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Energy efficiency features of vernacular house in Bosnia and Herzegovina: A case study of Svrzo's house complex

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Abstract

This paper analyzed sustainable principles of vernacular architecture in Bosnia and Herzegovina featured in the Svrzo's house complex in Sarajevo, which can serve as an example that can be utilized in contemporary architecture. An energy-efficiency analysis was performed by using DesignBuilder software. The aim was to investigate whether the building design, building's envelope materialization, and spatial organization comply with today's energy-efficiency standards and if such principles can be applied in contemporary design. The calculation of the energy demands for heating and cooling showed that the division of the house in winter and summer quarters is an energy-efficient approach that could be transposed into contemporary architecture. The calculations also showed that the materialization of the building envelope of the winter quarter is not energy efficient enough to be used in modern constructions, but the positive aspects of the building envelope materialization such as the use of natural, local materials with good heat capacity are important elements which could serve as guidelines for the materialization of contemporary buildings. Therefore, a new materialization was proposed on the basis of these principles. The calculations showed that the analyzed winter quarter became energy-efficient while maintaining sustainable principles borrowed from vernacular architecture.

Keywords: Sustainable design, Vernacular buildings, Natural materials, Energy efficiency, Contemporary architecture

1. Introduction

Through the ages, urbanization has been characterized by significant modifications, variations, and growth patterns, both in the spatial and social forms of cities, and still intensive growth of global urbanization is evident, supported by the estimation that by 2050, around 86% of the population of developed countries and 64% of the population from developing countries will live in cities [1]. Based on the dynamics of urban development, cities can be considered one of the greatest achievements of human civilization, but on the other side, they can also be seen as "humanity's most complex creation" [2]. The rise of population growth and emigration in the cities is the expected outcome, because a city, attractive with its lifestyle arrangements, basic urban services, and consumer goods, generally provides better opportunities for living, advancement, and development compared to rural areas [2, 3]. Urbanization of rural areas became a need due to the growing number of people and their needs, but also it led to the densification of cities [3].

However, every advantage that the city contains can also become a weakness [1], meaning that at one time, urbanization became a burden for cities, through increasing demands from the aspect of expanding the global space for the accommodation of residents and industrialization processes [1,4,5]. As it is described in [6], although cities are "energized crowding" places that generate growth and change, at the same time, according to the urban economist Edward Gleaser, are described as "the absence of physical space between people and companies; proximity, density, closeness" [7].

Economic considerations and activities in most cities are largely influenced by the shape of their structure, dominating the decisions regarding their processes of growth [4]. Population density, promises, opportunities, and productivity followed by the growing demands of the modern lifestyle and technological development, required that contemporary architecture in the urban settlements had to respond to it in the modern context, by suppressing the principles, approaches, and practices of traditional builders [4, 6, 8]. Under the surveillance of modernism and its subsequent demands, the growing disconnection from nature is evident, leading to the change of construction ideology towards natural surroundings [4, 9].

Regarding the negative changes that cities brought to the environment and to the city's inhabitants, it can be reflected through the example of the transition from vernacular to contemporary architecture. Construction ideology that was once in the context of harmony with the environment, humans, and culture of living, was soon replaced with the paradigm of designing new constructive "*artifacts*", and following infrastructure, described as "higher than mountains, with roads wider than the sea, yet crowded and congested" [4]. Parameters that had an important role in achieving building design harmonies, such as the orientation of the building, topography, sun, and wind orientation, were soon in the shadow of the innovative artificial controlled environments. Although the new building materials were suitable for the design and construction of high-rise buildings, on the other hand, they were incompatible with the environment and climate of the region [10]. Vernacular buildings, as an architectural heritage, were marked as a sign of poverty under the spotlight of modernism, although they survived through centuries due to their design and technical principles, which worked in harmonization with nature [10, 11].

Such shiny glazed facades reflected the dynamics of a hectic lifestyle and the reflection of green surfaces, which deceptively gave the impression of an achieved balance between the natural environment and the concrete jungle. As Stanislaw Lem [12] said "behind every glorious façade, there is hidden something ugly" in a less visible way, the burden of such gloriousness is paid through the high cost of increased environmental pressure and concerns – the rise of urban ecological footprint, increased fossil fuels use, deforestation and changes in land use, waste, and pollution [2,9]. High-rise buildings have led to higher energy consumption because it was not an important design criterion; on the contrary, the major consideration was the visual representation of the building design, and the buildings seemed in the end "both physiologically and psychologically inhospitable" [13]. The quality of life is still gradually worsening due to unbalanced and unplanned urban development, and excessive consumption of limited resources, leading to increased pollution in many segments. Values have breached the quality standards and led to environmental issues, resulting in a failure to comply with "obligations", necessary to prevent the degradation of the life quality in the cities [14].

As Sim Van der Ryn and Stuart Cowan describe: what do we learn from this kind of 'nowhere' environment? When living and working in nowhere places becomes normal, it is no wonder that we literally lose some of our sensitivity toward nature. Through the daily experience of the designed environment, we learn detachment… As nature has receded from our daily lives, it has receded from our ethics [15].

In recent years, there has been a significantly increased concern regarding the pace of modern life, constant reference to energy and climate needs, and financial and energy crisis, which altogether have led society to reconsider environmental, energy, and economic aspects of life in the cities, regarding the emissions of pollutants, energy consumption and building operating costs [5]. To find solutions that would effectively reduce and/or eliminate the negative and challenging sides of life in the city and maintain an equilibrium with nature, the imperative is for the cities to develop an adequate system to deal with the consequences brought by urbanization, focusing on the identification and implementation of aspects that could lead to an increase of the overall quality of the urban environment, contributing to people's mental and physical well-being [1, 14, 16]. Such strategies, if integrated into the urban framework, could include the implementation and adoption of energy-efficient techniques by integrating appropriate design interventions that would have a crucial role in achieving the sustainability of the cities in the future [1, 2].

In this work, sustainable features of vernacular residential architecture in Bosnia and Herzegovina (B&H) will be analyzed. The focus is on the traditional house complex, and one of the most representative, well-preserved examples of local traditional architecture from the Ottoman period is Svrzo's house, located in Sarajevo, B&H. Two aspects have been analyzed. First is the investigation of the presence of sustainable-bioclimatic criteria in the chosen case study, such as location and orientation of the object on the site; building form; use of local building materials with good thermal performance; courtyard and following bioclimatic elements (water and vegetation); passive systems for cooling and natural-induced ventilation; respecting the right to view and privacy. The second aspect is the energy-efficiency analysis of the Svrzo's house, with the aim to evaluate the annual energy consumption and actual average heat transmission values for all building envelope elements, and to estimate the efficiency in the context of energy-responsible design. The analysis will show if such traditional building design, with its concept in the context of sustainability, can be utilized in contemporary architecture, as a method for solving modern challenges of urban settlements (energy-inefficient construction, environmental pollution, urban heat island, lack of thermal and visual comfort, etc.).

