Comparative Longevity of Enclosing Structures Depending on Climatic Conditions and Architectural and Constructive Characteristics of Buildings

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Abstract. The article gives a comparative analysis of longevity of building enclosure, which is located in different climatic regions of the Russian Federation. Comparison for typical structural solutions of external walls, in which polymeric heat-insulating materials are used is carried out. Calculation of longevity according to the developed technique, which is based on the determination of equivalent operating temperatures of construction materials and loss of the specified thermal insulation properties of the polymer material is carried out. It is shown that the comparative longevity of a structure depends on a number of factors: the magnitude of the intensity of solar radiation on different surface orientations, the number of hours of sunshine, and also the wind speed in a given region. Shown the necessity of taking into account the orientation of the building on the sides of the horizon and its architectural and planning solution when determining the longevity of the structural solution of the external walls.

1. Introduction

Modern buildings are complex systems, which consists of a large number of structural and engineering elements. All these elements must ensure trouble-free operation of the building for a certain period of time. If some building element has a service life less than the building as a whole, it must be replaced during operation. Thus, the engineer in the design work must be able to determine the service life of each building element in order to make a plan for its trouble-free operation throughout its service life.

2. Relevance

The building enclosing structures simultaneously perform various functions: strength, insulation, noise protection, thermal protection. In this connection, the service life of the enclosing structures can be determined on the basis of a large number of criteria: loss of strength, cracking, deterioration of the decorative qualities of the facing layer, loss of noise insulation or heat insulation properties [1-5]. At present, when designing the enclosing structures, the greatest attention is paid to improving the thermal protection of buildings and reducing energy losses. In this connection, the preservation of the standard level of heat protection was chosen as a criterion for the longevity of various enclosing structures.

In turn, the process of loss of heat-shielding qualities of materials depends on the type of material. For enclosing structures of buildings in which polymer-containing thermal insulation materials are used (expanded polystyrenes of various types, mineral and glass wool on synthetic binders, etc.) the
service life may depend on the effect of high temperatures of solar radiation on the facade of the building, rather than on the processes of freezing and thawing [6-12].

The method of calculating the service life of the enclosing structure using a polymeric heat-insulating material by loss of the required degree of heat protection based on the determination of the operating temperature regime of materials is presented in [13].

According to this method, the temperature regime of an enclosing structure is determined by two kinds of factors: objective and subjective. The objective factors include the factors of the climatic influence of the environment. Subjective factors include the characteristics of the enclosing structure, the thermal characteristics of materials (thermal conductivity, thermal diffusivity, heat absorption), as well as the temperature regime of the building.

The engineer at designing can change subjective factors to vary a life of an enclosing structure. The objective factors change only after the climate change and the construction site. In this regard, the engineer must have information about how the climate of the terrain affects the service life of the enclosing structure.

The climate of the Russian Federation varies in a wide range of parameters: from subtropics to the Arctic. This entails significant changes in the service life of building enclosing structures, which are located in different regions of the country. A cumulative analysis of the objective factors of the climatic impact for the entire territory of the Russian Federation will make it possible to assess the comparative longevity of the enclosing structures of buildings designed in different regions of the country and to develop recommendations on the design of enclosing structures with different longevity or service life.

3. Theoretical basis of the method
The operating temperature regime of the enclosing structures, which continuously changes throughout the year, according to [13] can be determined through constant equivalent operating temperatures. Equivalent material temperatures are calculated from the temperature distribution across the section of the enclosing structure, which is located between the impact of the internal environment and the effect of the outdoor climate. These temperatures directly affect the longevity of the polymer insulating materials of the enclosing structure. Hence, after calculating the equivalent surface temperature of the enclosing structure for different climatic regions, it is possible to estimate the longevity of the enclosing structures in these regions. The final service life will also be affected by the subjective set of factors described above.

The equivalent temperature near the surface of the enclosing structure can be defined as the sum of two effects:

\[ T_{eq, tot} = t_{eq, ext} + t_{eq, sol}, \]

(1)

where \( t_{eq, ext} \) is determined by the effect of the outside air temperature and takes into account the outside air temperature \( T_{ext} \) and its distribution during the year \( \Delta \tau \):

\[ t_{eq, ext} = -\frac{E_a}{R} \ln \left[ \frac{1}{\tau_{year}} \sum_{j=1}^{\Delta \tau} \exp \left( -E_a / RT_{ext} \right) \right]^{-1}, \]

(2)

\( t_{eq, sol} \) is determined by the influence of solar radiation on the enclosing structure of a certain orientation and takes into account the intensity of solar radiation \( S_k \), the duration of sunshine \( \tau_{sol, k} \), the coefficient of surface absorption \( \rho \), and also the coefficient of thermal perception of the construction \( \alpha_{ext} \), which in turn depends on the wind speed near the surface of the enclosing structure:

\[ t_{eq, sol} = -\frac{E_a}{R} \ln \left[ \frac{1}{\tau_{sol}} \sum_{k=1}^{\Delta \tau_{sol, k}} \exp \left( -E_a / R \rho S_k / \alpha_{ext} \right) \right]^{-1}, \]

(3)

\( E_a \) – activation energy of the fracture process, J/mol;

\( R \) – is the universal gas constant, J/(K·mol).
Each of the above parameters is determined by the climatic conditions of the construction site. Since the territory of the Russian Federation is represented by different climatic zones, the temperature regime of the enclosing structures will also be different.

4. Influence of the climate factor on the equivalent temperature

For the analysis of the aggregate of climatic factors in different climatic zones and regions of the Russian Federation, some cities were chosen which differ in latitude and longitude and are evenly dispersed throughout the territory of the Russian Federation (Table 1).

