Energy Saving Architecture Concept: Buildings with Low Energy Consumption and Emissions in Kyrgyzstan

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Abstract.

The adopted concept and examples of energy-saving architecture were the basis for improving the energy efficiency and thermal microclimate conditions of the building, reducing its greenhouse gas emissions. The appropriate location, shape, orientation, and dimensions of the building, its rooms, and enclosures, especially windows, and doors, are determined. The daily, seasonal, and year-round effects on the building of renewable energy of incoming solar radiation and the environment – the energy of outdoor air, base soil, wind, sky, and surfaces facing the building are considered.

Buildings with small thermal envelope surfaces in a form of a national Kyrgyz yurt and a sphere have no architectural thermal bridges that cause microclimate disturbance and mold growth. The straw bale solar passive building has a similar performance to the Nearly Zero Energy building and the Green Building. It has minimal energy consumption, CO₂ emissions, embodied energy, and a low carbon footprint of used straw bales, wood frames, and clay plaster words.

Keywords: Energy Saving Architecture, Building, Energy Consumption, Microclimate, Building Shape, Building Orientation, Thermal Bridge, Mold Growth, Greenhouse Gas Emissions.

1 Introduction

Buildings account for about 40% of all energy consumption in the world, and this share is observed in many countries [1]. Buildings account for roughly 33% of global CO₂ emissions, according to 2020 UN data. If we take into consideration the same emissions observed in the production of used building materials, then the latter figure is 39%. The residential sector is responsible for 11.7% of global greenhouse gas emissions [2]. In addition, space heating accounts for a larger share of the energy consumption of households in cold-climate regions [2].
In Kyrgyzstan, buildings consume about 50% of all produced energy. Estimates of greenhouse gas emissions from buildings are also significantly higher than the world average, as more than 60% of the country's population lives in rural areas, where single-family home heat sources do not have flue gas cleaning systems.

Building space heating is required throughout the country. Specific annual energy consumption for building space heating is from 300 to 690 kWh per m² of the floor area, which is several times higher than in European countries. These figures can be much higher, especially in remote mountainous regions with harsh cold winters, where buildings are often built without the required designs and proper thermal insulation of external enclosures. The duration of the estimated heating period is observed within 135-365 days with 2450-9850 Degree days.

For buildings with high energy efficiency in years with warm winters, a significant reduction in the duration of the actual heating period can be achieved. This is facilitated by appropriate heat-protective and space-planning indicators of the building, adapted, for example, for active and passive use of the possibilities of solar space heating. During the summer, the energy consumption of buildings in the lowland regions is significant, as the outdoor air temperature often reaches 35-40 °C. Techniques, technologies, and devices for stationary and mobile sun protection of external fences are underutilized, especially windows on facades oriented to the East and West. It is important to use night cooling of buildings, because often in the conditions of the sharply continental climate of Kyrgyzstan, often by sunrise the outdoor air temperature becomes 20-25 °C lower than in the daytime.

In paper [3], for the reconstruction of a typical office building, zero energy consumption was achieved, taking into account the criteria of thermal comfort and visual comfort. An approach was adopted to optimize the building envelope, heat supply system, glazing parameters, and shading devices. An author of this paper proposed [4] a different approach – the architecture of the building should be taken from the position of solving the problem. The author in his report at an international conference in Prague (Slovakia) in 1998 presented the concept and theoretical basis of energy-saving architecture.

A building in natural conditions (when there is no internal thermal impact of people, heating, cooling, ventilation, lighting, and equipment) interacts [4] with the renewable energy of the environment and incoming solar radiation. Such thermal as well as aerodynamic interactions of the building, remaining variable by the hours of the day and throughout the year, should be the dictating condition for the design of energy-saving architecture. It is also important that energy-saving architecture will allow, firstly, the expedient interaction of the building with the indicated renewable energies, and secondly, to implement possibilities of energy-saving behaviour of people [4] in the building (for example, opening and shading windows, choosing the operating modes of household appliances, etc.).

Energy-saving architecture is also aimed [5, 6] at solving the multidisciplinary problem of providing a daily and year-round indoor microclimate and minimal energy consumption, taking into account the prevention of the influence of thermal bridges and mold growth [7]. Energy-saving architecture has two primary objectives [4]. Firstly, it aims to determine the appropriate location, volume, orientation, and size of the building, as well as its premises and fences, particularly windows and doors. Secondly, it focuses on implementing purposeful behaviours by people to not only reduce energy consumption but also create a comfortable internal microclimate.

