Influence of Orientation of Buildings Facades on the Level of Solar Energy Supply to Them

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Abstract. Energy-efficient building forms take into account the fundamentals given for passive houses and zero energy houses. One of them is to account for the amount of solar energy received on the facade surface. The paper describes the study of the influence of the orientation of buildings facades on the level of solar energy supply to them. The paper presents theoretical dependencies for determining the amount of solar energy input to the facade surface due to its orientation relative to the sides of the horizon. In addition to the appropriate orientation of houses for the use of solar energy, the paper considers the need to use this energy by equipment on walls or windows. It was calculated that the difference in solar energy received by the surface of the Southern, South-East and South-West is no more than 5%. The paper suggests approximation equations that allows to calculate the amount of solar energy received on the different orientation facade surface.

Keywords: Solar energy · Solar collector · Solar heat supply system · Building facade · Heating period

1 Introduction

The modern level of science and technology development makes it possible to effectively manage all components of modern buildings, in particular energy supply systems. The use of energy saving technologies to improve the energy characteristics of a building is a promising development direction [1]. For buildings, taking shape into account takes an important place in the design. Therefore, scientists and engineers are looking for new ways to implement effective solutions in construction. Such a solution, for example, is Smart Energy Networks (SEN). SEN this is a combination of renewable energy sources with cogeneration systems that are highly efficient. This solution allows you to integrate unconventional technologies into large-scale applications during construction [2–4].

It should be mentioned that one of the first energy-efficient buildings in Ukraine was built in Kiev taking into account the fundamental principles of energy-efficient building forms according to orientation on the sides of the horizon. In Ukraine, a number of projects for the construction of environmental, energy-efficient buildings have been implemented [5].

Z. Blikharskyy (Ed.): EcoComfort 2020, LNCE 100, pp. 499–504, 2021.
https://doi.org/10.1007/978-3-030-57340-9_61

Solar energy is a powerful source of life on Earth. Therefore, a number of works draw attention to the amount of energy received by this type of energy on the earth's surface. In works [6] is described the method developed for determining the potential of solar energy in large cities based on the typology construction. As a result of this method, the solar heat supply system on the roof of the building can be calculated taking into account shading from obstacles and with mounting distances.

Solar energy reaches the atmosphere in a directed flow, but the Earth's surface receives both direct flow and scattered atmospheric radiation. Solar radiation falling normally on the Earth's surface changes due to: changes in the distance between the Earth and the Sun; atmospheric dispersion of air, water vapor and dust by molecules; atmospheric absorption by oxygen, ozone, water and carbon dioxide [7]. The receipt of solar radiation on the surface of an energy-efficient form should be taking into account such moments.

2 Objectives the Formulation of the Problem

Improving the energy performance of the building is possible by implementing solutions at the design stage to account for the amount of solar energy received on the facade surface. In this regard, the actual direction of research is to determine the amount of solar energy input to the facade surface.

3 The Analysis of Recent Research and Publications

One of the publications that optimizes the geometric parameters of energy-efficient buildings is the thesis of V. Martynov. The paper provides recommendations on the use of polar diagrams in solving problems of designing the thermal insulation shell of buildings [8].

In practice, installations that are part of the construction of an external fence become popular [9]. The model shown in the work [10] is the structure is designed for a part of the building and is recommended for installation on the northern and southern parts of the coating. The similar design has the wall for heating the house described in the work [11]. Patented is the design of the solar panel of the house, which contains the partition, the circulation channel, thermal insulation made in the form of the conical frame with the base that is beveled towards the lower opening of the partition [12]. The solar wall structure described by Charlene Riegger has the perforated metal plate. The wall solar collector is effective on cloudy days, although on a smaller scale [13]. The design of the house is presented in the patent [14], which reduces heat loss due to horizontal channels. These horizontal channels are placed in the ground under the floor and others with North and South orientation in the house structure. The disadvantage of this design is the high cost.

It is worth noting that all the above-mentioned installations for converting solar energy require the preliminary calculation of the receipt of solar energy on the surface of the facade. As well as choosing among them the most optimal design for the particular region of construction.

