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The color in the vernacular bioclimatic architecture in Mediterranean region

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Abstract

The building sector plays a crucial role in relation to energy and environmental issues. For this reason, today, it pays great attention to the need of a bioclimatic architecture closely related to environment, history and traditions of the various places. In this context, the guidelines for careful planning of environmental issues can be traced precisely in vernacular architecture, the result of a close link with the territories and a great sensitivity towards nature.
This study focuses on an example of vernacular Mediterranean architecture, represented by the old town of Ostuni (Puglia, Italy). The objective is to analyze the peculiarities of the building and urban layout, with particular attention to the external coating with white lime base, showing in detail the influence of the staining on microclimatic conditions. The results of the carried out analysis highlight the benefits and weaknesses of studied constructive solutions. Thus, it is supported the view that it is necessary to rediscover and be inspired by the vernacular architecture, not representing them as anachronistic, but always drawing on the contributions of technical and scientific progress. The research points out the influence of exterior finishing surfaces on the energy performance of buildings as well as on the outdoor thermal and visual comfort of the inhabitants.

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Keywords: vernacular architecture; surface coatings' color; white lime wash; building envelope; energy performance; visual comfort.

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1. Introduction

In the last decades, there have been intense internationalization in architectural style, indifference toward local climatic conditions and tendency to mechanical control of hygrothermal parameters. However, the energy crisis and the environmental question have shown up the need of a renewed approach.

Thus, a new sensibility towards bioclimatic architecture has developed and has given rise to the definition of “passive-house”: in order to guarantee environmental comfort, it uses natural climatic resources and has a close connection to places’ and climates’ characteristics.

Manzano-Agugliaro et al. [1] show that bioclimatic architecture and passive strategies are, nowadays, studied a lot: such techniques are an integral part of contemporary design [2] and bioclimatic principles allow to cut down energy consumption and CO_2 emissions in the building sector [3].

In this regard, vernacular architectures are the result of an adaptation to climate and surrounding context, achieved thanks to experience and traditions [4]. Passive strategies in vernacular architectures contribute to create satisfactory microclimatic conditions and a certain indoor comfort. This is evident in Mediterranean architectures [5-8], characterized by great attention to orientation, limitation of openings, shading systems, great thermal inertia of envelope, light colored external coatings, exploitation of natural ventilation.

One of their most typical feature, but also one of the least studied, is the white color of the external finishing layer.

It is known that solar radiation affects thermal loads and energy needs of buildings [9] and the use of cool materials, with high solar reflection, is spreading in building envelopes to cut down energy requirements for cooling and CO_2 emissions [10-13]. However, very few authors dealt with the analysis of the influence of outer finishing’ colors in buildings [14,15]. This is due to lack of data on optical properties of materials. Such characteristic affects indoor microclimate and buildings’ energy need and it is an important aspect in vernacular Mediterranean architectures. Numerical analysis showed also that light, reflective and highly emissive external surfaces cut down the phenomenon of urban heat islands [16]. Besides, their high reflectance influences outdoor visual comfort: in some cases, visual performance decreases because of high levels of luminance that can reach 20.000-30.000 cd/m^2 [17] and glare problem; in other cases, such levels are lower and improve comfort thanks to better controlled lighting’s conditions, in particular urban configurations. It happens in old towns: dense urban fabric and high shading level, which influences lighting’s conditions along the streets and whose effects on buildings’ surfaces are a dynamic and complex problem [18], are made up for light and reflective surfaces that increase outdoor and indoor comfort. Visual comfort is, then, an added quality in an open space, which adapts itself to “luminous climate” of place [19].

This work results from these considerations and analyzes a typical case of Mediterranean vernacular architecture in the old town of Ostuni. The aim of the study is to investigate its chromatic feature and to know the effects on thermo-physical indoor behavior and on outdoor visual comfort.

2. Case study

2.1. Description of the context

Ostuni (Puglia, Italy) is a town characterized by a thousand-year history, which covers, with its small white houses, three hills of the Murgia, at an altitude of about 230 m above sea level. It is known as “the white town”, due to the white limestone that is the main building material in the old town, and the lime-wash finishing. The medieval old town of Ostuni has, from the urban point of view, an elliptic shape, with small closely assembled houses, separated by narrow and twisted streets that turn along the walls of the town and twine concentrically. Clearly, this scheme is not planned but spontaneous, due to people’s adaptation to topographic features (Fig. 1).

