Main Characteristics of Bioclimatic Residential Buildings

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Abstract. The prudent utilization of energy resources stands as one of the most urgent challenges of the 21st century. A viable solution involves a substantial reduction in the energy consumption of buildings. The inefficient and excessive use of energy for heating and cooling not only burdens the environment but also impacts the financial well-being of families. This article introduces key considerations crucial in the construction of bioclimatic residential buildings. Our primary objective is to organize the factors influencing construction principles and enhance existing residential structures. The article delves into the significance of bioclimatic features, maximizing benefits from geographical and climatic conditions, and the advantages of specific building shapes. We highlight the optimal distribution of internal building volumes, the importance of thermal conductivity coefficients for building materials, heat transfer coefficients for enclosing structures, and the role of thermal storage mass. Additionally, we analyze the significance of selecting an appropriate facade color, leveraging greenery, and utilizing renewable resources. The purpose of this work is to foster greater awareness regarding the use of energy-efficient approaches in residential construction, based on the judicious utilization of renewable resources to curtail energy consumption. Elevating the energy-saving standards of buildings and promoting industrial innovations contribute to effective environmental protection, mitigating undesirable consequences associated with global warming, and minimizing the impact of adverse phenomena and natural disasters.

Keywords: bioclimatic, energy saving, low energy buildings, renewable resources

1. INTRODUCTION

In November 2022, the 2022 Global Status Report for Buildings and Construction was published, revealing that buildings and the construction sector consume nearly 34 % of the total energy produced and contribute to 37 % of the total carbon dioxide emissions [1]. The escalating crises in economics, energy, and climatology underscore the imperative to advance decarbonization and enhance resource efficiency. A highly accessible and easily applicable method, particularly for residential buildings, is the integration of bioclimatic architecture.

Bioclimatic design has existed since ancient times, with its primary goal being the creation of an ecologically and energetically secure home adapted to the environment. Properly implemented, tailored to the local climate and annual seasons, and leveraging natural resources (sun, wind, rainwater, vegetation, etc.), bioclimatic design ensures optimal comfort for residents. This approach can be applied both in the construction of new residential buildings and in the enhancement of existing ones.

The purpose of this article is to present the key characteristics that qualify a building as bioclimatic.

2. THEORETICAL BASIS

2. 1. Orientation, Location and Climate

Considering the geographical location, the position of the sun above the horizon, and the climatic zone of the region, a bioclimatic building is designed to provide the most favorable living conditions while minimizing energy consumption.

Due to the Earth's axis inclination (23.44°) to the plane of rotation around the Sun, the most favorable orientation for a residential building is with its frontal part to the south, particularly when located north of the South Tropic. This ensures optimal solar energy and light exposure compared to other orientations. In cases where south-facing orientation is impractical, the next favorable direction is southwest.

The Earth’s movement around the Sun impacts its energy balance. When closest to the Sun, the Northern Hemisphere experiences winter with shorter days and the Sun at a lower angle. Conversely, during summer when the Earth is farthest from the Sun, days are longer, and the Sun’s rays strike the Earth more directly. Equinoxes mark equal light and dark hours. Understanding these positions is vital for designing a bioclimatic building.

Solar radiation analysis, considering local climatic features, is another crucial aspect in bioclimatic building design. A thorough study of climatic elements, such as solar energy irradiation, daily and seasonal temperature fluctuations, precipitation patterns, air mass direction and strength, altitude, and terrain relief, is essential. By applying the insights gained from this analysis to building structure, glazing, shading, and sheltering, energy consumption for heating, cooling, and lighting can be significantly reduced.

2. 2. Size and Shape of the Building

One way to enhance a building’s energy efficiency for heating and cooling is by optimizing its shape to meet the criteria for maximum internal volume and minimal contact area with the external environment. This approach allows better control of the heat load derived from environmental factors, primarily wind and sunlight.

To identify the most favorable external form, we considered various shapes for a residential building (see Table 1):

A. Rectangular, single-story, with dimensions WxD: 10 m x 20 m and a height of 3 m.

B. Rectangular, two-story, with dimensions WxD: 10 m x 20 m and a height of 6 m.

C. Rectangular, two-story, with dimensions WxD: 10 m x 20 m and a reduced area on two of the façade walls (WxD: 4 m x 10 m) and a height of 6 m.

D. Rectangular, two-story, with dimensions of the lower floor WxL: 10 m x 20 m and a reduced length of the second floor WxL: 10 m x 10 m, with a height of 6 m.

