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Thermal Performance Analysis of Vernacular Houses in the Danube Delta

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Wien, 2021

I confirm, that going to press of this thesis needs the confirmation of the examination committee.

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I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume. If text passages from sources are used literally, they are marked as such.

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Wien, September 2021 ....

ACKNOWLEDGMENTS

To George.

“When things get worse, let it be as it is now” – Gica Petrescu

ABSTRACT

The Danube Delta, a rural area situated in East Europe, faces a continuous shift towards the adoption of new construction methods and materials. Vernacular building elements like reed roofs and clay-based walls are giving way to new technologies and methods so bricks, concrete and plastic materials are spreading fast as can be seen through the adoption by the locals. Also, this movement was stated by the Union of Architects from Romania in the Architectural guide for introducing in the local specifics of the rural area the Danube Delta area (Duvagi et al. 2016). This natural environment requires proper management; thus, it is only necessary to understand the implications of the transition on thermal comfort and energy consumption. To highlight the differences between two analyzed building typologies, 24 families were interviewed whose opinions on thermal comfort and environmental impact were then compared. Moreover, a comparative, monitoring and simulation-based study was conducted between two houses located in close proximity; one made out of traditional materials and the other of contemporary elements.

The second quarter of the 20th century witnessed an accelerated transition from traditional to contemporary construction methods in the Danube Delta area. To better understand the factors of these changes and to examine whether arguments are justified from an engineering point of view, different aspects were observed. After a theoretical comparison of the materials used in the two building types, sensors were installed in each house to record temperature and humidity. The results were then extracted and compared to see the actual day-night humidity and thermal variations. A 3D model of the compared buildings was then generated according to the onsite reality, taking into account the materials used, the orientation, and the sun exposure of the buildings. State-of-the-art thermal building performance simulation software was used to analyze the thermal performance of the buildings. As subjectivity plays a vital role in comfort perception, this aspect was considered via a series of interviews with the occupants of both the vernacular and contemporary houses, in order to obtain insight on their comfort perception.

Key words: Contemporary, Traditional, Thermal Comfort, Vernacular, Environment, Danube

KURZFASSUNG

Das Donaudelta, ein ländliches Gebiet in Osteuropa, sieht sich mit einer kontinuierlichen Veränderung der Baupraxis konfrontiert, in welcher moderne Baumethoden und Materialien vermehrt eingesetzt werden. Vernakuläre Bauelemente wie Schilfdächer und lehmhaltige Wände weichen neuen Technologien und Methoden, so dass sich Ziegel, Beton und synthetische Materialien schnell ausbreiten. Im Spiegel des Donaudeltas als weitgehend naturbelassener Ort sollten die Auswirkungen dieser Entwicklung hinsichtlich thermischen Komforts und gebäudebezogenen Energieverbrauchs besser verstanden werden, um angemessene Empfehlungen für die Zukunft zu entwickeln. Um die Unterschiede zwischen zwei analysierten Gebäudetypen, jeweils zeitgenössisch und traditionell gebaut, zu beleuchten, wird der thermische Komfort und die Umweltbelastung anhand von Nutzerinterviews (24 Familien, die in unterschiedlichen Bauten leben) vergliche. Zwei nahe beieinander liegende Häuser werden darüber hinaus einer vertieften Monitoring- und Simulations-basierten Untersuchung unterzogen. Das eine Bauwerk kann als „traditionell“ gebaut betrachtet werden, während das andere als „zeitgenössisch“ gebaut bezeichnet werden kann.

Zum besseren Verständnis der Charakteristiken der Wohnhäuser, die bis Anfang des 19. Jahrhunderts für die städtebauliche Entwicklung des Donaudeltas charakteristisch waren, sowie der Veränderungen, die durch zeitgenössische Bautechnologien gebracht wurden, wurde eine Reihe von Aspekten beobachtet und berücksichtigt, beginnend mit grundlegenden Betrachtungen der Auswirkungen auf die Umwelt durch die Verwendung bestimmter Materialien, gefolgt von der Verwendung von Computerprogrammen wie EnergyPlus für Analysezwecke der thermischen Aspekte parallel zu sensorgestützter Erfassung von Innenparametern, sowie eine Reihe von Umfragen unter den Bewohnern der beiden Arten von Wohnungen.

SCHLÜSSELWÖRTER

Modern, Traditionell, Thermal Comfort, Umwelt, Donaudelta, Materialien

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1. INTRODUCTION

1.1 Overview

When comparing traditional (vernacular) with contemporary buildings, we cannot ignore the cultural, geo-spatial and temporal contexts. The standards and occupant expectations regarding comfort have significantly increased in recent years. As a result, the energy demand connected with conditioning indoor environments has increased accordingly.

Many of the old vernacular buildings were recently renovated or rebuilt using commercially available "contemporary" materials. This is also the case in the Danube Delta. However, the extent that these changes improve the quality of life in homes in this area of Romania is widely unknown. Hence, the scope of this master thesis. Results pertaining to this issue will be presented by comparing numerical data from case studies developed in the proposed work.

Thermal comfort is defined by ASHRAE Standard 55-2017 (2017, p. 5) as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". The level of comfort directly influences the state of wellbeing of each individual. Considering that a big part of our lives is spent indoors (with a higher percentage in rural areas), the thermal aspect of houses has to be studied for a better understanding of how they affect our lives.

There is a consistent number of studies regarding optimal thermal comfort conditions. As condensed in the paper of Victor Olgyay from 1963 - *Bioclimatic Approach to Architectural Regionalism*, along with Vernon's (1932) conclusions, the optimum interior temperature during summer is 18.94˚C while 16.72˚C during winter in an air movement of 50 fps or less. Additionally, Markham's findings (1947) conclude that the ideal temperature is between 15.55˚C and 24.44˚C with a relative humidity between 40% and 70%. However, the comfort zone involves a high degree of subjectivity. Therefore, in this paper, representative homes shall be analyzed mainly from a thermal point of view, but other aspects such as the opinion of inhabitants and the materials used for construction shall be considered.

Three approaches were used to better understand the thermal differences between vernacular houses from the Danube Delta area and houses built using contemporary materials. Firstly, sensors were installed in each house to monitor temperatures and humidity. The results were then extracted and compared to see the actual day-night thermal and humidity variation in each case. Secondly, dynamic building simulation software was deployed to analyze the buildings according to the onsite reality taking into account the materials used, the position, orientation, sun exposure, etc. Thirdly, to capture the subjective component of indoor conditions a series of interviews with occupants of both the vernacular and contemporary houses was conducted.

1.2 Motivation

While there are efforts in finding solutions to address the rising need of energy-efficient buildings, these solutions must be adopted with awareness. Therefore, an appropriate analysis is needed to understand both the implications and benefits of transitioning to modern methods.

By analyzing related studies on this subject, it is easier to identify its pioneering stage. While there are related studies conducted in China (Borong & Gang, 2004), Indonesia (Sangkertadi, 2008) and Spain (Martin & Mazarron, 2010), it is noteworthy that no study concerning thermal aspects of vernacular houses has been conducted particularly in the Danube Delta.

The 2010/31/EU directive of the European Parliament and the Council espoused strengthening energy efficiency regulations for the energy performance of new buildings and units (2010, p.20). They particularly stated that by December 31, 2020, all new buildings must have almost zero energy consumption (2010, p.21). On the other hand, as part of UNESCO's list of World Heritage Sites, the Romanian area of Danube Delta covering around 2,733 km^2 is considered a strictly protected area. As regulations states that all the materials used for construction should be natural and site-specific, future decisions in choosing building solutions and styles should be carefully singled out. Thus, this study aims to contribute to future architectural interventions for this region.

1.3 Objective

The objective of this work is two-fold:

- Firstly, this could be one of the few thermal behavior analyses made on an adobe house, a combination of clay, straws and animal waste. This construction material is widely spread worldwide, but the utilization of adobe materials with reed roof can give a distinction to this paper.
- Secondly, the actual comparison of the two construction types, a vernacular and a contemporary one, is a pioneer work carried out about the Danube Delta region. This will contribute to a better understanding of the transition phenomenon from old to new building methods which also occur in other parts of the world.

1.4 Background

1.4.1 General approach

According to the Adobe Construction report of the World Housing Encyclopedia (2011), as many as 3 billion people worldwide live in houses made out of clay; that is around 41% of the world's population. Around 2 million houses in Peru (almost 40% of the current total) are made out of earth, which means that there are around 9 million people that inhabit them according to the 2007 Census. In India, the 2001 Census report states that about 305 million people live in 73 million houses made out of clay.

The history of clay-made houses starts at around 8000 B.C. when simple earth rectangular blocks were placed in the sun to dry. Due to the use of this material in hazard-prone areas, a more resilient version was created, mixing pure yellow clay with straws and manure. This is similar to present day structures where concrete, just like clay and manure mixture, supports compression loads while metal bars, similar to straws, take on stretching forces. Also, manure acted as a humidity regulator, absorbing the excess water vapor and removing them in dry periods. (Blondet and Gladys, 2003).

Adobe houses are usually one story high and can be found in rural areas. Their walls are around 2.6 m high and their thickness ranges between 250 and 850 mm. As a manifestation of its versatility, three story houses made out of adobe have been reported in the Andes. However, in the Middle East, earthen houses built one over another are a common practice. A group of researchers from the Engineering Department of the Catholic University of Peru developed a project named *"development of communication materials and training methodology for the construction of seismic resistant and healthy adobe houses in seismic areas"*. In this project a reinforcement system which involved covering the walls of the adobe house with a plastic mesh called "geomesh" was developed. Although the general direction leads to more natural and ecofriendly buildings, there are countries like Argentina or Chile where adobe constructions are banned by law due to their earthquake resistance.

For years, vernacular constructions have been built worldwide, each having its own characteristics mainly influenced by the materials available on-site. As their complexity grew, they become more suitable for the climate of the area in which they were built. This so-called *development via trial and error* is often proved to be more suitable and with better final results than the constructions of the present day as it takes into account the precise reaction of an individual in the actual environment.

1.4.2 Literature review

Thermal aspects of buildings have been approached from many points of view over time. Due to the lack of experimental investigations until recently, the primary source of information on thermal comfort issues in houses was derived from field studies which was based on the so-called adaptive approach. The *adaptive approach* implies that the inhabitants of the space interact with it to reach the desired thermal comfort. This is done by adjusting the surrounding elements such as opening the windows, using fans when it is too hot, controlling the temperature during winter time, and losing or adding clothes.

Humphreys (1978) and Auliciems (1981) have found a strong correlation between the mean existing outdoor and indoor temperatures and the observed comfort temperature. Based on these findings, they have developed an *adaptive model* that considers the outdoor temperature relative to the expected clothing of the inhabitants.

Firstly, according to Building Research and Practice journal in 1978, Humphreys made more than 30 surveys all around the world regarding thermal aspects in houses and proposed a simple equation that is valid in a range between 10˚C and 34˚C mean monthly outdoor temperature.

$$T_{co} = 0.53 \times T_m + 11.9 \qquad (1)$$

Humphrey's findings were upgraded by Auliciems in 1981. This approach came with more recent field studies that combine data from passive and active climate control.

$$T_{co} = 0.48 \times T_i + 0.14 \times T_m + 9.22 \qquad (2)$$

Where T_{co} - comfort temperature

T_m - mean monthly outdoor temperature

T_i - mean monthly indoor temperature

Besides discoveries regarding human perception of comfort temperatures and other thermal aspects of buildings, a series of researches have emerged in which traditional houses have been analyzed and compared to contemporary ones in areas like Nagapatnam – India, Pelion – Greece, Yazd - Iran, Kenadsa – Algeria, and others.

The paper, *Thermal comfort design of traditional houses in hot dry region of Algeria* Algeria (Khoukhi and Fezzioui, 2012), concludes that the contemporary typical house seems inappropriate for the desert climate whereas the two other traditional houses remain more effective during summer in facing the heat problem. A similar conclusion was found in the research paper *Comparison of air temperature – traditional and contemporary buildings* (Shanthi et al. 2012) as presented in Figure 1.

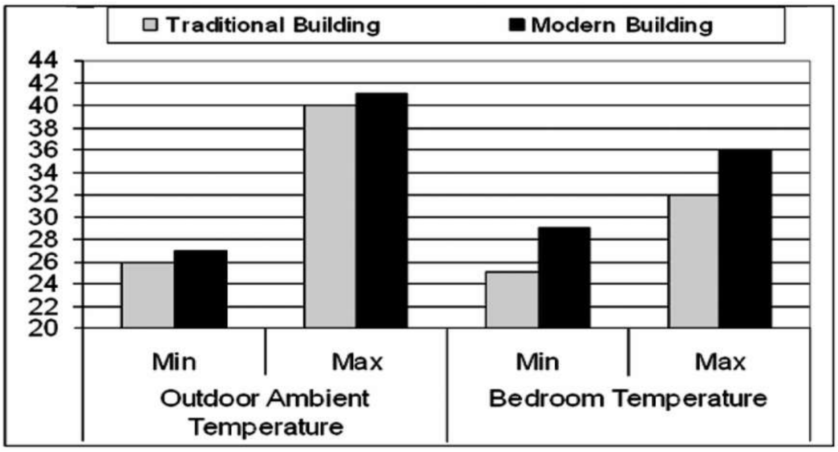


Figure 1 – Comparison of air temperature –traditional and contemporary buildings (Shanthi et al. 2012)

Although having its own particularities, the study performed in India, *Comparing the thermal performances of traditional and contemporary building in the coastal region of Nagappattinam, Tamil Nadu,* has the same conclusions with the aforementioned paper. This states that the vernacular residential building is thermally more comfortable than the contemporary building in the same surroundings, simultaneously possessing extremely low indoor temperatures with the same prevailing outdoor temperature. Moreover, Soleymanpour concludes in her paper, *Climate Comfort Comparison of Vernacular and Contemporary Houses of Iran*, that "*Vernacular houses could provide a higher level of climate comfort by using building design strategies that influenced by the outdoor environmental conditions and climatic zones"*. Figure 2(a, b).

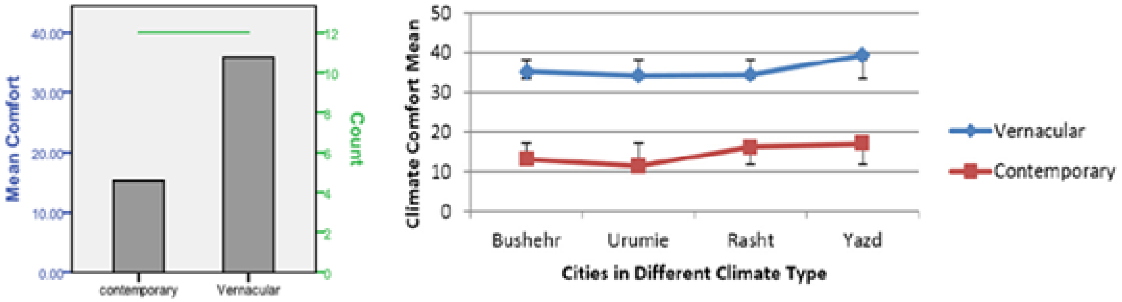


Figure 2 – (a) Level of climate comfort for each; (b) Differences between climate comfort for all the regions (Soleymanpour et al. 2015)

On the other hand, it must be noted that each of the analyzed cases has its own particularities that could influence the final results like specific weather, different materials used, unique building shapes, etc.

2. METHOD

2.1 Overview

Although there is a considerable amount of literature that describes conditions in which thermal comfort is achieved, the way in which each individual perceives optimal conditions is different. Thus, three different approaches were used:

- Monitoring-based approach: Data loggers were installed in two houses (traditional and contemporary) to record temperature and humidity levels. After that, the results were analyzed.
- Simulation-based approach: Using numeric simulation via EnergyPlus. The two houses subject to analysis were initially created in a 3D software program, imported to EnergyPlus and then assigned with the same materials, orientation, shading and solar radiation as in reality. After exact replication of on-site conditions, the thermal simulation was conducted.
- Qualitative interviews approach: A consistent number of people living in Danube Delta houses were asked to describe the thermal degree of satisfaction or discomfort at home. This approach is crucial if we keep in mind that thermal comfort is, in fact, a subjective feeling.

2.2 Danube Delta area

2.2.1 General characteristics

The Danube Delta is located in the eastern part of Romania and at the southeastern extremity of Ukraine. It is presented in the classical form of the letter delta, having the shape of a flat cone. Before the river flows into the Black Sea, it extends over an area of 100 km long x 100 km wide, and from here continues into the sea at a distance of about 15 km.

The Danube flows into the Black Sea through the three main branches that form the Danube Delta: the Chilia Arm, with the longest length (120 km); Sulina (64 km long) and Sfântu Gheorghe, the oldest arm (112 km long). About 15,000 people live in the Danube Delta, comprising 28 villages and a town (Sulina). The area consists of a complex network of waterways and lakes divided between the estuary’s three main canals. This area of floating reed islands, forests, pastures, and sand is home to a fascinating mix of culture and people, as well as a wide range of wildlife.

Being the 2nd largest in Europe and ranked 22nd in the world, Delta increases every year by about 40 m². Out of this area, only 10% is land. More than 3,000 km² are represented by natural aquatic and terrestrial ecosystems, intended for ecological reconstruction. These areas are included in the UNESCO patrimony within the “Man and Biosphere” program.

The Danube Delta has approximately 564,000 ha, of which 442,300 ha is on the territory of Romania and 124,000 hectares on the territory of Ukraine. The Danube Delta is an exotic land, where you can see over 1830 species of trees and plants, over 2440 species of insects, 91 species of mollusks, 11 species of reptiles, 10 species of amphibians, 320 species of birds and 44 mammal species. Many of these are declared unique species and monuments of nature. Some of which are presented in the two pictures below: (Figure 3, 4).

Figure 3 – Wild horses near Letea Forest (Dumitrache 2016)

Figure 4 - Flock of pelicans (Dumitrache 2016)

2.2.2 History and inhabitants

Recorded history notes that the Dacians lived in the Danube Delta before the Romans conquered it. After later invasion by the Goths, the region changed hands many times. During the 15th century, the Danube Delta became part of the Ottoman Empire. In 1812, following the Russo-Turkish War, the Ottoman and Russian Empires borders were set by the Kilia and Old Stambul Channels of the Danube, and by the St. George Channel in 1829. The Treaty of Paris in 1856, which ended the Crimean War, assigned the Danube Delta to the Ottoman Empire and established an international commission that undertook a series of works to help navigation. In 1878, following the Ottoman Empire’s defeat by Russia and Romania, the border between the two countries was set by the Kilia and Old Stambul Channels.

In 1991, the Romanian part of the Danube Delta became part of UNESCO's list of World Heritage Sites. Around 2,733 km^2 of the delta are strictly protected areas.

In 1998, under UNESCO's Programme on Man and the Biosphere, the 6,264.03 km^2 of the Danube Delta were established as a biosphere reserve, shared by Romania and Ukraine.

Historically, in Romania, part of the Danube Delta was marked as a reserve in 1938.

In Ukraine, the Danube branch of the Black Sea State Reserve was established in 1973. In 1981, it was reorganized into the Natural Reserve "Danube Fluxes", and in 1998, it was further extended into the Danube biosphere reserve.

The Danube Delta is perhaps the least inhabited region of temperate Europe (*wikipedia.org*). On the Romanian side live about 20,000 people, out of which 4,600 people reside in the port of Sulina. This gives an average density of approximately two inhabitants per km^2. The rest of the population is scattered among 27 villages, of which only three, all situated marginally, had more than 500 people in 2002. At the western edge of the delta, the city of Tulcea has a population of 92,000 (in 2002) which represents the node of the region and the gate to the delta.

Its acute isolation and harsh living conditions, based mainly on subsistence, made the Danube Delta a place of emigration, or transit at the least. Very few of those born in the region stay there through adulthood. Notably, the origins of its inhabitants vary widely, as people from many parts of Romania can be found in the delta. The total population has remained more or less constant throughout the 20th century. There were 12,000 inhabitants in the 1890s and 14,000 before the Second World War. Romanians account for approximately 80% of the population, and Ukrainians for 10%. Other people living in the delta include ethnic minorities such as Greeks, Turks and Bulgarians (1992). Distinctive to the region, but rare as an ethnic entity, are the Lipovans, descendants of the Orthodox Old-Rite followers who fled from religious persecution in Russia during the 18th century.

On the Ukrainian side, located at the northern edge of the delta, the town of Izmail has a population of 85,000, Kiliya a population of 21,800, and Vilkovo, the center of the Lipovan community, a population of 9,300.

The active population in the reservation represents 35.3% of the total, having an occupancy rate of approximately 81.4% distributed differently by activities: agriculture and forestry (29%) industry, construction, trade, services (15.7%) tourism, transport, communications (15.4%) fishing and fish farming (15.3%), public administration (13.5%) education, education, culture (5.7%) other activities (3.6%) health (1.9%). An authentic Delta fisherman can be seen below in Figure 5.

Figure 5 - Fisherman from the Danube delta (Dumitrache 2016)

2.2.3 Hydrographic network

The Danube River divides into three main branches from north to south, as follows: Chilia Branch, Sulina Branch and St. George's Branch, presented in the image bellow (Figure 6). They transport 60%, 21%, and 19% of the Danube waters at lower level, respectively and at a high level, 72%, 11% and 17%, during the water rise period.

Chilia, in the north, is the longest, youngest, and most vigorous, with two secondary internal deltas and one micro delta in the full process of formation at its mouth (to Ukraine).

Sulina is the central and thus the shortest arm, to the reason behind its extensive use for traffic and severe transformation. The main port is located at its mouth and it is the single settlement with urban characteristics of the Romanian part of the delta. Because of the alluvium deposited at its mouth, a channel gradually advancing into the sea (presently it has 10 km) was built to protect navigation.

Saint George in the south is the oldest and most sparsely populated. Its alluvium has led to the creation, beginning in 1897, of the Sacalin Islands, which today measures 19 km in length.

Figure 6 – Danube delta branches (Dumitrache 2016)

The Danube Delta is second in size in Europe after the Volga Delta (18,000 km^2), followed by the Padua (1,500 km^2). Dust, clay, mud and peat predominate in the river delta, while the organic sands predominate in the maritime delta. It is particularly characterized by the faint presence of sand.

The maritime sector in front of the delta stretches over a wide strip of about 15 km. The water circulation is mainly under the influence of winds and it is characterized by the presence of currents with a general direction from northeast to southwest. As a special physical-geographical unit, the Danube Delta is also distinct from a climatic point of view. The climatic elements are generated mainly by solar radiation and atmospheric circulation. They have specific characteristics due to large stretches of water and its proximity to the sea. The Danube Delta is located in an area of interference of air masses which forms over the Atlantic Ocean, the Mediterranean basin and the Eurasian continent. The continental character of the climate becomes less predominant as it approaches the coast.

2.2.4 Climate

The Danube Delta climate is continental with strong influences from the vicinity of the Black Sea and its prevalent amphibian environment. It is the driest and sunniest region of Romania. The mean annual temperature is 11 °C (−1 °C in January and 22 °C in July), with mean precipitation between 400 mm/year and 300 mm/year, decreasing from west to east. The highest precipitations happen where the Danube starts, in Tulcea City with the monthly fluctuation presented below Figure 7. Evaporation is around 1,000 mm/year, amplified by intense and frequent winds, resulting in long periods of drought during summer. The northwest winds cause frequent storms in spring and autumn. In the interior of the delta, the continental character of the climate is pronounced.

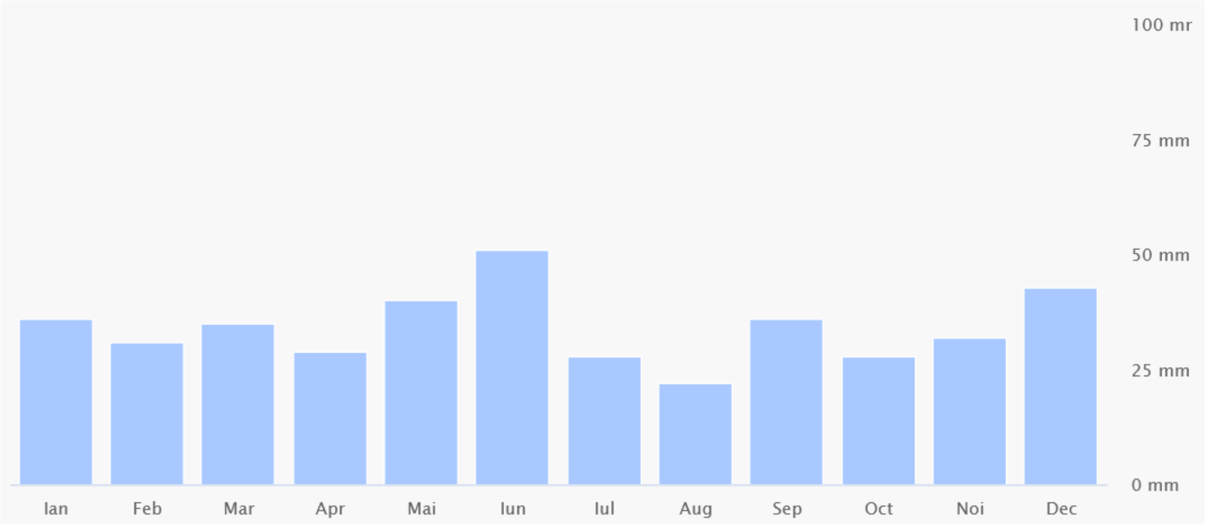


Figure 7 – Monthly precipitations distribution in Tulcea, Romania (Meteoblue 2017)

The winds are the dominant climatological element, Statistics in Tulcea show about 95 days of calm per year, while in Sulina there are only 31. In general, the winds from the north dominate, especially in autumn and winter when their intensity rises to average values over 20 ms^{-1}, often turning into storms. Such frequencies and intensities also exist in spring, especially in April, when there are changes of the east and west winds, which dry the earth and produce dust clouds. Sea breezes occur on the coast during summer. Meanwhile, inside the Delta the winds gradually become moderate, and stop for an extended period of time during August and September. Wind speed and direction can be observed in the graphical presentation below (Figure 8).

