International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2023	Issue 55	Volume 15	Number 2	Pages 134-140

DETERMINATION OF CONDITIONAL ATMOSPHERE TEMPERATURE FOR ENERGY CERTIFICATION OF BUILDINGS

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Abstract- During the energy certification of buildings, the exchange of long-wave radiation between the building and the environment is taken into account very roughly. However, a more accurate accounting of it will significantly im-prove the veracity of energy efficiency of the projected building. Construction climatology standards provides data of thermal radiation of the atmosphere and the Earth, but they are not used in the regulatory methodology of accounting of long-wave radiation in the energy certification of buildings. The article proposes a method for calculating the conditional temperature of the atmosphere depending on the vertical angle at which an elementary section of the surrounding space is observed and the use of standards data for calculating the thermal radiation of a building into the atmosphere.

Keywords: Thermal Radiation, Sky Temperature, Coefficient of Thermal Radiation.

1. INTRODUCTION

Figure 1 shows a diagram of the average heat balance of the system of Space, Atmosphere and Earth. As can be seen from the diagram, long-wave radiation has a very significant intensity. Underestimating it in the design of energy efficient buildings can lead to unsuccessful decisions. A value of the energy brightness of long-wave radiation coming from the elementary part of the sky depends on the thickness of the atmosphere in the direction of this part and the characteristics of the clouds.

The energy brightness of the sky near the horizon is maximum and decreases with height. In addition, the energy facades lighting of buildings is affected by thermal radiation of the earth's surface, which significantly increases it.

In the current methods of calculating the energy efficiency of buildings [1-5] thermal radiation is taken into account depending on the apparent temperature of the atmosphere, which is assumed to be the same for any orientation of the irradiated surface and does not take into account cloud conditions. Therefore, the issue of developing a better methodology for its definition is relevant.

2. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Since the 20th century, many researchers have proposed different models of sky temperature [6-9]. Typically, these models cover local weather conditions and study the transfer of thermal radiation only on a horizontal surface.

Article [10] researches influence of sky temperature on the air temperature in the building. It is determined, that rising or decreasing sky temperature by 2°C changes the indoor air temperature in the building by 1°C. Using inaccurate sky temperature input parameters in software to assess the thermal characteristic of buildings, for example, Autodesk Computational Fluid Dynamics (CFD) or EnergyPlus, lead to determining the incorrect indoor air temperature in the building. Rising or decreasing sky temperature by 10 °C gives an error of more than 20% in comparison with real temperature.

In standards methods of calculation [1-3] the additional heat flow emitted by thermal radiation to the atmosphere for the corresponding shell element of the building Φ_r, W, is determined by Equation (1) [3]:

$$\Phi_r = F_r \cdot R_{se} \cdot U_c \cdot A_c \cdot h_r \cdot \Delta\theta_{er} \quad (1)$$

where, F_r is the coefficient of form between the element of the building and the sky, which is accepted: 1.0 is for unshaded horizontal roof, 0.5 is for unshaded vertical wall; R_s is the external thermal surface resistance of the opaque part, m^{2}K/W, take 0.043 m^{2}K/W; U_c is thermals coefficient of the opaque part, W/(m^{2}K); A_c is the element projection area, m^2; h_r is emitted thermals coefficient of the outer surface, W/(m^{2}K); $\Delta\theta_{er}$ is the average difference between the outdoor air temperature and the imaginary atmosphere temperature, °C, for temperate latitudes take $\Delta\theta = 11$ K.

Emitted thermals coefficient of the outer surface h_r, W/(m^2·K), calculated by the Equation (2):