1.1. Vernacular architecture in the context of sustainability

One approach that can contribute to regaining pro-environmental behavior that would further promote and strengthen a sustainable future and society, by rising the significance of the human-nature connection, is through exploring how can architecture contribute to the fostering of that connection [3]. It is challenging because architecture is seen as something that has destroyed many natural environments through urban development, thus leading to the question of how something that takes away natural spaces can again reconnect with them. What is indisputable is that behind the "façade" of city lifestyle, as a physical barrier that has seemed to divide humans and nature, there is still an "ingrained desire to connect" to the natural world; nature is an important part of human development that has been proven to contribute to "well-being, health, and cognitive development" [3, 17].

Building, as a place of residence, should not just be considered as a physical space, a shelter to just fulfill physical needs, but also as a space that responds to "individual's social, cultural and emotional needs" [17]. The core of that holistic approach lies in the design process which should consider all the important parameters during the life cycle of building use, from energy, building form, construction processes, and materials. As such, the principle of sustainability in the bioclimatic concept should be based on a comprehensive approach, with the aim of achieving practical solutions that are livable for future generations and not represent solutions that only satisfy immediate needs [18, 19]. Past architectural design strategies recognized the importance of the human-nature relation, by respecting bioclimatic principles and transferring them into the architectural context, known as vernacular architecture [3]. Its principles are supported by its origin, from the Latin word *vernaculu*s, meaning native, domestic, indigenous, and vernacular architecture can be defined as "local investigation of a building" or "a type of local or regional construction, using traditional materials and resources from the area where the building is located" [20].

Geographical features, traditions, and culture of every region have a great influence on building design, therefore vernacular buildings represent a valuable heritage that should be well preserved and kept [23]. Building forms are simple and easily integrated in accordance with the lifestyle, culture, climate, and physical conditions of the community, establishing a harmonious relationship between architecture, natural parameters, and people. Builders, listening to the needs of the environment, adapted the design concept to inevitable changes under the influence of various ecological, social, and economic factors while respecting bioclimatic principles [21, 23]. Vernacular architecture involves the values of today's sustainable architectural principles, defined as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" [17, 24]. The common goal of these practices is to provide solutions in environment-friendly constructions, without denying tradition, simultaneously creating a new long-life architecture in accordance with modern human needs and requirements, and is compatible with surrounding conditions [17, 25].

As bioclimatic components in the architecture designing process are considered to be a critical concept for achieving the sustainability of contemporary buildings, the same can be recognized in the applied design principles in most vernacular buildings, through the understanding of climatic parameters of the site, including the choice of location, built-form orientation and configuration, typology of the settlement, enclosure design and façade, utilizing environmental sources such as wind, solar radiation, temperature and humidity and landscaping [20]. Vernacular, as a traditional architectural language, tended to achieve durability and versatility of its design, in the environmental context, with a tendency to use available resources and materials that are climate responsive, from the nearest environment, and by utilizing traditional technologies, structures were adapted to "the seismic, geographic and topographical features, as well as to local climates" [17]. Following bioclimatic elements in architecture from the aspect of achieving a sustainable design process, optimal internal comfort conditions can be achieved by using preferably architectural elements and avoiding complete dependence on mechanical systems, while reducing energy demands for electricity [18, 19].

Along with technological global development, the contribution of the sustainable aspect to architectural design is growing in parallel and as a contribution to it, many examples of traditional buildings across the world serve as "living" exhibits for revisiting the past in order to understand sustainable architectural design principles of vernacular architecture [27]. This design philosophy, which is actively propagated today, within the framework of sustainable development, considers three important elements: maximizing the quality of the building environment, especially from the aspect of energy efficiency and energy conservation, minimizing the impact on the environment, and giving the attention to human health and comfort [18].

The right approach is to learn from the past, based on "the wisdom and experience of society, and the norms […] being appropriate to its built environment" [26]. All the good traditional principles can be transposed into the new contemporary models, with respect for traditional principles, the existing environment, and its values, while taking care not to compromise aesthetic representativeness and whereby contemporary architecture must be in the spirit of the time in which it is created [10, 22, 28]. In the process of transferring vernacular knowledge and sensitivity (practice) from our past to present, and from present to future generations, relating to the physical structures of the buildings (their tangible assets), the importance of reviewing, analyzing, and revealing the relations of traditional settlements with nature and passing this knowledge to the future, change the way of building design with deep respect to connecting to rather than disconnecting from nature [25]. Inspiration could be found in the excitement of providing possibilities to integrate sustainable architecture principles based on the experience and norms of the past centuries, while others could find inspiration in the deeper insight of "the philosophy, the environmental and humanistic approach behind it" [17].

2. Research methodology

Today, meaningful designs of vernacular architecture and unique heritages [29], which have preserved their prominent, recognizable features for centuries can be found in Bosnia and Herzegovina. Certain rehabilitation measures have been implemented, with the aim to be effectively used and witnessed as an expression of a specific architectural culture. Most of the traditional houses in B&H, that are still standing, were built during the 18th and 19th centuries, partly as a consequence of the common use of organic traditional materials, particularly wood, and infill made of adobe brick [29].

One of the most representative and authentic examples of residential architecture from the Ottoman period, a well-preserved 18th-century Svrzo's house complex can be found in Sarajevo, the capital of Bosnia and Herzegovina. Due to its significance that contributes to the richness of the history of vernacular architecture, the Commission to Preserve National Monuments designated the Svrzo's house complex as the National Monument of Bosnia and Herzegovina. Bosnians appreciated the Ottoman period as it reflected the prosperity and great achievements, perhaps because Sarajevo formed new and specific architectural forms of settlements and residential culture that were the combination of the experiences from the East and the local needs [29, 30]. Sarajevo's oriental architecture can be clearly explained from the description view of the famous architect and town planner Juraj Neidhart, "he saw the panorama as marvelously harmonious, calm and all-embracing – the very image of an old civilization. Referring to this, he reiterated that overall, the urban landscape appeared as a unique higher form, which he concluded was a result of local people's nature connectedness" [31].

The main purpose of this paper is to analyze the vernacular residential architecture in B&H and its principles from the aspect of sustainability, indicating the significance of integrating the concept of the vernacular architectural elements through the implementation of energy-efficient design strategies in modern building concepts. The sustainable elements of the vernacular Svrzo's house complex in Sarajevo were also analyzed, serving as an example that can be utilized in contemporary architecture as a method for solving modern challenges such as the absence of care for the environment, energy-inefficient construction, environmental (air and noise) pollution, all the factors that represent a major challenge today in urban areas of B&H. The performed analysis can be divided into three parts.

In the first part, an analytical-historical analysis was performed to address the challenge of contemporary architecture and the significance of the vernacular architectural concept by respecting the inter-relationship between humans, nature, climate, and local surroundings. The emphasis is on the evaluation of sustainable and bioclimatic features in vernacular practices, regarding the use of natural, local materials, construction characteristics, orientation, natural ventilation, and greenery, according to the local climate and topography.

The second part of the study involves an energy-efficiency analysis of the selected vernacular residential building by using a white box software tool, DesignBuilder, which is an interface for EnergyPlus Simulation Engine, to evaluate the annual energy consumption, for the estimation of the efficiency in the context of energy-responsible design. The aim has been to investigate if the construction, building's envelope, and spatial organization satisfy today's energy-efficiency standards and if such structure can be applied in contemporary design. For the selected case study, based on the complement data and layout drawings obtained from the observation of site location and study literature, a detailed survey was conducted regarding the presence of sustainable design principles, such as construction characteristics, the use of local materials, orientation, building layout and form, natural ventilation, bioclimatic elements such as water and greenery. In the third part, the aim has been to design structures that respect vernacular sustainable design principles, while meeting modern needs.