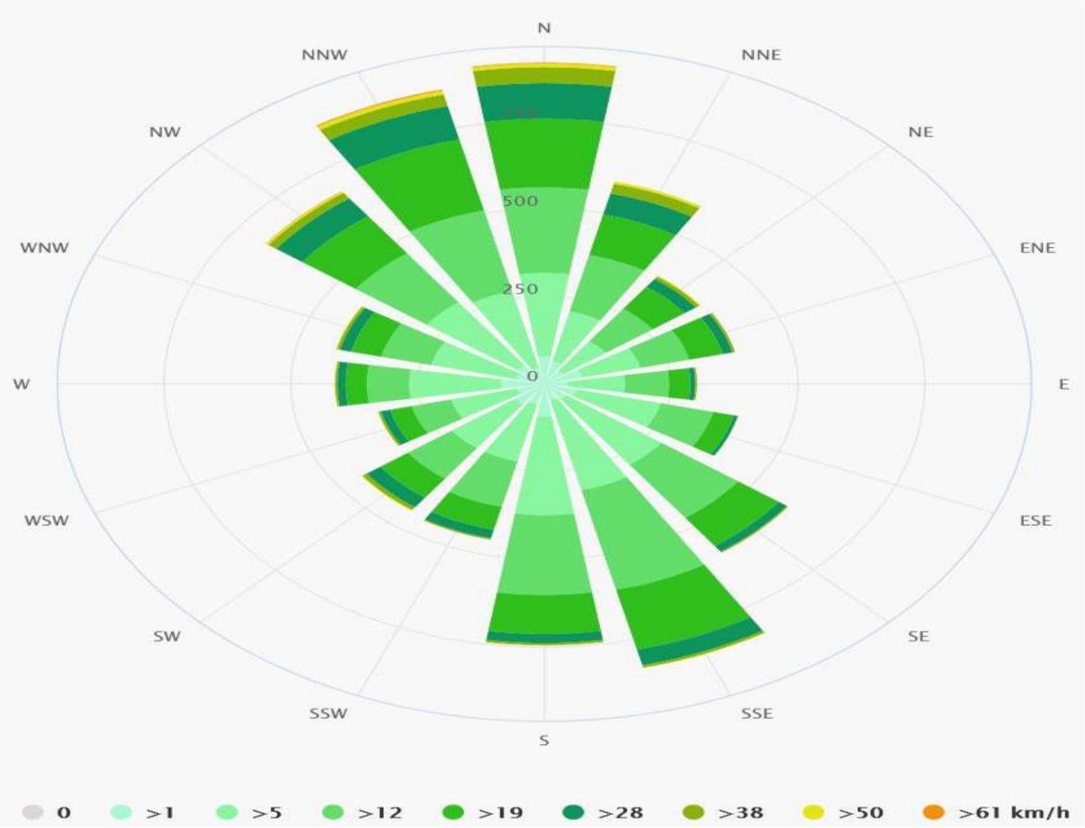


Figure 8 – Wind's speed and direction distribution in the Danube Delta (Meteoblue 2017)

The sunshine duration is high, with a multi-annual average of 2250 hours. However, its duration can reach up to 2600 hours in years of low cloudiness. The temperature is distributed unevenly over the delta surface. Multi-annual averages indicate the rise in temperature from west to east. In Tulcea, the biggest city of the Delta, the average multiannual temperature is 10.94 °C, as illustrated in the picture below (Figure 9), while in the flooded area (Gorgova village), the average is 10.96 °C. Near the shoreline (Sulina city) mean temperature is 11.05 °C, whereas in the Black Sea (Platform Gloria), the average temperature rises to 11.86 °C.

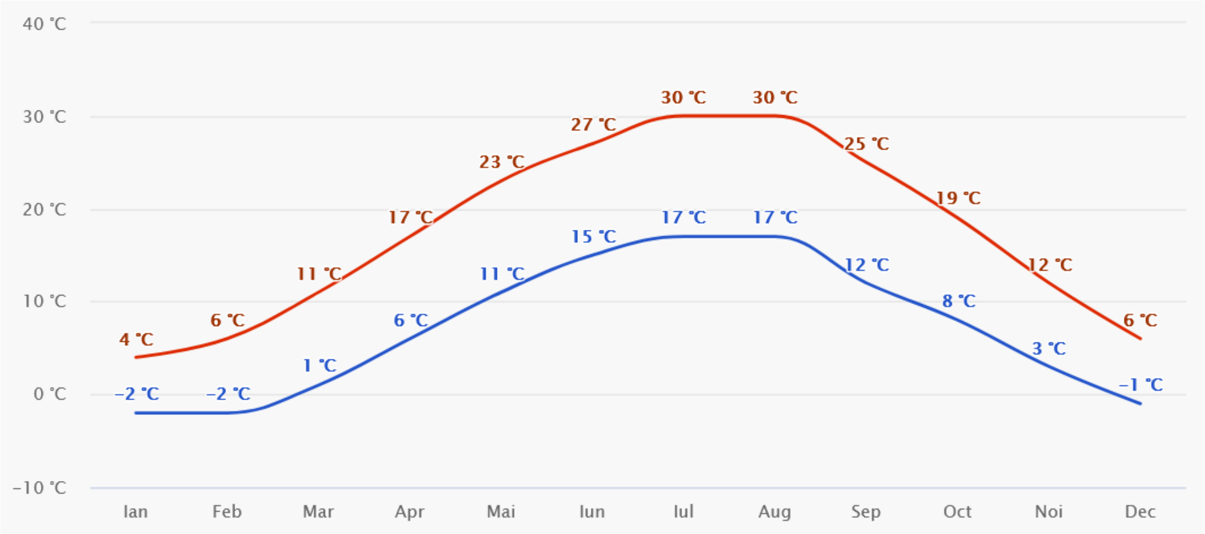


Figure 9 – Minimum and maximum monthly average temperatures in Tulcea, Romania (Meteoblue 2017)

Daily average amplitudes reflect the large differences due to the nature of the active surface. Gorgova varies between a maximum of 9 °C (in July) and a minimum of 3.8 °C (in December), Sulina between 2.8 °C (in July) and 1,4 °C (in November), and at Gloria Station between 2.3 °C (in July) and 1 °C (in December and February). The humidity of the air records the highest values on the territory of Romania. The relative humidity of the winter varies between 88 - 84% in Gorgova and 89 - 85% in Sulina and Sfantu Gheorghe. In summer, air humidity varies between 69 - 71% in Gorgova and 77 - 80% in Sulina and Sfantu Gheorghe. Precipitation is quantitatively reduced, and decreases from west to east due to the effect of the active Delta area and the Black Sea. There is a multiannual average of rainfall of 450 mm at the Danube Delta entrance (Tulcea) and 360 mm in Sulina. Most of the delta receives between 350 and 400 mm of rain while on the delta coast and most of the lagoons receive below 350 mm.

The snow layer is thin and it keeps short periods only in the harshest winters. Such situations took place in 1928-1929, 1953-1954, and 1984-1985 when the shore’s sea waters were frozen for 45-60 days. The dominant wind direction is N-S with the most intense winds recorded during the winter and in the transition seasons. The seasons are distributed unevenly within the Danube Delta. At the entrance to the Delta, in Tulcea, 90-year averages reveal that there are 142 days of summer and 60 days of winter while springtime lasts almost as much as autumn time. At Sulina, the same multiannual environments indicate 145 days of summer and only 15 days of winter, with the spring lasting longer (122 days) than autumn (83 days).

In the Danube Delta, especially in the river watershed from July until the end of September, summer is known as the most beautiful season. The autumns are dry during the first part, but later on set in slowly. From November 10-15, the weather becomes cool, with rain and fog. Precipitation is continental and is generally reduced to 400mm per year. These precipitations that usually reach the heated soil, causing rapid evaporation, are added to prolonged periods of drought. In contrast to this aspect, there are also hefty rains whose amount of water exceeds 100 mm in 24 hours.

2.3 Vernacular houses in Danube Delta

2.3.1 Description of traditional houses

This paper aims to thermally analyze two types of constructions at the Danube Delta. Situated in Romania, traditional houses were developed in this area since the VIIth century. As time went by, adaptations have been made to better respond to people’s needs and improve their level of comfort. Earth, stone and reed are the three central elements of the delta constructions. The backdrop of the houses is made of stone, the walls of adobe, and the roof of wooden structure covered with reed. The specific materials of the house include rods, earth, straws and animal feces processed as adobe, reed, stone and wood. Houses generally have white or blue facades (as the one presented in Figure 10), sometimes with decorative elements that remind of glory mythology constructed of wood planks through the technique of trampling (Duvagi et al. 2016).

Figure 10 – Typical vernacular Danube Delta house (Union of Architects from Romania, 2016)

Therefore, the primary materials used are clay, wood and reed. Yet, from the point of view of construction techniques, we can distinguish between those on forks with pillars of oak or acacia and those houses made entirely out of adobe (similar to the one presented in Figure 11). The height regime is a ground floor, rarely with a basement or a semi-basement.

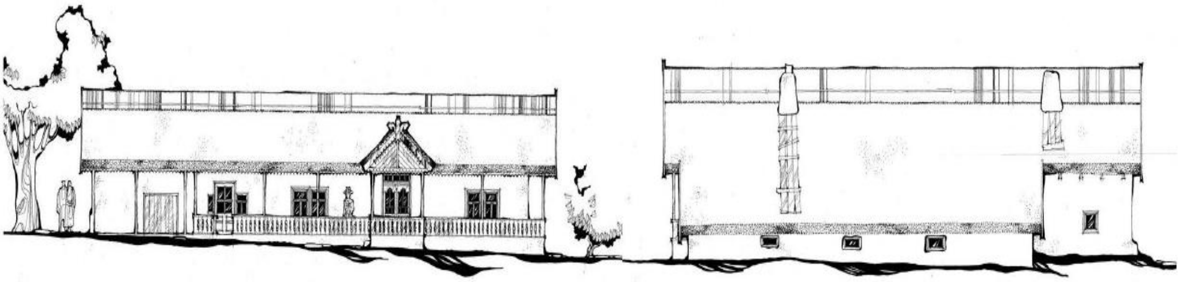


Figure 11 – Side view of traditional house (Union of Architects from Romania, 2016)

The characteristic of the houses are the porches on the long side, with pillars placed all over the length of the entrance. The extra rooms are set in a linear array, with windows facing the porch.

Construction plan often features tricellular houses, with two symmetrically arranged rooms distinct to both Russian households and Ukrainian or Romanian ones. They are small, dominated by reed roof with two or four steep slopes as seen in Figure 12.

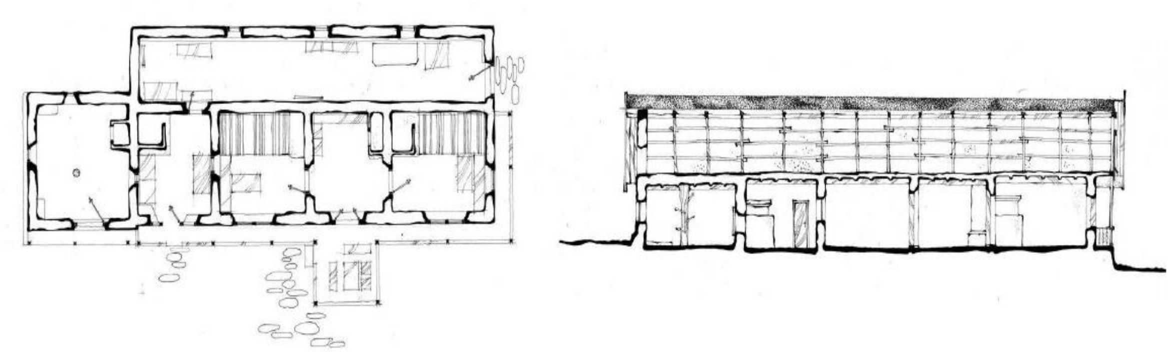


Figure 12 – Typical vernacular Danube Delta house (Union of Architects from Romania, 2016)

2.3.2 Construction elements

ROOF

Traditional roofs are divided into two types: one with reed covers and the other with ceramic tiles. Both roof types have two or four slopes similar to the ones shown in Figure 13. The steepness of the slope depends on the type of material used for cover. Nowadays, the ceramic tile cover has been replaced with those that are made out of concrete or metal tiles.

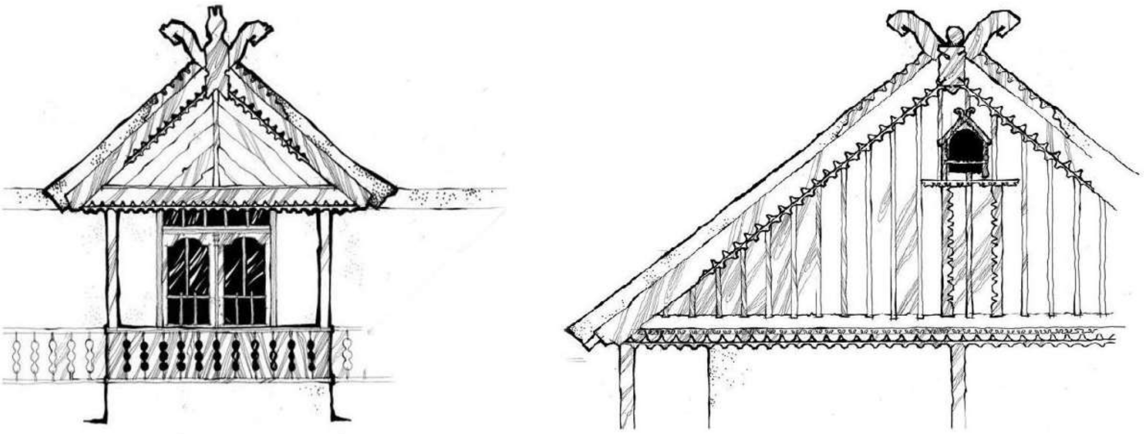


Figure 13 – Roof windows (Union of Architects from Romania, 2016)

Other traditional materials used for roofing, depending on the settlement specificity, are mix-material structures made out of clay, straws and reed. The framing consists of wood. In some villages, small skylights rarely appear on the roofs with two slopes.

The framework of the roof has a medium width. A layer of reed or straw, which is thermo-insulating, is sometimes placed underneath the ceramic.

Generally, the traditional roof is not used as a living space nor does it benefit from skylights or other functional voids, except those through which the chimney passes.

The framework's structure is made of wood, based on local technologies that use renewable natural materials. Depending on the cover materials, the slopes are up to 30^0 with ceramic and around 45^0 when the reed is used.

Heat insulation and waterproofing materials for covering are natural. Building solutions (Figure 14) are used to allow the exchange of vapors between the interior and exterior, thereby ensuring an optimal indoor/outdoor climate. At the same time, increased attention is paid to the constructive details around chimneys, skylights, crossbeams, etc.

Figure 14 – Roof window (Union of Architects from Romania, 2016)

WALLS

Traditional constructions consist of masonry systems for the main constructions. Most of the time, the walls are thick, made of adobe, and represent the load-bearing masonry's resistance structure. Adobe is a mixture of clay, straws and generally includes animal feces. The feces are either sun-dried in rectangular form and then arranged to form the structure or shaped like round balls, built in the wall's shape and then allowed to dry (as presented in Figure 15). An essential factor is their thermal insulating qualities: with high thermal inertia, the insides are kept cool during summer and warm in the wintertime. The pillars are made of wood, usually placed at equal distances.

Figure 15 – Adobe wall (Union of Architects from Romania, 2016)

Other construction techniques used are the "forks", with oak or acacia columns, connected via wooden joints. Then, a wattle and daub system is set up, after which the voids are filled (by beating) with clay mixed with straws. In particular cases, when stone masonry is used for thermal insulation of the building, a 10 cm layer of clay is inserted between two layers of stone. The walls are supported by a foundation made out of stones or wooden columns that also protect against moisture in the soil.

FOUNDATIONS

The foundations made out of stone can be found in the areas where raw material is within reach. Usually in walls of certain dwellings, some of the annexes and the outside fences are also made of stone. When a porch does not exist, the entrance is at the same level as the soil. Otherwise, the stone socket is typically covered with clay as the one from Figure 16.

Figure 16 – Vernacular house (Union of Architects from Romania, 2016)

Since the beginning of this type of structure, foundations consisted of mixed thick stone or wooden columns. Usually, the socket is small or missing. Home raised on the socket resulted from the need to solve the level difference in order to rise above the flooding level. Semi-basements are not specific to the area. Home households had holes covered with earth and straw where winter food could be stored.

WINDOWS AND WOODEN CARPENTRY

Initially, houses had one entrance. Its bedrooms had a single window and the living room would receive light through the door's glass mesh and from its fixed excess. Located on the long wall towards the porch, the doors and windows are made up of two or three movable wooden panels. Divided into meshes, these panels are either rectangular or even arched at the top, sometimes with two rows of sashes. A window may also appear on a side wall, facing the street. This sometimes has wooden shading panels painted as the rest of the carpentry as presented in Figure 17. Artistic diversification led to the possibility of coupling two double-leafed windows, resulting in the modification of the window-wall ratio in favor of glazed surfaces. However, secondary facades are practical without glazing surfaces.

Figure 17 – Traditional shutters (Union of Architects from Romania, 2016)

These aspects shaped the image of the traditional house, offering specificity and individuality of old buildings. The carpentry is made of painted wood, with comprehensive decorations made with sills, and is finished with oil paints in specific colors depending on the zone.
In the Danube Delta, it is specific to find wooden shutters painted in the carpentry color. Remote shading methods such as eaves, porch and vegetation are also used.

Exterior carpentry and shadings or other decorative elements are painted in different shades of blue, green, gray, brown, depending on the specificity of each village. The shades of paint are unsaturated, with natural pigments that do not change the appearance of the wood fiber and do not exhibit the appearance of wet or shiny, as seen in Figure 18. As a variety, the natural appearance is preserved by varnishing with a matt shade. Transparent paint for wood is also used to penetrate the wood’s texture and leave its natural drawing visible.

Figure 18 – Vernacular house from Danube Delta (Union of Architects from Romania, 2016)

2.3.3 Energy Performance

Interior heating of vernacular houses is provided by stoves or fireplaces fueled with wood during cold days as illustrated in Figure 19.

For the thermo-insulation of walls, floors and roofs, ecological systems are used using materials from the local environment (wool, hemp, straw, sawdust). The vertical closure system may be, for example, made of double, spaced adobe walls with thermal insulation between them.

Figure 19 – Traditional fireplace (Union of Architects from Romania, 2016)

Inside the house, an original Lipovan (Russian) and Ukrainian element, taken over and adopted in the Romanian houses, is the “lijanca”, an ingenious construction represented in Figure 20. This is a kind of a bed of earth, built near and connected to the stove which heats up during winter time.

Figure 20 – Traditional fireplace with sleeping area - “lijanca” (Union of Architects from Romania, 2016)

Based on recent experiences, locals affirm that they avoid using polystyrene for insulation because the house “does not breathe,” resulting to condensation, dampness, or mold.

Thermal insulation with wool is particularly recommended. Using wool also supports the local processing industry. Wool, currently found abundantly in Dobrogea, is generally discarded. Although insulation with wool is relatively new in Romania, it is used on a large scale in most European countries.

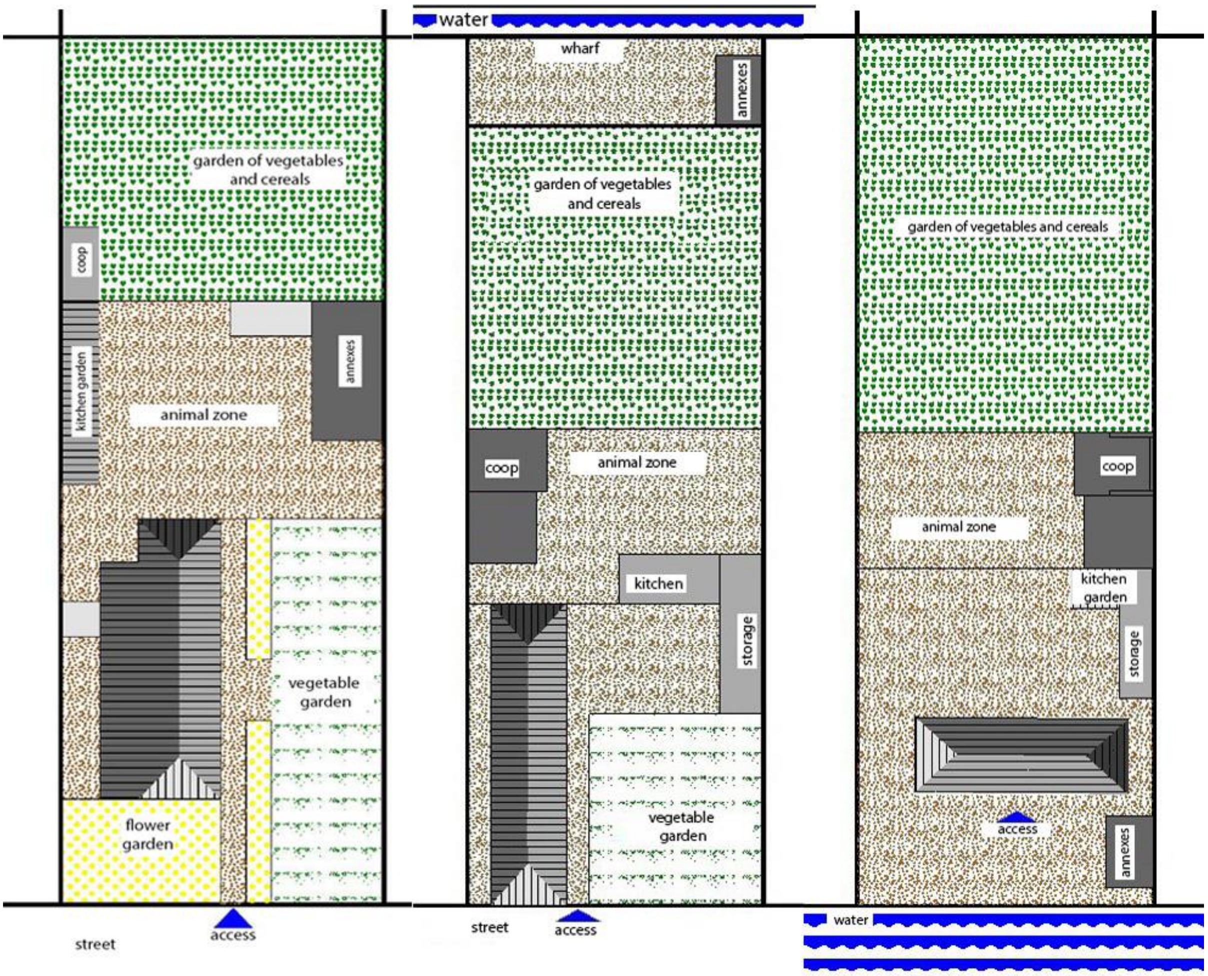
Generally, the ceiling is the weakest thermally insulated element because agricultural products (grains, corn) or animal straw stored in the attic during the winter, have the role of keeping the heat inside the house. Existing wooden carpentry may favor significant heat losses due to defective, old closing mechanisms or flatness changes due to poor maintenance and moisture exposure. Adobe walls have always been good heat insulators. To achieve the right thermal insulation technology, it is crucial to solve the joining details with the base and the carpentry as in Figure 21.

Figure 21 – Traditional insulation (Union of Architects from Romania, 2016)

Traditional households of the Danube Delta are developed directly with access ways such as the street or the water nearby as illustrated in Figure 22. Considering the positioning components structure, the following characteristics were found:

- Segmentation of the household space in the courtyard, the animal zone and the vegetable garden;
- The presence of household annexes;
- The houses orientation towards the road; orientation of the annexed buildings concerning the dwelling, depending on the access and needs.

HOUSEHOLD TYPOLOGIES



Example 1 - household layout
The house is positioned with the short side towards the street whereas the garden of vegetables and cereals, the annexes, summer kitchen and cottage unfold in the back. The house is withdrawn from the street, leaving room for the flower garden.

Example 2 - household layout
The house has a straight porch with its short side close to the road and facing the garden; the annexes and the the land for vegetables and cereals being behind. In the back there is easy access to water, where the pier and annexes are located in order to facilitate to fishing activity.

Example 3 - household layout
The house is located parallel to the waterway, and the access is made by boat. Annexes and fisheries tools are in front of the house, whereas in the back housekeeping and gardening elements can be found.