$$h_r = 4\varepsilon\sigma\left(\theta_{ss} + 273\right)^3 \quad (2)$$

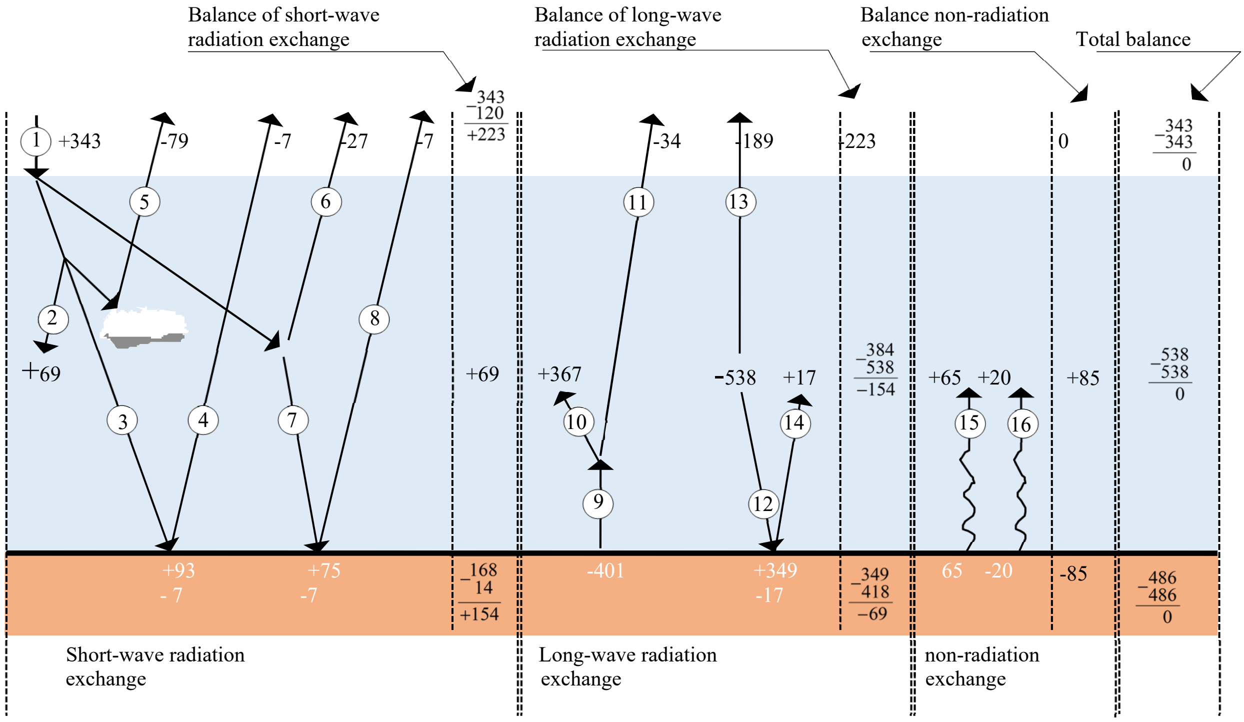

Figure 1. Thermal balance of Space, Atmosphere and Earth system (W/m^2) [3]:
1- Incoming solar radiation to atmosphere; 2- Solar radiation absorbed by atmosphere; 3- Earth surface insolation; 4- Insolation reflected by the Earth`s surface; 5- Solar radiation reflected by clouds; 6- Diffused solar radiation back to Space; 7- Incoming diffused solar radiation to the Earth`s surface; 8- Diffused radiation reflected by Earth surface back to Space; 9- Emitted radiation by Earth surface; 10- Earth radiation absorbed by atmosphere; 11- Earth radiation outgoing to Space; 12- Counter radiation; 13- Atmosphere radiation outgoing to Space; 14- Counter radiation reflected by Earth's surface; 15- Earth's heat emanating from its surface during water evaporation; 16- Earth's heat emanating from its surface during thermal conductivity and convection process

where, ε is thermal radiation coefficient of the outer surface; σ is the Stefan-Boltzmann constant: $\sigma = 5.67\times10^{-8}$ W/(m^{2}K^4); θ_{ss} is arithmetic mean temperature of the surface and atmospheric temperature, °C.

In the first approximation, h_r is assumed to equal 5ε W/(m^{2}K), which corresponds to an average temperature of 10 °C. According to [9], the value of $\Delta\theta$ for subpolar latitudes is 9 °C and for tropical 13 °C.

The normative methodology simplified counts the orientation of the receiving surface and the conditions of real clouds. In [11] is presented Applied Software «Atmospheric Radiation», is aimed at solving the problem of optimizing the shape of houses and solving other problems related to the analysis of the radiation flux on surfaces of complex shapes in construction. The model is implemented in the environment of «MATLAB». Structure of the software is shown on Figure 2.