3. Significant features of vernacular architecture in B&H – *mahalla*

The foundations of what is now understood as the Bosnian architectural and cultural tradition, in particular when it comes to residential architecture, originate from the time when Bosnia was ruled by the Ottoman Empire. One of the historical traditional structures that were significant due to its conceptualization from the Ottoman period was the *mahalla* [32]. Followed by its meaning "to occupy" or "to settle", it represents a micro district, that "helps people live in peace and harmony and determines the culture and life of its inhabitants" [33], or today, recognized as neighborhoods in large cities. Such a relationship had a much deeper meaning than just urban settlement, preserving the closeness of the citizens, harmony, and discipline of life in the city [34].

Sarajevo's *mahallas* represent residential neighborhoods and peri-urban settlements developed on the slopes of the mountains that surround the city [35]. Harmony with the topography was achieved by following the contours of the slope, providing a wide view, sunshine, and intimacy. Each *mahalla* consisted of one main street, with several smaller winding streets, or *sokaks*, branching off on both sides, where were entrances to the houses with courtyards [36]. Considering the architectural experience of the space in these vernacular residential examples, the combination of architecture and nature by greenery and water, in both utilitarian and aesthetic roles, has a significant dimension in the construction of this era [37]. Environmental compatibility of traditional Bosnian individual houses is established by using local materials, respecting climate, and meeting residents' needs [38]. Figure 1 shows the layout of the *mahalla* on the slope of the mountains in Sarajevo, and Figure 2 shows the view of the *sokak* in the *mahalla*. Figures are taken from the Historical Archive of Sarajevo.

Figure 1. The layout of the *mahalla* on the mountain slope in Sarajevo [38]

Figure 2. View of *sokak* in the *mahalla*, surrounded by high, white walls in Sarajevo [38]

Two sequences play an important role in viewing the space - the access, or entrance sequence, and the internal sequence. From the street, the houses blend into the ambiance and form an integral part of the *mahalla* [36, 37]. The entrance sequence is the physical boundary between the built and unbuilt environment that manifests itself through a gate, door, portal, etc. For the visitors, the house is hidden and protected from outside views by a high white wall with a characteristic courtyard door and a protruding dock [37]. The access sequence has the task of making the visitor interested in the object, referring to the curiosity about what happens behind the walls. The interior sequence defines the interior of the architectural object or the shape and relationships of the environment [37].

Organizationally, a typical Bosnian house from the 17th century consisted of five main elements, with an accent to the differentiation between the private and public "zone": a tall wall that faced the street and had a purpose to differentiate private from the public, a courtyard usually built of pebble or stone for easier maintenance, an outdoor fountain (*šadrvan*) for hygienic purposes, a lower level "semi-public" private space, winter floor, called the *hajat* where the family would gather, and the *divanhan*, an upper-level semi-private/private space, summer floor, used for relaxation and enjoyment [26,30]. Every individual house in the *mahalla* was built in a way that does not obstruct the view of the neighbor's residential unit and the wall was not exclusively in function of separation, but to bring together the earth – sky and to open the house to the sky through the courtyard and the free view that is sought to be achieved in all its parts [36].

Courtyards are an integral part of every house in the *mahalla*, and the necessity to "protect" the intimacy of the house from the outside emphasized the need to enrich it with nature [26]. Utilization of the microclimate elements such as wind, sun, vegetation, and local breezes, inspired the architectural landscape design, such as the indispensable parts of the courtyard – a fountain with a stone trough, stone pavement, wooden materialization, and greenery, creating a comfortable, pleasant, and healthy microclimate environment for a living [37]. The conceptual approach that nature is an important part of the architectural composition, and that the house must be inseparable from nature, has led to the effort to find the best possible views, to value and preserve every tree, and to effectively use the orientation and the sunny side of the location. The design of the houses was primarily conditioned by the location, therefore, each design is different, but similar due to the identical materialization and formative motives [39]. The external shape of the house is characterized by cubic forms, gently sloping roofs made of stone slabs or tiles, unornamented walls, loggias, verandas, courtyards, and *doksat* (protruding part of the house), which form a rich and dynamic facade. The materials most frequently used were wood and adobe brick [40].

Such houses, with a tendency to achieve a balance of aesthetics and function, through the relationship between the architectural object and nature, represent an important part of the heritage of Bosnia and Herzegovina [37]. The house exuded lightness and imagination and it was adapted to the needs of people and their relationship to nature, the social environment, and themselves [41]. The entire complex was built exactly according to the needs of the way of life at that time [37]. Even today, in most cities in Bosnia and Herzegovina, the large number of architectural monuments that were preserved, belong to the classic Ottoman style, expressing oriental physiognomy due to their architectural and urban characteristics [42].

Due to the growing demands of modern life, which differed in many aspects compared to the past traditional lifestyle, the tasks of architects of this time are more complicated due to the concerns regarding architectural uncertainty and careless design "in which the design parameters and priorities of just some years ago are no longer valid and have to be revised, reordered or redefined" [5]. Reinterpretation of vernacular features such as described in the example of *mahalla*s, as a form of a connection with nature through passive design strategies and bioclimatic approaches, such as architectural design, building orientation, building envelope, natural local building materials and landscape elements such as greenery and water, can be transposed into contemporary architecture, providing optimal solutions for environmentally friendly, sustainable architecture [39].

4. Analysis of the case study – Svrzo's house complex

Svrzo's house complex in Sarajevo has been selected as a case study building for the evaluation of the energy efficiency of vernacular houses from the Ottoman period in Bosnia and Herzegovina. The construction works on the house started in the 17th century and it was completed in 1832. The Svrzo's house complex is well preserved and represents one of the valuable national monuments of Bosnia and Herzegovina. The house was owned by the Svrzo family until 1952 when it was sold to the Sarajevo Museum. It was then refurbished to serve as a museum building. The housing complex looks modest from the street view and very luxurious behind the high wall that separates public space from private living space.

This typical Ottoman residential architecture and this type of residential architecture are in accordance with the way of life at that time [37]. Integration of nature and water in residential architecture is another important part of the tradition, therefore the houses were not built where there were no trees. The ancient builders showed their respect for nature in a way that they tried to preserve every tree in the location, which can be clearly seen in the Svrzo's house complex.

This house is a great example of bioclimatic vernacular architecture in Bosnia and Herzegovina. Sustainability is reflected in spatial concepts, the orientation of the building, using natural and local materials, passive cooling, and natural wind-induced ventilation. To evaluate the energy efficiency of this concept of housing, energy demands for heating and cooling will be examined, considering the seasonal spatial division of the housing complex.

4.1. Location

The selected house complex is located in Sarajevo in Glođina Street (*mahalla*) which managed to preserve its most authentic appearance to this day. The location of the Svrzo's house complex is shown in Figure 3 and Figure 4. The housing complex has been built on a slope with respect for the neighborhood and with respect for nature. Also, the orientation towards the sun was very important in planning the construction concept. The house concept is adapted to the climatic conditions of the location.

