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PRINCIPLES AND SOLUTIONS OF BIOCLIMATIC ARCHITECTURE ON THE PROJECT OF A FAMILY HOUSE IN KRAŠIĆI, MONTENEGRO

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Abstract

The aim of the presented work is to present the design of a residential house on the Montenegrin coast in the town of Krašići, designed according to the principles of bioclimatic architecture with reference to the systems whose implementation is foreseen during the design process. They refer to the applied measures of reducing total energy consumption, achieving thermal comfort during the winter and passive cooling during the summer. The work shows how solutions such as a green roof, glasshouse, green facade and other solutions are implemented during the design process in order to achieve the mentioned goals. Due to the increased construction of buildings in cities, the need for energy also increases, which is mainly satisfied by the use of non-renewable sources, known for leaving lasting consequences on the environment. Green construction and rational use of energy can contribute to saving resources and preserving the environment. The presented solution of the family house is trying to reduce the need for energy necessary for its efficient use throughout the year through a smart analysis of the location's potential. Coastal architecture, to which Montenegrin architecture belongs, is recognizable by its architecture in stone, stable and authentic. The author's aim is to create a modern house that is in step with the times with its design expressions and applied systems, while at the same time respecting the Mediterranean tradition of building with stone. The family house, in addition to the desire of implementing the principles of bioclimatic architecture, first of all required a well-designed function so that, all together would result in a high-quality space for a family to stay on the attractive Montenegrin coast. Given that almost 90% of the time is spent in buildings, the family house, in addition to the desire to implement the principles of bioclimatic architecture, first of all required a well-solved function so that, all together, it would result in a quality space for the family to stay on the attractive Montenegrin coast.

Key words: *Bioclimatic architecture, Montenegro, Krašići, Sun energy, Sustainable design, Green architecture, Greenhouse, Green roofs, Green facades*

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1. INTRODUCTION

The location intended for the construction of a family residential building is located in the town of Krašići in the Bay of Kotor, opposite the town of Tivat on the Montenegrin coast. The climate in Krašići is characterized by a large number of warm and sunny days, the average temperature in the summer period being around 27ºC (the month of August is the warmest with a temperature of 27.3ºC), with a relative humidity of 61%. During the winter days, the average temperature is around 5.1ºC (the month of January is the coldest with a temperature of 2.7ºC), while the relative humidity is around 74.6%. During the winter, the bay is protected by high hills from strong winds, while during the autumn, southerly winds are present, which bring rain. The corner plot on which the house is planned to be built has an irregular geometry, formed on the north-west and south-west sides by streets, while the other two sides are shared with the neighboring plots. The terrain is on a slope that extends parallel to the longer borders of the plot oriented in the southwest-northeast direction. The plot is positioned in a neighborhood dominated by individual residential buildings, raised to the highest elevation with open views to the sea that stretches to the north and east. The content necessary for the permanent stay of a family of four is defined by the project assignment. A deeper analysis of the climate of this area and the architecture of these spaces defined the functional schemes and the concept of implementation of some of the principles of bioclimatic architecture, so that the house would meet modern high standards of housing, sustainability and energy efficiency. Applying sustainable construction effectively contributes to global sustainability goals, creating prosperous communities, while also stimulating economic growth. Its influence is also directly reflected in the quality of life and harmonizes it with the local climate, tradition and culture throughout the life of the building. When designing, it is necessary to take into account that weather influences, the type of constructive system of the building, then the physical characteristics of the materials used in construction, as well as the AHC systems (air conditioning, heating and cooling) can affect the energy performance of the building itself [6]. Another of the more important reasons for applying sustainable construction solutions and applying bioclimatic architecture solutions is to increase the value of the structure.