Figure 22 – Danube Delta traditional household typologies (Union of Architects from Romania, 2016)

TYPOLOGIES OF HOUSES - FLOOR PLAN

The arrangement of the houses and annexes within the household may differ, including its variations as illustrated in Figure 23.

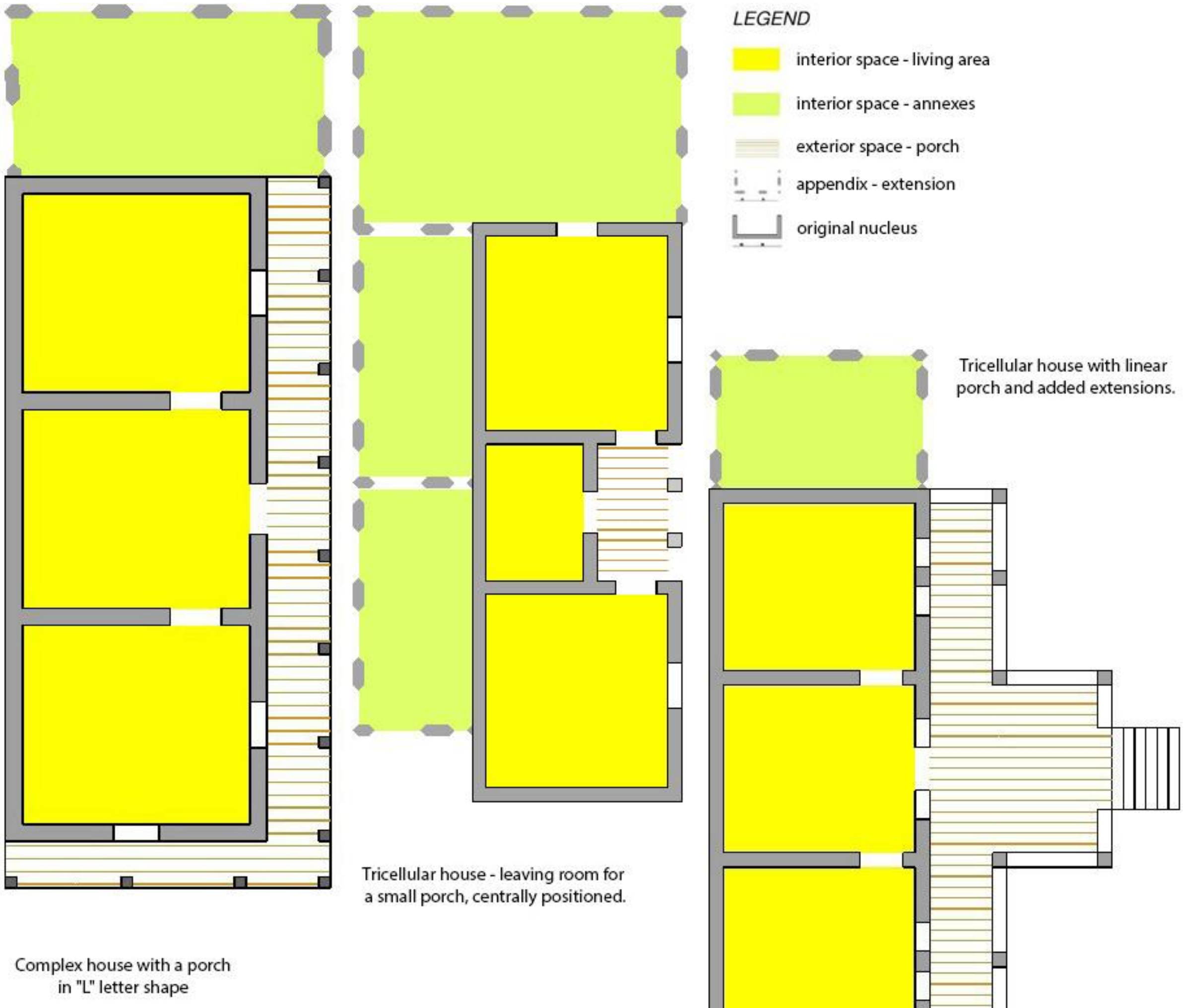


Figure 23 – Danube Delta traditional household typologies (Union of Architects from Romania, 2016)

2.4 Method 1 - On-site house analysis

To conduct the on-site research, two houses in close proximity, possessing similar geometric characteristics but constructed with different materials were compared. A Summary of the characteristics is illustrated in Table 1 and Figure 24.

Table 1 – Houses' comparison

Characteristics	House 1 - Vernacular	House 2 - Contemporary
Surface [m2]	120	80
Orientation	NE-SV	NE-SV
Location	Murighiol, Tulcea, Romania	Murighiol, Tulcea, Romania
Construction year	1879	1996
Roof type	reed	metal boards & wool insulation
Main materials	wood and adobe (manure+ clay+ water)	autoclaved concrete
Insulation	none	10 cm polystyrene
Windows	2 x single layer glass with wooden frame	triple layer glass with PVC frame

Figure 24 – Houses' comparison – traditional (left) vs. contemporary (right)

Data loggers were installed in each of the two houses with similar conditions. Information about temperature and humidity were further derived. At the same time, an extra sensor recorded the outside thermal indicators.

Access to the analyzed buildings is an essential factor that may influence the outcome of the research. Therefore, this problem was taken into consideration and was dealt with from the concept stage so that placing sensors, collecting data or any other changes and investigations were possible.

Besides accessibility, it is critical to consider the influence that human activity has on thermal behavior. As such, the residents were asked to keep a record of their indoor activity as diligently as possible, and to note the daily ventilation time and the period in which it took place. This is to keep track of the time and period when the house is actually occupied, by how many people, and other factors that may exert an influence on the final outcome.

Human influence is one of the most subjective among all factors. Thus, keeping an accurate history of it and correctly taking it into account could prove to be a demanding task. With the aforementioned premises considered, the engagement of the residents is a significant factor to rely on.

2.4.1 Location

House nr. 1 – Vernacular

The construction is situated in Eastern part of Romania, just in the heart of the Danube Delta as presented in Figure 25.

House nr. 2 – Contemporary materials

The building is located in the same village of Murighiol, Tulcea.

Figure 25 – Houses' location (Google Maps 1, 2017)

2.4.2 Orientation

Both buildings have a rather the same orientation, as illustrated in Figure 26, so that the sun influence is similar in both cases.

[2]

[3]

Figure 26 – Houses' orientation –Traditional [top] vs. Contemporary [bottom] (Google Maps 2, 3 -2017)

ILLUSTRATIONS

Figures 27 and 28 present the analyzed houses.

Figure 27 – Images of the traditional house; left- SW side view; center- interior bedroom; right- SE side view

Figure 28 – Images of the contemporary house; left- NE side view; center- SE side view; right- SW side view

Sensors were installed in the bedroom of each of the two houses in similar condition, as the bedroom is where inhabitants spend most of their time inside. This way, the temperature fluctuations throughout the day and their impact on people during sleep were monitored.

Thermal inertia, being an important element that influences the state of wellbeing within buildings, was also considered by installing a sensor outside. This records changes in temperature which are reflected sooner or later on the inside (depending on the inertia of materials).

Therefore, three data loggers were installed from 16.03.2016 until 22.09.2016: one inside the contemporary house, one inside the vernacular house and one at the exterior. Given the close proximity and the identical atmospheric conditions of the houses, only one external sensor was used for both of them.

2.4.3 Sensor arrangement

Sensors were positioned in each of the houses so that the influence of misleading factors is limited, according to Figures 29 and 30.

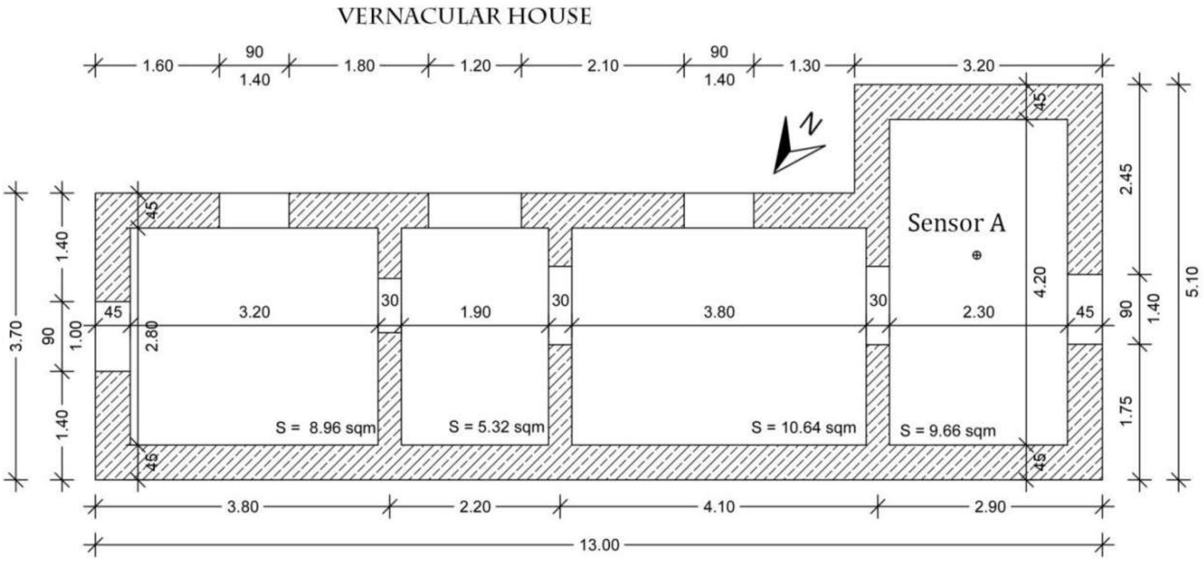


Figure 29 – Floor plan of the analyzed traditional house with sensor positioning

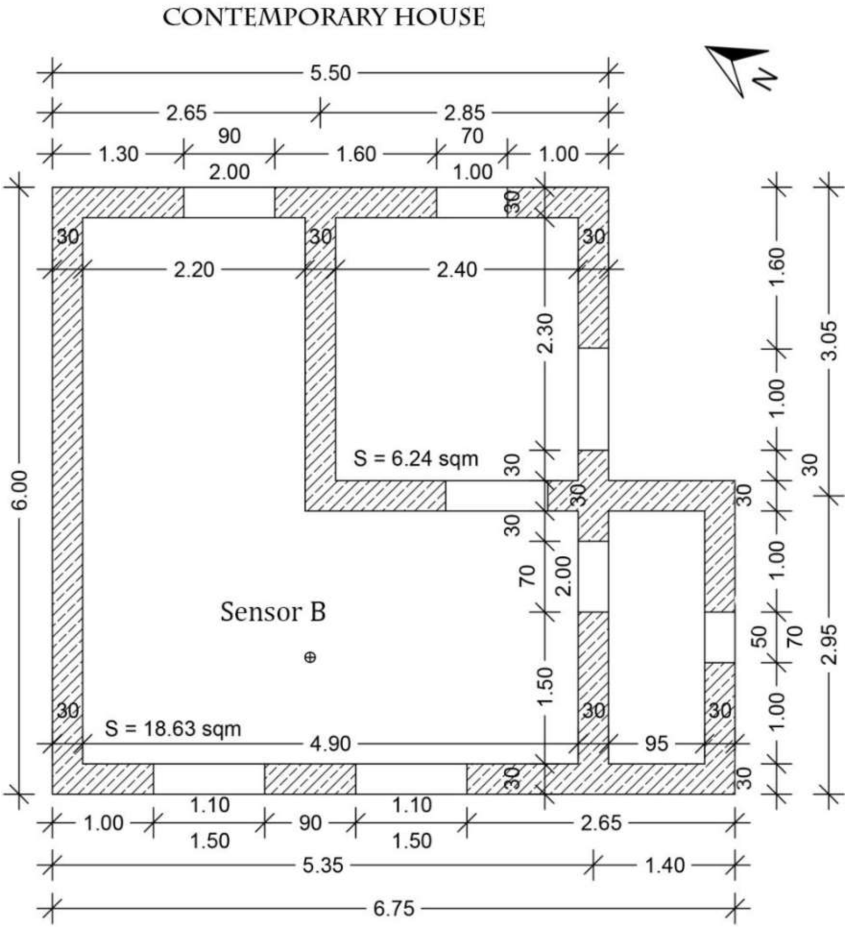


Figure 30 – Floor plan of the analyzed contemporary house with sensor positioning

2.4.4 Factors of potentially misleading results / Uncertainties

This study was particularly posed with the risk of the measurement tools being interfered by external factors which could lead to false results. Thus, to ensure accurate analysis, factors like ventilation, sun radiation, heating, air conditioning or human interaction were taken into account, and methods were applied to minimize their falsifying effects as presented in Table 2.

Table 2 – Sources of error

Variation factors	**Cause of errors**	**Ways to resolve interferences**
Human's influence	Different human interaction	Room with same destination was chosen - bedroom
		Houses have 2 inhabitants each
		Assumed proportional human interferences with the number of persons in the house
		Was taken into account when analyze was made
Heating	Human need depending on perception	The control-period was chosen so that no extra heating was needed
Air conditioning	Human need depending on perception	None of the rooms with the sensors had any air conditioning system
Ventilation	Human interaction due to traffic activity / desired ventilation	Human activity was considered equivalent in both cases once the room has the same destination
		A record of daily ventilation periods was kept by the occupants
		Was taken into account when analyze was made
Glazing surface	Different glazing on analyzed room	Rooms with the sensors have almost same glazing surface
Sun radiation	Different location / different cloud coverage	Weather was taken into account and sun coverage was included in calculation
		Houses and analyzed rooms have the same orientation

The most relative factor that could influence the final result is represented by human interaction. Their physical activity, number, and interaction with the environment are all factors which may vitiate the outcome. Thus, to motivate similarity in human activity, sensors were mounted in bedrooms in each house. It must be noted that both of the houses are inhabited by couples around 62 years old in age.

As the ojective was to understand the performance of the houses in a passive operational scheme, the schedule for the building monitoring was selected in a season that reduced the likelihood of heating system use.

Ventilation influence is another factor that was taken into consideration. A protocol, presented in Table 3, that records every single opening or closing of the windows was created. Each of the occupants was asked to note when actions took place.

Table 3 – Template for ventilation protocolling for building occupants

Date	**Opening hour**	**Closing hour**	**1/4 opened**	**1/2 opened**	**3/4 opened**	**Fully opened**
…	…	…		x		
…	…	…			x	
…	…	…		x		
…	…	…				x

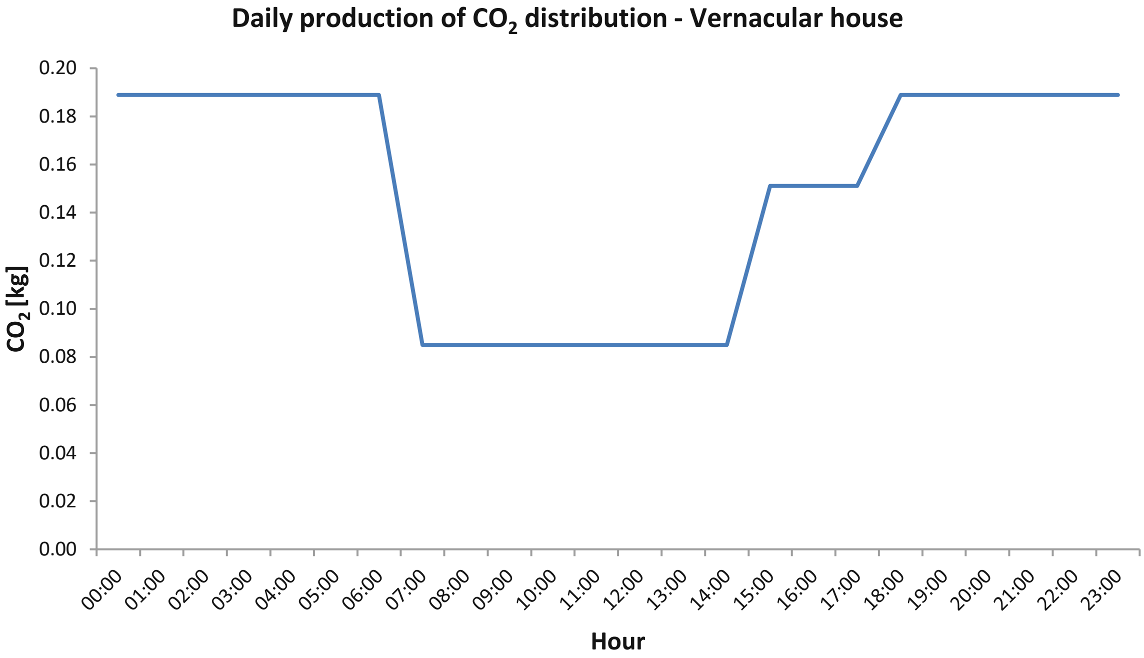
2.5 Method 2 – Computer Based Simulation

2.5.1 Overview

The second analysis method for thermal comfort assessment is represented by numeric simulation via EnergyPlus.

A number of conditions were considered to ensure an objective analysis of the conditions in the two types of constructions:

- The period considered for the simulation is the same as the one in which the field measurements were performed, 16.03.2016 - 22.09.2016.
- The same degree of occupancy was considered in both cases, thus eliminating the subjective influence of the human factor. An example of people's interaction with the inside environment is presented in Figure 31.



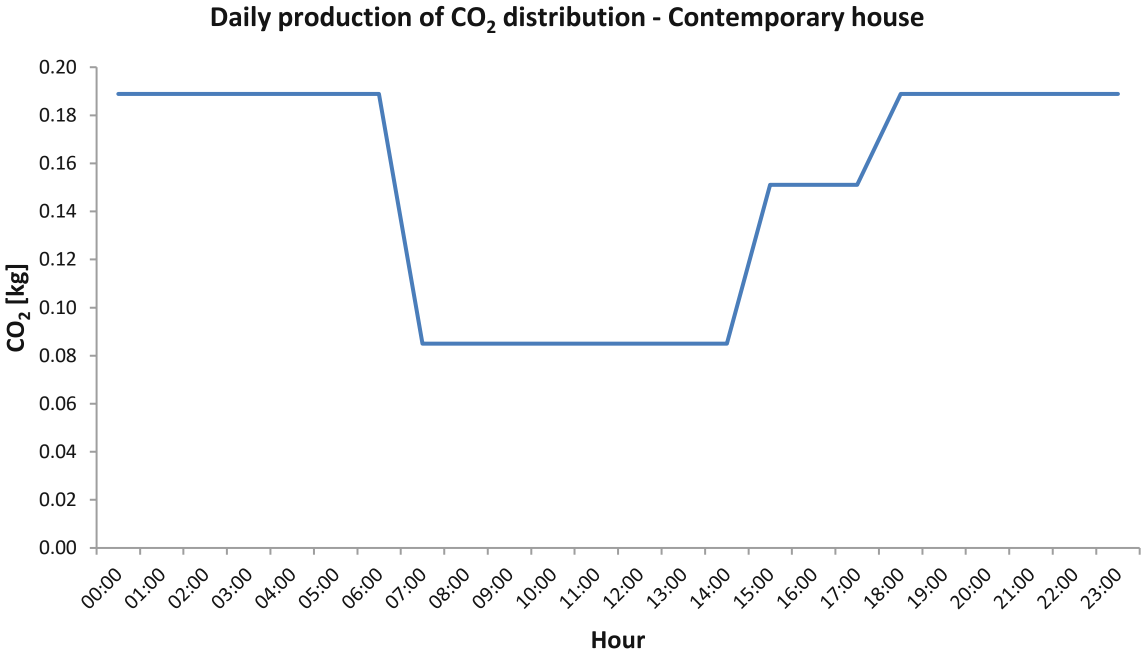


Figure 31 – Traditional [top] and Contemporary [bottom] daily Co_2 level variation (based on Energy Plus tool)

- Both constructions were modeled 3d wherein which the position was kept the same as in the field, both being oriented NE-SW and located in Murighiol Romania as illustrated in Figure 32.

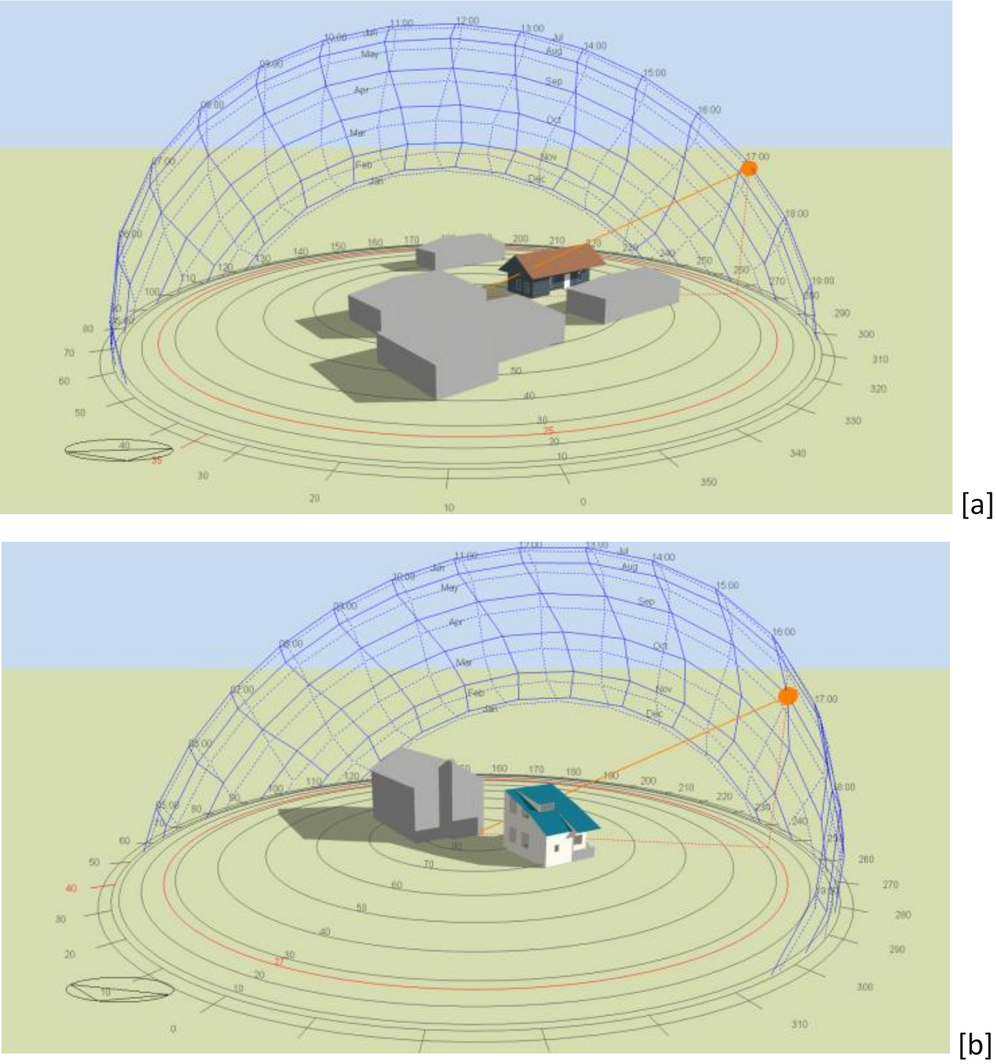


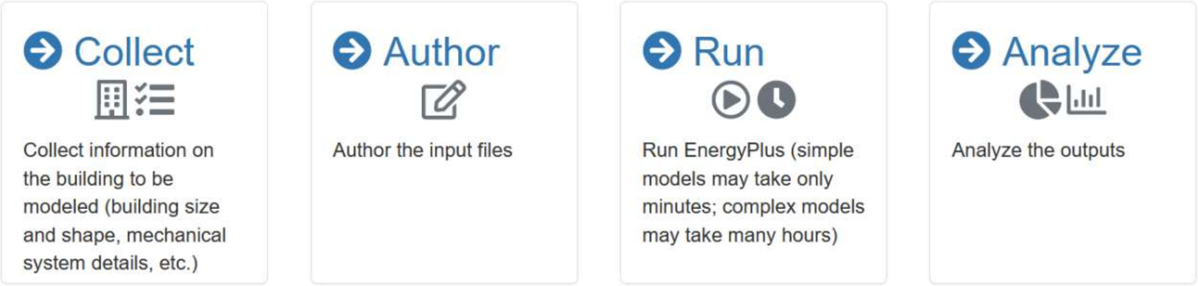
Figure 32 – Houses' sun orientation; a- Traditional [top]; b- Contemporary [bottom]; – (based on tool EnergyPlus)

2.5.2 Simulation software

EnergyPlus is an energy analysis and thermal load simulation program representing a tool aimed at performing thermal simulations of 3D models.

Based on a user's description of a building's geometry, construction materials, usage, and systems, EnergyPlus can calculate the heating and cooling loads necessary to maintain thermal control set points, conditions throughout secondary HVAC system and coil loads, and the energy consumption of primary plant equipment. It also includes many other simulation details that are necessary to verify that the simulation is performing as the actual building would.

EnergyPlus is a command-line tool that takes input files and produces output files. The general simplified model for running EnergyPlus is illustrated below in Figure 33:



Collect

Collect information on the building to be modeled (building size and shape, mechanical system details, etc.)