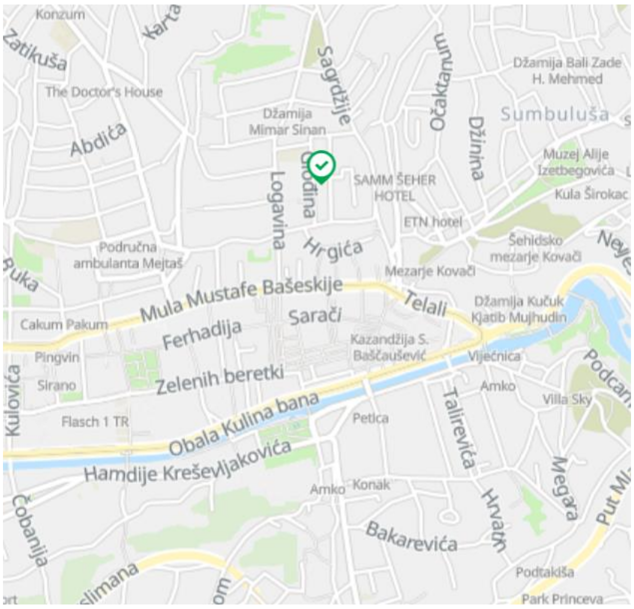

Figure 3. Topographic map of Sarajevo with marked location of the Svrzo's house complex [44]

Figure 4. The main entrance to the Svrzo's house complex from *sokak* (Source: authors)

Sarajevo has a moderately continental climate. The average annual temperature for Sarajevo is 12.5°C. Meteorological data needed to calculate the building heating and cooling energy demands have been obtained from Meteonorm. The software Climate Consultant was used for the graphical presentation of the data obtained from Meteonorm.

Figure 5 shows the monthly temperature range, while Figure 6 shows average temperature values and solar radiation values for Sarajevo. The heating period (October to April) is significantly longer in Sarajevo than in the cooling period.

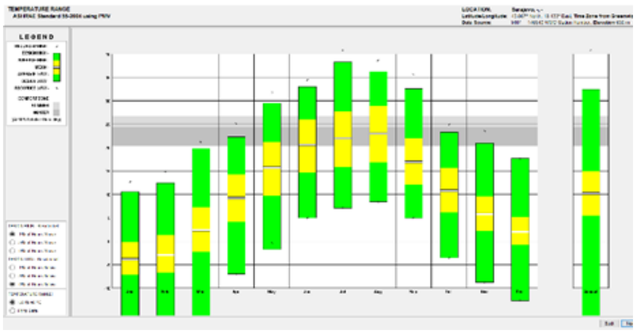

Figure 5. Monthly temperature range for Sarajevo (Source: authors)

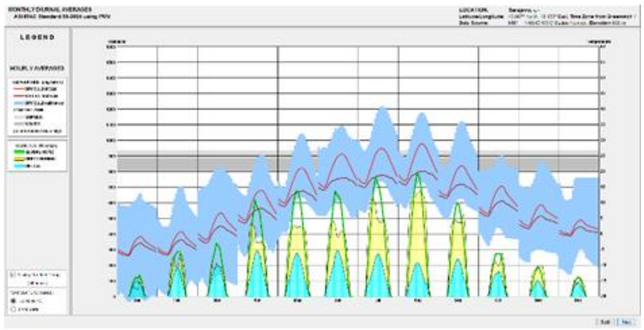

Figure 6. Average temperature values and solar radiation values for Sarajevo (Source: authors)

4.2. Spatial concept

The primary concept of spatial organization is a three-space division into a closed area, a semi-closed area with courtyards, surrounded by a high stone wall, and an open garden area. This type of spatial division creates intimate interior spaces hidden from the street which represents a harmonious unit of closed spaces imbued with the open spaces of gardens and cobbled courtyards where contact with nature is a basic rule of traditional housing (Figure 7). Fountains and wells are also an important part of the spatial composition, as shown in Figure 8. This all creates a humane and very pleasant living environment where human needs come first. The spatial disposition was carefully considered to fulfill the needs of family life in the most quality way and in accordance with the life philosophy of the given time.

Therefore, the spatial organization in a horizontal sense is based on the division into the men's part of the house called *selamluk* (Figure 9), and the women's intimate part of the house called *haremluk* (Figure 10) with the associated courtyards, while the ancillary spaces are functionally separated from the residential part of the house.

Figure 7. Cobbled courtyard with fountain (Source: authors)

Figure 8. Garden with a well (Source: authors)

Figure 9. *Selamluk* with courtyard (Source: authors)

Figure 10. *Haremluk* (Source: authors)

In a vertical sense, the housing complex is designed on a twofold principle: the winter quarter is geometrically solid, made from thick adobe brick walls, located on the ground floor, and the summer quarter is made of light *bondruk* construction filled with a thin layer of adobe bricks, located on the upper floor, where closed and semi-closed spaces intertwine. The ground-floor plan and the first-floor plan are given in Figure 11 and Figure 12.

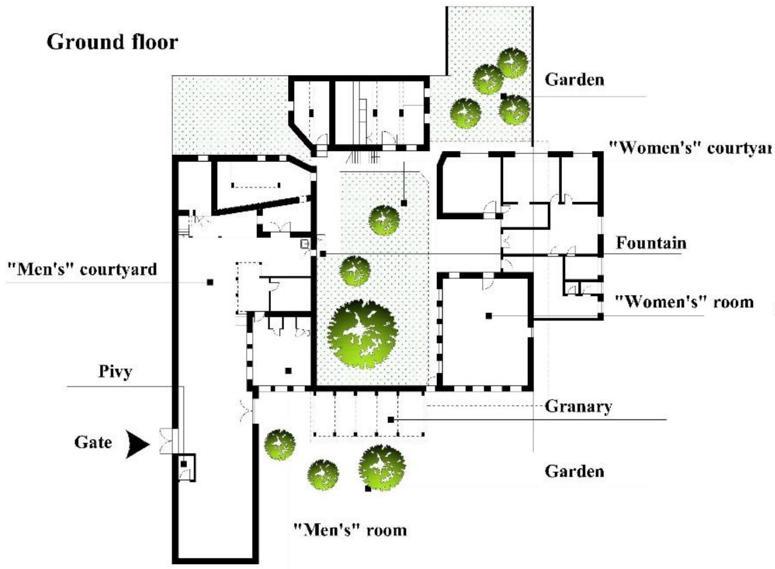

Figure 11. Ground-floor plan (Source: authors)

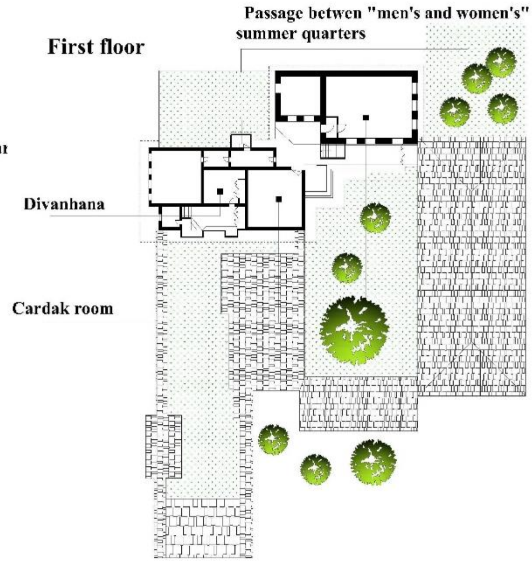

Figure 12. First-floor plan (Source: authors)

4.3. Envelope materialization

The materialization of the envelope differs in the winter and summer quarters of the house. The winter quarters of the house are built using adobe bricks, reinforced with tie beams. Massive adobe brick walls have a good heat capacity [45], which is an important characteristic of building materials during the winter to release absorbed heat from the sun and heating during the day slowly into the room during the night. Also, the smaller windows in the winter quarters of the house contribute to heat loss reduction. Massive adobe brick walls allow the stationary flow of water vapor in the parodifusion process and prevent water condensation in the layers of the walls. The summer quarters of the house are made of thin, light, half-timbered walls, with adobe brick infill [46]. In contrast to the walls in the winter quarters of the house, the walls in the summer quarters of the house have much less heat capacity, therefore they provide fast cooling over the night.