E. Rectangular, two-story, with dimensions WxL: 6 m x 20 m and an additional part on the first floor with dimensions WxL: 10 m x 10 m and a height of 6 m.

Heat naturally moves from areas of higher temperature to lower temperature. To minimize heat, transfer through the building envelope, it’s essential to ensure that the building shape is as compact as possible, aiming for an optimal surface-to-volume ratio of $S/V \leq 0.7$ m-1 [2]. Larger buildings generally achieve a more favorable surface-to-volume ratio compared to smaller ones due to geometric factors; larger geometric bodies inherently have a lower surface area to volume ratio. Moreover, taller buildings possess greater thermal mass, providing additional benefits.

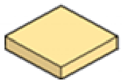
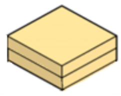
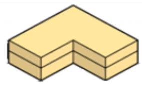
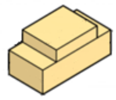
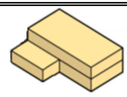
Another crucial ratio is the coefficient of heat loss concerning the shape, which connects the building envelope area (S) to its net floor area (S_{hf}). Using net floor area is vital, assuming that 15 % of the surface is occupied by walls and enclosing structures. The coefficient falls between 0.5 and 5, and a lower value signifies greater efficiency, indicating lower heat losses for the corresponding floor space.

It’s worth noting that an unfavorable solar orientation can potentially be mitigated by adjusting the heat loss coefficient based on the shape. This consideration becomes particularly relevant when planning for future constructions in the vicinity that may obstruct the favorable solar orientation.

2. 3. Layout of Internal Parts

The arrangement of rooms in a home is subjective, but understanding each room’s needs contributes to creating greater coziness, a healthy environment, and thermal comfort. Inappropriate placement, relative to their functional purpose, can result in increased energy consumption and the use of heating or cooling systems in overly warm spaces. Additionally, it may lead to the unnecessary use of artificial lighting when natural light could suffice.

TABLE 1. Comparison between different building shapes

	 **A**	 **B**	 **C**	 **D**	 **E**
Height	3 m	6 m (2 floors)	6 m (2 floors)	6 m (2 floors)	6 m (2 floors)
Width	10 m	10 m	6 m	10 m	6 m
Reduced width	-	-	4 m	-	4 m
Length	20 m	20 m	20 m	20 m	20 m
Reduced length	-	-	10 m	-	10 m
Length of second floor	-	-	-	10 m	20 m
Width of second floor	-	-	-	-	5 m
General heated floor area * (S_{hf})	150 m^2	300 m^2	240 m^2	225 ^{m2}	210 ^{m2}
Shell area (S)	580 ^{m2}	760m2 –	680 ^{m2}	650 ^{m2}	616 m2
Volume (V)	600 m^3	1200 m ^{3}	1104 m ^{3}	900 m ^{3}	840 m3
Coefficient of heat lost relative to form (S/ S hf)	3.87	2.53	2.83	2.89	2.93
Surface to Volume Ratio (S/V)	0.97 m $^{-1}$	0.63 m $^{-1}$	0.62 m $^{-1}$	0.72 m $^{-1}$	0.73 m $^{-1}$
* gross built up area			75%		

2. 3 Layout Of Internal Parts

The arrangement of rooms in a home is subjective, but understanding each room's needs contributes to creating greater coziness, a healthy environment, and thermal comfort. Inappropriate placement, relative to their functional purpose, can result in increased energy consumption and the use of heating or cooling systems in overly warm spaces. Additionally, it may lead to the unnecessary use of artificial lighting when natural light could suffice.

Maintaining an ideal room temperature is dependent on various factors, with year-round consistency being crucial. Studies suggest that the healthiest indoor temperature falls around 21-22°C throughout the year.

Optimal humidity levels in the home range from 40-65% RH. Another critical aspect of home comfort is sound and noise isolation. Regular exposure to sound and noise pollution is a primary contributor to various heart and nervous diseases, which can abruptly impact health.

Ensuring the presence of fresh air is essential for renewing the microclimate and combating indoor pollution. The primary goal of ventilation is to eliminate stagnant air from the premises and replace it with fresh outside air. This process should facilitate air exchange while preventing drafts. Open interior spaces enhance cooling, heating, and ventilation efficiency by promoting adequate heat transfer and air circulation.

