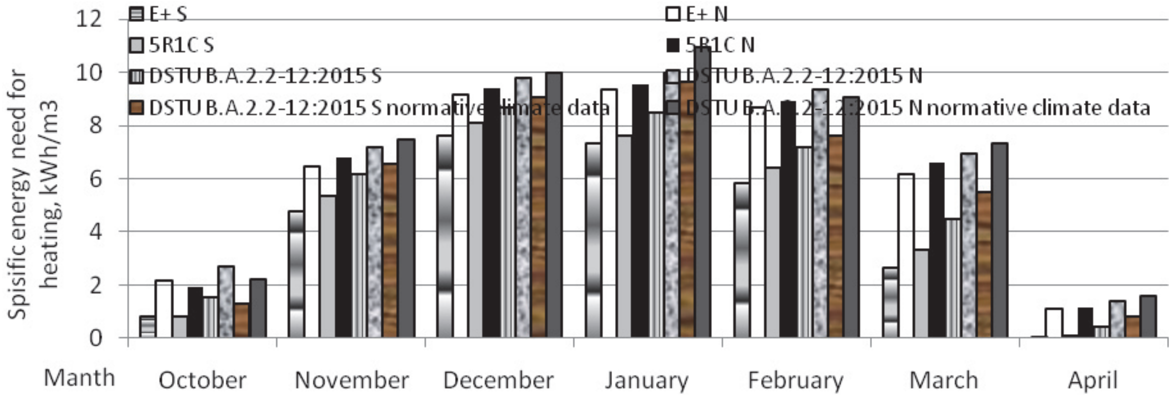

FIGURE 4. *Diagram for heating energy consumption depending on the heating period month*

In general, the lowest values of the monthly energy need for heating are for results based on E+, rather close values are obtained on the basis of 5R1C model; the average monthly difference of received calculations is 2 kWh/m³ or 5% for S and N. The average monthly difference in the calculation using DSTU B.A.2.2-12-12: 2015 according to IWEC with the results obtained on the basis of E+ model is 3 kWh/m³ (12%) for S and N. According to the results based on normative climatic data the difference is greater 4-5 kWh/m³ (13%). The national method of calculation has the highest values of heating energy demand using IWEC climatic data, compared with other considered methods, and when using normative climatic values, these values are increasing.

As the first measure of increasing the buildings energy efficiency in Ukraine, the thermo-modernization of buildings is considered, where the consumption of the building is analyzed annually. The next step in improving energy efficiency is to regulate the amount of heating during the day, which reduces the consumption of thermal energy during non-working hours or hours of peak solar activity. The analysis of methods for solving such problems is carried out on the basis of dynamic models. In this work, two dynamic models are considered based on the 5R1C model and the E+ software product.

Tendencies in the behavior of heating energy need graphs for hourly dynamic modeling using E+ and 5R1C are almost the same. Figure 5 shows the non-stationary hourly calculation of the heating energy need for a zone oriented to the South using the average daily and average monthly values of exterior air temperature and solar heat gains by 5R1C model and the results obtained on the basis of the national calculation method of DSTU B.A.2.2-12: 2015.

Built on the basis of the hourly calculation of heating level change for the average daily and average monthly values of t_{ext} and Q_{sol}, the annual heating energy need using 5R1C model is almost unchanged. The results of hourly energy need for heating using monthly values of weather conditions by 5R1C model have a smooth transition between months, which is due to the heat-inertial features of the model, in contrast to the method of DSTU B.A.2.2-12: 2015. The average monthly energy consumption based on hourly calculation of heating load is almost the same as the hourly calculation results for average daily and average monthly values of t_{ext} and Q_{sol}, but the latter does not allow analyzing the possibility of regulating the heating system during the day.

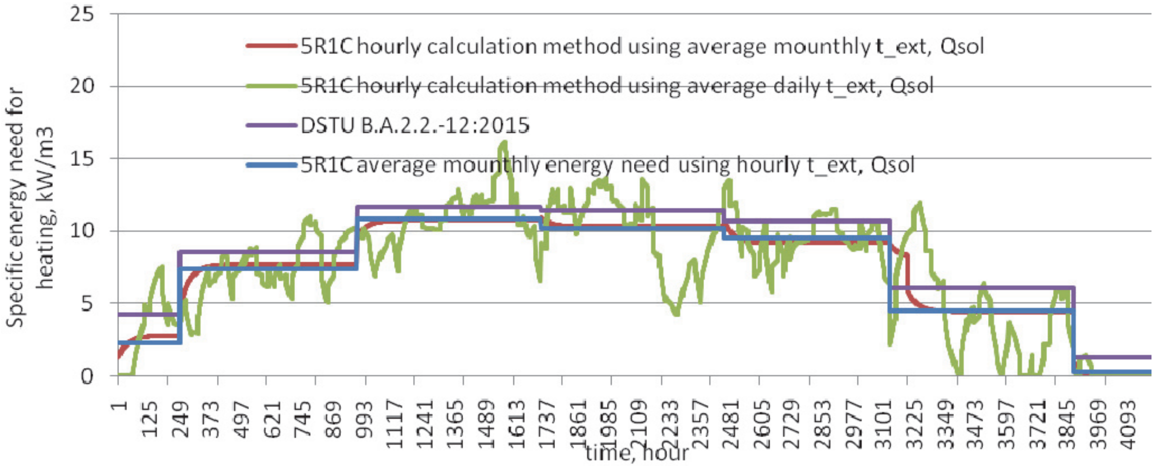

FIGURE 5. *Hourly change of heating level during the heating period for the zone oriented to the South*