4 The Main Material

Due to the movement of the Earth around the axis and around the Sun, the supply of solar energy is uneven and depends on many factors. Therefore, there is a need to optimally orient the solar collectors, that is, to find such optimal angles at which the maximum possible amount of solar energy will be obtained.

The maximum annual amount of direct solar energy is achieved when the surface is tilted $\beta = 0{,}9\ \varphi$. Moreover, the surface should be oriented to the equator with the slope for summer $\varphi + 10^{o}$ and for winter $\varphi - 10^{o}$. It is known about the results of studies of the influence of the azimuthal angle γ of irradiation on the surface of solar energy. Furthermore, when $\gamma = 0^{o}$ and $\gamma = 22.5^{o}$ for latitude to $\varphi = 45^{o}$ the difference in relative annual exposure differs only by 2%. It is also indicated that every 15° the azimuth angle causes the shift in the daily distribution of solar energy by about 1 h in the direction of the morning hours, if γ there is a positive, and in the afternoon, if γ is negative [7].

The average monthly value of the total solar energy received on the horizontal surface was calculated taking into account the normative data on the receipt of solar energy on the Ukraine territory. Within Ukraine this value is approximately equal 345 MJ/m^2 (Fig. 1).

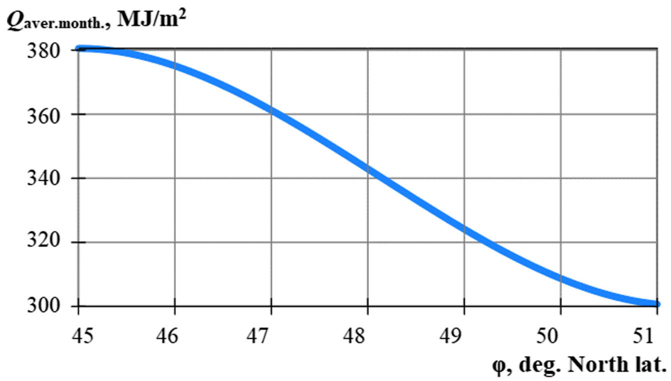

Fig. 1. The average monthly total solar energy $Q_{\text{aver.moth.}}$, MJ/m^2, received on a horizontal surface on the Ukraine territory

Based on the data in Fig. 1, was obtained the Eq. (1):

$$Q_{\text{aver. moth.}} = 0{,}6389 \cdot \varphi^3 - 92{,}2857 \cdot \varphi^2 + 4{,}4243 \cdot 10^3 \cdot \varphi - 7{,}0054 \cdot 10^4, \text{J/m}^2 \quad (1)$$

where, $Q_{\text{aver. moth.}}$ – annual average monthly total solar energy, MJ/m^2; φ – the value of latitude, deg. North. lat.

According to the integral estimation of the amount of solar energy, it is advisable to separate its receipt on the horizontal surface seasonally and in the heating period. After all, installing solar collectors on the facades of buildings requires an additional assessment of the solar energy amount to be able to use them during the heating period. As a result of analysis of seasonal fluctuations of solar energy on the territory of Ukraine for a year, the total solar energy increases most in the spring and summer season. In the winter season, the minimum total solar energy is 87 MJ/m^2.

The total solar energy is sufficient to partially cover the load on fuel and energy costs during the heating period. For example, at latitude 51, the average monthly total solar energy during the heating period is 164 MJ/m^2, which is 26% less than the 45th geographical latitude of Ukraine.

In autumn, the significant decrease in direct solar radiation from September to November leads to the decrease in total solar energy by up to 45%. The summer season is characterized by the increase in the receipt of direct solar radiation by about 10 times in relation to the winter period. Therefore, the efficiency of flat solar collectors increases during the summer period.

The amount of total solar radiation (direct and scattered) received on the surface during the year for Ukrainian cities was obtained (Fig. 2).