The program "Thermal radiation" calculates the brightness of the long-wave radiation of the atmosphere in an arbitrary direction for different values of meteorological parameters. This makes possible to determine the conditional atmospheric temperature for any direction of radiation.

Currently, software packages for calculating radiation characteristics have been created, such as DISORT [12], FASCODE [13], ECHAM-HOPE [14], IOS "Atmospheric radiation" [15], and other [16, 17].

The well-known program library LIBRADTRAN [18], which is based on individual programs, allows you to create new computer packages for radiation calculations. All of them require a sufficiently large number of service programs, and more a priori meteorological information. Only highly qualified meteorologists can make calculations using the mentioned programs. Programs are not adapted to the needs of designers in the construction industry.

The influence of climatic parameters of the construction area and the orientation of the outer enclosing surfaces on the energy efficiency of the building is considered in many studies [19-26]. These studies indicate the need for proper consideration of temperature, humidity, cloudiness and other climatic parameters, as well as the orientation of external surfaces in the design of energy-efficient buildings.

3. PURPOSE

To propose a method for the analytical determination of the average irradiance of long-wave radiation the calculation period for an arbitrarily oriented in space plane.

Based on the results obtained, develop a method for calculating the sky temperature in an arbitrary direction of observation, which is recommended to be used for the energy certification of buildings.

4. METHODS

Methods of computer and geometric modeling of phenomena and processes occurring in the atmosphere, methods of building and building heat engineering, were used.