Table 1. Cities of the Russian Federation

| Latitude (°N) | Cities                                      |
|--------------|---------------------------------------------|
| 44           | Sochi, Vladivostok                          |
| 46           | Astrakhan, South-Kurilsk                    |
| 48           | Khabarovsk                                  |
| 50           | Borzya, Rostov-on-Don                       |
| 52           | Irkutsk, Orenburg, Voronezh                 |
| 54           | Kaliningrad, Petropavlovsk-Kamchatsky, Omsk, Barnaul, |
| 56           | Moscow, Kazan, Yekaterinburg, Tomsk, Krasnoyarsk |
| 58           | Bodaibo                                     |
| 60           | St. Petersburg, Vologda, Khanty-Mansiysk, Magadan |
| 62           | Syktyvkar, Oymyakon, Yakutsk                |
| 64           | Arkhangelsk, Anadyr                         |
| 68           | Verkhoyansk, Murmansk                       |
| 74           | Dixon                                       |

For each city, according to formulas (1-3), the equivalent operating temperature of outdoor temperature and of the effect of solar radiation on facades that are directed to the South and East, and also on the horizontal surface was determined. Equivalent operating temperatures were calculated for the surface of the model enclosing structure with averaged subjective parameters \(E_a = 100 \text{ kJ/mol}, \rho = 0.65\) to exclude their influence on the comparison of longevity depending on climatic conditions.

The calculation results are shown in the graphs, Figures 1-4.

The distribution of the equivalent outdoor air temperature (by formula 2) for the territory of the Russian Federation is rather well correlated with the latitude of the terrain (Figure 1). The temperature is higher for southern regions, for northern regions it is lower. Some variation in the temperature values is due to the presence of cities with marine and continental climate.

![Figure 1. Distribution of the equivalent outdoor temperature for the territory of the Russian Federation](image-url)
Figure 2. Distribution of the equivalent temperature on the surface of the eastern orientation for the territory of the Russian Federation
a) solar radiation temperature; b) total temperature (solar + outdoor temperature)

Figure 3. Distribution of the equivalent temperature on the surface of the southern orientation for the territory of the Russian Federation
a) solar radiation temperature; b) total temperature (solar + outdoor temperature)

Figure 4. Distribution of the equivalent temperature on a horizontal surface for the territory of the Russian Federation
a) solar radiation temperature; b) total temperature (solar + outdoor temperature)
The distribution of the equivalent temperature of solar radiation (by formula 3) for the territory of the Russian Federation is affected by a change in three factors simultaneously: the intensity of solar radiation, the duration of sunshine and the speed of the wind. In the article [14] it was shown that for the territory of the Russian Federation the duration of sunshine increases to southern latitudes. The increase in the intensity of solar radiation is associated with the orientation of the enclosing structures and the angle of inclination of the sun’s rays to the normal of the surface, respectively: for vertical surfaces the intensity increases to the northern latitudes, for horizontal surfaces - to the south. In this connection, the distribution of the equivalent temperature of solar radiation for vertical surfaces is almost constant for all latitudes, and for a horizontal surface increases to southern latitudes, especially without taking into account the influence of the wind (Figures 2-4, a, triangle marks).

The distribution of wind speed over the territory of the Russian Federation is practically not related to the latitude of the terrain, it is determined by the closeness of the territory to the sea or the ocean. This makes a corresponding contribution to the distribution of equivalent temperatures of solar radiation. Calculation of the equivalent temperature of solar radiation is performed for the average wind speed for winter and summer conditions, respectively (Figures 2-4, a, round marks). In addition, it is known that the speed of the wind in the city is greatly influenced by the configuration of buildings. The scientific and reference literature [15] shows a rather large number of examples in which the wind speed can both increase and decrease with a different configuration of buildings on the site. Coefficients of conversion are in the range from 0.3 to 1.8. From the point of view of longevity, it is important to take into account the actual coefficient of wind speed conversion, especially in the direction of its decrease.

The Figure 5 shows the distribution of total equivalent temperatures with minimum values of wind speed (up to 1.0 m/s). It can be seen that the increase in temperature for some cities reaches 15 °C, which is significant in determining the service life of the enclosing structure by the criterion of heat protection.

![Figure 5](image)

*Figure 5.* Distribution of the total equivalent temperature on vertical surfaces, taking into account the minimum wind speed in the cities for the territory of the Russian Federation
a) eastern orientation of the surface; b) southern orientation of the surface

The distribution of the total equivalent temperature for the territory of the Russian Federation due to the influence of the outside air temperature correlates with the latitude of the terrain to a sufficient extent, regardless of the orientation of the enclosing structure. Temperatures are higher in the southern latitudes, and lower in the northern latitudes. The values of the equivalent surface temperatures of the model enclosing structure make it possible to evaluate its service life in different climatic conditions (Figure 6).
5. Conclusions
The values of the service life of the enclosing structures of buildings in this case should be considered only as a comparative assessment of longevity. This is due to the fact that only objective factors that affect longevity and service life were taken into account. The analysis revealed the following:
- the effect of outdoor temperature on equivalent operating temperatures has a correlation with latitude of terrain for the territory of the Russian Federation;
- the effect of solar radiation on equivalent operating temperatures is virtually unrelated to the latitude of terrain for vertical surfaces; for horizontal surfaces it has a correlation with the latitude of the terrain;
- the wind speed has a significant effect on the temperature of solar radiation;
- the service life of southern surfaces is on average higher than the eastern surfaces; this is due to the difference in the temperature of the solar irradiation;
- the service life of the enclosing structures with polymer insulator tends to increase to the northern regions of the Russian Federation due to lower operating temperatures.

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