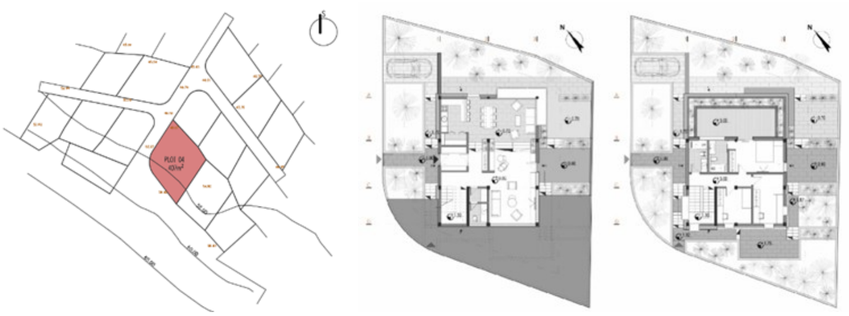
a)

b)

Figure 1. a) Landscape of Krašići; b) Map of Montenegro with the position of Krašići sources: a) https://sh.wikipedia.org/wiki/; b) https://sh.wikipedia.org/

2. THE DESIGN PROCESS

The examination of the site's potential initially refers to the orientation and approaches, while at the same time searching for the best position of the building on the plot, taking into account urban parameters, regulations and terrain configuration. Construction on the slope terrain brings with it the problem of overcoming heights, but also conditions the house‘s shape potential, which must not exceed the prescribed maximum values with its surfaces. In this regard, it is of great importance to correctly set the input data that define the guidelines for the development of the initial idea. The restrictions included a defined building and regulatory line, the maximum development of the plot, the required distance of the building from the neighbors, the maximum height of the same, as well as the minimum percentage of greenery in direct contact with the ground.



a) b) *Figure 2. a) Position of the given plot, source: Author's archive; b) Site plan with the position of the system for collecting atmospheric water*
Source: Author's archive: (Authors: Vukašin Stefanović and Anđela Stevčić)

By adopting the central position of the house on the plot, with dimensions that are in accordance with the permitted values of the parameters, the first outlines of the form in the architectural sense were defined. The basic zoning of contents within the framework of functional schemes implies the long-accepted practice of organizing daily contents within the ground floor, while the first floor is reserved for private rooms. By researching the local architecture of stone houses, research was actually carried out on the topic of designing buildings in areas with a very warm climate. The main task of the architect in such situations is to provide thermal comfort for users who need cooled rooms in the summer and heated rooms in the winter. It is precisely the old architecture of coastal houses that shows how effective the application of massive stone walls is, which prevent heat from entering the interior in the summer, while retaining it in the winter. Old builders also used increased room heights to create pleasant spaces, as well as frequent darkening of windows with blinds and similar elements. Also when the terrain is sloping, it is a common practice to bury certain parts of the house in order to achieve the aforementioned thermal comfort.

The temperature of the earth at a certain depth is a constant 12.2ºC, which is about 8-10ºC difference from the required 20-24ºC, which can easily be replaced by an efficient heating system during winter days.

Houses protected by the earth tend to lose less heat during the winter (the earth is then warmer than the outside air), which means that much less energy is needed to heat the house than for buildings with completely free facade walls, which, together with the carpentry, are responsible for 70% of the heat losses of buildings. Also, the temperature of the earth during the summer is lower than the air temperature, which greatly helps to create a pleasant climate inside the house during hot summer days. Other advantages of burying the building in the ground are soil retention, i.e. the soil can be used for greening the plot and has further benefits in terms of receiving atmospheric water, protecting the house from vibrations and earthquakes, which leads to achieving good sound comfort in the interior. The soil also protects the buried walls from freezing, which can damage the building's structure, and effectively provides protection from wind blows [8].