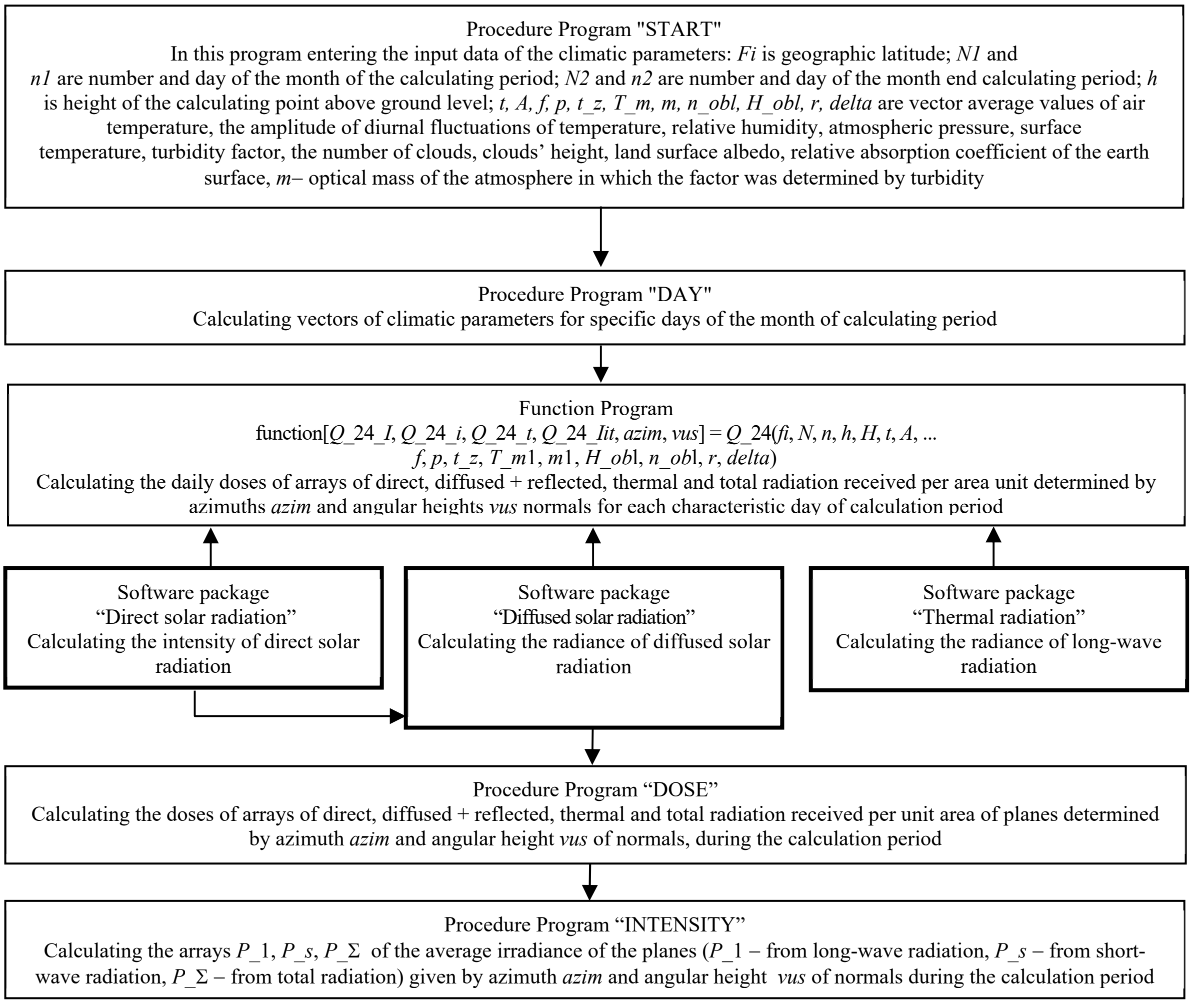

Figure 2. Structure of the PC application software "Atmospheric Radiation"

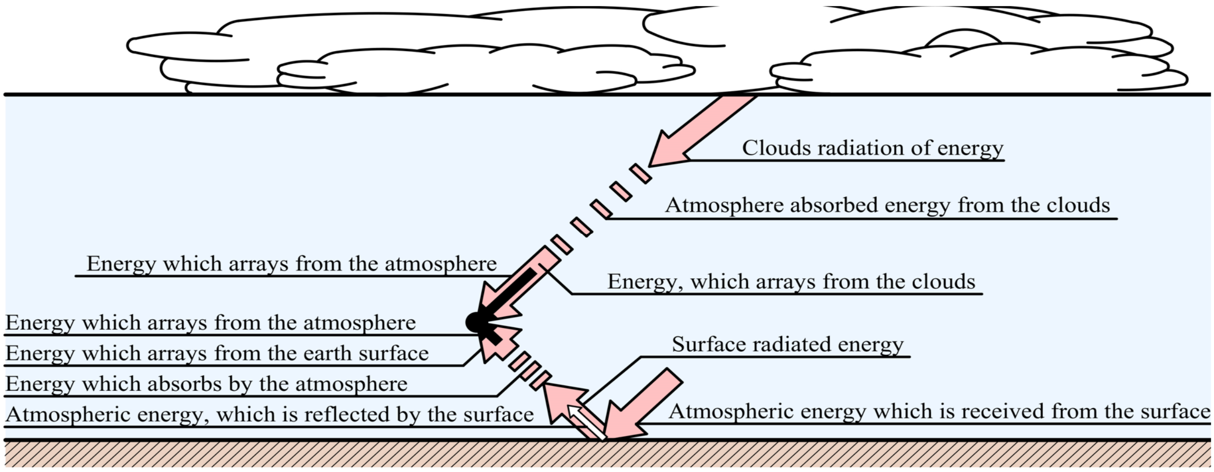

Figure 3. Physical picture of long wave radiation exposure at center of action for overcast sky

5. RESULTS

Calculation of the radiance of the long-wave radiation is based on the known integral equations of the transfer of thermal radiation in the atmosphere [27]. However, these equations do not consider the curvature of the atmosphere, causing a significant error in determining the radiance of the atmosphere near the horizon.