2. 4 Building Materials And Thermal Characteristics Of Building Envelope

When choosing building materials, it should be taken into account that the total specific energy consumption for the construction of the building can significantly exceed the specific and energy costs of its heating for the entire estimated service life and the costs of the further utilization of the building.

To reduce environmental impacts, toxic emissions and carbon footprint, it is suggested to use materials that meet at least one of the following criteria:

- materials that can be supplied from nearby locations - this is aimed at reducing transport costs, respectively, of emitted harmful gases. The transportation of building materials is 30% of all road freight.

- materials that, although used once, are suitable for use - during their production, they have already left their carbon footprint and, due to their intact integrity or minimal deviations and injuries, are allowed to be used again.

- non-synthetic and non-toxic materials - natural products, with minimal or almost no harmful impact on humans and the environment.

- waste or recycled materials - those that require minimal processing to make them usable again and with good structural characteristics. After processing, waste products become secondary raw materials.

Choosing such products minimizes construction waste, limits the destruction of habitats and the premature depletion of natural resource stocks.

Since there is a temperature difference between the heated space and the environment, heat energy is transferred from the warmer to the colder place through the enclosing elements of the building under the influence of thermal conductivity. The heat-technical properties of the enclosing elements are characterized by the heat transfer coefficient U and the heat transfer resistance R (see formulas (1) and (2)):

$$U = \frac{1}{R}\left(\frac{W}{m^2K}\right) \qquad (1)$$

The limit values of the heat transfer coefficient U for all elements of the structure are specified in the REGULATION No. RD-02-20-3 of November 9, 2022 for the technical requirements for the energy characteristics of buildings and cannot be higher than them.

$$R = R_{SI} + R_1 + \cdots + R_N + R_{SE} \quad \left(\frac{m^2K}{W}\right) \quad (2)$$

where:

- R_{SE} - the heat transfer resistance of the external surface of the building element
- R_1, . . . R_N – heat transfer resistance of the individual uniform layers in the building element such as plasters, linings, thermal insulation, masonry, etc.;
- R_{SI} – heat transfer resistance of the internal surface of the building element;

The principle of calculating the heat transfer resistance consists in determining the thermal resistance of the individual homogeneous layers of the enclosing element, adding the heat transfer resistances from the air to the surfaces (internal and external) of the element

$$R_i = \frac{d_i}{\lambda_i}\left(\frac{m^2K}{W}\right) \qquad (3)$$

where:

- d - the thickness of the corresponding layer [m]
- λ - calculation coefficient of thermal conductivity for the relevant material [W/mK].

An important rule is that if the coefficient of thermal conductivity λ of the material is not sufficient, this can be compensated by its thickness. All edges, corners, joints and penetrations must be planned and executed with great care to avoid thermal bridging.

2. 5 Facade Coloring

Color is a characteristic tied to the perception of various electromagnetic waves within the visible light spectrum (380-750nm). Each wave possesses a distinct length and frequency of oscillation, following the principle that shorter waves have higher frequency and energy. The color of surrounding objects arises from their absorption and reflection capacities concerning light waves, indicating selectivity in transmitting visible electromagnetic waves.

Research has established that the exterior color of a facade influences internal temperature. Through measurements of surface temperatures using an infrared thermographic camera and simultaneous monitoring of facade illuminance, incident solar energy, ambient air temperature, and relative humidity, there is evidence favoring light-toned facades [4].

2. 6 Natural Illumination

Sunlight is the healthiest lighting for the human body. The use of sunlight is also one of the most important technical solutions for reducing electricity consumption for lighting purposes. That is why the presence of natural lighting in the home is of particular importance.

In order to obtain maximum benefits from building glazing, it must meet several requirements.

Table 2 Comparison between the coefficient of thermal conductivity of different materials **[3]**

Material	Coefficient of thermal conductivity λ W/m*K	Material	Coefficient of thermal conductivity λ W/m*K
Aluminum	230	Plaster dry	0.21
Cooper	380	Polyurethane foam panels	0.025
Concrete (reinforced concrete)	1.7	Polyvinyl chloride	0.19
Concrete (foam concrete)	0.3	Polystyrene	0.082
Cardboard built. multi-layered	0.13	Sand - 20% humidity	1.33
Sawdust wooden dry	0.065	Steel	52
Air	0.026	Glass cotton wool	0.05
Corky planes	0.043	Ordinary glass	1.15
Wave	0.04	Bricks hollow	0.44
Gypsum construction	0.35	Bricks dense	0.67
Wood - boards	0.15	Cement plate	1.92
Stone	1.4	Plaster cement	0.9
Granite , basalt	3.5	Cardboard thermal insulation	0.04

- sizes where the width is greater than the height. Thus, it will be possible to receive more light in the interior during the daily movement (from east to west) of the sun.