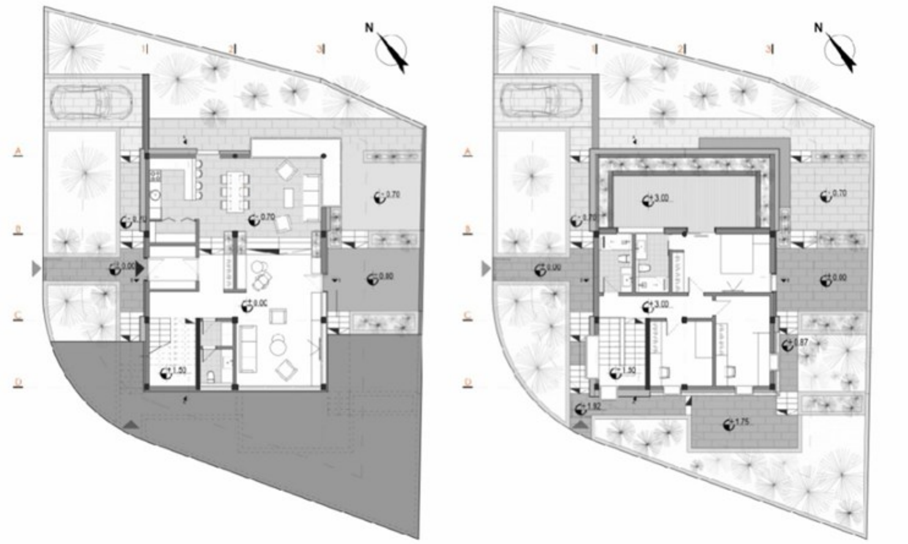


Figure 3. Functional schemes - Ground floor and first floor plans
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

The ground floor was formed in accordance with the orientation and available views, all in accordance with the sloping terrain. The north-east organization of living rooms on the one hand represents a gain, but at the same time a minus that manifests itself during the winter days. Speaking of which, the functional organization and utilization of views requires the organization of daily contents in the north. In order to avoid such a positioning of the main room, a living room is planned in the southern part of the house, partially buried in order to prevent overheating of the interior space during hot summer days. This achieved the positioning of the living room in the south, tucked away by massive walls and earth, while an "extension" was defined in the north, which can be used both in summer and in winter, enjoying the soothing views of the sea. Due to the penetration of views into the deepest part of the house (southern living room), within the base of the ground floor, the height grading of two rooms is applied, which achieves an increased room height of the north-east part, constructively developed in accordance with the slope of the terrain. The southern living room is lit by tall windows positioned in such a way as to bring natural light into the interior but also to avoid overheating the space with the strong southern sun. The slightly overhanging volume of the first floor also helps to form a sharp angle of intrusion of light. As already mentioned, the night area or in another words, private area has been moved upstairs and includes two children's and parent‘s bedrooms, equipped with separate bathrooms. The children's rooms are oriented to collect as much southern light as possible, while the parents' room with a spacious roof terrace faces the sea. The reduced area of the first floor in an architectural sense provides a fine gradation of the mass, the upper cube drawn towards the steep terrain, which dynamically develops the volumes of the house following the fall of the terrain.

Figure 4. Three-dimensional view of the house
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

Figure 5. Three-dimensional view of the house
source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

At the same time, the set-up of the floor together with the base of the ground floor gives the maximum allowed built-up area at the given location. Defined functional schemes and a rough definition of the volume of the building in further elaboration required the refinement of fine architectural details that round off the appearance of the facade planes. The positioning of the openings and their dimensions were adjusted according to the orientation in order to maximize energy gains throughout the year. Also, certain parts of the house receive certain systems of bioclimatic architecture that provide the already mentioned thermal comforts.

The dominant materialization of the house, which emphasizes the load-bearing volumes, is local stone, which, in addition to achieving an appropriate aesthetic impression, achieving continuity of design with the environment, and a pleasant climate in the interior, also reduces the costs of transportation, exploitation, etc. in favor of sustainable construction.