The tasks of designing an energy-efficient apartment building [8] and optimizing window glazing [9] on a South-facing facade are solved taking into account the embodied
energy of the used building materials. It is known that the greater the embodied energy of a material, the greater the greenhouse gas emissions observed during its production.

2 Practice in Kyrgyzstan

The energy-efficient passive building shown in Fig. 1, is built with straw bales [4].

![Multifunctional building made of straw bales with optimized window positions relative to the roof cornice in a village Jardy Suu: (a) South facade; (b) construction phase (with reducing energy consumption and CO₂ emissions by approximately 84 %).](image)

Fig. 1. Multifunctional building made of straw bales with optimized window positions relative to the roof cornice in a village Jardy Suu: (a) South facade; (b) construction phase (with reducing energy consumption and CO₂ emissions by approximately 84 %).

It has a minimal embodied energy of straw bales, wood frames, and clay plaster. Its net effect on greenhouse gas emissions is also minimal due to the fact that this building belongs to the category of Nearly Zero Energy buildings. The energy-saving architecture was adopted [4] on the basis of computer simulation. Depending on the year-round and daily trajectory of the Sun, mutually agreed upon dimensions were determined, firstly, the ledge (on 1000 mm) of the roof, and secondly, the optimal positions of the upper and lower borders of window glazing. As a result, the following was achieved [4, 10]: a) maximum shading of windows during the hottest hours of the day during the hottest period of summer; b) a significant influx of solar heat into the room, since direct solar radiation penetrates the windows from sunrise to sunset.

It should be noted that this building has all the indicators of a green building. It has minimal environmental impact by using minimal resources during the planning, design, construction, operation, and demolition phases. It is also important that after the demolition of the building, construction materials are harmlessly and usefully integrated into the natural environment. In addition, the low carbon footprint of the used natural local materials, construction technology, and machinery, as well as transport, make the building more climate neutral.

Fig. 2 shows a photograph of the building of a medical clinic in the center of Bishkek. The building is recognized by the public not only as a green building but also claims to be a carbon-neutral building. The building participates in the global process of combating climate change; on the one hand, mitigating the effects of climate warming with its relatively high energy efficiency, on the other hand, in the process of adaptation to climate change, as it absorbs CO₂ by green forest plantations above the building.
Fig. 2. A medical clinic building with a tree plantation on a flat roof in Bishkek (reducing energy consumption by approximately 24 % and net CO₂ emissions by 60-70 %).

In the green park area of the capital of Kyrgyzstan, the building appears to be absent because the area it occupies is part of the urban forest plantation. Such a beautiful part of the territory of the city park, artificially erected above the city, absorbs city dust and noise, and is also a place for the concentration and nesting of birds.

The building has an energy-efficient thermal envelope: its external enclosures have a high heat-shielding capacity. For this reason, it has low energy consumption for heating and air conditioning. In this aspect, the shape of the building, close to a cube, which has a minimum surface in comparison with the shape of conventional buildings in the form of a parallelepiped, has great importance.

Fig. 3 shows the appearance of a residential building with energy-saving architecture. It has a compact shape, close to a cube.

Fig. 3. Energy efficient house with solar heating and night cooling due to an across-vertical ventilation and long-wave radiation of the sky in Bishkek (with reducing energy consumption and CO₂ emissions by approximately 40-47 %).
The main rooms and windows are located on the south side of the building. The areas of glazing of windows oriented to the South are larger than required for using the heat of solar radiation during the cold period. Windows on the eastern, western, and northern facades are adopted with minimal areas. Such architectural solutions are connected by the dynamics of the annual, seasonal, and daily changes in the outdoor air temperature and the trajectory of the sun. So, on the territory (located between geographic northern latitudes 39° and 40°) of mountainous Kyrgyzstan, the inflow of direct solar radiation through windows oriented to the East and West: a) are minimal during the cold period, respectively, the contribution of solar heat to reduce heat consumption for space heating is insignificant; b) are maximal during the hot period and cause an increase of energy consumption for air conditioning. These windows are also the cause of the daily and seasonal deterioration of the thermal microclimate conditions of the rooms: in winter, such windows, especially at night, are a source of cooling of rooms, in summer they are a source of overheating, especially in hours close to the morning and evening.