- maximum glazing (up to 70-80%) on the southern facade of the building. The number and size of windows should be chosen in such a way that the sun's rays can penetrate as deep as possible into the room at any time of the year (winter and summer). During the winter months, sunlight from the large south-facing windows is absorbed by the concrete walls and floor during the day to be released at night.

- for the eastern (20-30%) and western (0-10%) side, windows that are smaller in size and quantity are recommended. They hardly contribute to the transfer of energy, but are necessary for natural lighting. On the windward side, the number of windows should be as few as possible and of the smallest possible dimensions.

- minimal glazing on the north side of the building. There is practically no sun on this side and the presence of windows is an ideal prerequisite for heat loss. They must be selected to minimize heat loss in winter, but still meet the requirements for daylighting. Attention should be paid to their increased thermal insulation, which will guarantee minimal heat loss. A good option is the use of a combination of white and so-called K-glass (an important requirement is that the K-glass be installed from the inside to the room), due to their specificity for passing short-wave (solar) radiation and retaining long-wave heat radiation created inside the room.

- For windows located in the south, east and west, it is appropriate to use a package including high-energy or so-called "4 seasons" glasses. In the summer, they limit the penetration of sunlight, thus helping to maintain a constant cooler climate in the premises, and in the cold seasons, they keep the heat inside, thus favoring the reduction of heating costs. In addition, let's mention that a mandatory condition is the use of triple glazing or higher for all rooms in the house.

In addition to their lighting properties, the sun's rays can also be useful with the infrared component of their spectrum. They can significantly increase the temperature in the building, which is a desired effect in winter, but not in summer. The control of sunlight is achieved by using shading elements - pergolas, canopies, movable shades, even plant species. With their help, it is possible to control the strength of the sun's rays and the overheating of the premises in the summer with minimal costs.

2. 7 Vertical landscaping

Vertical landscaping involves creating green areas in a vertical plane, incorporating climbing creepers, tall shrubs, and trees. This approach is employed for both decorative purposes and to shield buildings from noise, wind, dust, and overheating. Additionally, it aids in purifying the air within the structure by filtering out harmful emissions and enriching it with oxygen. Moreover, these vertical elements can serve as effective shading tools, deflecting or softening intense sunlight.

Creeping plants planted near the walls of the building will not only decorate it, but also create favorable microclimatic conditions. Planted on the south or east wall, they will regulate the thermal regime of the building and reduce the heating of the walls. Cold-resistant species planted near the north or west wall will act as a kind of insulator, absorbing and reducing air gusts on the building.

For the interior landscaping of walls, moss is most often used. It grows very slowly, requires almost no maintenance care and is an excellent indicator of air quality and cleanliness (eg it dries up when the humidity level in the room is very low). It does not require much light, does not retain dust and odors and helps to purify the air (dust particles are deposited on the surface of the plant, and the bacteria on it process them into biomass). Absorbs sound up to twice as successfully compared to other materials of the same volume and thickness. It withstands high temperatures and prevents the base on which it is placed from burning. Due to its excellent ability to absorb moisture, it can also play the role of a stabilizer - absorbing moisture from the air when the humidity is high, and then releasing it back into the air when the humidity is low.

2. 8 Use Of Rainwater

Harnessing rainwater via specially designed systems is an excellent way to fully integrate a home with natural resources. This practice not only conserves drinking water but also reduces reliance on centralized water supplies.

A cost-effective approach involves installing rainwater collection devices on downspouts. The only prerequisite is that the materials used should be free of harmful substances that may interact with water. The collected rainwater can serve various household purposes.

3. CONCLUSIONS

The incorporation of bioclimatic components in residential buildings offers several advantages for the residents:

- Cost reduction: Better energy management and integration with the environment result in lower overhead costs.
- Optimal thermal comfort: Easier maintenance of internal temperature throughout the year.
- Lower carbon footprint: Reduced greenhouse gas emissions through optimized energy consumption.
- Improved sustainable habits: Promoting more sparing and reasonable use of energy and water.
- Implementation of investment innovations: Utilizing "smart" building installations and renewable energy systems.

The shift of the construction industry towards sustainable development is not only crucial for mitigating climate change effects but also for enhancing the thermal comfort and energy security of households.

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