Therefore, we clarified and corrected them. For the numerical solution of the equations, it is formulated and justified appropriate assumptions. And on their base the equations of thermal radiation transfer in the atmosphere with a clear sky have been obtained:

$$\begin{cases} G(h,\beta)=\sum\limits_{\lambda=1}^{37}\int\limits_{h}^{25000}\sum\limits_{j=1}^{3}k_{\lambda_j}(\zeta)\rho_j(\zeta)k_\beta(\zeta)E_\lambda(\zeta)e^{-\int_h^\zeta\sum_{j=1}^{3}k_{\lambda j}(\xi)\rho(\xi)d\xi}d\zeta; \\ U(h,\beta)=\sum\limits_{\lambda=1}^{37}\Big[\Big(\delta E_\lambda(0)+2(1-\delta)\int\limits_0^{\pi/2}G_\lambda(0,\beta)\cos\beta\sin\beta\,d\beta\Big)e^{-\int_0^h\sum_{j=1}^{3}k_{\lambda_j}(\xi)\rho(\xi)d\xi}+ \\ +\int\limits_0^h\sum\limits_{j=1}^{3}k_{\lambda_j}(\zeta)\rho_j(\zeta)k_\beta(\zeta)E_\lambda(\zeta)e^{-\int_\zeta^h\sum_{j=1}^{3}k_{\lambda_j}(\xi)\rho(\xi)d\xi}d\zeta\Big] \end{cases} \tag{3}$$

where, h is the calculation point level relative to the ground; β is the beam tilt angle to the horizon plane; G and U are the brightness of the integral radiation, respectively, of the upper and lower halves of space; G_λ and U_λ is the same as G and U, but only for monochrome radiation on the strip λ; $k_{\lambda j}$ is absorption coefficient of a respective gas (water vapor, carbon dioxide, ozone); k_β is coefficient which accounts for the increase in the mass of the atmosphere in the direction β and in relation to the direction of the zenith; ρ_j is density of the current gas; E_λ is radiance of blackbody radiation on the strip λ at a temperature of the atmosphere at a height h; δ is a relative absorption coefficient of the earth surface. Similar equations are obtained for the overcast sky:

$$\begin{cases} 0\le h\le H_{\mathrm{cl}}; \\ G(h,\beta)=\sum\limits_{\lambda=1}^{37}\left(E_\lambda(H_{\mathrm{cl}})e^{-\int_h^{H_{\mathrm{cl}}}\sum_{j=1}^{2}k_{\lambda_j}(\xi)\rho_i(\xi)d\xi}+\int\limits_h^{H_{\mathrm{cl}}}\sum\limits_{j=1}^{2}k_{\lambda j}(\zeta)\rho_j(\zeta)k_\beta(\zeta)E_\lambda(\zeta)e^{-\int_h^\xi\sum_{j=1}^{2}k_{\lambda j}(\xi)\rho_j(\xi)d\xi}d\zeta\right); \\ U(h,\beta)=\sum\limits_{\lambda=1}^{37}\Big[\Big(\delta E_\lambda(0)+2(1-\delta)\int\limits_0^{\pi/2}G_\lambda(0,\beta)\cos\beta\sin\beta\,d\beta\Big)e^{-\int_h^{H_{\mathrm{cl}}}\sum_{j=1}^{2}k_{\lambda_j}(\xi)\rho_j(\xi)d\xi}+ \\ +\int\limits_0^h\sum\limits_{j=1}^{2}k_{\lambda_j}(\zeta)\rho_j(\zeta)k_\beta(\zeta)E_\lambda(\zeta)e^{-\int_\zeta^h\sum_{j=1}^{2}k_{\lambda j}(\xi)\rho_i(\xi)d\xi}d\zeta\Big] \end{cases} \tag{4}$$

where, H_{cl} is the cloud level relative to ground.

Absorption of long wave radiation of only two gases - water vapor and carbon dioxide because height of the clouds, except in very light clouds - pearl and silvery, much lower than the reduced height of the layer of ozone is taken into account in the equation [27]. Pearlescent (height of 22-27 km) and silvery clouds (82-85 km) is not observed in Ukraine. They can be ignored in the calculations.

The physical picture which is described by the Equation (4) is shown on Figure 3. In the calculations according to Equations (3), (4) the following assumptions were made:

– There are 100 contact layers of variable thicknesses in the atmosphere, from 0.4 m at ground level to 700 m on the height 25 km. The physical properties of the atmosphere are constant in each layer;

– Underlying surface – gray isotropic body;

– Clouds are absolutely black-body for thermal radiation.