Numerous large windows in the summer quarters of the house, through careful disposition, are enabling cross ventilation through the opening windows at the same time over the house during the night in the summer. Semi-closed spaces further contribute to the wind flow through good cross ventilation (Figure 13). *Doksat,* the protruding part on the upper floor of the summer quarters of the house, is made of wood planks, as shown in Figure 14.

Figure 13. Semi-closed space in the summer quarters of the house (Source: authors)

Figure 14. *Doksat* overhanging the street (Source: authors)

The external walls of ancillary spaces are massive and made of stone, as can be seen in Figure 15. The ceiling construction toward the attic is made of half logs filled with clay. The floors are made of deal planks placed on a compacted clay base [46]. All roofs are sloped with deep roof eaves which provide sun shading during the summer and prevent indoor places from overheating. The roof construction is a wooden roof frame, while the roof covering is made of hollow tiles, Figure 16.

Figure 15. Ancillary room with massive stone walls (Source: authors)

Figure 16. Sloped roof with hollow tiles covering (Source: authors)

All windows have wooden frames and single glazing. In the summer quarters of the house, windows have sun-shading elements called *mušebak*. It (Figures 17 and 18) acts as a double-skin facade, airflow is established because of the space between two wooden membranes, and solar radiation is reduced due to the achieved shading and lower temperature [47].

Figure 17. *Mušebak* in Svrzo's house complex – inside view (Source: authors)

Figure 18. Schematic representation of established airflow between two wooden membranes of *mušebak* [47]

Detailed building envelope parameters are given in Table 1.

Table 1. Building envelope parameters

Type of construction	Material	Thickness (cm)
External adobe brick wall	lime mortar	2.00
	adobe brick	60.00
	lime mortar	2.00
External wall with wooden frame and adobe brick infill	lime mortar	2.00
	wooden frame/adobe brick infill	18.00
	lime mortar	2.00
Ground floor	carpet	0.50
	wooden floor	2.50
	a layer of compacted clay	20.00
Doksat	wood	12.50
	a non-ventilated layer of air	25.00
	wooden floor	2.50
	a layer of compacted clay	17.00
	wood	7.00
	a non-ventilated layer of air	30.00
	wood	2.00
	lime mortar	2.00
Ceiling construction towards the attic	wood	2.00
	a non-ventilated layer of air	10.00
	wood	12.00
	a layer of compacted clay	12.00
Windows	wooden frame	single frame, single glazing

4.4. Calculation of energy demands for heating and cooling

To calculate energy demands for heating and cooling in selected residential buildings, the EnergyPlus Simulation Engine was used. EnergyPlus is integrated with Method Heat Balance (HB) for simulation zones [48]. A dynamical model was used and the following equation is solved:

$$C\frac{dT}{dt} = Q_{conv,i} + Q_{CE} + Q_{i,ve} + Q_{sys} \quad (1)$$

Abbreviations:

C - the air heat capacity in the zone,

T - temperature,

t - time,

$Q_{conv,i}$ - natural convection between surfaces and the air in the zone,

Q_{CE} - the heat transferred to the air from internal sources,

$Q_{i,ve}$ -the heat gained or lost due to infiltration and/or ventilation,

Q_{sys} - the heat delivered or removed from the space.

From (1), the heat load for cooling and heating is calculated in each time step given by equation (2):

$$Q_{sys,j} = \sum_{i=1}^{ns} A_i h_{Ci,i,j}\left(T_{si,i,j} - T_{in,j}\right) + Q_{CE} + Q_{i,ve} \quad (2)$$

where:

A_i - the area,

h_{Ci} - the heat transfer coefficient from the inside of the wall,

T_{si} - the temperature of internal surfaces and

T_{in} -the air temperature in the zone.

EnergyPlus does not have a visual interface, therefore DesignBuilder software was used, which is an interface for EnergyPlus that allows conceptualization of the building. Heating and cooling energy generation systems with set operating times for heating/cooling activate to provide the set indoor temperatures. The final result is the annual energy demand for heating and cooling per square meter (kWh/m^2). The calculation of energy demands for heating and cooling was calculated separately for the winter and the summer quarters of the selected housing complex and then for the whole house.

First, the housing complex was modeled in DesignBuilder, Figure 19. Then the heated and unheated zones were determined, as shown in Figure 20.

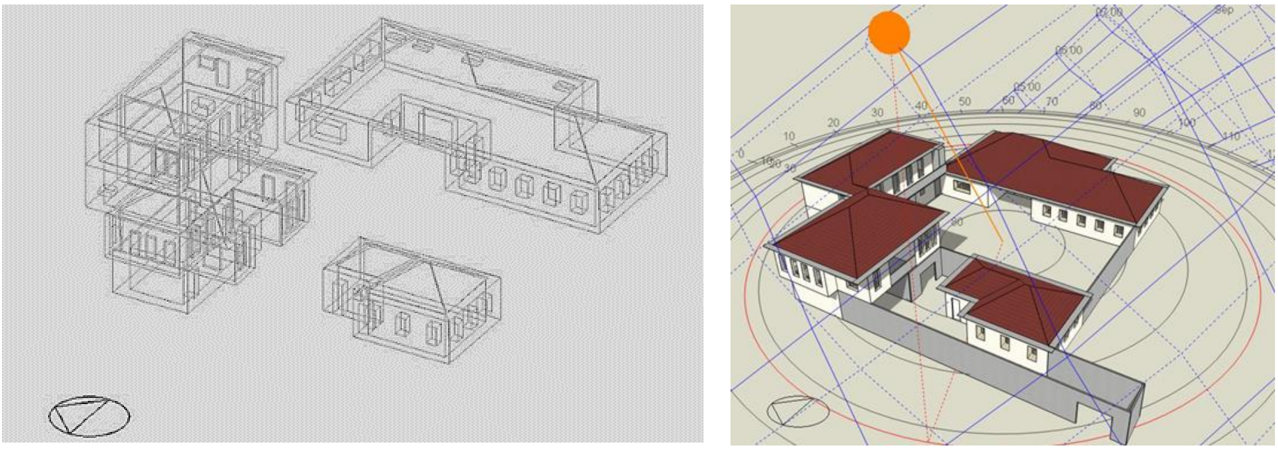

Figure 19. The model of Svrzo's house complex designed in DesignBuilder - Wireframe model (left), Rendered model (right) (Source: authors)

Afterward, the materialization of the building envelope, temperature setpoint for heating/cooling, and operating time for heating/cooling systems have been determined.