Author

Author the input files

Run

Run EnergyPlus (simple models may take only minutes; complex models may take many hours)

Analyze

Analyze the outputs

Figure 33 – General model of EnergyPlus (energyplus.net)

Thermal simulation allows one to model a building before it is built or before renovations are started. Consequently, it offers various energy alternatives to be investigated and compared to one another.

Simulation, which leads to energy-optimized buildings, is much less expensive and less time-consuming than actual experimentation. Yet, this paper can offer another perspective when comparing two houses, except people's subjective opinions and real-time measurements during field comparison.

The simulation software works by enacting a mathematical model that provides an approximate representation of the building. BEM includes whole-building simulation and detailed component analysis through specialized software tools that address specific concerns, such as moisture transfer through building materials, day lighting, indoor air quality, natural ventilation, and occupant comfort. It also gives an alternative approach that encourages customized and integrated design solutions which offer deeper savings. Using BEM to compare energy-efficient options, help in decision making before construction, but also can guide existing building projects to optimize operation or to explore retrofit opportunities.

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.

2.5.3 Software input data

The accuracy of software results depends on a number of factors such as: accurate 3D modeling of real constructions, correct geographical positioning, human influence and others. Among the elements introduced in the software analysis, the influence of weather factors is essential. Since the thermal behavior of buildings also depends on the intensity and duration of the sun, it is important that they are similar with reality. Since the analyzed houses are in the same village, and the exterior influence is practically the same, the results represent the behavior of the buildings to the same input data.

The solar energy received by the two houses is represented in Figure 34 below.

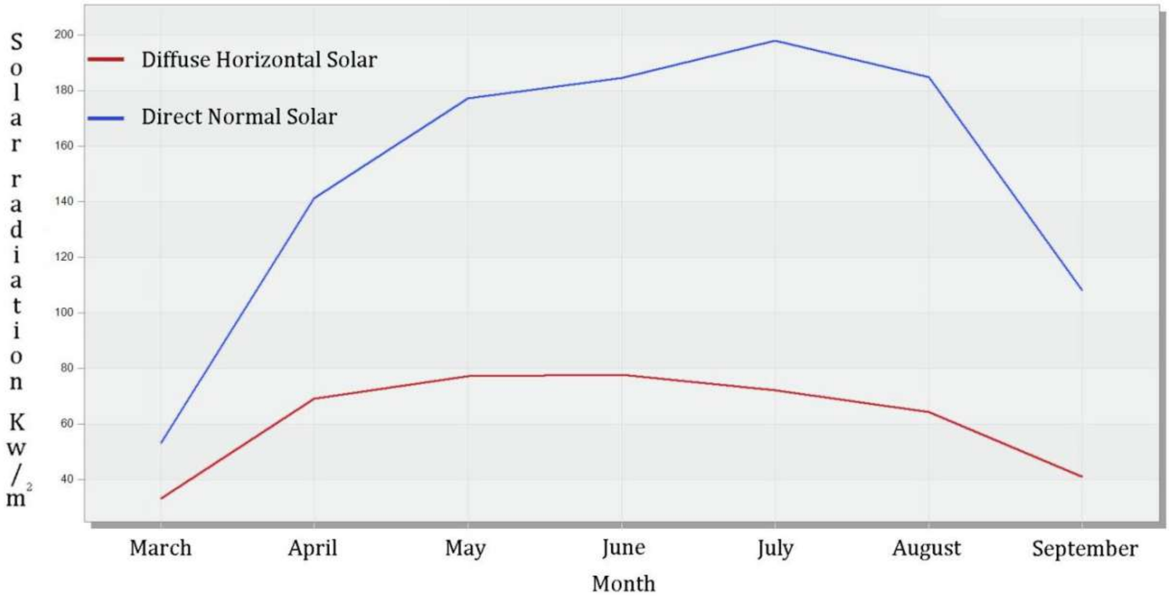


Figure 34 – Direct and diffuse solar radiation (based on Energy Plus tool)

2.5.4 Characteristic of building elements

To obtain accurate results, constructive elements were modeled as faithfully as possible in the thermal simulation program. An important step, after the respective 3d constructions, was to allocate the thickness and layer characteristics for walls, roofs, floors, etc.

The degree of thermal comfort of the inhabitants certainly depends on the temperature exchange between the inside and outside environment that are influenced by constructive elements. The walls represent the largest contact surface between a house and the environment. As a result, their influence on comfort is substantial. The more insulated the walls are, the lower the variation in interior temperatures will be.

For additional thermal insulation, materials such as polystyrene and mineral wood are used for this purpose. While air is the best thermal insulator, these materials are based on the existence of micro-air compartments. On the other hand, the low density of the constructive elements leads to a lower thermal inertia which, in effect, influences how the tenants experience the temperature fluctuations.

Tables 4 and 5 illustrate the characteristics of the external walls of the compared houses.

Table 4 – External wall of traditional house – layers

Element - traditional house	**Material nr.**	**Materials (from interior to exterior)**	**Thickness [m]**
External wall	1	Plaster	0.015
	2	Adobe- mud wall	0.45
	3	Plaster	0.015

Table 5 – External wall of contemporary house – layers

Element -contemporary house	**Material nr.**	**Materials (from interior to exterior)**	**Thickness [m]**
External wall	1	Plaster	0.015
	2	Aerated Concrete Block	0.2
	3	Polystyrene	0.1
	4	Plaster	0.015

The roof significantly influences the building’s interior temperatures along with the exterior walls. How much the roof influences the interior-exterior temperature exchange differs from house to house. However, it is inarguable that a poorly insulated roof will induce thermal discomfort.

Especially in winter, when the outside temperatures are lower than the inside ones, a thermally insulated roof exerts a significant influence in creating a state of thermal comfort. As the warm air rises inside the rooms during an excessive exchange of temperature outside through the roof, discomfort increases.

Tables 6 and 7 represent the arrangement of the layers, constituting the roofs in the traditional and contemporary houses.

Table 6 – Roof of traditional house – layers

Element - traditional house	Material nr.	Materials (from interior to exterior)	Thickness [m]
Roof	1	Wooden board	0.025
	2	Reed	0.4

Compared to a contemporary house, the roof of a traditional house in the Danube Delta is probably the most isolated element. This is because the primary material, the reed, which contains layers of air inside, is found in abundance in the area. As it grows around lakes and watery areas, the reed is free and abundant for locals. Hence, Romania being one of the leading reed exporters in Europe, with over 24000 ha exported annually (Duvagi et al. 2016).

Due to its physical properties, the reed is an ideal construction material: it is light and stable. Additionally, the air in and between the reed wires provides superior thermal and sound insulation that ensures high comfort. It can also be combined with other construction materials such as clay, wood, clay, lime and cement. These qualities are appreciated in modern architecture as well. In this context, prefabricated reed materials have proven their effectiveness through its physical and ecological attributes. Their production requires low energy consumption and takes place without the use of chemical components and without emissions or residues. The slabs can also be turned into compost.

The use of reed in the Danube Delta can provide the traditional culture an economic and ecological impulse towards sustainable development. Like no other natural resource, reed is an integral part of the ecology and economy of the delta. It serves as an important habitat and a natural purifying plant. It is also a versatile raw material well reflected in traditional architecture.

Thatching is the art of building a roof of dry vegetation such as straws, rushes, and reeds. The vegetation is layered so that water can drain outside without entering inside. It is an old method of covering houses and has long been used both in tropical areas and in areas with temperate climates. Notably, the technique is still used in some developed countries, particularly chosen by those who want a rustic look for their house or those who have already bought a house covered with reeds.

Table 7 – Roof of contemporary house – layers

Element - contemporary house	**Material nr.**	**Materials (from interior to exterior)**	**Thickness [m]**
Roof	1	Metal board	0.025
	2	Wood derivatives - plywood	0.015
	3	MW stone wool	0.1
	4	Roofing felt	0.005
	5	Wood derivatives - plywood	0.015

The roof of contemporary constructions that uses metal tiles possesses a similar durability, or even higher in some cases, to that of reed roofs. While a reed roof can have superior thermal insulation with the same costs, it lacks fire resistance compared to a contemporary roof. The flammable trait of the reed compels owners to choose fireproof materials when building new houses.

2.5.5 U value comparison

In acquiring an overview of the compared buildings' energy performance, a thermal transmittance expressed as a U value [$W \cdot m^{-2} \cdot K^{-1}$] is used as an essential indicator. This factor is vital in providing a numerical value on the thermal insulation quality of materials and the constituent elements of construction. The lower the thermal transmittance is, the more isolated the construction will become. This subsequently decreases the possibility of thermal dissatisfaction on the part of the inhabitants.

The inhabitant's satisfaction level is influenced by U value, without being entirely defined by it. Several other elements need to be considered to provide an accurate picture of the degree of comfort inside buildings, such as thermal inertia of materials, the glazed surface of windows and their orientation, how natural ventilation is done, and many others.

Tables 8 illustrates the U value in the case of the vernacular house, taking into account the constituent materials and their respective thicknesses.

Table 8 – U value traditional house

Element - traditional house	Material nr.	Materials (from interior to exterior)	Thickness [m]	Thermal conductivity $[W\cdot m^{-1}\cdot K^{-1}]$	R value $[m^2\cdot K\cdot W^{-1}]$	Specific material U value $[W\cdot m^{-2}\cdot K^{-1}]$
External wall	1	Plaster	0.015	0.35	0.04	**0.85**
	2	Adobe- mud wall	0.45	0.41	1.10	
	3	Plaster	0.015	0.35	0.04	
Roof	1	Wooden board	0.025	0.16	0.16	**0.26**
	2	Reed	0.4	0.11	3.64	
Partition Wall	1	Plaster	0.015	0.35	0.04	**1.22**
	2	Adobe- mud wall	0.3	0.41	0.73	
	3	Plaster	0.015	0.35	0.04	
Ground Floor	1	Clay under floor	0.3	1.28	0.23	**2.44**
	2	Brick Slips	0.025	0.42	0.06	
	3	Cast Concrete	0.1	1.28	0.08	
	4	Flooring screed	0.03	1.4	0.02	
	5	Clay	0.02	1.28	0.02	
External floor (Roof unoccupied)	1	Mortar	0.0125	0.35	0.04	**0.45**
	2	Wood derivatives	0.015	0.16	0.09	
	3	Air gap	0.05	0.026	1.92	
	4	Wood derivatives	0.025	0.16	0.16	

Table 9 represents the U value of the materials from the contemporary house, while table 10 summarizes the thermal transmissivity characteristics of both buildings.

Table 9 – U value contemporary house

Element - contemporary house	Material nr.	Materials (from interior to exterior)	Thickness [m]	Thermal conductivity [$W.m^{-1}.K^{-1}$]	R value [$m^2 \cdot K \cdot W^{-1}$]	Specific material U value [$W \cdot m^{-2} \cdot K^{-1}$]
External wall	1	Plaster	0.015	0.35	0.04	**0.26**
	2	Aerated Concrete	0.2	0.16	1.25	
	3	Polystyrene	0.1	0.04	2.50	
	4	Plaster	0.015	0.35	0.04	
Roof	1	Metal board	0.025	72.8	0.00	**0.31**
	2	Wood derivatives - plywood	0.015	0.16	0.09	
	3	MW stone wool	0.1	0.034	2.94	
	4	Roofing felt	0.005	0.037	0.14	
	5	Wood derivatives - plywood	0.015	0.16	0.09	
Partition wall	1	Cement plaster	0.015	0.35	0.04	**1.41**
	2	Aerated Concrete	0.1	0.16	0.63	
	3	Cement plaster	0.015	0.35	0.04	
Ground floor	1	Clay under floor	0.3	1.28	0.23	**2.41**
	2	Brick slips	0.025	0.42	0.06	
	3	Cast concrete	0.1	1.28	0.08	
	4	Flooring screed	0.03	1.4	0.02	
	5	Ceramic tiles	0.02	0.92	0.02	
External floor (Roof unoccupied)	1	Cement plaster	0.0125	0.35	0.04	**0.22**
	2	Wood derivatives - plywood	0.015	0.16	0.09	
	3	Wood derivatives - cellulosic insulation	0.16	0.038	4.21	
	4	Wood derivatives - plywood	0.025	0.16	0.16	
	5	Flooring screed	0.03	1.4	0.02	
	6	Ceramic tiles	0.02	0.92	0.02	

Table 10 – U value comparison

Element	U value traditional house [$W \cdot m^{-2} \cdot K^{-1}$]	U value contemporary house [$W \cdot m^{-2} \cdot K^{-1}$]
External wall	0.85	0.26
Roof	0.26	0.31
Partition wall	1.22	1.41
Ground floor	2.44	2.41
External floor (Roof unoccupied)	0.45	0.22

Comparing the two buildings from the point of view of U value as shown in Figure 35, it stands to reason that each is more energy efficient on certain constituent elements. In particular, the roof and interior walls of the traditional house are more insulating, while the contemporary house is thermally better on the exterior wall, floor and ceiling.

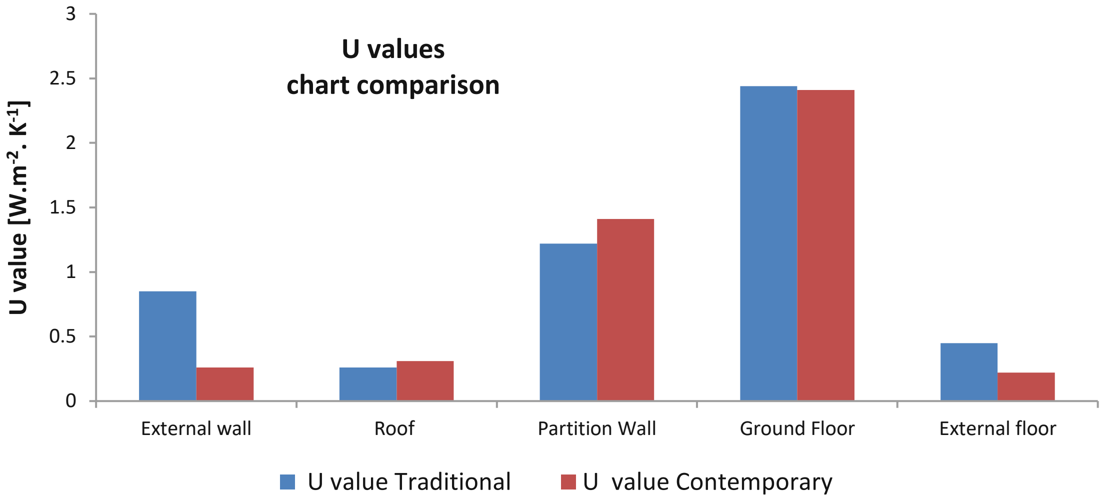


Figure 35 – U values chart comparison

At first glance, the contemporary house offers slightly increased thermal comfort to the inhabitants. However, this attribute varies depending on a larger number of factors.

2.6 Method 3 – Subjective assessment by building occupants

2.6.1 Overview

Thermal comfort is defined by ASHRAE Standard 55-2017 as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Thermal neutrality is the condition of a person in which he prefers neither warmer nor cooler surroundings. This situation is most desired by people because it represents the state of simple comfort and it is in an environment where a person performs their best. Man’s intellectual, manual and perceptual performance is, in general, highest when he is in thermal comfort. A series of variables influence the neutral thermal state such as the activity level (heat production in the body), air temperature, mean radiant temperature, the thermal resistance of the clothing (clo-value), relative air velocity and water vapor pressure in ambient air.

The ASHRAE thermal sensation scale, which was developed for use in quantifying people's thermal sensation, is depicted as presented in Table 11:

Table 11 – ASHRAE PMV scale

ASHRAE (PMV) scale		**DISC scale**	
Numerical scale	**Feelings note**	**Numerical scale**	**Feelings note**
-3	cold	no scale	
-2	cool	no scale	
-1	slightly cool	no scale	
0	neutral/comfort	0	comfortable
1	slightly warm	1	slightly uncomfortable
2	warm	2	uncomfortable
3	hot	3	intolerable

On-site measurements correlated with the thermal software simulation of the contemporary and vernacular houses offer a clear picture of the analyzed thermal aspects. However, it is inarguable that comfort is, in essence, a subjective sensation. Therefore, a series of discussions with the locals and the occupants of both the traditional and contemporary houses were conducted. Inhabitants of 24 houses, 12 traditional and 12 contemporary with two persons in each home, were included in the experiment. The objective was to find out their perception of thermal comfort during daytime. They were required to fill out a questionnaire on an hourly basis, regarding the thermal perception inside the house. Each subject was free to wear whatever clothes they prefer, but a value of 0.5-0.7 clo seemed to be the average. Ventilation took place through the windows depending on an individual's need, but uniformity is observable in all cases. The doors were usually closed and the windows partially opened.

2.6.2 Types of questionnaires

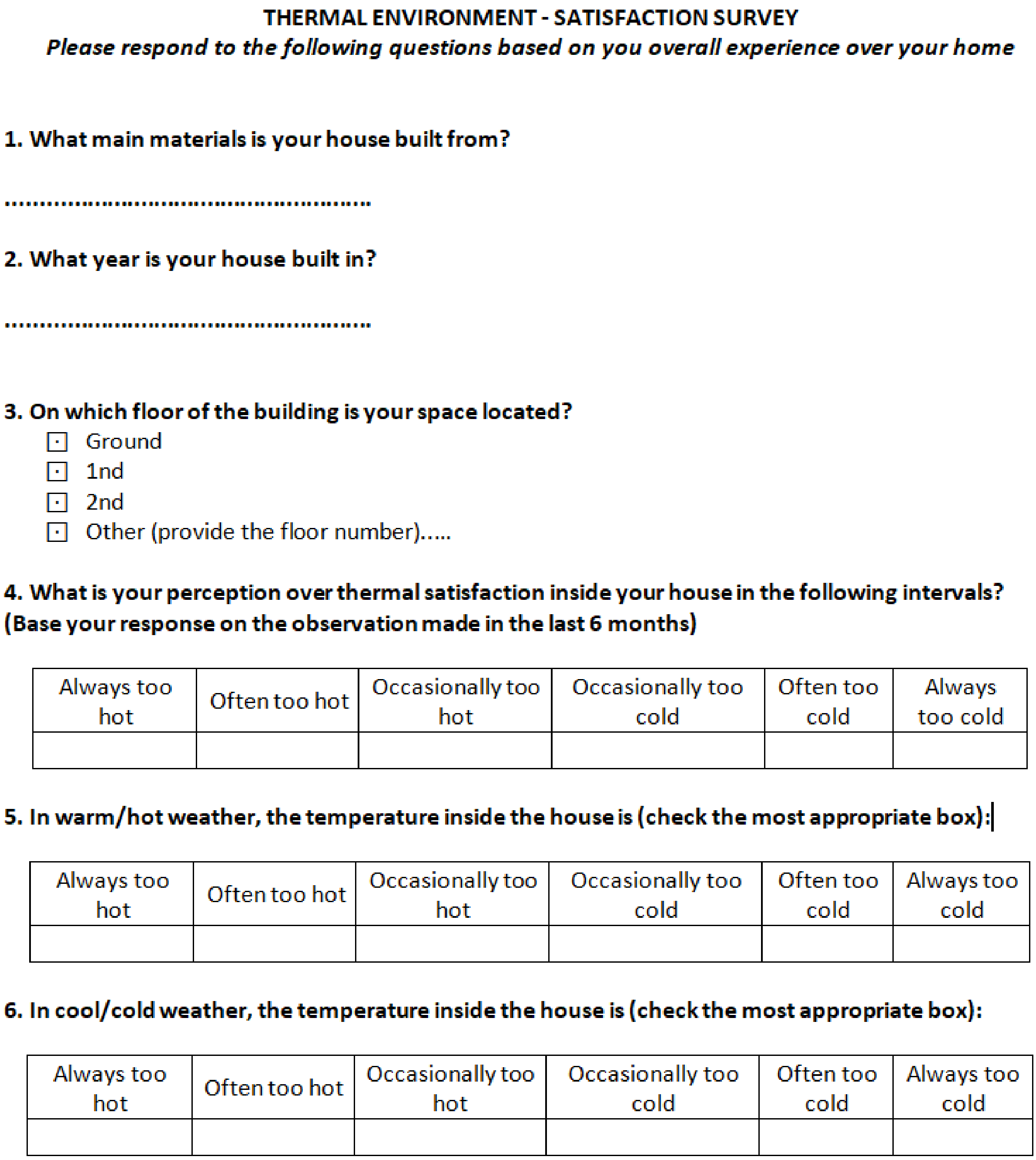
The survey on contemporary and vernacular houses was conducted in August over two weeks with temperatures ranging between 17˚C and 41˚C. None of the houses were equipped with air conditioning or other mechanical ventilation systems. From 8:00 am to 8:00 pm, each person participating recorded their thermal perception per hour for 14 days using a template as shown in Table 12. That means a total of 12 hours daily multiplied by 14 days multiplied by 24 is equals a number of 4032 votes.

Table 12 – Hourly perception interview table

Date:							
House type:							
House number:							
Time/ Perception	**Cold**	**Cool**	**Slightly cool**	**Neutral/ comfort**	**Slightly warm**	**Warm**	**Hot**
08:00 - 09:00							
09:00 - 10:00							
10:00 - 11:00							
11:00 - 12:00							
12:00 - 13:00							
13:00 - 14:00							
14:00 - 15:00							
15:00 - 16:00							
16:00 - 17:00							
17:00 - 18:00							
18:00 - 19:00							
19:00 - 20:00							

At the end of the survey, based on the ASHRAE 55 sensation scale, a total score representing the absolute values from the numeric scale was calculated for each building. Subsequently, the results were compared. A higher score corresponds to a lower level of comfort.

To confirm the hourly recording results, each participant filled out a general questionnaire regarding the overall thermal comfort of their home (see Figure 36). If the assumptions regarding all calculations and data recordings are correct, it should represent a summary of this paper.



THERMAL ENVIRONMENT - SATISFACTION SURVEY

Please respond to the following questions based on you overall experience over your home

1. What main materials is your house built from?

……………………………………………….

2. What year is your house built in?

……………………………………………….

3. On which floor of the building is your space located?

- ☐ Ground
- ☐ 1nd
- ☐ 2nd
- ☐ Other (provide the floor number)…..

4. What is your perception over thermal satisfaction inside your house in the following intervals? (Base your response on the observation made in the last 6 months)

Always too hot	Often too hot	Occasionally too hot	Occasionally too cold	Often too cold	Always too cold

5. In warm/hot weather, the temperature inside the house is (check the most appropriate box):

Always too hot	Often too hot	Occasionally too hot	Occasionally too cold	Often too cold	Always too cold

6. In cool/cold weather, the temperature inside the house is (check the most appropriate box):

Always too hot	Often too hot	Occasionally too hot	Occasionally too cold	Often too cold	Always too cold

Figure 36 – General perception interview template

Although it is possible that there could be a link between the participants' declared comfort levels and the inhabitants' high degree of expectations over contemporary houses, we shall assume that the declared thermal sensations represent the honest and untainted sensation of the subjects and reflect their genuine experience.

3. RESULTS

3.1 On-site house analysis

3.1.1 Temperature variation

After the measurements were conducted, the results representing the conditions related to thermal comfort that were obtained between 16.03.2016 - 22.09.2016 are presented in Figure 37.

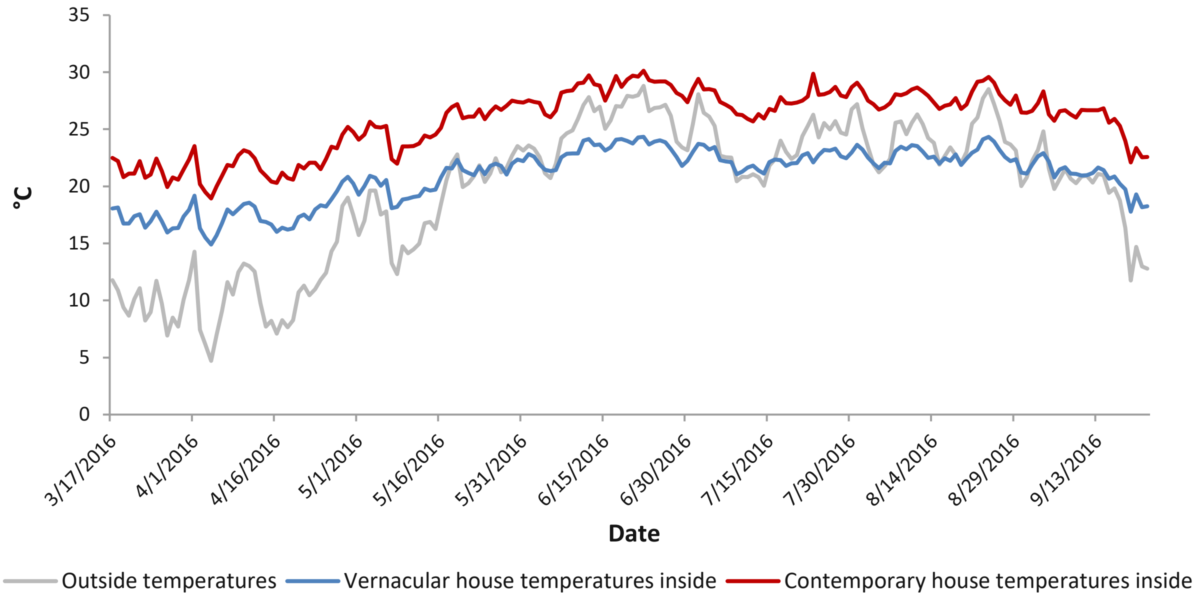


Figure 37 – Daily temperatures measured on-site

As expected, temperatures collected from the outside and inside the houses follow the same path both in vernacular and contemporary cases.