3. ANALYSIS OF THE APPLIED PRINCIPLES OF BIOCLIMATIC ARCHITECTURE

The basic definition of bioclimatic architecture implies a design methodology that, at the beginning of the creation of the solution, thoroughly investigates the natural and created conditions of the site where the construction is planned so that the end result is a building that provides users with all the comforts that improve their quality of stay. Bioclimatic architecture emphasizes sustainability and energy efficiency, so an important aspect is the design of the facade envelope, which ensures a favorable microclimate inside the building, as well as the use of natural materials that have no negative impact on the environment. The goals of bioclimatic design are largely directed towards the popularization of systems that produce energy using clean and renewable energy sources in order to generally reduce the consumption of impure energy sources that leave a carbon footprint.

Some of the bioclimatic design systems were taken from old construction techniques, modernized and placed in today's context of technological innovation, primarily by the application of new materials.

In order for the presented solution of the house to better fit into the climatic conditions of Krašići, the following principles have been implemented that help create a more pleasant microclimate:

1) green roofs
2) green facades
3) natural ventilation – passive cooling
4) glasshouse
5) air collector

The enumerated principles belong to the so-called passive systems of bioclimatic architecture, but the house is also equipped with a system of photovoltaic panels for the independent production of electricity, as well as a tank system for collecting and processing atmospheric water.

3.1. Green roofs

The application of green roofs is not a new concept. Throughout history, it has been used for a long time, starting with certain ancient civilizations, through the Middle Ages, the Renaissance, until today, when the importance of their use in times of global warming is increasingly being recognized. The advantages of using green roofs are multiple, from processing polluted air, improving the quality of atmospheric water, collecting dust particles, protection from noise, positive impact on the human body, etc. The efficiency of green roofs is determined by various factors such as the thickness of the soil layer (a larger layer of soil means better cooling of the interior and greater possibilities in terms of planting different plant species), greenery and its planting density (greenery creates a shadow that has a favorable effect on cooling), climatic elements (precipitation, insolation, relative humidity, etc.). The division of green roofs includes three types: extensive (requires minimal maintenance), simple intensive (requires occasional maintenance) and intensive (requires intensive maintenance). Considering the size of the house and the total surface area of the roof, the application of an extensive green roof is the most rational for the presented project, both from the aspect of maintenance and the cost of construction. For such roofs, a mixture of sedum plants is generally used, which are selected according to local conditions. These are mostly drought-resistant perennial plants that grow in difficult conditions in their natural habitat. Maintenance of the roof involves a year's maintenance and cultivation. This roof design has a direct effect on the coolness of the bedrooms of the presented project, which are located directly under the roof slab, at the same time providing a better integration into the coastal environment.

The use of green roofs can reduce the need for cooling during the summer by 30-100%, while their vegetation can lower the temperature of the roof structure by as much as 50ºC. Due to the aforementioned efficiency, their application can be an excellent way to save energy during summer days in the Mediterranean climate [9]. The importance of green roofs and their wider applications go beyond the needs of individual buildings that can realize certain benefits. Their distribution greatly improves the state of the environment, which has been largely damaged as a result of intensive urbanization.

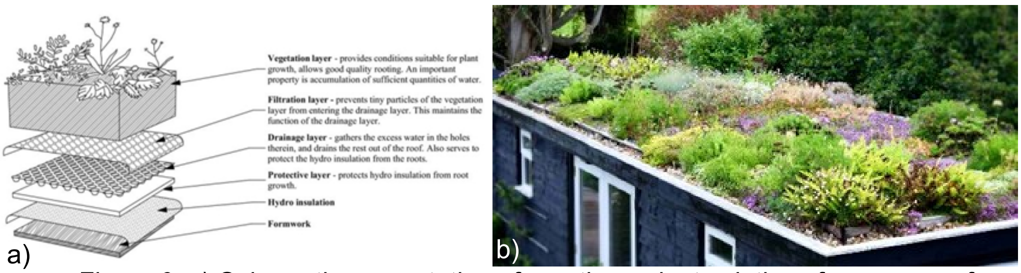


Figure 6. a) Schematic presentation of one the variant solutions for green roof construction; b) An example of a green roof with abundant greenery source: a)https://www.pinuphouses.com/; b) https://herbidacious.calamus.graphics/

First of all, their application is important for mitigating the effect of heat islands, which are even more pronounced in areas where the climate is warm and dry during summer days.