The sky brightness under average cloud conditions is obtained by linear interpolation of the values of brightness in clear skies and continuous cloudiness depending on the value of the lower cloudiness of the sky. The result of the package "Thermal Radiation" work is the value of the radiance of the long-wave radiation shown on Figure 4.

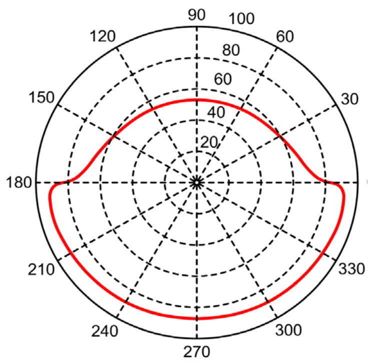

Figure 4. Example the diagram of distribution of long-wave radiation in the vertical plane (W/m^2·sr)

According to the values of brightness, it is possible to obtain the value of energetic luminosity of the atmosphere R, W/m^2. On the other hand, it is known, that the degree of blackness system of two bodies ε_r during heat exchange by radiation between bodies, one of which has an area F_1 and the degree of blackness ε_1 and is inside the second body with area F_2 and the degree of blackness ε_2, is equal to [28]:

$$\varepsilon_r=\left[1/\varepsilon_1+\left(F_1/F_2\right)\left(1/\varepsilon_2-1\right)\right]^{-1} \tag{5}$$

If the $F_1 << F_2$, that F_1/F_2 and $\varepsilon_r=\varepsilon_1$.

In determining the effect of long-wave radiation on the energy efficiency of the building ε_r is equal to ε the outer surface of the fence. So,

$$R = \varepsilon\sigma\theta^4 \tag{6}$$

where, θ is atmosphere temperature, K.

From Equation (6) we obtain:

$$\theta = \sqrt[4]{\frac{R}{\varepsilon\sigma}} \tag{7}$$

To determine the additional heat flux from the enclosing structure of the building due to thermal radiation into the atmosphere Φ_r, W, can be used Building Climatology standards [29], which provides data on the average monthly amounts of thermal radiation coming to the horizontal and vertical surfaces under clear skies and under average cloud conditions for all regional centers of Ukraine. In this case, in Equation (1) should be taken $F_r = 1$ regardless of surface orientation.

In difference to the methodology [12-14], the value of the sky temperature significantly depends on the orientation of the surface and clouds presence. For example, for the city of Kiev, the temperature of the atmosphere in January under average cloud cover for a horizontal covering is -12.2 °C, for a vertical wall -5.96 °C, with a clear sky -23.9 °C and -10.2 °C, respectively. According to the existing methodology, this temperature considering the F_r coefficient for the coating is -15.5 °C, for the wall -7.69 °C, regardless of cloudiness. The mistake of calculation of additional heat flow due to thermal radiation into the atmosphere Φ_r for vertical surfaces can exceed 100%. This significantly depends on cloudiness in the construction area.

6. SCIENTIFIC NOVELTY AND PRACTICAL SIGNIFICANCE

The exchange of long-wave thermal radiation between the building and the atmosphere significantly affects the energy balance of the building. The proposed method for determining the conditional temperature of the atmosphere makes it possible to consider the orientation of the outer surfaces of the thermal envelope of the building and the actual cloudiness conditions.

Determining the sky temperature according to the prohibited method will increase the reliability of the calculation of energy efficiency of the building during energy certification.

7. CONCLUSIONS

Geometric modeling of the processes occurring in the atmosphere made it possible to develop the "Atmospheric Radiation" software. On its basis, it became possible to calculate the doses of thermal radiation that enter an arbitrarily oriented surface with real meteorological parameters. For the purposes of energy certification, a simplified method is proposed for determining the additional heat flux to the enclosing structure during the calculation of thermal radiation into the atmosphere, which uses data from standards.

Determining the temperature of the sky according to the proposed method will increase the reliability of calculating the energy efficiency of the building during energy certification. Using the Software "Thermal radiation" allows you to calculate the temperature of the atmosphere for an arbitrarily oriented surface under conditions of real cloudiness.

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