3.1.2 Diurnal temperature variation

Increased attention was paid to the day-night temperature amplitudes, as illustrated in Figure 38, which are influenced by many factors including thermal insulation of the building, thermal inertia of the constituent materials, etc.

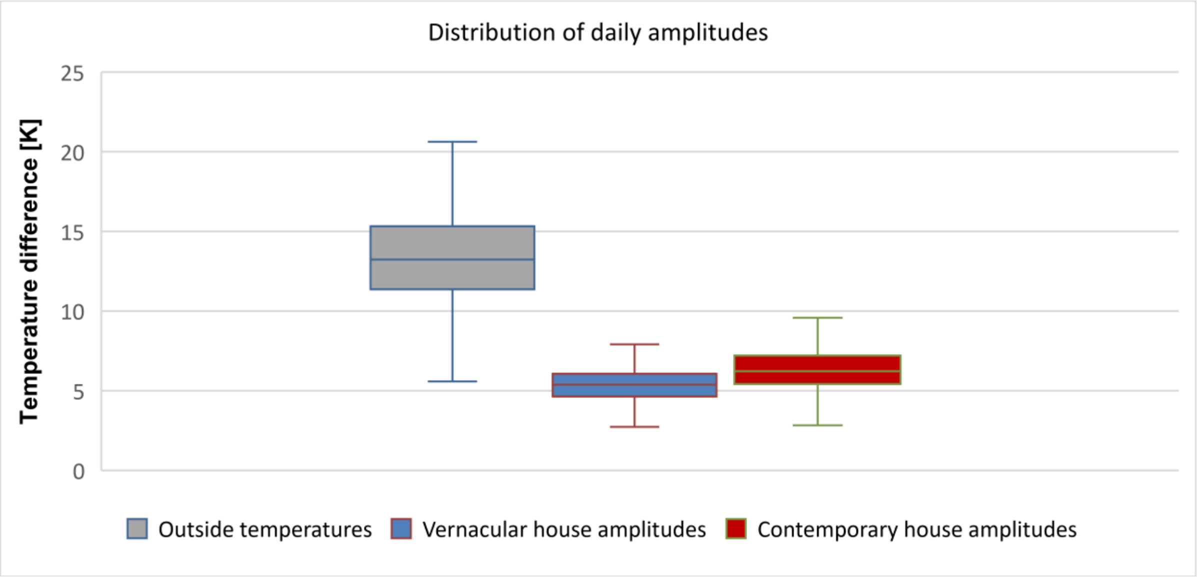


Figure 38 – Diurnal temperature variation of on-site measurements

As an overview of the day-night variations, the same path of amplitudes was observed in all three cases as expected. As the differences in temperatures of the inside measurements between day and night are relative and proportional with the outside weather, it is crucial to look into the sum of the day-night amplitudes during the 16.03.2016 - 22.09.2016 period.

This sum is presented in Figure 39.

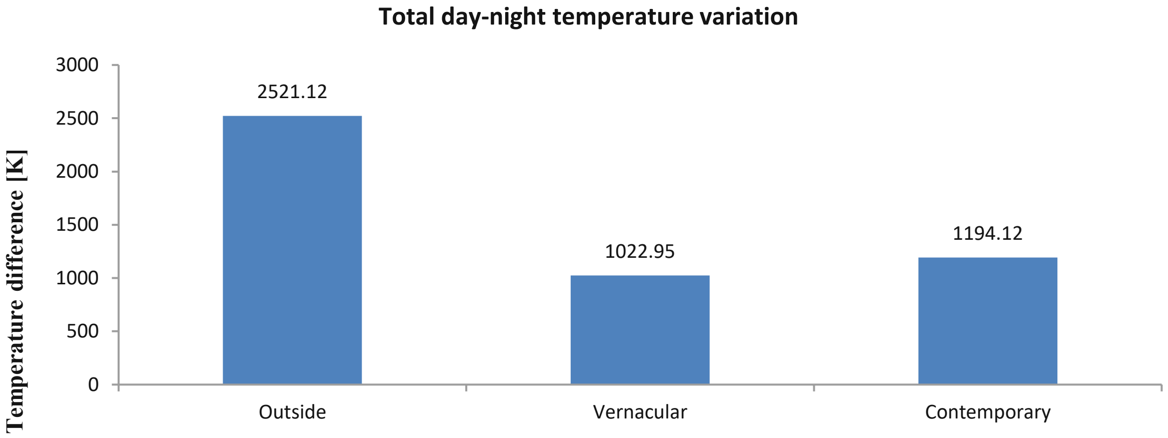


Figure 39 – Sum of diurnal temperature variation

The upper graphic represents the sum of day and night variations during the analyzed period. In normal conditions, the higher the temperature variation the human body is subjected to, the greater the degree of discomfort.

In this period, the amplitude of the differences recorded between the 2 cases is over 18%. This is an indicator of the human comfort degree and a consequence of human interaction with the building, the materials used and the indoor-outdoor temperature transfer, etc.

3.1.3 Mean temperatures

This indicator of human comfort is reliable only if it is correlated with the mean temperatures recorded in the two cases, as seen in Figure 40. While high thermal amplitudes are perceived as a feeling of discomfort by people, it is important to also analyze the average temperatures and compare them. Therefore, the mean temperatures were calculated, as displayed below.

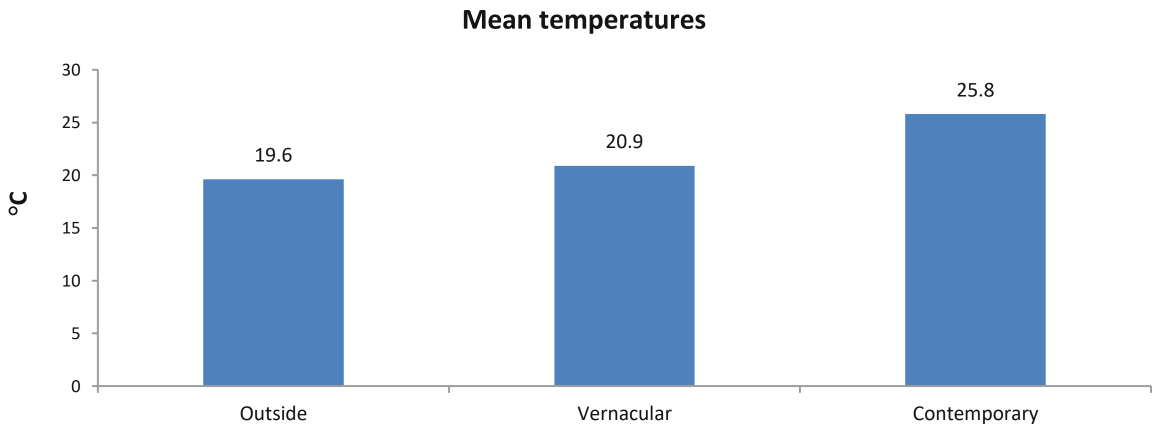


Figure 40 – Mean temperatures for on-site measurements

The represented values were obtained following the measurements during the hot season, without the intervention of the temperature control devices. To have an image of the degree of comfort during the recorded temperatures, it is necessary to compare them with the comfort temperatures defined by the ASHRAE 55 standard and by Humphrey’s definition of the optimal temperature.

Humphrey:

$$T_{co} = 0.53 \times T_m + 11.9$$

where, T_{co} - comfort temperature; T_m - mean outdoor temperature

$$T_{co} = 0.53 \times 19.6 + 11.9$$

$$= 22.3\ °C$$

Traditional mean variation: $|T_{co} - T_{traditional}|$ $= 22.3 - 20.9$

$= 1.4$ °C

Contemporary mean variation: $|T_{co} - T_{contemporary}|$ $= |\ 22.3 - 25.8|$

$= 3.5$ °C

Using Humphrey's definition, the difference between the calculated comfort temperature and the results obtained after the performed measurements is higher in the contemporary house. Therefore, the temperature felt in the traditional house was, for a longer period, closer to the comfort temperature.

3.1.4 Distribution of measured temperatures

Analyzing the distribution of values recorded by the sensors in both of the two situations, it is clearly observed in Figure 41 that the traditional house had lower temperatures compared with the contemporary one.

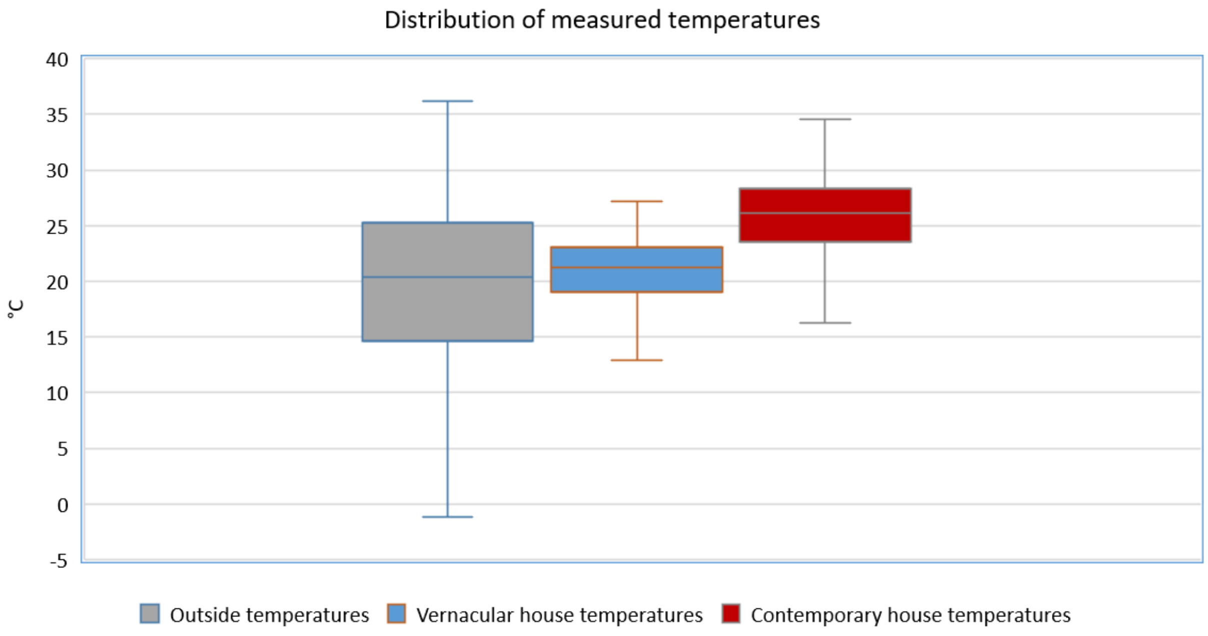


Figure 41 – Box Plot distribution of measured temperatures

Given the low temperatures in Romania during the winter, heating the living space is necessary. Thus, raising the room's temperature can be easier as a fireplace exists in every house. In contrast, an air conditioning system is not a necessity.

As specified in most calculation formulas, comfort temperature varies depending on the building's exterior temperatures. In particular, the data indicate that in Murighiol, Romania, the traditional house seems to offer a higher degree of comfort.

3.1.5 ASHRAE 55 PMV and PPD

According to ASHRAE 55, six primary factors must be addressed when defining conditions for thermal comfort. When analyzing the vernacular and contemporary building typologies, the metabolic rate and clothing insulation (personal factors), air temperature, radiant temperature, airspeed and humidity (environmental factors) were taken into account.

The thermal comfort equation was established by P.O Fanger in the 1970s, penned as "Fanger's Comfort Equation". Using Fanger's equation, the Predicted Mean Vote (PMV) indicator was calculated. The Predicted Mean Vote is the tool used to predict the Percentage of People Dissatisfied (PPD). This offers a strong indication of how the occupants of an area judge the climate of their environment. This PMV model has become the internationally accepted model for describing the predicted mean thermal comfort of occupants in indoor environments.

The predicted mean vote was calculated for each of the measurements taken. The mean monthly value is illustrated in the graph below (see Figure 42). This indicator was later used to calculate people's degree of dissatisfaction. As a hypothesis, the following elements that are part of the calculation formula were considered:

Metabolic Rate: 1.2 met (activity: standing/relaxed)

Clothing level: 0.5 (typical summer indoor clothing)

Air speed: 0.16 $m \cdot s^{-1}$

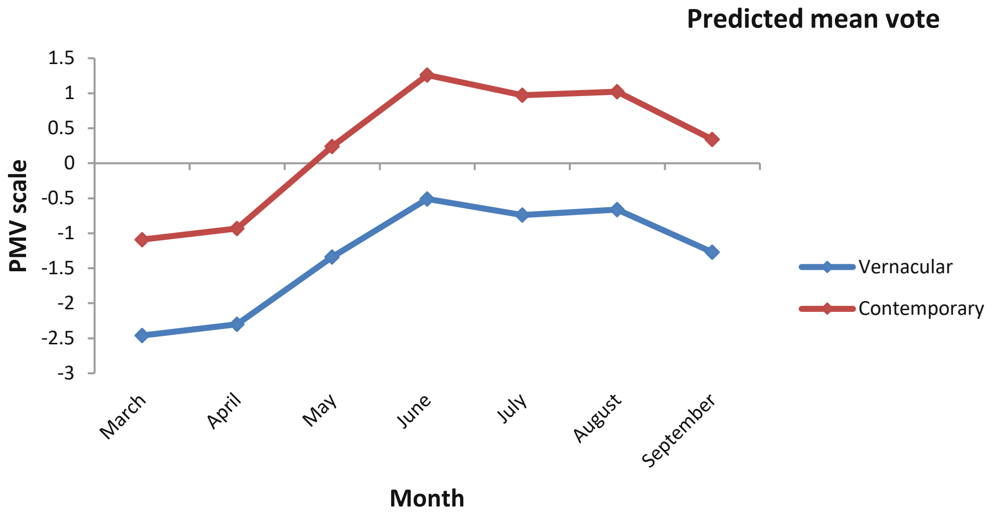


Figure 42 – Predicted mean vote for on-site measurements

As the predicted mean vote for each month is farther away from 0, the degree of dissatisfaction is higher. The closer this indicator gets to -3, the inhabitants' perception of colder increases. On the other hand, if this indicator goes to 3, the feeling of warmth gets more intense. The values from the Predicted Mean Vote graph above are obtained from the calculation and not as a consequence of any survey. As a hypothesis for easier comparison of the two houses the same clothing level of 0.5 clo was used for all of the months of the measurements, although during cooler months inhabitants would probably wear thicker clothes.

Considering the fact that also during the night, the lowest temperatures are compensated by the use of blankets, thicker clothes or other elements for heating during sleep, we shall eliminate from the calculation of the *predicted percentage of dissatisfied* the months with the lowest temperatures, namely March and April.

Figure 43 represents the index PPD – Predicted Percentage of Dissatisfied, a consequence of the Predicted Mean Vote (PMV) calculation.

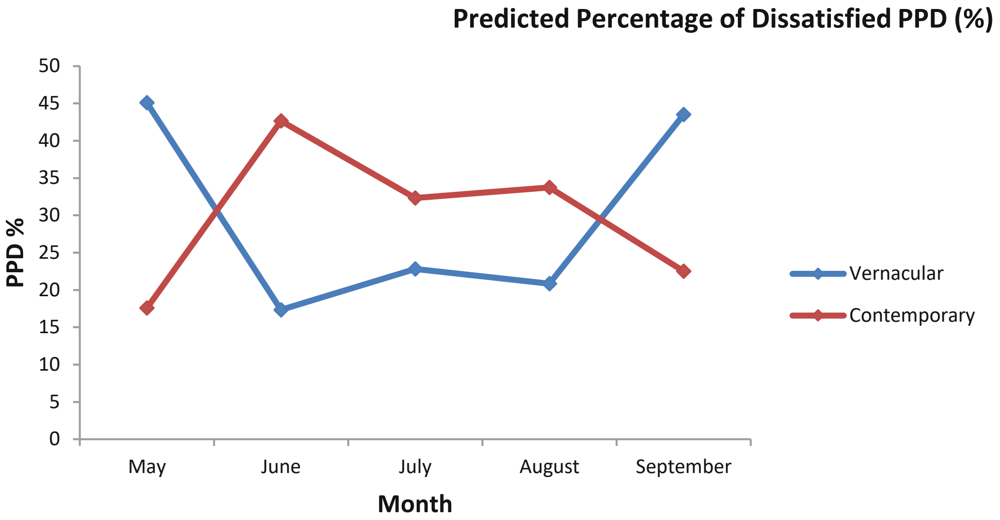


Figure 43 – Predicted percentage of dissatisfied for on-site measurements

Values illustrated in the graph above vary from around 17 to 45. As this value is smaller, it means that the number of people dissatisfied with the internal temperature of the house decreases. While there no alternatives to lower the temperature of an environment during high temperature periods apart from opening the windows, the inhabitants of the houses actually have the possibility to dress thicker or to light a fire during low temperature periods to increase the temperature. Thus, it is highly observed that the levels of dissatisfaction caused by increased temperatures, not by low temperatures, are to be considered representative.

Figure 44 illustrates the PMV index. In this graph representing the Predicted Mean Vote, the more the represented values vary from 0, the more the calculated thermal discomfort will increase. However, we can see in the case of the traditional house that these values of Predicted Mean Vote are negative, consequent to the feeling of discomfort caused by low temperatures. As this phenomenon can be easily counteracted by wearing thicker clothes, blankets or even by starting a fire, we will only consider the source of discomfort as relevant due to high temperatures.

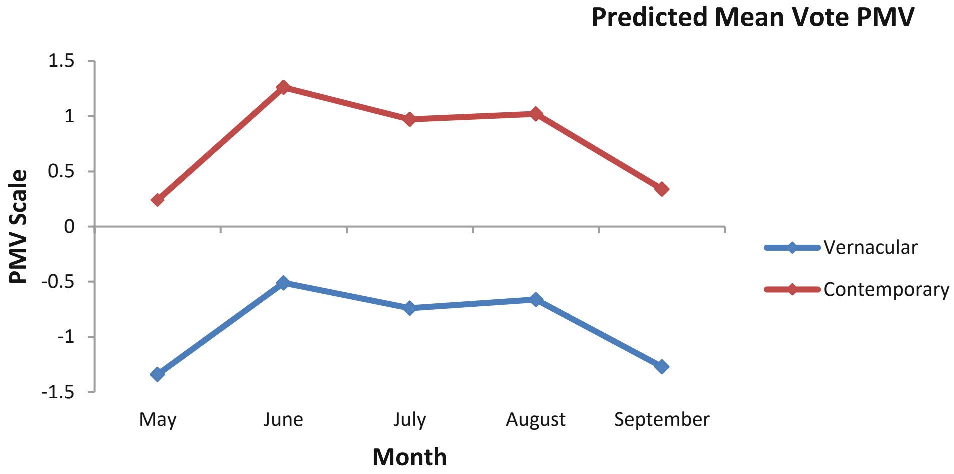


Figure 44 – PMV for on-site measurements in the hottest months

3.1.6 Psychrometric charts

The degree of discomfort due to high temperatures was calculated in the case of the contemporary house. The graphs were obtained as PPD was calculated for each measurement and then an average of those values was made. An illustration thereof can be seen in the monthly graphs below. Figure 45 represents the PPD of the contemporary house in the month of May.

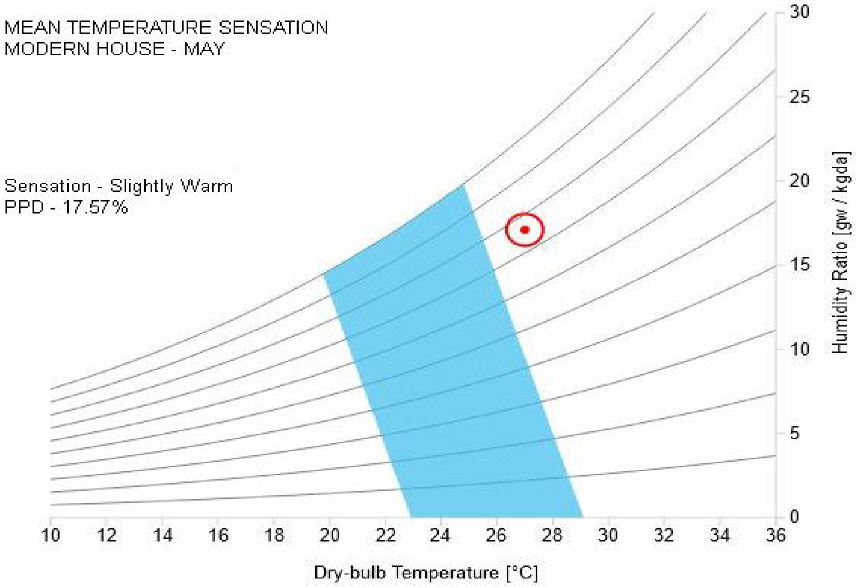


Figure 45 – PPD of contemporary house in May from on-site measurements (Center for the Built Environment software tool)

Figures 46 and 47 illustrate PPD of the contemporary house in the months of June and July.

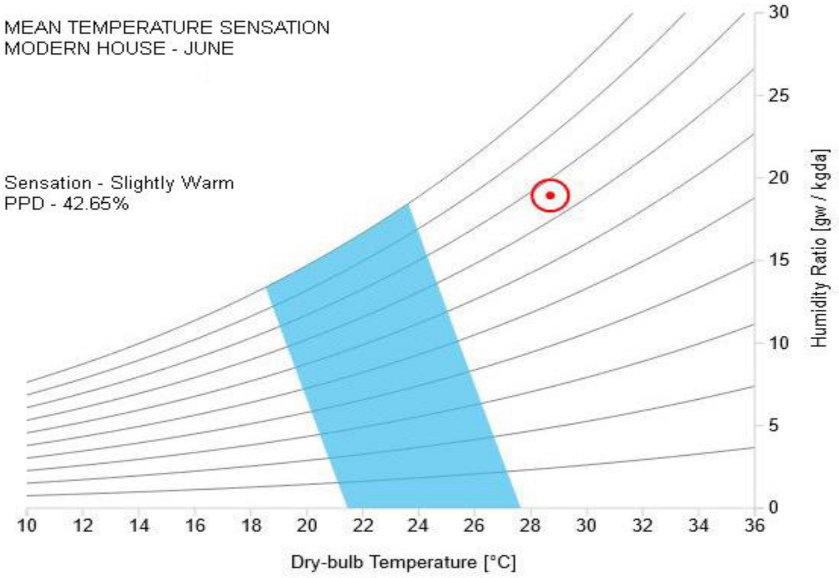


Figure 46 – PPD of contemporary house in June from on-site measurements (Center for the Built Environment software tool)

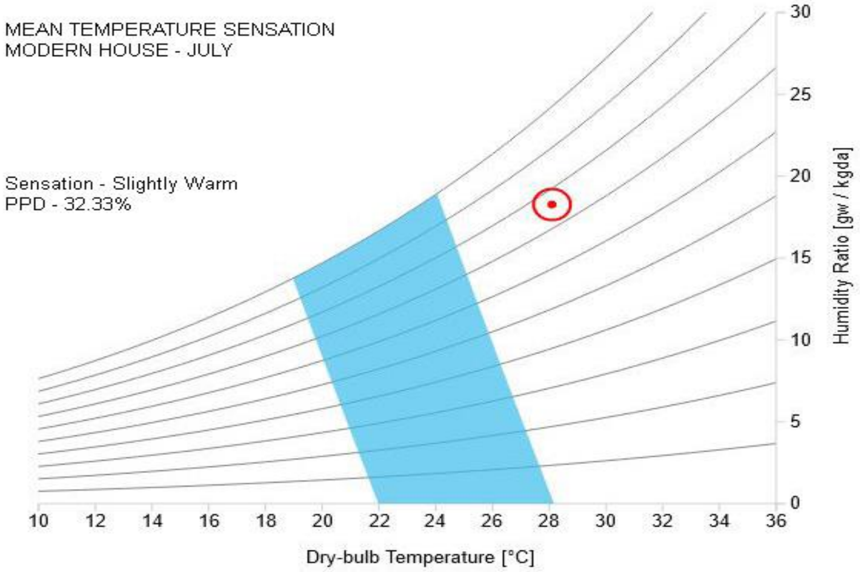


Figure 47 – PPD of contemporary house in July from on-site measurements (Center for the Built Environment software tool)

Figures 48 and 49 illustrate PPD of the contemporary house in the months of August and September.