3.2. Green facades

Similar to the roof planes, the walls are starting to be treated with layers of greenery in order to reduce the heating of the space, form picturesque urban views, but also reduce CO2 emissions and form a pleasant climate in urban areas where green areas have been replaced by concrete ones. According to the installation method, green facades are divided into: green facades and living walls. When it comes to green facades, their installation involves planting plants in the ground (base), which during growth climb up the specially designed elements of the structure of such walls until they reach full capacity. The plants used for this type of wall construction are mainly vines and creepers. In order to achieve full coverage, the facade needs 3-5 years for the plants to fully form. Living walls, on the other hand, involve the installation of ready-made panels or modules with planted plants that are placed on a load-bearing facade wall or some other frame structure. In addition to panels, plants can be arranged in bags or boxes. The panels are made of plastic, EPS (expanded polystyrene), synthetic fibers and other materials, depending on the plant species being planted. An important aspect of the durability of such a facade is regular maintenance and nutrition of the vegetation. Green facades have a positive effect on air purification, temperature reduction, noise reduction, creation of a pleasant environment, restoration of biodiversity, but also increase the durability of walls and make buildings more resistant to fire. In the case of the presented solution, the green facade system was applied to prevent overheating of children's rooms facing south and southwest. The warm coastal climate can affect the formation of an overheated space, so a green facade is an effective solution that will prevent this.

Research conducted in an area with a Mediterranean climate shows that green walls can reduce heat load from the Sun by up to 20%, especially if green walls are provided on the east side of the building [10][11]. The facade designed in this way necessitated the use of cantilevered windows so that greenery would not grow around them and prevent the entry of light. This provides children with a healthier space that positively affects their stay and development.

Designing such a facade system brings a new dimension and picturesqueness to the design of facade planes. The construction of green walls consists of a primary (constructive) wall that serves as a base for the installation of a metal structure (which can also be designed independently when necessary) and a space intended for plants that can be planted in cassettes, bags or can be applied as panels on the base (the solution most often used in the interior - Moschito moss panels).

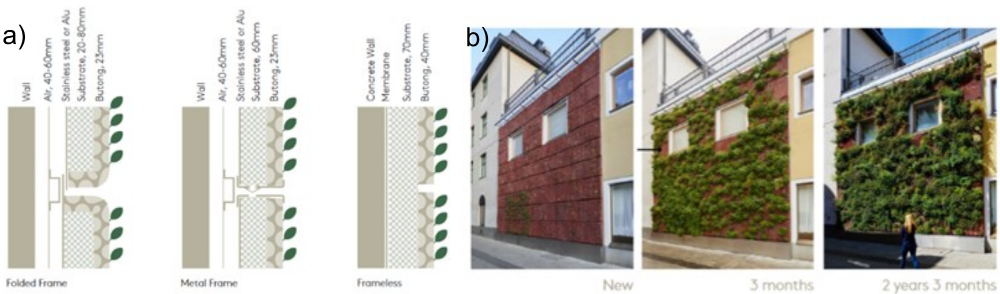


Figure 7. a) Three types of green facade solutions; b) The method of forming a green facade, source: https://butong.eu/