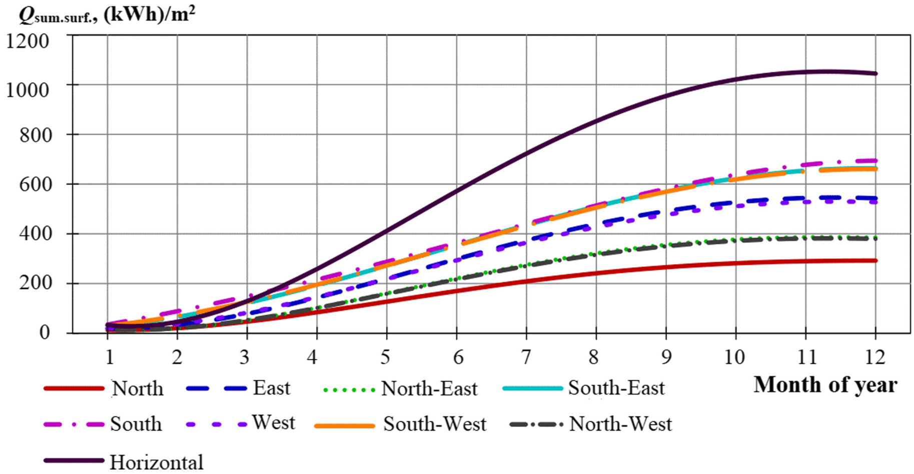

Fig. 2. Amount of total solar radiation $Q_{sum.surf.}$, kWh/m^2, which comes on the surface of different orientation for Kiev

It is analyzed that the horizontal surface receives more than 1000 kWh/m^2. The surface of the Southern orientation receives the same amount of total solar energy as the surfaces of the Southwest and Southeast, and the difference between them is no more than 5%.

On the basis of Fig. 2 approximation equations of solar radiation input on the surface of different orientation are obtained. Also, on the example of the city of Kiev, the formula for the total amount of solar radiation received on vertical and horizontal surfaces is obtained.

$$Q_{\text{North}} = -1{,}26 \cdot x^2 + 45{,}77 \cdot x - 59{,}38 \tag{2}$$

$$Q_{\text{North-East}} = -1{,}63 \cdot x^2 + 61{,}22 \cdot x - 87{,}09 \tag{3}$$

$$Q_{\text{East}} = -1{,}86 \cdot x^2 + 80{,}01 \cdot x - 110{,}02 \tag{4}$$

$$Q_{\text{South-East}} = -1{,}61 \cdot x^2 + 85{,}61 \cdot x - 94{,}35 \tag{5}$$

$$Q_{\text{South}} = -1{,}21 \cdot x^2 + 80{,}68 \cdot x - 68{,}26 \tag{6}$$

$$Q_{\text{South-West}} = -1{,}58 \cdot x^2 + 84{,}33 \cdot x - 88{,}84 \tag{7}$$

$$Q_{\text{West}} = -1{,}87 \cdot x^2 + 77{,}9 \cdot x - 102{,}57 \tag{8}$$

$$Q_{\text{North-West}} = -1{,}59 \cdot x^2 + 59{,}93 \cdot x - 84{,}2 \tag{9}$$

$$Q_{\text{Horizontal}} = -3{,}7 \cdot x^2 + 157{,}65 \cdot x - 233{,}05 \tag{10}$$

$$Q_{\text{Sum.+Horizontal}} = -16{,}3 \cdot x^2 + 733{,}11 \cdot x - 927{,}75 \tag{11}$$

where, x – serial number of the month (from 1 to 11).

Approximation Eqs. (2)–(11) allows to calculate the amount of solar energy received on the facade surface. In addition, equations could calculate the amount of energy in the month during which the installation will account for the greatest generation of energy, depending on the orientation of the facade relative to the sides of the horizon.

5 Conclusions

The maximum annual amount of direct solar energy is achieved when the surface is tilted $\beta = 0{,}9\ \varphi$. The surface should be oriented to the equator with the slope for summer $\varphi + 10^{\circ}$ and for winter $\varphi - 10^{\circ}$.

It is advisable to calculate the amount of solar energy on the surface during the season and during the heating period. It was found that direct and scattered solar radiation is most important in the spring-summer season as the result of the analysis of post-season fluctuations in solar energy on the Ukraine territory. In the heating period, the total solar energy is 60% more than in winter and sufficient to partially reduce the use of traditional energy sources.

The approximation equations described in this paper allows to calculate the amount of energy received on the facade surface. If the building's facade contains the solar collector, this will allow to take into account the seasonal operation of the solar collector.

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