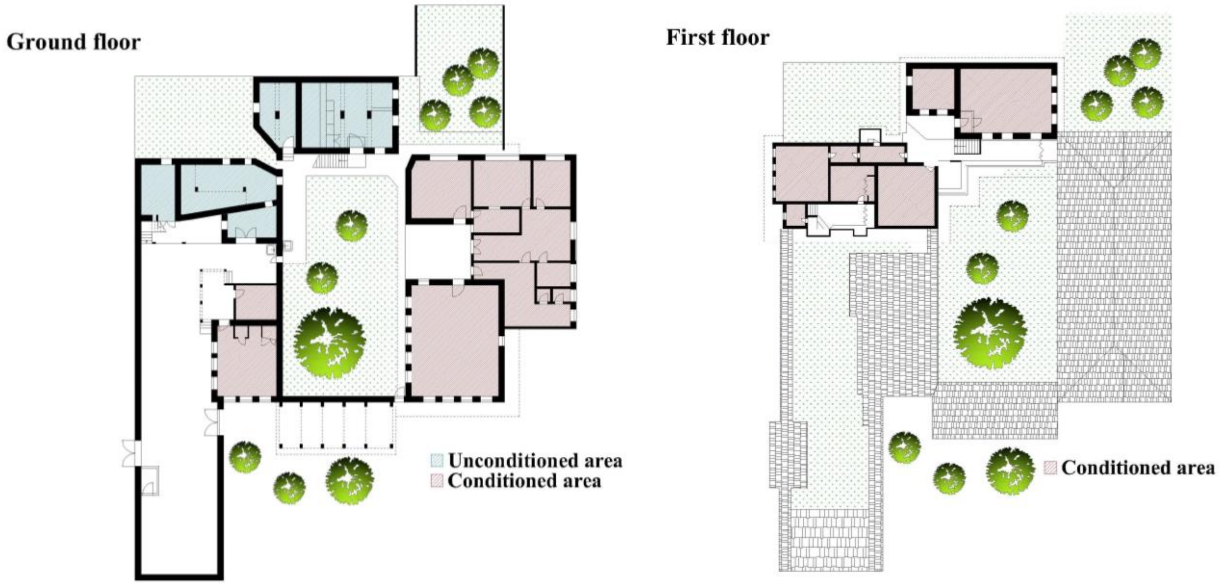

Figure 20. Svrzo's house complex – ground-floor zoning (left), first-floor zoning (right)
(Source: authors)

Building data for selected building are given in Table 2 and Table 3.

Table 2. Data for the selected residential building – winter quarters of the house

Building data	Unit	Value
Number of floors	-	1
Conditioned spaces	-	The whole ground floor
Nonconditioned spaces	-	Unheated attic
Basement	-	None
Net conditioned floor area	m^2	201.09
Net conditioned volume	m^3	514.80
Operating time for heating system	h	06:00-22:00 – 7 days per week
Operating time for cooling system	h	06:00-22:00 – 7 days per week, when needed
Temperature setpoint for heating	°C	20
Temperature setpoint for cooling	°C	25

Table 3. Data for the selected residential building – summer quarters of the house

Building data	Unit	Value
Number of floors	-	2
Conditioned spaces	-	The whole first floor
Nonconditioned spaces	-	Unheated attic and ground floor
Basement	-	None
Net conditioned floor area	m^2	127.80
Net conditioned volume	m^3	327.17
Operating time for heating system	h	06:00-22:00 – 7 days per week
Operating time for cooling system	h	06:00-22:00 – 7 days per week, when needed
Temperature setpoint for heating	°C	20
Temperature setpoint for cooling	°C	25

Table 4 shows the average and allowable values of the heat transmission coefficient (U-value, W/m²K) of the building envelope elements, according to the Rulebook on minimum requirements for energy performance of buildings (Official Gazette FBiH 81/19).

Table 4. The average and the allowable values of the heat transmission of the building envelope elements

Type of construction	U-value (W/m²K)	Allowable U-value (W/m²K)
External adobe brick wall	0.70	0.35
External wall with wooden frame and adobe brick infill	1.72	0.35
Ground floor	0.97	0.40
Doksat	0.26	0.25
Ceiling construction towards the attic	0.59	0.25
Windows	5.00	1.40

Data in Table 4 shows the actual average heat transmission values for all building envelope elements are higher than the allowable heat transmission values. The calculation of energy demands for heating for the winter quarters of the house, the summer quarters of the house, and the whole house are shown in Figure 21.

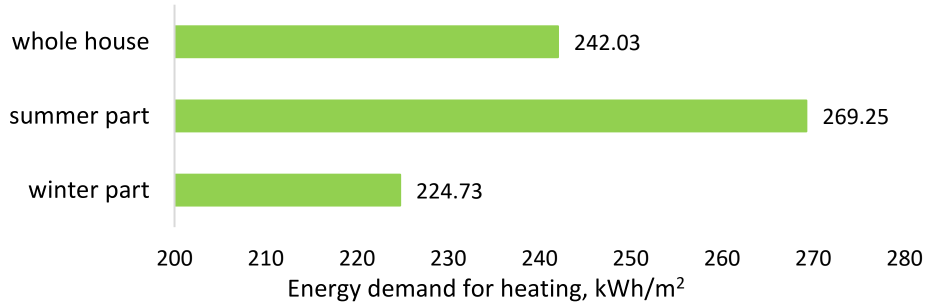

Figure 21. Energy demands for heating (Source: authors)

The calculations for the winter quarters of the house, the summer quarters of the house, and the whole house have shown that the lowest energy demand for heating is in the winter quarters of the house, while the highest energy demand for heating is in the summer quarters of the house. The energy demand for heating in the summer quarters of the house is 19.81% higher than in the winter quarters of the house, while the energy demand for heating the whole house is 7.69% higher compared to the winter quarters of the house only. The calculation of the energy demands for cooling for the winter quarters of the house, the summer quarters of the house, and the whole house are shown in Figure 22.

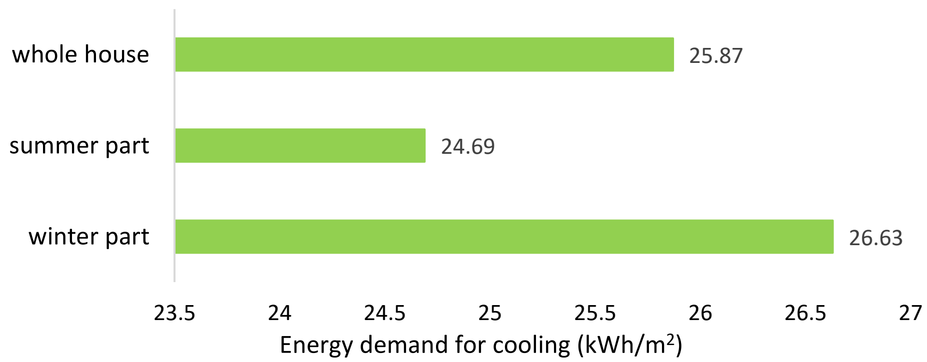

Figure 22. Energy demands for cooling (Source: authors)

The calculations for the winter quarters of the house, the summer quarters of the house, and the whole house have shown that the lowest energy demand for cooling is in the summer quarters of the house, while the highest energy demand for cooling is in the winter quarters of the house. The energy demand for cooling in the winter quarters of the house is 7.86% higher than in the summer quarters of the house, while the energy demand for cooling the whole house is 4.78% higher compared to the summer quarters of the house only.