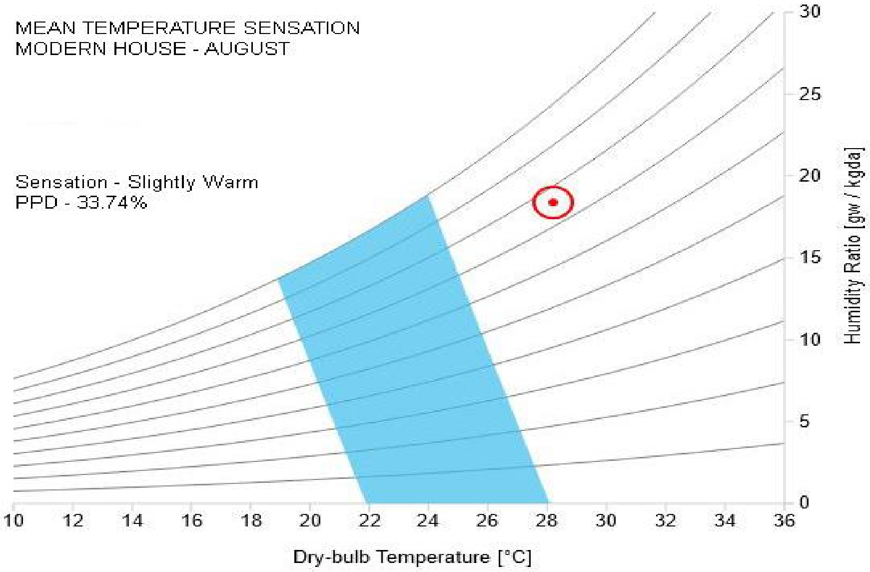


Figure 48 – PPD of contemporary house in August from on-site measurements (Center for the Built Environment software tool)

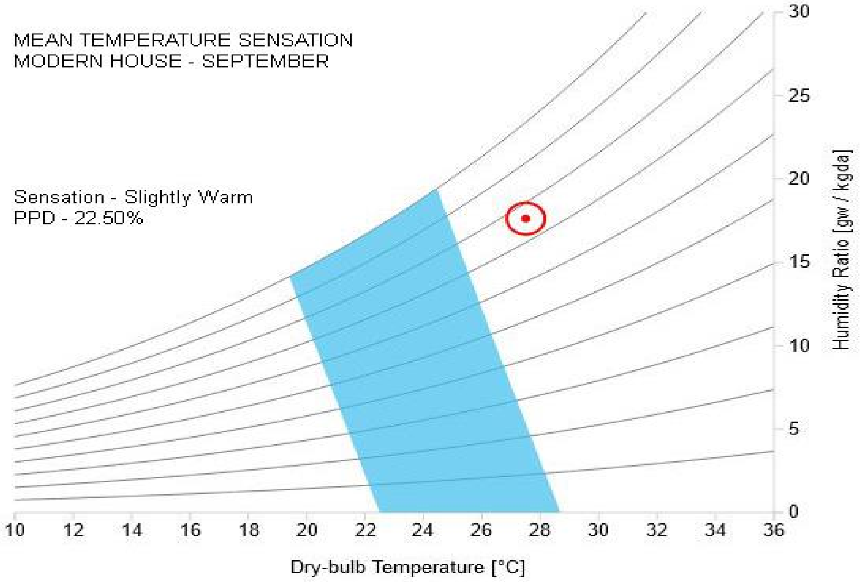


Figure 49 – PPD of contemporary house in September from on-site measurements (Center for the Built Environment software tool)

3.1.7 Cumulative distribution of temperatures and humidity

The Cumulative Distribution Function is the probability that a continuous random variable has a value less than or equal to a given value.

To better understand how temperatures were distributed during measurements they are illustrated in a cumulative distribution graph below in (Figure 50).

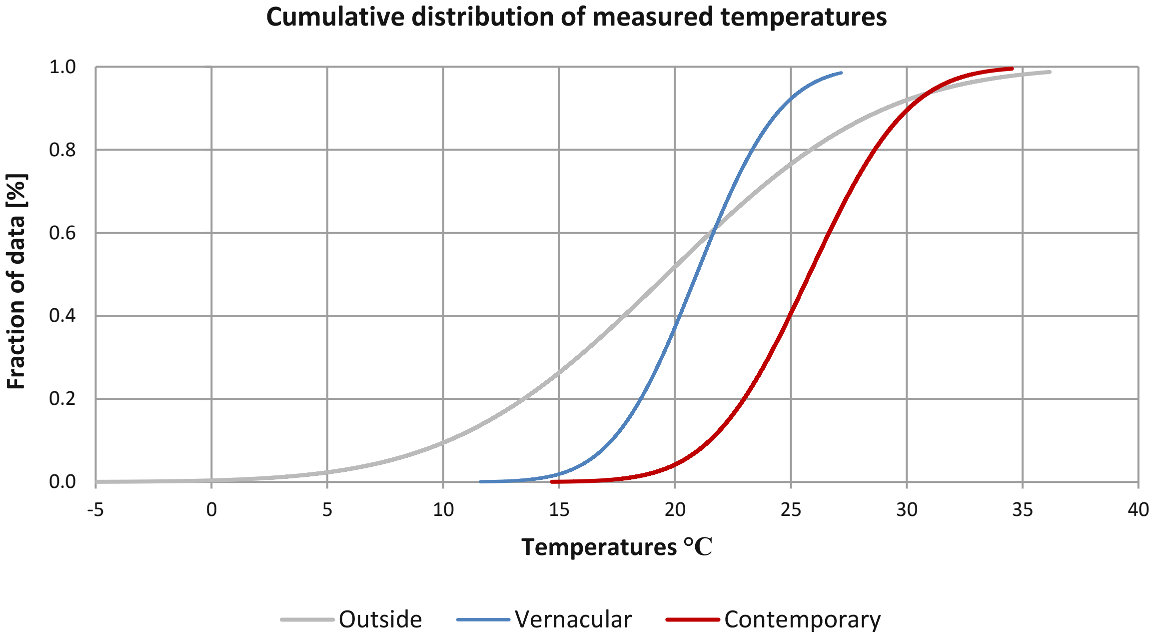


Figure 50 – Cumulative distribution of measured temperatures 16.03.2016 - 22.09.2016

The graph above represents the distribution of temperatures in each of the three cases. The most likely values are associated with those where the CDF is steepest. In this case, the majority of the values from the vernacular house seem to be between 18 and 23 °C, whereas for the contemporary one they are between 23 and 27 °C.

Most of the people living in the contemporary house could experience extreme heat sensation during summer. This is hard to counteract without air conditioning. On the other hand, in the vernacular home temperatures seem to be optimal during summer, with only some occasional moments when they drop below 15 °C. The feeling of cold that inhabitants could experience inside the house can be easily compensated with warm clothes or in other convenient ways.

Therefore, it is to be observed that the contemporary house offers many values of overheating during the time in which the measurements were made. The majority of the temperatures in the more modern house are over 23 °C so the inhabitants are more likely to experience discomfort due to heat. One the other hand, temperatures obtained in the vernacular house case are lower.

To fully understand all the aspects that influence thermal comfort, humidity must also be taken into account. Thus, a comparison chart of the humidity cumulative values is presented in Figure 51 below.

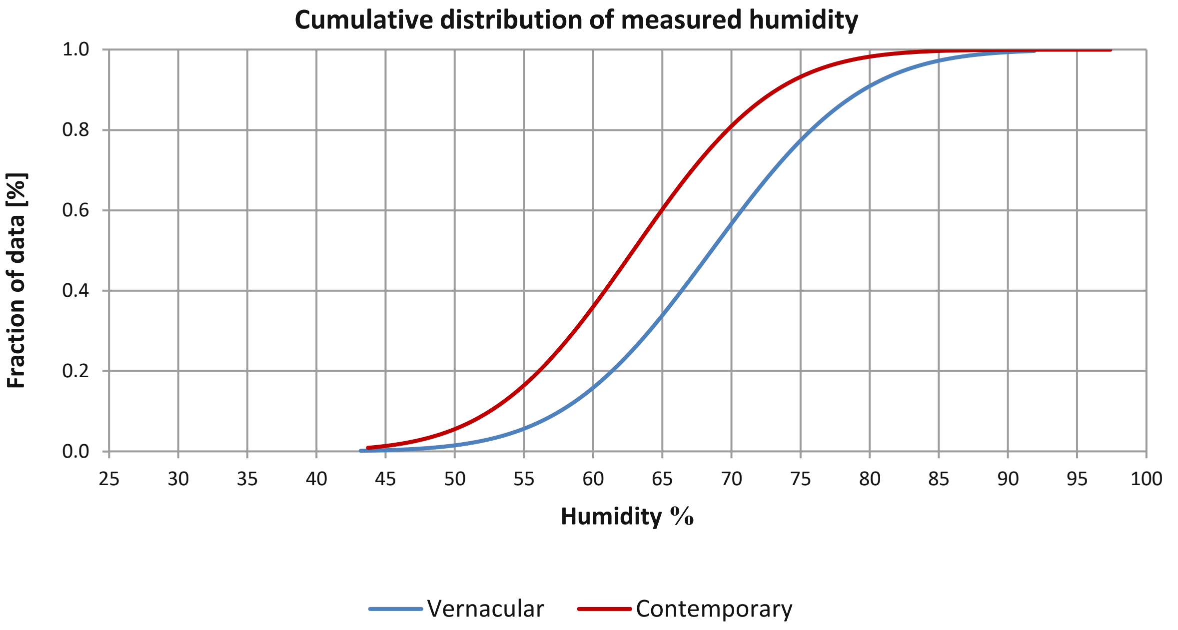


Figure 51 – Cumulative distribution of measured humidity values 16.03.2016 - 22.09.2016

According to the values represented above there is a higher possibility of increased humidity in the vernacular house. The frequency of lower humidity values is higher in the case of the contemporary house. This trend depends of the same factors that influence the temperature inside such as: house materials, geometry, natural ventilation, etc.

3.2 Computer Based Simulation

3.2.1 Temperature variation

As per the simulation conducted with EnergyPlus during the same period (16.03.2016 - 22.09.2016), the following results presented in Figures 52 were obtained:

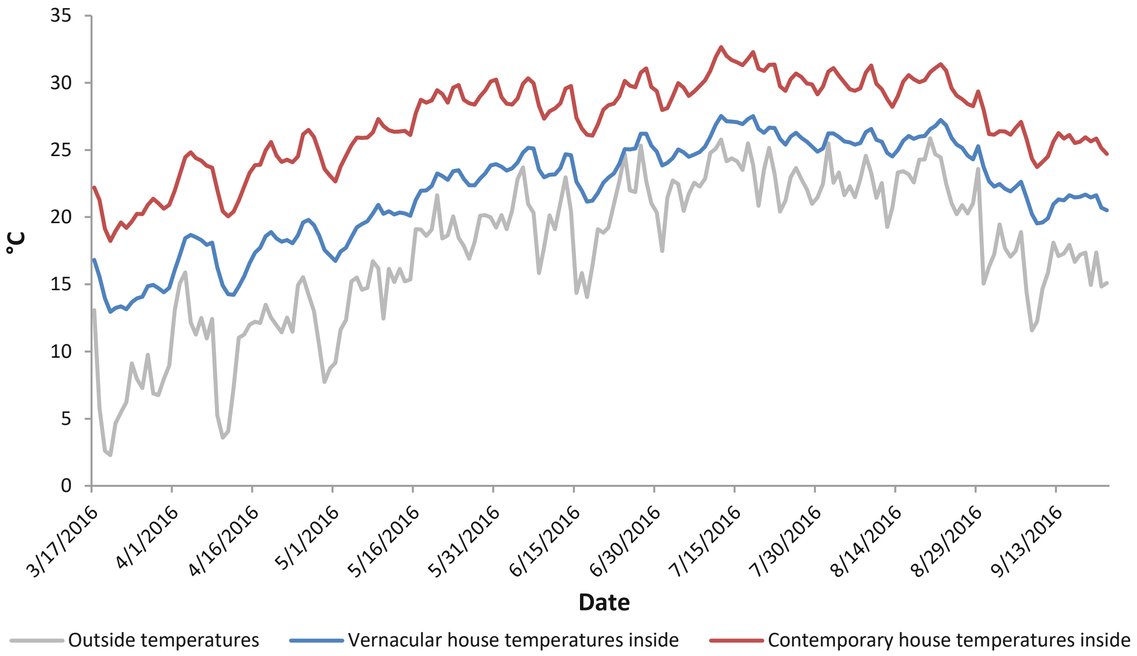


Figure 52 – Daily temperatures from computer simulation

Comparing the two graphs above, without having to make an in-depth analysis of the result in EnergyPlus, it is noticeable that the simulated average temperatures in the case of contemporary construction are higher than those in the traditional house.

3.2.2 Diurnal temperature variation

As in the case of field analysis, it is essential to see the day and night temperature amplitudes (see illustration in Figure 53) and the actual extreme temperatures that offer the significant sensations of discomfort in order to derive an objective idea of the sensation perceived by individuals.

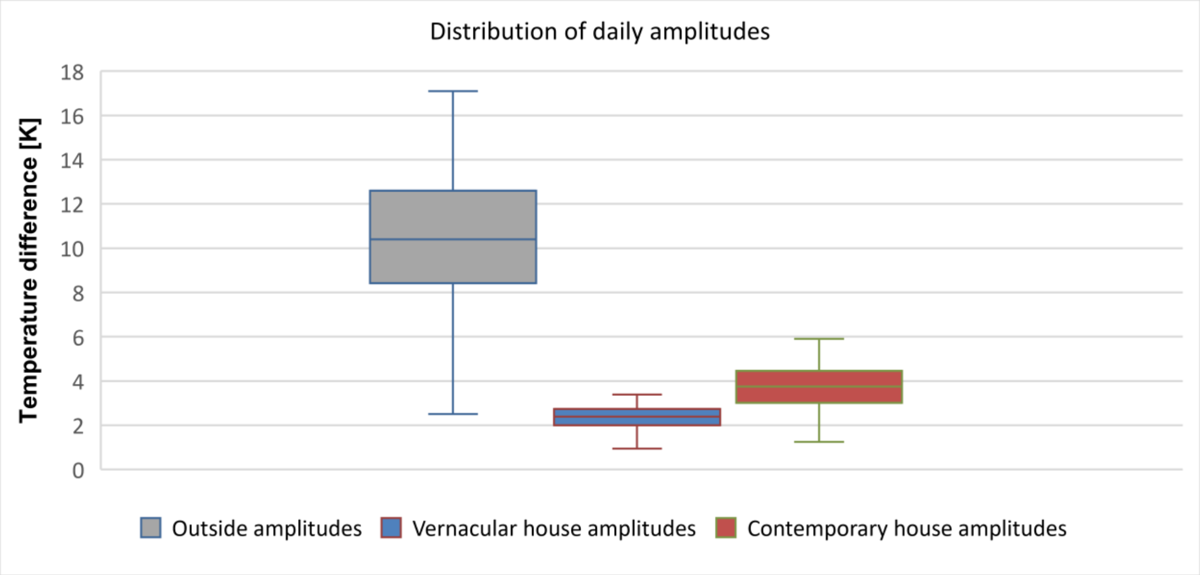


Figure 53 – Diurnal temperature variation from computer simulation

When the difference in temperature between the day and night is larger, it is expected that the discomfort felt by the human body will also be higher. This increased variation is due to several factors, including the thermal inertia of the materials from which the houses are built, the exchange of temperature with the outside, the degree of thermal insulation, and others.

The graph from Figure 54 represents the sum of the diurnal temperature variation between day and night simulated during the same period (16.03.2016 and 22.09.2016). Although the sum of the thermal amplitudes is smaller than in the case of field measurements, their proportion is even higher. As a result, daily differences in the traditional house were smaller by 35% than the contemporary one.

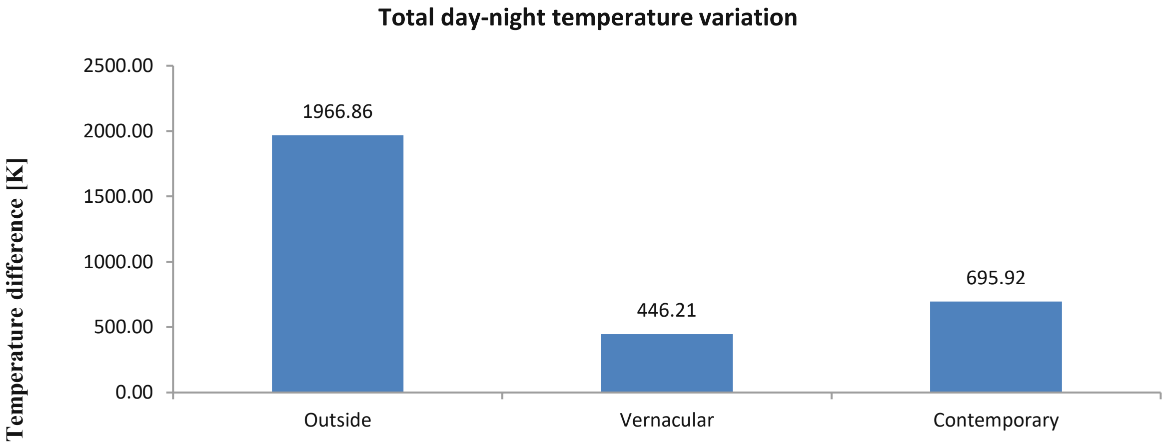


Figure 54 – Sum of diurnal temperature variation from computer simulation

3.2.3 Mean temperatures

This increased variation in the contemporary house's case translates as an additional factor of discomfort for its inhabitants as they are subjected to more extreme temperatures. However, this finding only makes sense if it is correlated with the reference temperature from which this variation took place. The average temperatures simulated in the two situations were analyzed and illustrated in Figure 55. Findings show that the contemporary construction offered significantly increased temperatures inside in comparison with the traditional one.

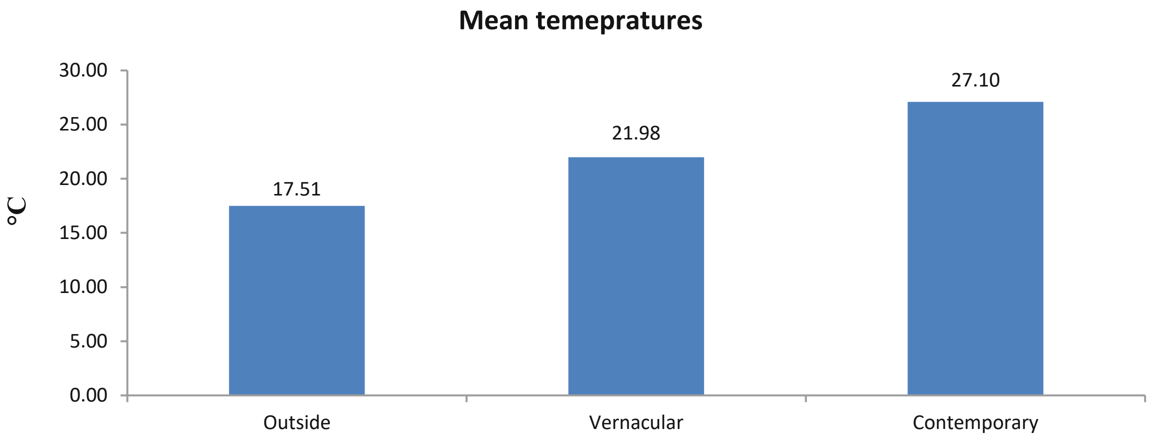


Figure 55 – Mean temperatures from computer simulation

3.2.4 Distribution of simulated temperatures

The average temperatures are the references from which the variation of the diurnal temperature is analyzed. Fig 56 illustrates that, although the simulation was taken during the summer season, it is more likely that the inhabitants of the contemporary building could suffer from scorching conditions.

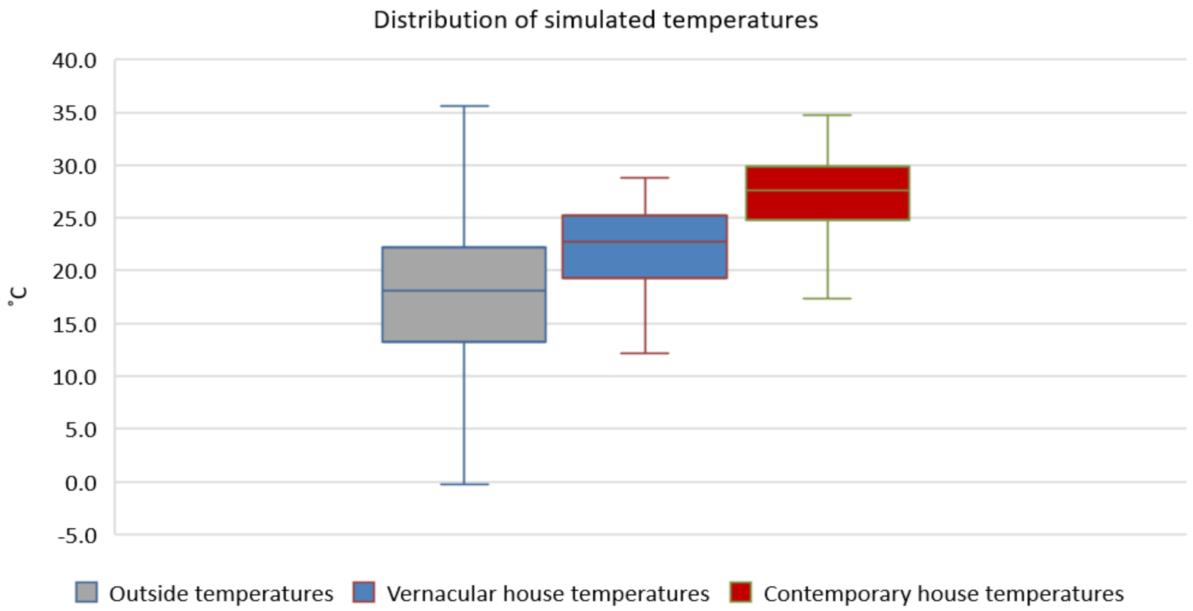


Figure 56 – Box Plot distribution of simulated temperatures

According to data provided in Figure 56, the simulated minimum and maximum temperatures in the vernacular home are lower than the ones in the contemporary building. Moreover, the inhabitants of the modern house are more susceptible to suffer from heat, while those of the vernacular house are more likely to feel the sensation of cold.

Although one of the hypotheses of this study is to analyze the conditions without the interference of temperature regulators, the fact that the inhabitants of rural areas in Romania have several methods to avoid cold than to protect themselves from high temperatures is taken into account. Therefore, we can anticipate that in the following analysis using the ASHRAE 55 Standard, thermal discomfort will come from the high temperatures of the contemporary building.

3.2.5 ASHRAE 55 PMV and PPD

To establish the degree of comfort offered in each of the two simulations, it is necessary to compare the expected temperatures with the ASHRAE 55 reference standard.

The ASHRAE thermal sensation scale, which was developed for use in quantifying people’s thermal sensation, is defined as presented in Figure 57 below:

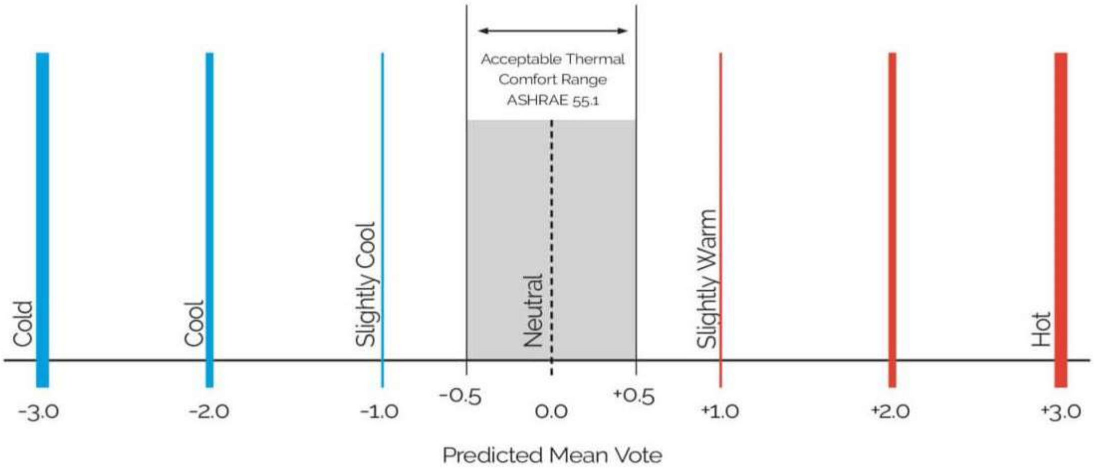


Figure 57 – ASHRAE thermal sensation scale (payette.com)

The predicted mean vote (PMV) model uses heat balance principles to relate the six key factors for thermal comfort to the people’s average response on the above scale. The predicted percentage of dissatisfied (PPD) index is related to the PMV. It is based on the assumption that people voting +2, +3, –2, or –3 on the thermal sensation scale are dissatisfied and, in simple terms, that PPD is symmetric around a neutral PMV.

The closer the predicted mean vote value approaches the negative minimum -3, the higher the thermal discomfort is due to the cold sensation. The closer the vote value to the +3 maximum, the more we can expect the inhabitants to feel discomfort due to excessive heat.

Based on the data presented in Figure 58, the inhabitant’s thermal discomfort in both constructions in March and April is due to low temperatures, while discomfort in May in the contemporary house is caused by higher temperatures. In the vernacular house during the months with the highest annual temperatures in Romania (June, July and August), the comfort curve is closer to 0. This means that the inhabitants of this building consider the indoor temperatures optimal.