3.3. Natural ventilation – passive cooling

One of the basic conditions for a quality stay indoors is a sufficient amount of fresh air. In order to provide the necessary amount into the interior of the house, and to avoid using mechanical ventilation systems, the use of natural driving forces is usually practiced, as one of the primary principles of bioclimatic design. Natural driving forces are wind, thermal thrust and a combination of their influences. Thermal thrust occurs when there is a difference in density between outside and inside air, caused by a difference in temperature. Due to the formation of the difference, the air from the inside moves to the outside, while the outside air enters the inside. Wind ventilation occurs when there is a difference in wind pressure on the facade of the building, that is, the difference affects the wind entering the building from the side of the facade that is exposed to its impacts, while it exits from the side that is protected from those impacts. The mentioned natural mechanisms can appear independently, but very often they act simultaneously. Thermal pressure mainly occurs in winter, when it is cold outside and the interior of buildings is heated, while the effects of wind are dominant during summer. The direction of the air flow through the house depends on the position of the external and internal openings and other partitions of the internal space. Knowing the principles of movement and exchange of external and internal air, we can recognize the following methods of natural ventilation. The division implies one-sided and two-sided ventilation or chimney effect. One-sided ventilation takes place through openings that are defined on only one side of the building, and in order to be effective, the optimal depth of the room must be 2-2.5 times greater than its room height. On the other hand, double-sided ventilation requires the opening of the facade on two opposite sides so that the air can move.

Practically, double-sided ventilation is the already explained principle of wind movement, the efficiency of which increases if the depth of the room is about 5 times greater than its room height. The chimney effect is mainly used in buildings with higher floors compared to family buildings and works according to the principle of air removal through drains positioned on the highest level of the building, while fresh air enters the interior on the lower floors through ventilation ducts. In order for this principle of ventilation to be effective, a height difference is needed between the air intake and exhaust openings, but it can also be improved by increasing the room height of the rooms, introducing an atrium or increasing the slope of the roof planes if the flat roof solution is not applied. The openings in the presented project of the family residential building are defined in such a way as to enable the movement of air in several directions. By opening all sides of the facade, cross ventilation is enabled, which effectively cools the interior. The warm air of the ground floor moving upwards is discharged through the roof dome above the staircase and other openings when necessary [2].

3.4. Glasshouse

The glasshouse concept appeared in the seventies, as one of the new solutions that can help users to live in harmony with nature in their homes, along with other sustainable systems based on passive energy gains. There are several ways of designing it. It can be solved as: 1) window 2) loggia or balcony 3) independent 4) attached or extended 5) partially built in or integrated 6) fully built in or atrium. The glasshouse belongs to the systems of indirect gains and can be combined with different wall partitions in order to maximize its performance depending on the function and the need of the space. In this specific project, the position of the plot, the orientation and the opening of attractive views determined the position of the glasshouse oriented mostly to the east, so that it captures a small part of the south. The gains from the eastern orientation are not the same as from the southern side, but they are not negligible. The glasshouse space is designed as an air space between transparent glass partitions that do not block views in winter, but still generates a certain amount of warm air that helps heating the spacious space of the ground floor. In the architectural sense, it becomes an important part of the design, which defines the architecture of the ground floor in harmony with the first floor in the part where the green facade is designed. The window-glasshouse solution can be used in children's bedrooms.

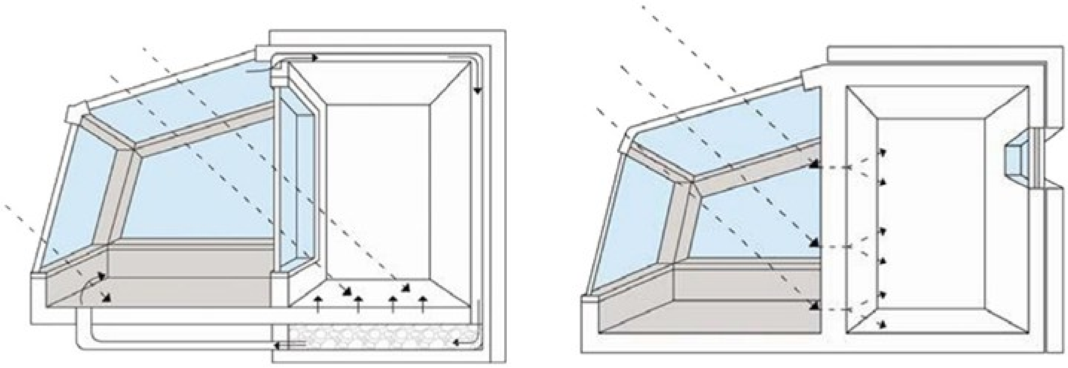


Figure 8. Two variants of glasshouse functioning, source: Lectures on Bioclimatic architecture I (Professors: Miomir Vasov, PHD and Veliborka Bogdanović, PHD – Faculty of Civil Engineering and Architecture, University of Niš)