Hourly changes in the heating level are significant and lead to the fact that in the heating system adjusting mode there are some hours of operation when it is necessary to switch off the heating. This is typical for off-season period, as well as for the anomalous climatic data values for February (the lowest temperatures and the highest values of solar radiation for winter months).

The application of the above discussed methods depends on the tasks being solved. In terms of daily change, data on average monthly and average daily values do not allow tracking of dynamic characteristics, therefore hourly changes in external weather conditions should be used for forecasting or dynamic regulation tasks.

Analysis of the specific indicators of energy need for heating using different mathematical models

On the basis of the above methods of energy need for heating calculation, specific indicators of building energy performance are established and compared with the normative values (table 1). This building refers to the old building stock. Current normative values are used for buildings energy certification, so table 1 also shows current normative values and normative values used for buildings during 1970s.

TABLE 1. *Indicators of the specific energy need for heating obtained by different calculation methods (average for southern and northern orientation)*

KTM-204	DSTU N B A. 2.2.5: 2007	DSTU B.A. 2.2-12: 2015	5R1C	E+	The norms of the 2000's	The norms of the 70's
kWh/m3						
40	35	42	38	36	31	47

The specific value of energy consumption in the whole building will be somewhat greater than the values given in table 1, as the calculation was made for the space having one external wall. Heat losses through the roof and floor will also bring a slight increase in specific indicators. For old buildings, the norms of energy consumption for heating are higher compared to the current standards, due to the increased requirements for the thermal characteristics of building envelope during the construction/design phase. Specific energy consumption indicators for non-stationary calculation methods are lower compared to stationary approaches, with the exception of the HDD method by DSTU N B A.2.2.5: 2007.

Conclusions

The paper analyzes and compares the normative climatic data used in Ukraine and the international weather file of IWEC when used to determine the energy need for heating. IWEC climate files is created for Kyiv (I climate zone). The normative climatological data used in Ukraine shows the average monthly values of the external air temperature and solar heat gains on the vertical and horizontal surfaces, which is sufficient in the stationary and quasi-stationary methods of calculation. When calculating the buildings energy need for heating and/or cooling by dynamic methods, hourly climatic values are needed. The international climatic weather file for the considered city of Ukraine almost does not differ from the average monthly values of the outside air temperature from the normative climatology of Ukraine. The solar heat gains given in the IWEC file cannot be immediately used to compare climate databases or to calculate the buildings energy needs for heating, therefore, the Duffy's methodology for calculating solar heat gains is used. The solar heat gains to the vertical and horizontal surfaces according to the IWEC file are significantly different from the current climatology in Ukraine. The average difference in solar radiation on vertical surfaces is about 40%, on the horizontal – up to 10%.

Unlike experimental methods of the analysis, the calculation methods allow not only to evaluate a number of influential factors in a complex, but also to evaluate their influence on the value of energy need for heating separately. In the paper, five methods of calculation are compared starting from the aggregated annual indicators and ending up with detailed hourly calculation methods. Stationary methods of calculation significantly overestimate the annual energy need for heating and do not allow the analysis in the daily context. The calculation based on the national method has the greatest difference with non-stationary calculation methods. The calculated heating energy need for orientation according to the aggregate indicators (KTM-204) gives a difference of about 40%, sectoral norms – up to 60%, the detailed method of the HDD (DSTU N B A.2.2.5: 2007) has the lowest difference which is about 5% for southern orientation and 10% for northern orientation, for DBN B.A.2.2-12: 2015 is 12% for northern and 28% for southern orientation. The dynamic methods E+ and 5R1C give almost the same value of energy need for heating difference up to 7% for all orientations.

The model based on 5R1C model is easily adaptable to new input parameters (geometric sizes, thermal characteristics of enclosures, climatic data) unlike the E+ software product. The software E+ allows analyzing a larger range of parameters: it considers separately the accumulation of internal and external walls, takes into account the air flows between zones, the inertia of the heating system. E+ uses climatic data of the typical year; therefore, in simulating the current situation, the IWEC file must be adapted to actual climatic conditions, which adds additional difficulties in implementing on the basis of the information provided on the meteorological sites. Dynamic calculation methods allow conducting hourly, daily analysis of energy consumption for heating and can be used in predicting the heating level and/or for intermittent heating mode.

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