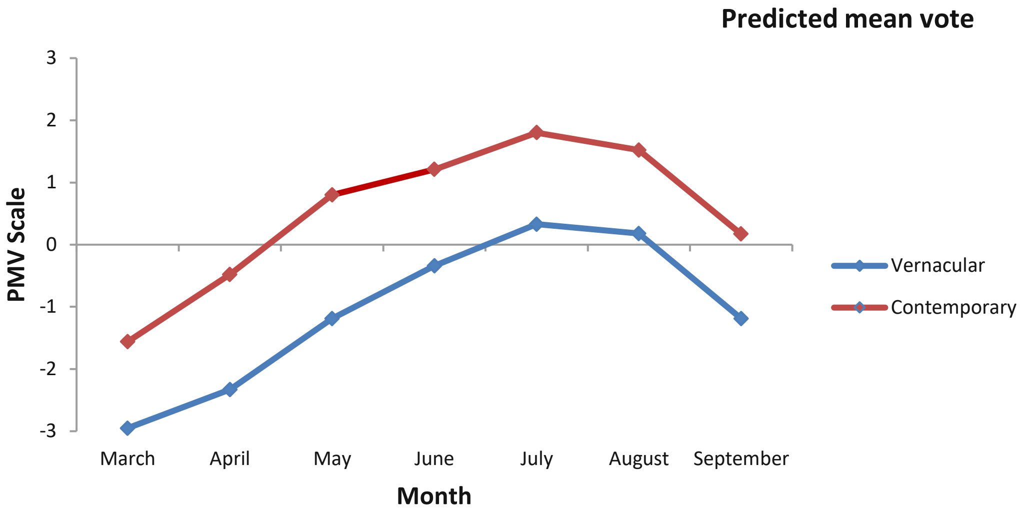


Figure 58 – Predicted mean vote from computer simulation

The predicted mean vote is an indicator of a state of well-being. The predicted percentage of dissatisfaction which represents the percentage of people who consider discomfort due to temperatures can be calculated.

As illustrated in fig. 59, during the first two months of the simulation, a higher percentage of thermally dissatisfied people are found in the traditional house. During the summer months (June, July and August), the contemporary house is more thermally unsuitable for the inhabitants as the degree of people dissatisfied with temperatures exceeds 40%.

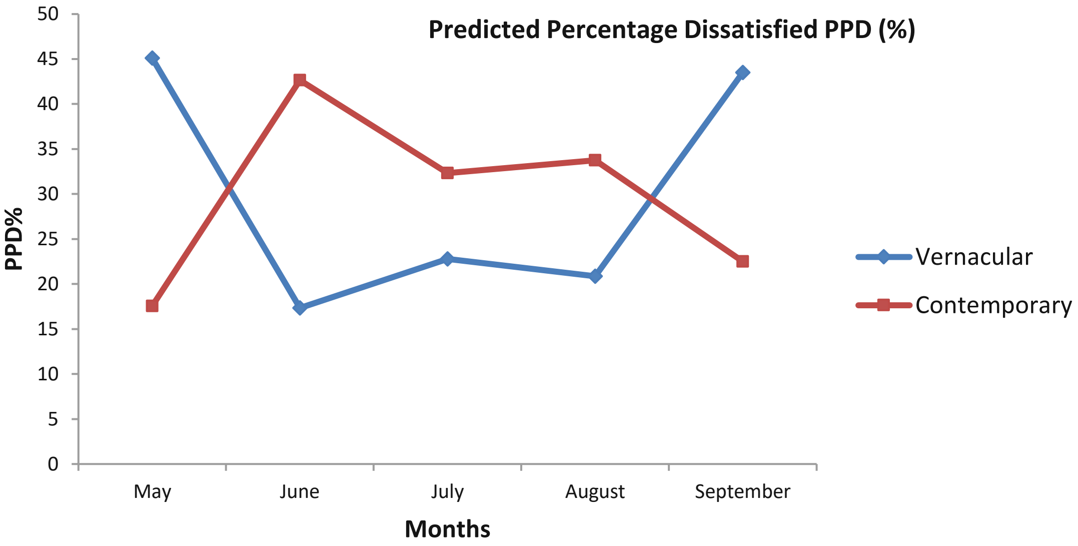


Figure 59 – Predicted percentage of dissatisfied from computer simulation

It is noteworthy that in field measurements, the vernacular house offers lower temperatures indoors in the first two months which can be easily compensated by warm clothes or other methods. On the other hand, the temperatures in the contemporary building during the summer are higher. In the absence of air conditioning units, people living in these conditions will be dissatisfied from a thermal perspective. Given these conditions, it is necessary to analyze only the months in which high temperatures cause discomfort.

Figure 60 represents the months that have predicted mean vote (PMV) positive – those months in which high temperatures offer thermal discomfort. The PPD is positive in the case of traditional house only during July and August, with values less than 11%, offering a good thermal satisfaction level for the inhabitants. Comparing these low values with the percentages related to contemporary houses that exceed 28% in May, June, July and August (with a dissatisfaction percentage of 63% in July), it can be seen that contemporary construction seems less suitable for the climate in Murighiol, Romania.

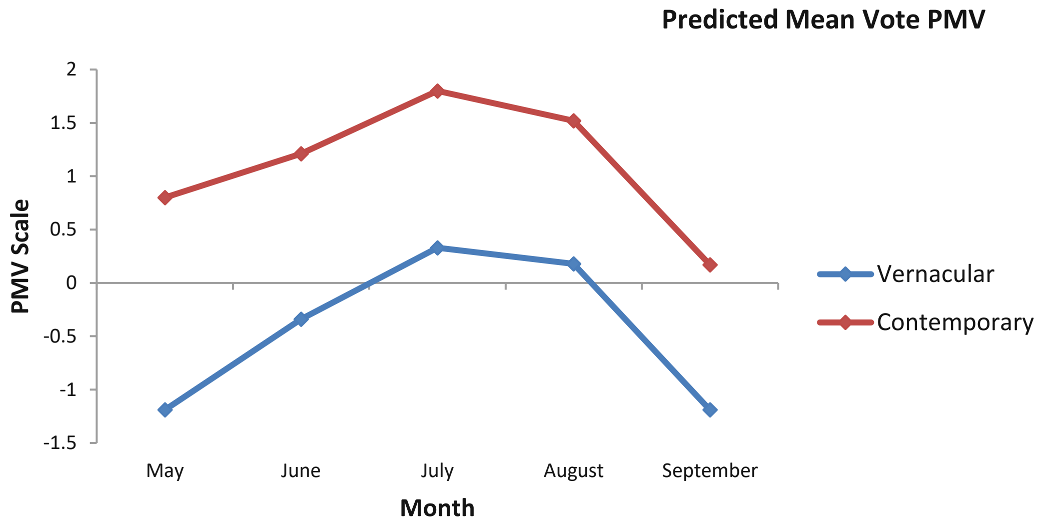


Figure 60 – PMV from computer simulation

3.2.6 Psychrometric charts

According to ASHRAE 55-2017, the six factors that influence the feeling of thermal comfort can be transposed in a graph similar to the ones below.

Based on the graphs in Figures 61 to 67, it is observed that the temperatures in the vernacular house in July and August are higher. However, months from May to September are too hot for a comfortable experience in the contemporary house, with extremes in July and August where PPD reaches 63.17%. Figures 61 and 62 illustrate the PPD in traditional house in the months of July and August.

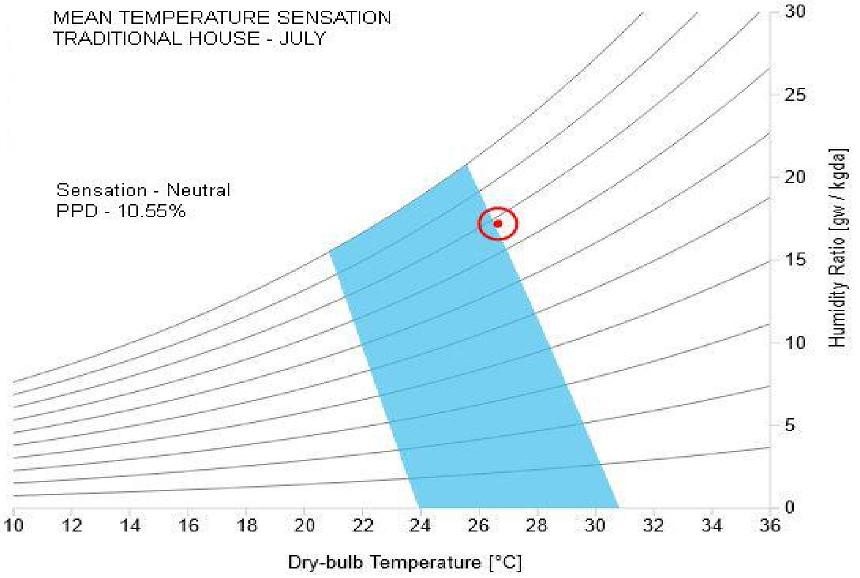


Figure 61 – PPD of traditional house in July from computer simulation (Center for the Built Environment software tool)

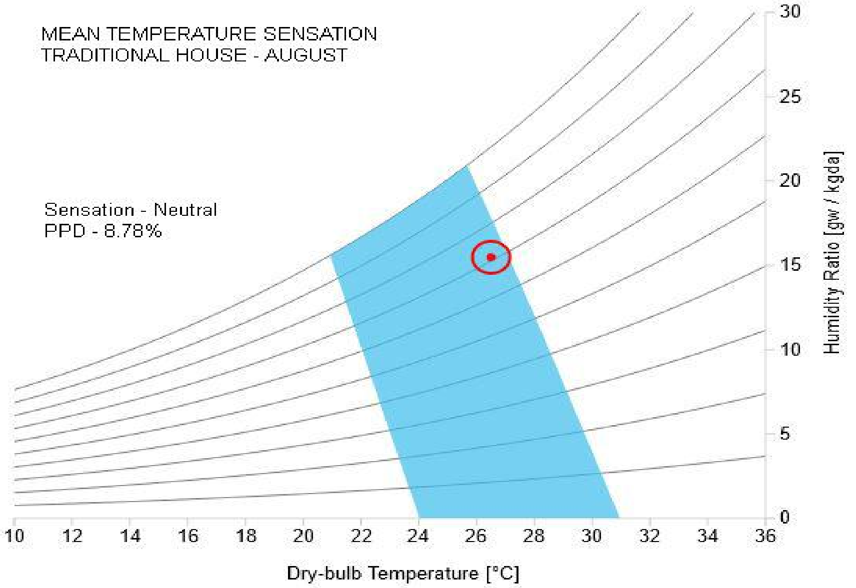


Figure 62 – PPD of traditional house in August from computer simulation (Center for the Built Environment software tool)

Figures 63 and 64 illustrate the PPD in contemporary house in the months of May and June.

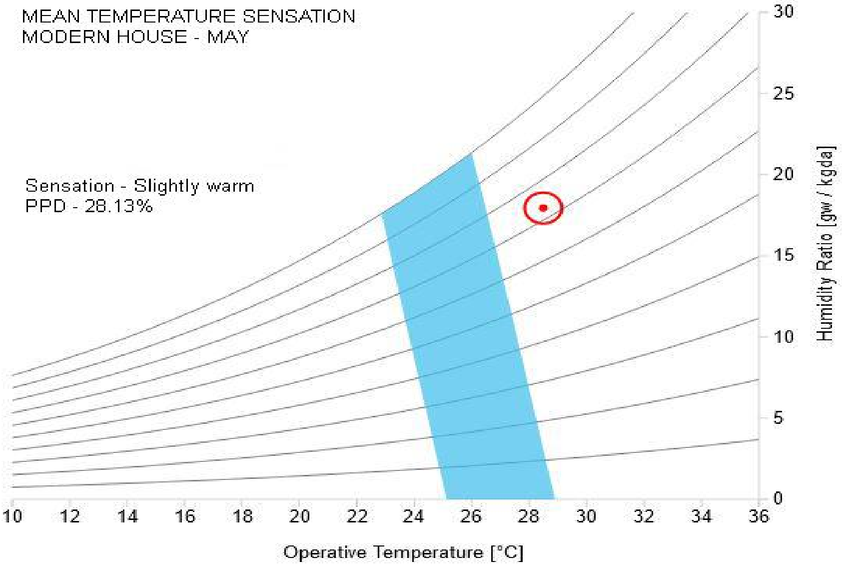


Figure 63 – PPD of contemporary house in May from computer simulation (Center for the Built Environment software tool)

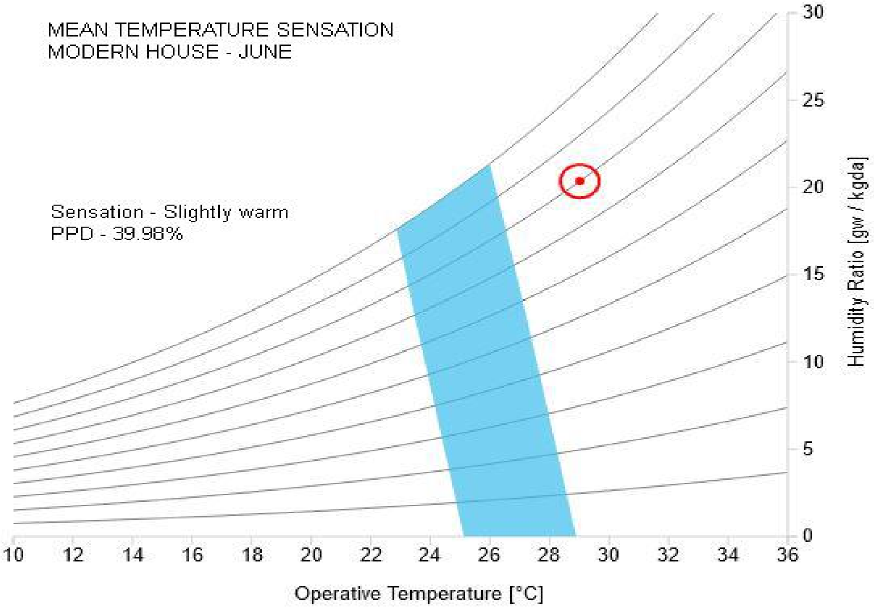


Figure 64 – PPD of contemporary house in June from computer simulation (Center for the Built Environment software tool)

Figures 65 and 66 represent the PPD in the contemporary house in the months of July and August.

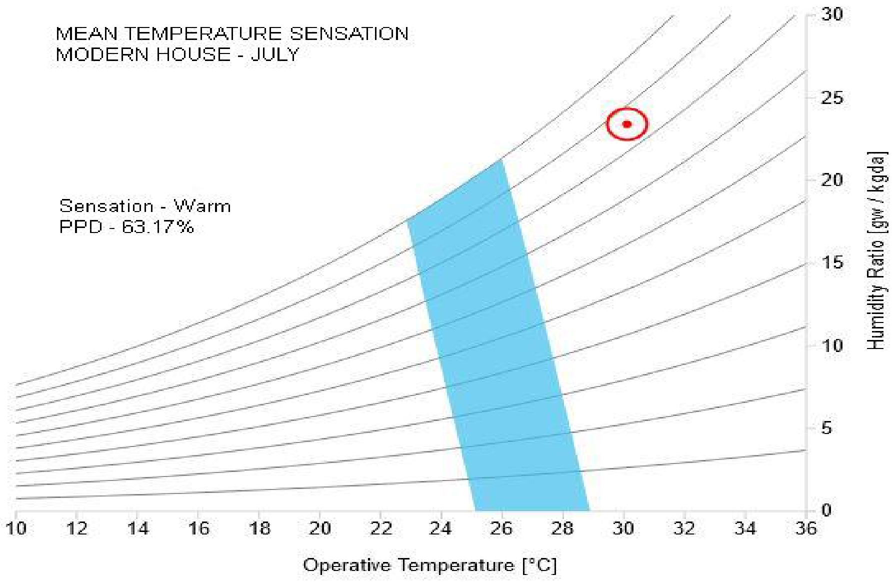


Figure 65 – PPD of contemporary house in July from computer simulation (Center for the Built Environment software tool)

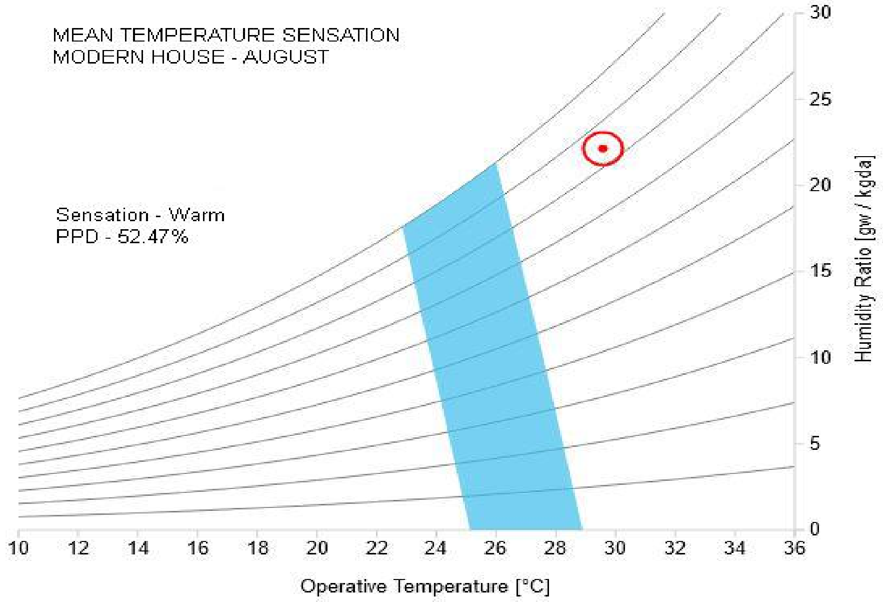


Figure 66 – PPD of contemporary house in August from computer simulation (Center for the Built Environment software tool)

Figure 67 represent the PPD in the contemporary house in the month of September.

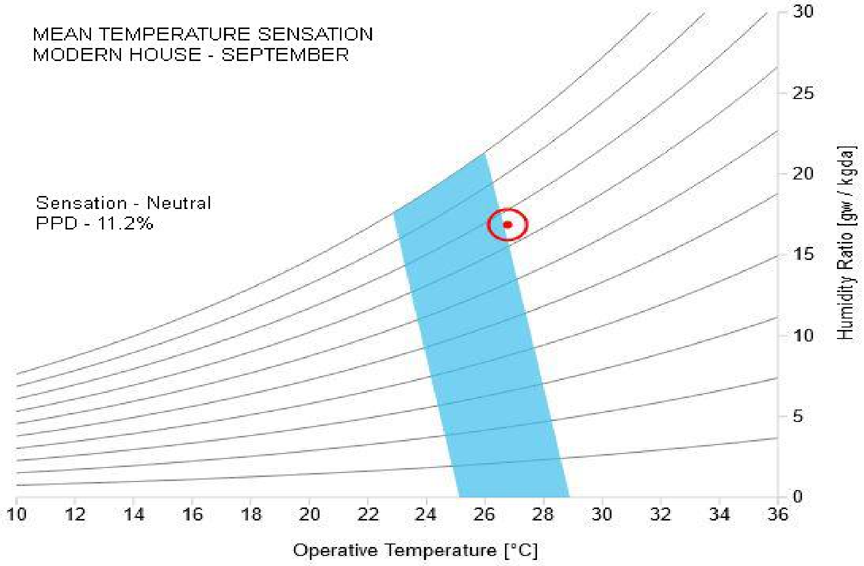


Figure 67 – PPD of contemporary house in September from computer simulation (Center for the Built Environment software tool)

3.2.7 Cumulative distribution of temperatures and humidity

To better understand the temperature distribution from computer simulation, they are illustrated in a cumulative distribution graph below in (Figure 68).

The cumulative distribution function (CDF) calculates the cumulative probability for a value on the x-axis, in our case, for temperatures and humidity, to be less than or equal to a certain value, higher than a certain value, or between two values.

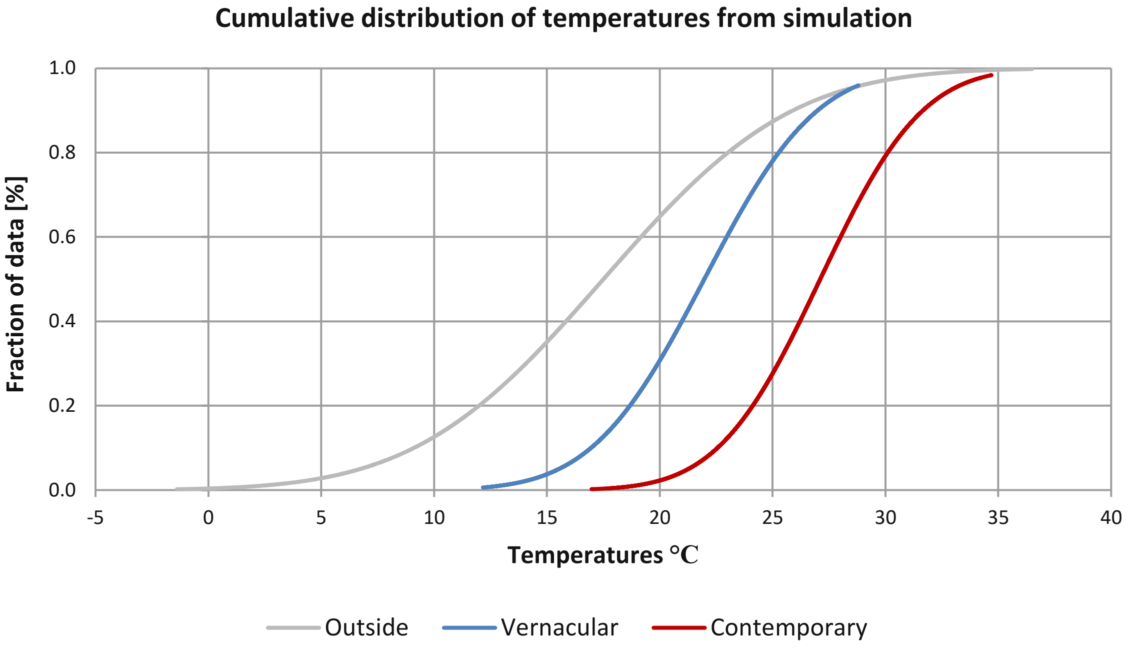


Figure 68 – Cumulative distribution of temperatures from computer simulation 16.03.2016 - 22.09.2016

The most likely values are associated with those where the CDF is steepest. Therefore, it is to be observed that the contemporary house offers many values of overheating during. The majority of the temperatures in the more modern house are over 25 °C so the inhabitants are more likely to experience discomfort due to heat. One the other hand, temperatures obtained in the vernacular house case are lower. They seem to offer higher thermal comfort with the steepest part of curve in the cumulative graph is between 20 and 25 °C.

The factor of humidity has a great influence on thermal comfort of people; hence it is important to assess it. The values of humidity inside the two homes are summarized below as cumulative distribution graph in Figure 69.

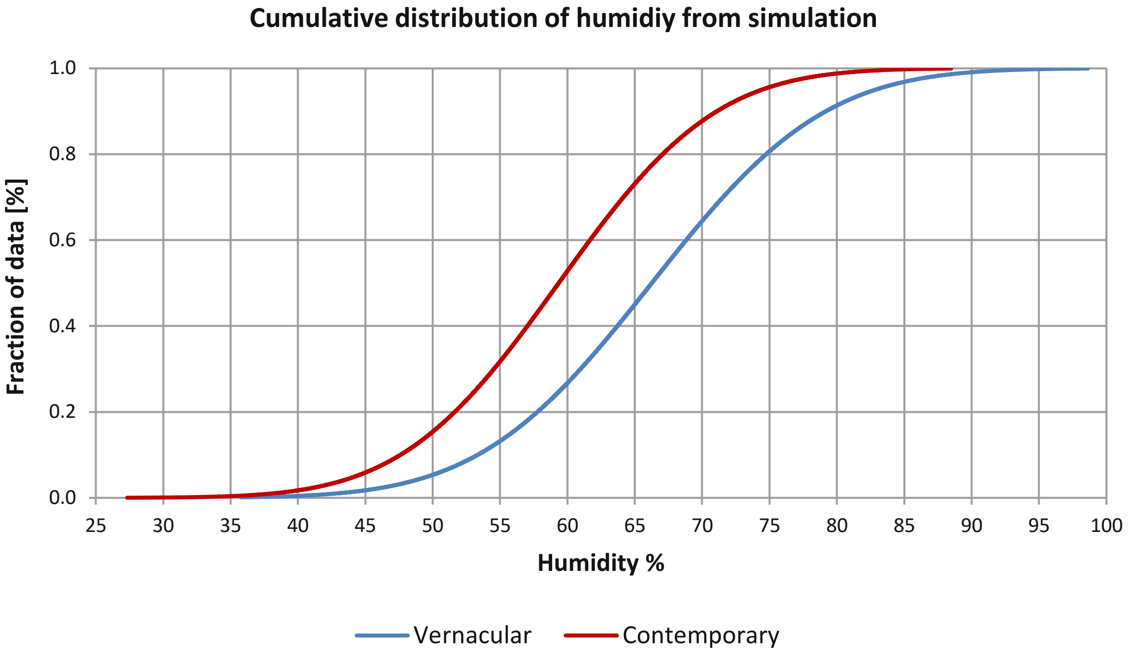


Figure 69 – Cumulative distribution of humidity from computer simulation 16.03.2016 - 22.09.2016

According to the cumulative distribution chart above it seems that there is a higher number of lower humidity values in the case of the contemporary house. In other words, the humidity in the vernacular house is higher most of the time than that in the contemporary one.