In a similar way as on the ground floor, the window boxes, which due to the cantilever overhang have a larger volume, can be closed with another glass partition from the inside so that the air space is directly heated in winter under the influence of the Sun and then heats the room. Cantilevered windows have become a characteristic detail of the design of the house [2].

Figure 9. Three-dimensional view of the solution - Glasshouse detail source:Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

3.5. Air collector

Often in sloping terrain, it is possible to build buried rooms under the houses in order to form an air collector. In this case, the installation of a tank for collecting atmospheric water required digging below the dimensions of the ground floor, so the unevenness of the level was used to build a double slab at the level of the foundation in order to provide space for servicing the mentioned system.

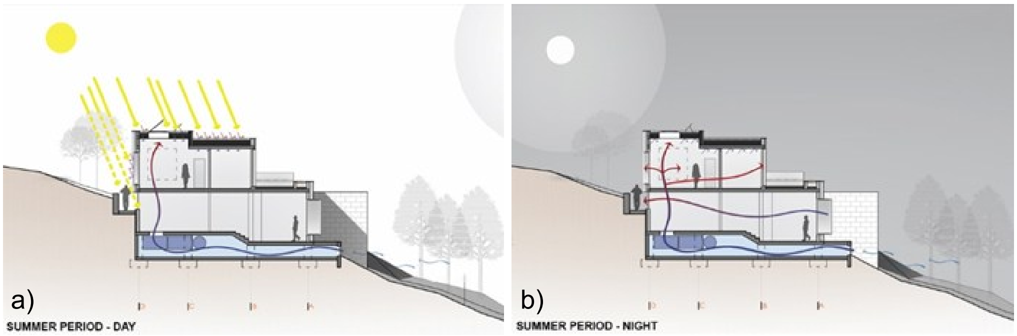


Figure 10. a) Scheme of fresh air movement during summer days - Passive cooling and air collector; b) Scheme of fresh air movement during summer nights - Passive cooling and air collector source: Author's archive (Authors: Vukašin Stefanović and Anđela Stevčić)

The same space is used to direct the air coming from the sea, it is cooled in a chamber where the temperature is lower due to its installation in the terrain, and it is further distributed to the rooms on the ground floor through the floor openings. In this way, the circulation of fresh air through the house is completed. If necessary, the external openings, as well as the internal floor openings, can be closed. The system was implemented as a modification of the old ventilation systems used in Africa and Eastern countries, which function through a network of underground tunnels that direct the air through "wind catchers" [2].

4. CONCLUSION

Bioclimatic design implies much more than the mentioned principles, which can be seen in the large projects of advanced architectural practices in the world. The beginning of such design is not the analysis of location and impact, but it starts with creating the sense for awareness of the importance of environmental preservation, from which comes the way of solving needs through sustainable solutions. The presented solution is a response to the modern requirements of functionality, healthy space and preservation of the environment, which created a "machine for living" with a significantly reduced negative impact on the environment. Returning to the old construction methods combined with modern and clean technologies can be a solution in the fight against invasive construction that is not in harmony with nature. The importance of maximum utilization of the location's potential where the construction of the facility is planned and the implementation of solutions based on the obtained data certainly brings great savings during a longer period of use of the house, even though the initial investments are higher. It is especially important that principles such as air collector, natural ventilation and greenhouse represent completely clean methods of bioclimatic design.

The key to transformed cities and implemented systems is probably the education of new architects who must develop environmental awareness and literacy so that in the future they will be in a position to insist on the implementation of such solutions in order to realize the idea of sustainable use and development.

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