From this analysis, it can be concluded that different materialization of the building envelope elements and different building designs of the winter and summer quarters of the house are justified considering that during the winter the lowest energy demand for heating is in the winter quarters of the house, while during the summer the lowest energy demand for cooling is in the summer quarters of the house. Also, a comparison of energy demands for heating and cooling of the whole house, to the seasonally divided parts of the house shows justification for seasonal division of the house because excessive floor area wastes heating and cooling energy needlessly.

A comparison of energy demands during the winter and summer shows that energy consumption is significantly higher during the winter than during the summer. Consequently, lightweight walls with less heat capacity, numerous large windows, carefully disposed to enable cross ventilation, and outside sun-shading elements of the summer quarters of the house can provide a comfortable indoor climate during the summer. Considering the high energy demands for heating during the winter and considering that a fireplace was the only heat source back in the day, it can be concluded that it was not possible to achieve quality thermal comfort in the winter quarters of the house. Although the outside walls are massive, with good heat capacity, without proper thermal insulation, energy efficiency cannot be met.

5. A proposal to increase the energy efficiency of Svrzo's house complex - a model for contemporary building design

The calculation of the energy demands for heating and cooling showed that the division of the house in winter and summer quarters with the different materialization and different building designs of those parts, represent an energy-efficient approach that could be transposed into contemporary architecture. The calculation results have also shown that the materialization of the building envelope elements of the winter quarters of the house is not energy efficient enough to be used as an example of the materialization of modern constructions. Considering that any interventions on the building envelope of Svrzo's house to improve energy efficiency are not allowed due to the fact that it is a national monument, this chapter will analyze the case of a contemporary building that will have the same building layout as the winter quarters of Svrzo's house. The aim is to improve the building envelope's thermal performance in order to reduce energy demands for heating by using eco-friendly materials that will preserve all the positive sustainable principles taken from vernacular architecture.

Improvement of buildings' resilience and increase of building's energy efficiency can be achieved in a sustainable way [49], using natural, local materials with good heat capacity. Considering that 40% of energy consumption and approximately 30% of the CO_2 emissions are generated by the buildings sector [48], one of the main goals of sustainable development in the building sector is to design and construct buildings with a minimum negative impact on nature, with minimum energy consumption in the construction process, and with low environmental pollution. Selection of safe or eco-friendly materials means that it has a lower negative impact on the environment, contributing to the healthy microclimate of the building and to the outdoor climate from the aspect of minimal toxic substances of materials [50].

5.1. Selection of sustainable building materials with good thermal properties

For the selection of building materials with good thermal properties, several factors need to be considered. An important factor in the decision-making process is not only to consider the physical characteristic of the material, but also the environmental and health impact, known as "ecological footprint," considering embedded energy, resource usage, energy consumption, and environmental pollution – greenhouse gas emissions (GHG) in the production process [50]. To achieve these goals, it is necessary to incorporate into contemporary building design economically profitable and sustainable solutions - the use of natural and environmentally friendly construction materials, which will improve the energy efficiency of the buildings. For the materialization of the outside walls of the winter quarters of the house, a new material, hempcrete has been chosen. Hempcrete is a composite, lightweight construction material, consisting of hemp hurds mixed with lime. [48, 51]. Lime is used as a binder material. Although other binder materials such as cement can be used, lime is preferable as it has lower carbon emissions compared to cement. Mostly hydraulic lime is used due to its hydration properties. Hydraulic lime carbonizes upon reaction with water [52]. Wooden structures were mainly used for construction with hempcrete infill. There are several techniques for building with hempcrete. Hempcrete can be constituted on-site and poured into the walls, or it could be sprayed by using an industrial sprayer. Another technique is building with hempcrete blocks. There is also a technique of using prefabricated panels, manufactured in fabrics, and assembled at the building site.

Regarding the thermal insulation properties, hempcrete has been described in [50] as a "heat-source battery," due to its good heat capacity, meaning that in winter, during a sunny day, solar energy is being accumulated in the hempcrete insulation layer [50]. In the evening and during the colder period, accumulated heat is transferred into the building, creating a comfortable and pleasant environment. However, it has been shown in France that during the summer, overheating can occur [52]. For that reason, this material is preferable to use only in cold climates or for winter houses if the building is seasonally divided. The thermal conductivity of hempcrete varies between 0.06 and 0.27 W/m^{2}K depending on the ratio of components in the composite. Also, the entrapped air in the pores of hempcrete contributes to low thermal conductivity [52]. Since hempcrete is a breathable material that enables the stationary flow of water vapor in the parodifusion process, it naturally regulates the inner humidity in a given range [50]. Also, this material is considered fire-resistant, due to the high content of lime [53]. The physical properties of the material are given in Table 5.

Table 5. Physical properties of hempcrete

Density, kg/m^3	Thermal conductivity, W/mK	Specific heat capacity, J/kg	Water vapor diffusion resistance
330.00	0.06	1,700.00	4.84

Considering that manufacturing of building materials is responsible for 11% of all GHG emissions on a global scale, there is a need, not only to reduce energy demands for heating to reduce GHG emissions but also to choose building materials with low embodied carbon dioxide (CO_2). The production of hempcrete has a much lower manufacturing emission than conventional building materials and can store carbon during the life cycle of the material i.e., considered "a fixative of CO_2 due to its natural origin, and can result in a negative carbon footprint that helps to reduce the global impact of a building" [48, 50, 54]. For example, the manufacturer of one hemp construction system, which is a prefabricated hemp-based timber-frame envelope system, estimates about 80% smaller carbon footprint, compared to the traditional construction method [54]. Figure 23 shows values of embodied carbon dioxide for conventional building materials and for building materials that will be used in the selected house [55, 56].

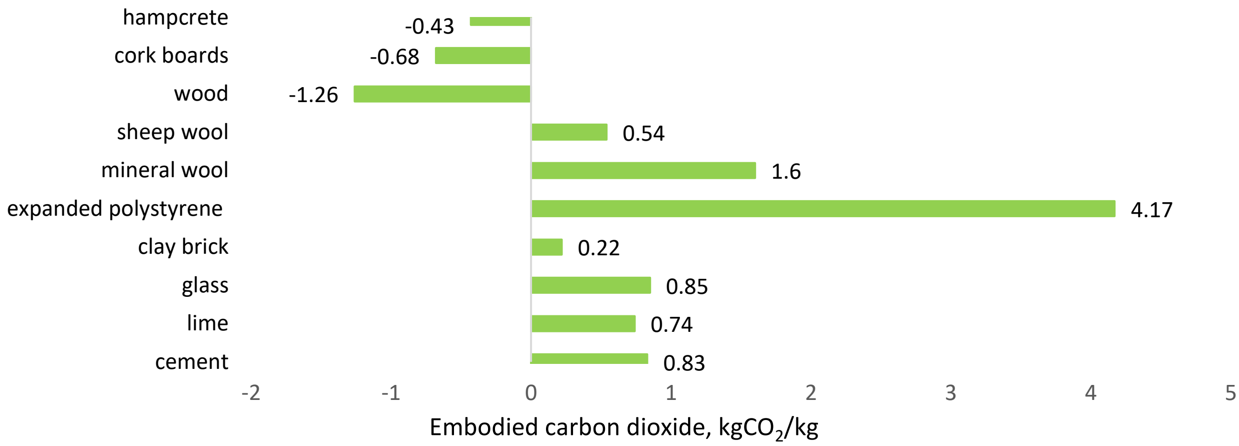

Figure 23. Embodied carbon dioxide in building materials (Source: authors)