The increased level of humidity in the traditional homes may be due to the fact that they are made out of adobe. This material stores water vapors and releases them gradually during the dry periods.

3.3 Subjective assessment by building occupants

3.3.1 In-Detail Survey

In this study, 24 families were selected to participate in interviews on the thermal comfort offered by their respective houses. Particularly, 12 of which living in vernacular houses and 12 in contemporary ones are older than 50 years.

Each of the 24 families was asked to fill in a form regarding the thermal sensation felt inside their own house every hour between 08:00 - 20.00 for 14 days from 16.03.2016 - 22.09.2016. To provide a more accurate representation of the two types of construction's thermal quality, 2 days of each month were selected, particularly on the 20th and 21st where the participants were asked to complete a form similar to the example in Table 13.

Table 13 – Example of hourly perception interview table

Date:	20.03.2016
House type:	Traditional
House number:	1

Perception	Cold	Cool	Slightly cool	Neutral/ comfort	Slightly warm	Warm	Hot
Interval							
08:00 - 09:00		x					
09:00 - 10:00		x					
10:00 - 11:00		x					
11:00 - 12:00		x					
12:00 - 13:00			x				
13:00 - 14:00			x				
14:00 - 15:00				x			
15:00 - 16:00				x			
16:00 - 17:00				x			
17:00 - 18:00			x				
18:00 - 19:00			x				
19:00 - 20:00		x					
Total	0	5	4	3	0	0	0
Numeric Scale	-3	-2	-1	0	1	2	3
Result	0	-10	-4	0	0	0	0

After completing the hourly questionnaires, the average thermal perception of every family in each month was calculated. The results are illustrated in the graphs below from pictures 70 to 76. Figure 70 is a comparative representation of the PMV in the month of March.

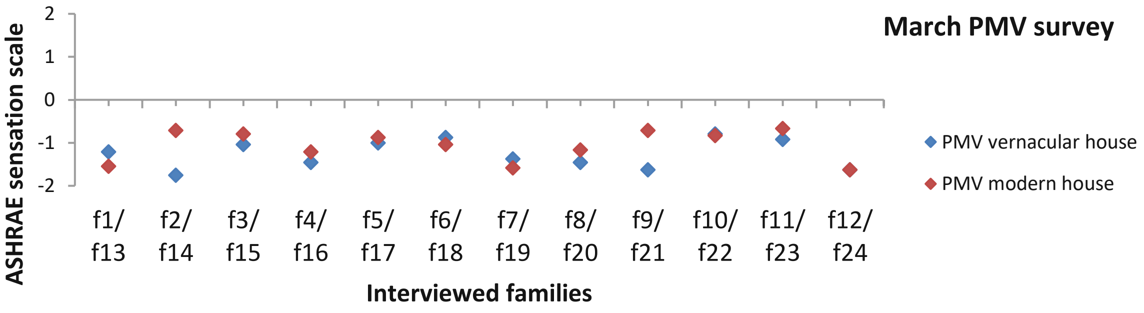


Figure 70 – PMV survey March results

Houses of families are compared 2 by 2, one vernacular and one contemporary as being as close to each other and having the highest number similarities between them.

Figures 71, 72 and 73 represent a PMV comparison in the months of April, May and June.

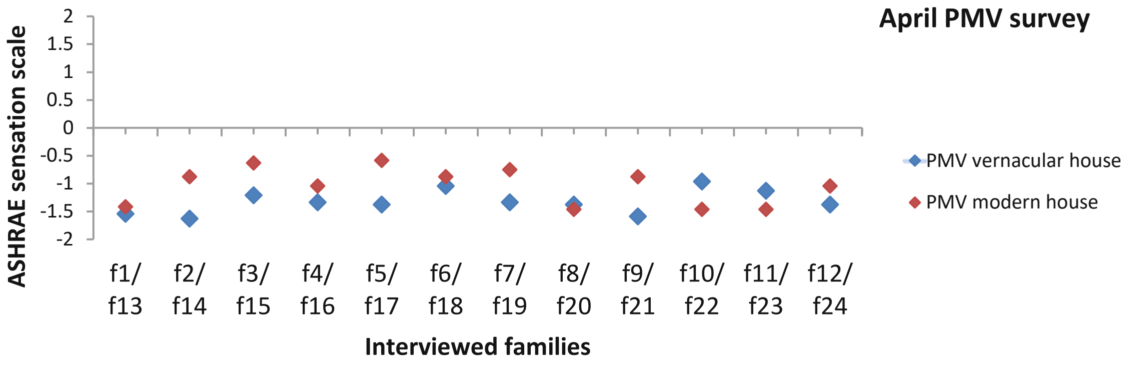


Figure 71 – PMV survey April results

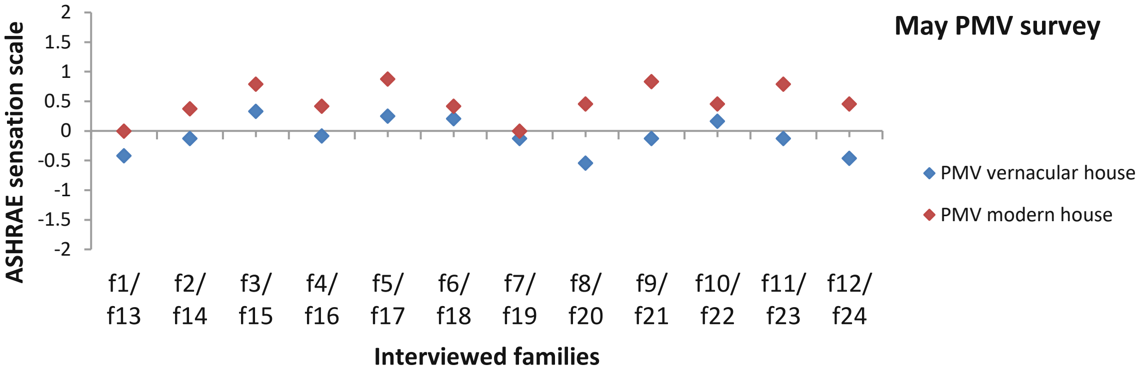


Figure 72 – PMV survey May results

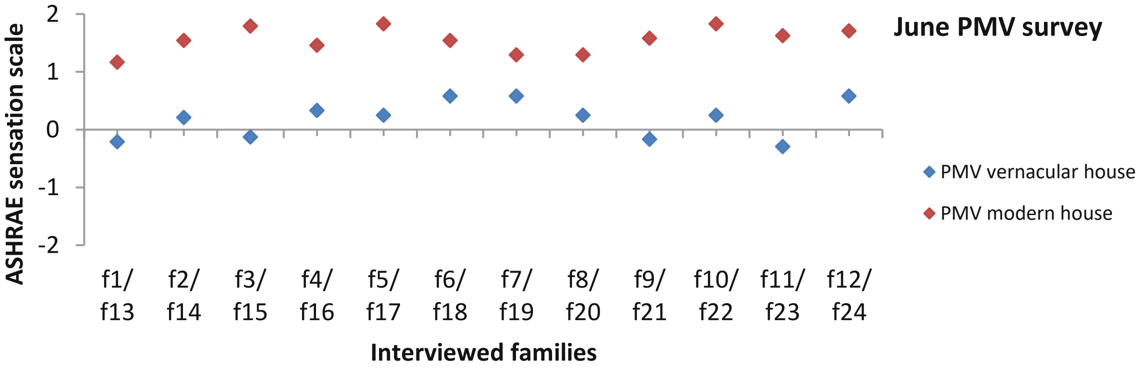


Figure 73 – PMV survey June results

Figures 74, 75 and 76 represent a PMV comparison in the months of July, August and September.

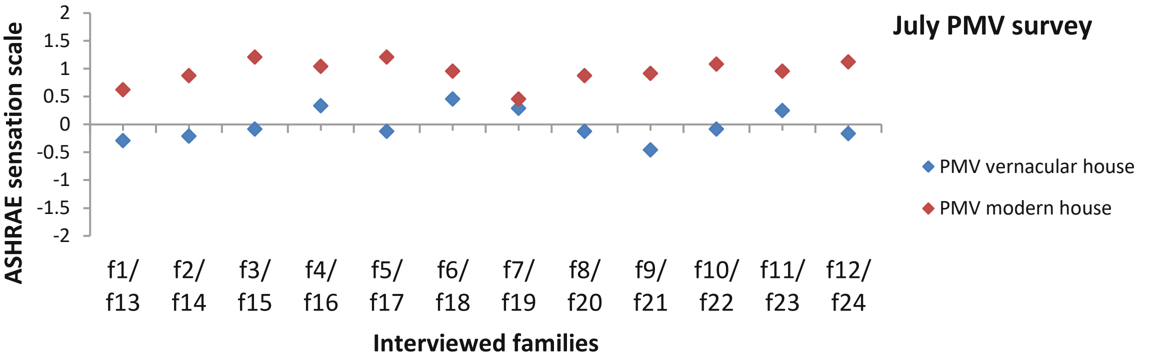


Figure 74 – PMV survey July results

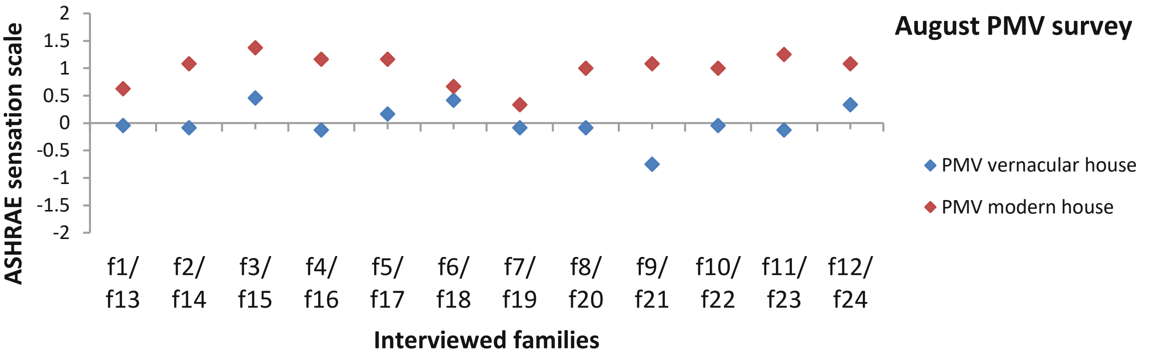


Figure 75 – PMV survey August results

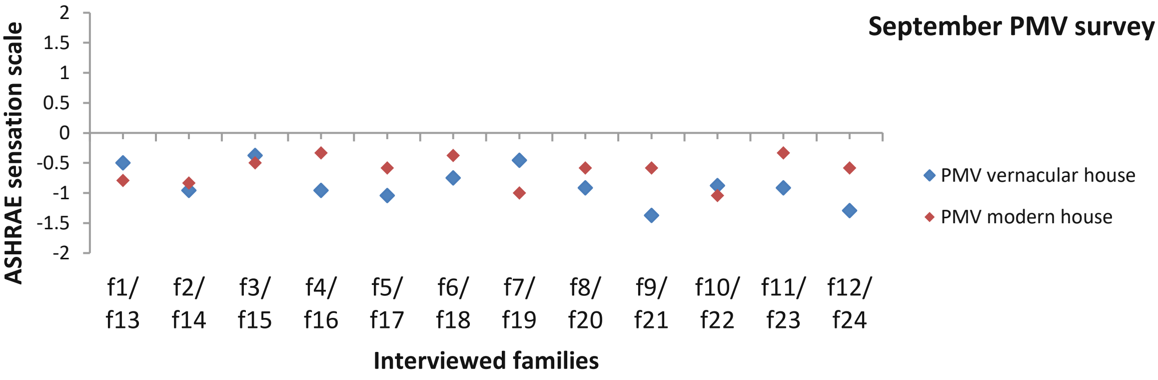


Figure 76 – PMV survey September results

The graphs above represent the average thermal sensation perceived by the 24 interviewed families. Such results pertain to the selected two days of each month in which the hourly record of indoor temperatures was addressed.

It is obvious that the families living in traditional houses will experience lower temperatures than those living in the contemporary ones. This is valid both in the colder months, and in the hotter summer ones where there is a feeling of superior thermal comfort during the peak summer temperatures.

In most months, especially in the hot summer ones, the PMV indicator of the inhabitants of traditional houses is generally closer to the value 0 which represents the thermal comfort zone.

However, we must also take into account that the interviews represent a purely subjective aspect. It must be considered that the inhabitants of the vernacular houses are simpler individuals with lower demands of thermal quality. This factor is most likely to influence their answers which indicate a greater state of comfort compared to the inhabitants of contemporary houses.

The fact that most interview responses tend to give traditional houses credit for a superior state of coolness during the summer offers an important clue. However, this must be correlated with another type of interview that reflects the inhabitant’s general opinion about the houses they live in.

3.3.2 Thermal Environment – Satisfaction Survey

This second type of survey was conducted about the overall experience of the inhabitants over their homes.

Questions and processed answers are presented below:

Question 1: “Which are the main materials your house built from?”

All inhabitants of the traditional houses listed the specific materials from the Danube Delta (adobe, reed, stone) while the inhabitants of the contemporary homes mentioned autoclaved concrete, polystyrene, cement-based plaster and metal tile roof.

Question 2: “What year is your house built in?

The vernacular houses were at least 45 years old, with the oldest one being constructed over 120 years ago. On the other hand, the contemporary has appeared in this traditional village only in the last three decades.

Question 3: “On which floor of the building is your space located?”

As the price of land in the village of Murighiol is not high and as each household benefits from generous space, it is easy to understand why all of the 24 interviewed families have their main living space on the ground floor.

Question 4: “What is your perception over thermal satisfaction inside your house in the following intervals?” (Base your response on the observation made in the last 6 months)

Tables 14 and 15 below represent an example filled by locals at question number 4 of the thermal environment survey.

Table 14 – Contemporary house - 6 months thermal perception

Modern houses												
Sensation/ Family	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12
Always too hot								x				
Often too hot			x			x	x		x			x
Occasionally too hot	x	x		x	x						x	
Occasionally too cold										x		
Often too cold												
Always too cold												

Table 15 – Traditional house - 6 months thermal perception

Traditional houses												
Sensation/ Family	f13	f14	f15	f16	f17	f18	f19	f20	f21	f22	f23	f24
Always too hot												
Often too hot												
Occasionally too hot							x					
Occasionally too cold	x	x		x	x			x			x	x
Often too cold			x			x			x	x		
Always too cold												

Participants were asked about the perception of their home temperatures in the last 6 months.

As a general point of view, the inhabitants of contemporary houses had the opinion that the temperature perception in their dwellings was often too hot, while the inhabitants of vernacular houses considered the temperatures to be occasionally too cold.

The answers to the general type interviews are consistent with those of the in-detail survey along with the results of field measurements and the findings in 3D simulations.

Question 5: In warm/hot weather, the temperature inside the house is (check the most appropriate box):

Tables 16 and 17 below represent an example filled by locals at question number 5 of the thermal environment survey.

Table 16 – Contemporary house - hot weather thermal perception

Modern houses												
Sensation/ Family	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12
Always too hot			x			x		x				
Often too hot	x	x		x	x		x					
Occasionally too hot									x			x
Occasionally too cold										x	x	
Often too cold												
Always too cold												

Table 17 – Traditional house - hot weather thermal perception

Traditional houses												
Sensation/ Family	f13	f14	f15	f16	f17	f18	f19	f20	f21	f22	f23	f24
Always too hot												
Often too hot				x								
Occasionally too hot	x	x			x	x		x		x		x
Occasionally too cold			x				x		x		x	
Often too cold												
Always too cold												

Considering that none of the 24 houses is equipped with air conditioning, the main period of thermal discomfort can occur during the summer, particularly in months with the highest temperatures.

Based on the responses of the 24 respondent families, it appears that there is a difference in thermal perception during excessive heat. Those in contemporary homes feel discomfort due to too high temperatures while those in traditional ones perceive a feeling of slightly hotter than a neutral state.

This particular survey question is probably the most important as it summarizes most clearly the difference between the thermal efficiency of the two building types.

As the cold sensation inside can be counteracted by a series of measures (thicker clothes, intense physical activity and others), there are no methods to cool the body or the environment without mechanical interventions. As a result, the high temperatures during the summer represent the main source of thermal discomfort considering the annual temperatures in the village of Murighiol, Romania.

Question 6: In cool/cold weather, the temperature inside the house is (check the most appropriate box):

Tables 18 and 19 below represent an example filled by locals at question number 6 of the thermal environment survey.

Table 18 – Contemporary house, cold weather thermal perception

Modern houses												
Sensation/ Family	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12
Always too hot												
Often too hot												
Occasionally too hot		x						x				
Occasionally too cold	x		x	x	x	x	x		x		x	x
Often too cold										x		
Always too cold												

Table 19 – Traditional house - cold weather thermal perception

Traditional houses												
Sensation/ Family	f13	f14	f15	f16	f17	f18	f19	f20	f21	f22	f23	f24
Always too hot												
Often too hot												
Occasionally too hot												
Occasionally too cold			x	x			x	x			x	x
Often too cold	x	x			x	x				x		
Always too cold									x			

Question number 6 mainly refers to the months of the year warm enough not to warrant the use of fire inside, but so cool that it does not provide a feeling of extra warmth in the houses.

Although the difference in thermal comfort during high-temperature periods between the two building types was considerable, we notice that in the cool months, the inhabitants of the vernacular houses are slightly more bothered by the cold than those in the contemporary dwellings.

4. DISCUSSION

Although the phase is incipient at this stage of analysis, the results can represent a basis for future studies on this subject. This also paves way for future legislative direction in which the constructions in this area will be made exclusive with traditional materials.

It is recommended to perform a financial analysis between the construction of buildings in contemporary and traditional style where a greater number of factors will be considered such as the architectural style and framing, construction cost, impact on the environment and the community, etc. All the factors that corroborated this paper's results can lead to certain legislative changes by which probable occupants in the area can be influenced to use local materials. New building materials are becoming easier to procure while craftsmen adept at using local elements will be increasingly difficult to find. The instinct of builders is to use what is new on the market. However, it is important that the decisions of these builders must be made with awareness so as to better understand the financial forecasts, the comfort they will experience in the future, and the impact they will have over the environment and the community.

While traditional building elements are being easily replaced with more modern ones, it is not in all cases convenient and desirable. In the Danube Delta, the authority dealing with this area may restrict the use of certain materials for house constructions. Supposing this measure is supported by arguments such as the findings of this paper, the financial factor, and others, residents will nevertheless choose the vernacular option not in sheer compliance with the law but also out of belief.

One factor that could also be addressed to shift the direction of used materials in new construction is the link among the impact that production, transport and destruction of these new building elements has on the environment. When local renewable materials are used, the harmful effects on the environment caused by production and transport of materials are eliminated while the destructive effects of traditional materials are minimal in the event that they are no longer needed.

5. CONCLUSION

As this research nears completion, a three-way approach is needed to formulate a complete conclusion.

Firstly, it is necessary to synthesize the results in the first variant of comparison of the two types of constructions, namely the field measurements. The extreme temperatures recorded by the sensors following the measurements were between 11.6° and 27.2° Celsius inside the vernacular house, between 14.7° and 34.5° Celsius respectively in the contemporary house. Compared to the temperatures considered to be comfortable from the ASHRAE 55-2017 standard and other reference works, it can be stated that in this first case of measurements that the vernacular construction is more suitable for people living from a thermal point of view. Following an analysis of the PMV and PPD indices, it was found that the state of discomfort caused by too high temperatures during the summer, these being those that cannot be counteracted in the absence of air conditioning systems, was recorded from May to September only in the case of contemporary construction.

Secondly, the comparison between the 2 types of constructions was made with computer-based simulation, and the results were relatively similar to those of field measurements. The average temperature in the simulated period was 21.9° Celsius in the traditional house and 27.1° Celsius in the contemporary one. Also, the temperature variation was between 12.2° and 28.8° in the traditional construction, while in the contemporary one there were values between 17° and 34.7° Celsius. In the situation using EnergyPlus, positive values of the PMV indicator were found in the case of the traditional house only in July and August, while much higher values of this indicator resulted in the case of contemporary construction in the months from May to September. The second comparison methods conclusion is similar to the first one; the inhabitants of the vernacular construction felt more comfortable from a thermal perspective.

Finally, the third way of comparing the two types of constructions was probably the most important even if it included a greater degree of subjectivity - interviews with locals. Two types of interviews were conducted, a "detailed survey" and a "degree of satisfaction survey". Both were taken over 24 families, 12 in each type of building; in the first one, families were asked to fill in a form regarding the thermal sensation felt inside their own house every hour between 08:00 - 20.00 for 14 days from 16.03.2016 - 22.09.2016. The results indicate that the families of traditional houses feel lower temperatures than those living in the contemporary ones. This fact is valid both in the colder months and in the very hot summer ones, offering a feeling of superior thermal comfort during the peak summer temperatures.

In almost all months, especially in the hot summer ones, the PMV indicator of the inhabitants of traditional houses is more often close to the value 0, which represents the thermal comfort zone. The second type of survey was conducted based on the overall experience of the inhabitants over their homes. According to the answers provided by the 24 families, there is a difference in thermal perception during excessive heat, in the sense that those in contemporary homes feel discomfort due to too high temperatures. In contrast, those in traditional ones perceive a feeling slightly hotter than a neutral state. As the cold sensation inside can be counteracted by a series of measures (thicker clothes, intense physical activity and others), there are no methods to cool the body or the environment without mechanical interventions. As such, the high temperatures during the summer represent the main source of thermal discomfort considering the annual temperatures in the village of Murighiol, Romania.

In conclusion, all the 3 ways in which the comparison of the traditional vs. contemporary house was made led to the same result: The vernacular house offers a higher degree of comfort to the inhabitants, especially during the summer when the temperatures are at their highest peak. In the absence of air conditioners, but in the presence of fireplaces, the inhabitants encounter thermal inconveniences, especially during summer. Therefore, all three comparative approaches claim that the vernacular houses in Murighiol, Romania are more suitable for the inhabitant’s thermal comfort than the contemporary ones.

This paper argues for returning to traditional materials in the construction of houses in the Danube Delta area. The result of the present research presented in the conclusions section is even more convincing as all three comparative analysis methods led to the same result, namely, the vernacular construction is more comfortable from a thermal point of view than the contemporary one.

If the thesis has the effect of changing the perception of those who want to build a house by addressing the technical aspect of thermal comfort, the community will benefit from several points of view, even financially when money will no longer be directed towards big companies but will remain in the community to support local workforce.

When the building solution is chosen, a series of factors are taken into account, such as costs, environmental impact, resistance over time, thermal comfort of the new construction, etc. Suppose most of these factors can be easily analyzed by the one who chooses the structural materials. The thermal comfort of the future construction approached by this paper represents the missing link in this chain that can lead to a paradigm shift.

There is a general trend of adopting new elements stemming from the idea that they bring extra comfort in everyday life. Usually, this consequence is real, but in this paper it has been proven using three different approaches that in terms of thermal comfort, the vernacular constructions are superior. It is intuitive to say that it is not appropriate to replace an old construction method developed over thousands of years by "trial and error" with a modern one, especially knowing that it does not bring any benefit, at least in terms of thermal comfort.

In an age of fast depleting resources learning from the adaptive and flexibility principles of the vernacular, it should not be an option, but a necessity.

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6.3 List of Equations

$T_{CO} = 0.53 X T_M + 11.9$ (1) 5
$T_{CO} = 0.48 X T_I + 0.14 X T_M + 9.22$ (2) 5

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8. APPENDIX

8.1 Interviews

Interview – Contemporary House Family 1

Interview – Contemporary House Family 2

Interview – Contemporary House Family 3

Interview – Contemporary House Family 4

Interview – Contemporary House Family 5

Interview – Contemporary House Family 6

Interview – Contemporary House Family 7

Interview – Contemporary House Family 8

Interview – Contemporary House Family 9

Interview – Contemporary House Family 10

Interview – Contemporary House Family 11

Interview – Contemporary House Family 12

Interview Contemporary - general perception

Interviews - General perception

Interview – Traditional House Family 1

Interview – Traditional House Family 2

Interview – Traditional House Family 3

Interview – Traditional House Family 4

Interview – Traditional House Family 5

Interview – Traditional House Family 6

Interview – Traditional House Family 7

Interview – Traditional House Family 8

Interview – Traditional House Family 9

Interview – Traditional House Family 10

Interview – Traditional House Family 11

Interview – Traditional House Family 12

Interview Traditional - general perception

Interview – Traditional PMV

Interview - PMV contemporary

Interview - PMV traditional

Satisfaction survey – Thermal Environments

Traditional vs. Contemporary interview PMV comparison

8.2 Computer based simulation

CO2 Sub-hourly Contemporary house

CO2 Sub-Hourly Traditional House

Comfort Sub-hourly Contemporary House

Comfort Sub-Hourly Traditional House

Internal Gains Sub-hourly Contemporary house

Internal Gains Sub-Hourly Traditional House

Material construction layers Contemporary house

Material construction layers Traditional house

Site Data Sub-hourly Contemporary house

Site data Sub-Hourly Traditional House

Sun path Contemporary house

Sun path Traditional house

8.3 On-site measurements

Contemporary measurements inside

Day-night temp variation

Exterior measurements

PMV and PPD results

Vernacular measurements inside

Sensors positioning Contemporary house

Sensors positioning Vernacular house