The architecture of the building is also aimed at the implementation of its night cooling during the hot summer period. Through direction and vertical natural ventilation of the building is realized by using cooler outside air. Such ventilation (starting from 21:00 to 05:00) is carried out by opening windows on the South and North sides of the building under the influence of a night breeze directed to the south facade from the mountain in the South.

To enhance vertical ventilation, the staircase leads to the third floor and as a thermal tower creates a vertical airflow. For nighttime cooling the long-wave thermal radiation from the sky is utilized which effectively cools the terrace floor. This terrace floor also serves as a cover for the lower floor rooms, providing additional thermal protection.

After many years of operation, this building (the author's own house) has demonstrated that it is possible to maintain a favorable microclimate in the main rooms without the need for air conditioning. Even on hot days, when the outside air temperature reaches 33-35°C around noon and drops to 20-23°C by sunrise, a comfortable internal air temperature of 26-27°C can be achieved. This is facilitated by the significant thermal mass of external and internal brick walls, concrete ceilings, and ground floor. Such sufficient thermal mass accumulates cold during the hot period and solar thermal energy during the cold period.

The author proposed [11] a theoretical definition and practical classification of thermal bridges in building enclosures, categorizing them into architectural, structural, and operational thermal bridges. Architectural thermal bridges, for instance, occur in the corner areas of external walls.

The outer wall of the building in the form of a national Kyrgyz yurt (Fig. 4,a) does not have architectural thermal bridges. As a result, there are no zones on the local internal surfaces of such walls that cause intense heat losses or disrupt the microclimate conditions due to lower temperatures on these surfaces.

The building in Fig. 4,b integrates the benefits of the national Kyrgyz yurt and the ideas of the energy-saving architecture of buildings presented in Fig. 1 and Fig. 3.

The energy consumption of the building is significantly reduced through various measures. Firstly, natural lighting is utilized to minimize the need for artificial lighting. Secondly, during the cold period, the building maximizes passive solar heating through large windows. Lastly, in the hot period, the windows are effectively shaded by the extended roof edge, which provides ample protection from direct sunlight.

The building also features large doors on the south and north sides, enabling nighttime cooling through natural mountain breeze ventilation. The cylindrical outer walls and domed roofing help reduce heat transfer through them and minimize the impact of architectural thermal bridges.
Fig. 4. Restaurant buildings in the form of a national Kyrgyz yurt in Bishkek: (a) a yurt without windows; b) a building with large windows (with reducing energy consumption and CO\textsubscript{2} emissions by approximately 15-20 %).

The most energy-efficient building form is a sphere-shaped building that has the smallest area for a given volume. The building shown in Fig.5 has the advantage of a spherical building.

Fig. 5. Office spherical building in Bishkek (with reducing energy consumption and CO\textsubscript{2} emissions by approximately 30-40 %).

The placement and size of vertical windows are determined based on the timing and intensity of direct solar radiation. The dynamics of changes in the shaded zone area of windows located on different floors are taken into account.

The building has a small number of architectural thermal bridges. The total area of the heat-protective envelope of the building is 14\% smaller compared to a building with a shape formed by the outer sphere frame.

The heat losses of this building during the cold period are approximately 40\% less than those of the building in the parallelepiped form with the same volume. As a result, the
building occupies 21% less area of the city territory. The indicated heat losses will become even less if the total area of the windows is reduced.

3 Discussion

In this article, the improvement of the thermal envelope of the building was carried out in relation to the indicators of the internal microclimate in the building [12], its energy efficiency [13, 14, 15], and geometric data [16], as well as to the reasons of thermal bridges formation [17, 18, 19] and mold growth [7, 20] in enclosures.

The author of the paper [21], as well as the author of this study, concluded that improving the architecture of the building makes it possible to increase its energy performance.

4 Conclusions

The concept of energy-saving architecture is aimed at ensuring the expedient daily and year-round interactions of the building with renewable energies of the environment and incoming solar radiation.

The environment influences the building through thermal effects from outside air, foundation soil, wind, sky, and surfaces facing the building. The wind also has an aerodynamic potential, causing, in particular, the natural air exchange of the building. Energy-saving architecture is aimed at increasing the level of daily and seasonal energy efficiency and creating a comfortable microclimate in the building. Accordingly, architecture serves as the foundation for reducing energy consumption for heating, cooling, ventilation, and lighting, thereby reducing greenhouse gas emissions into the atmosphere.

References