The advantages of using hempcrete are mostly related to environmental and health issues, in the sense of “possibility to reuse, low level of toxins, convenient installation, without irritating fibers, higher acoustic performance, robustness in handling, transportation, and onsite construction, vapor permeability” [50, 51]. While considering the use of this construction material, it is also necessary to consider its limitations from the aspect of physical and economic properties, which refer mostly to the production site (not always locally) which can influence higher prices [51].

5.2. Calculation of energy demands for heating for the building's envelope proposed materialization

Detailed building envelope parameters for the new, proposed materialization of the building envelope's elements of the winter quarters of the house are given in Table 6.

Table 6. The proposed building envelope layers

Type of construction	Material	Thickness (cm)
External wall	lime mortar wooden frame with hempcrete infill lime mortar	2.00 30.00 2.00
Ground floor	cork boards concrete hydro isolation concrete	12.00 10.00 1.00 15.00
Ceiling construction towards the attic	wood planks wood beams/sheep wool wood planks	2.50 20.00 2.50
Windows	wooden frame	Single frame, triple glazing

As shown in Table 6 featuring the new calculations of energy demands for heating the house winter quarters the basic wooden construction of the attic and the roof has been kept and the thermal insulation layer has been added. Considering the selection of materials with low embodied carbon dioxide, sheep wool was chosen. For the ground floor construction, the concrete slab was chosen, with the cork boards as a final layer, as they have good thermal insulation properties, low embodied carbon dioxide, and can be left as a final layer in the interior. As for the windows, a wooden frame construction has been kept, but the single glazing has been changed into triple glazing. In Table 7, the average and allowable values of the proposed building envelope elements are shown.

Table 7. The average and the allowable values of the heat transmission of the proposed building envelope

Type of construction	U-value (W/m^2K)	Allowable U-value (W/m^2K)
External wall	0.19	0.35
Ground floor	0.37	0.40
Ceiling construction towards the attic	0.23	0.25
Windows	0.80	1.40

As indicated in Table 7, all proposed building envelope elements have that transmission values within the allowed limits. The results of the energy demand calculation for heating of the winter quarters have shown that with the proposed materialization of the building envelope, the energy demand for the heating is 81.16 kWh/m^2. Compared to the actual building, it is a reduction of 63.88% in energy demands. Therefore, it can be concluded that with this type of materialization, the house became energy efficient, while at the same time sustainable principles taken from vernacular architecture were maintained, because most of the proposed building materials are natural and have low embodied carbon.

6. Conclusions

Throughout history, people used to live in harmony with nature. Buildings were built with natural, locally available materials and the design of the building was adapted to the local climate and the place of construction. Later, with the development of society and new technologies, especially after rapid industrialization, the responsible relationship of people towards nature disappeared. Due to intensified human activity and negligence towards nature, today the ultimate limits of human activity that nature can bear have almost been reached. The construction industry has a great impact on nature, and it is the area in which the implementation of energy-efficient and environmentally acceptable solutions is a necessity to achieve the goals of sustainable development. Learning from vernacular architecture might be a method for solving increasing global problems such as lack of care for the environment, energy-inefficient constructions, and the use of construction materials that may have harmful effects on human health, and environmental pollution.

Based on the results of the energy efficiency calculations of the Svrzo's house complex, chosen as one of the most representative surviving examples of vernacular residential architecture from the Ottoman period in Bosnia and Herzegovina, it can be concluded that there are many sustainable elements from this vernacular residential building that can be applied in contemporary buildings. One of the major characteristics of vernacular residential buildings in Bosnia and Herzegovina was the seasonal division of houses into winter and summer quarters. A comparison of energy demands in the winter quarters and summer quarters of the analyzed building showed that the seasonal division of the house with the different materialization and building design of those parts can represent an energy-efficient approach that could be transposed into contemporary architecture. It is based on calculation results of energy demands for heating and cooling, which showed that during the winter period, the lowest energy demands for heating were in the winter quarters of the house, while during the summer period, the lowest energy demands for cooling were in the summer quarters of the house.

Also reducing the area needed for air conditioning, without lowering the quality of living, is justified because excessive floor area wastes heating and cooling energy. The calculation results have shown that the materialization of the building envelope elements of the summer quarters of the house which consists of lightweight walls with less heat capacity, numerous large windows carefully disposed to enable cross ventilation, and outside sun-shading elements, can provide a comfortable indoor climate during the summer. It is an energy-efficient approach that could be transposed into contemporary architecture. The calculation results have also shown that the materialization of the building envelope elements of the winter quarters of the house is not energy efficient enough to be used as an example in modern constructions.

The positive aspects of the building envelope materialization, such as the use of natural, local materials with good heat capacity can be kept, but thermal advancements of building envelope elements are necessary. Therefore, a new materialization of the house's winter quarters building envelope was analyzed with the aim of improving the thermal characteristics and reducing the energy demands for heating. Considering that any interventions on the building envelope of Svrzo's house to improve energy efficiency are not allowed due to the fact that it is a national monument, the case of a contemporary building that has the same building layout as the winter quarters of Svrzo's house was analyzed. Construction materials have been carefully chosen with the following characteristics: natural materials with low thermal conductivity, good heat capacity and low embodied carbon. To achieve these goals, for the materialization of outside walls, a new material, hempcrete has been chosen because it has all the previously mentioned qualities: a good heat capacity, low thermal conductivity, in the manufacturing process emits much less carbon dioxide than conventional building materials, and also has the ability to store carbon during the life cycle of the material. With the other parts of the building envelope, the original materialization was preserved if it corresponded to sustainable principles. To achieve good thermal properties, on the attic floor a layer of sheep wool thermal insulation has been added, and on the floor, cork boards were added as a final layer, because both materials have low thermal conductivity, natural origin and low embodied carbon. Windows are also selected based on the same principles, the wooden frame has been kept, but single glazing has been replaced with triple glazing to achieve better thermal properties.

The results of the calculations of the energy demands for heating have shown that, with the new, proposed materialization of the building envelope, the analyzed winter quarters of the house became energy-efficient, while maintaining sustainable principles taken from vernacular architecture. Consequently, the types of constructions based on the mentioned sustainable principles, are creating a healthy, pleasant environment with a low impact on the climate, which can be implemented in contemporary architecture.

Author contribution

The contribution to the paper is as follows: S. Martinovic, N. Zecevic: study conception and design; S. Martinovic, N. Zecevic: data collection; S. Martinovic: analysis and interpretation of results; S. Martinovic, N. Zecevic: draft preparation. All authors approved the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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