From the building point of view, here there are three typical features of the traditional Mediterranean architecture: thick walls with high thermal inertia; few, small and deep window openings; the white color of the lime-wash. The building typologies of the so-called “white houses”, in the old town of Ostuni, are: row houses (arranged on single or double line), block houses and mixed building units.

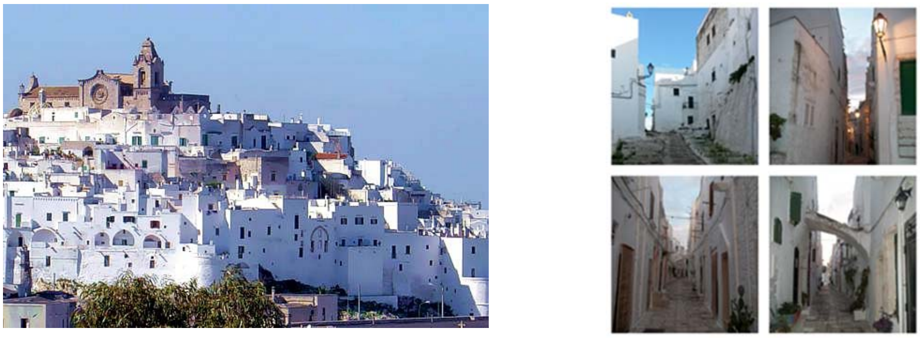


Fig. 1. Ostuni: the white town.

In this study, it is considered the row house typology. It is characterized by a deep site, a small front on street and a very simple planimetric organization, generally, with a basement consisting in only one room with barrel vault and an upper floor, consisting in a single room with a cross vault. As regards materials and building characteristics, it is possible to note, mainly, the use of white limestone for walls and vaults, slabs of Cursi stone as roofing and plastering with white lime-wash. In ancient times, when laws of physics were not known, there were, basically, three main reasons, which determined this regular use of the lime-wash: easy availability, low cost, simple production and laying; the discovery that its white color reflects solar radiation, so the places, where it is used, and, in particular, the narrow streets of the old town, seem to be larger; considerable hygiene and brightness, thanks to direct and reflected light.

2.2. Simulations

As case study, a row house in a small portion of the old town of Ostuni was considered and analyzed (Fig. 2a).

a) b)

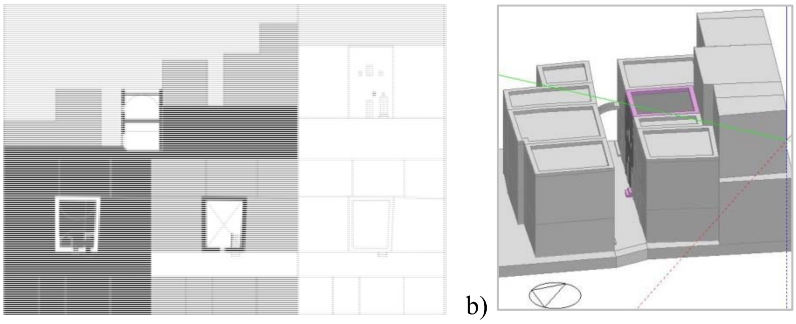


Fig. 2. a) The house object of study: vertical section, front, basement's floor, upper floor and roof; b) Model built in DesignBuilder.

Once the morphological and typological features of these buildings were studied, dynamic simulations were carried out through the software DesignBuilder, v. 4.7 (Fig. 2b) in order to evaluate the influence of the building peculiarities on microclimatic conditions. The climatic file was generated by the software Meteonorm. The highest dry bulb temperature of 38.2°C is registered on 21st July, while the lowest one, about -2°C, on 12th January.

Once the structure was defined, materials and stratigraphy of building components were implemented. House's walls and vaults are made of semi-hard limestone and plastered on the inner side. Windows are characterized by a clear single pane and wooden frame, while external doors are made of solid wood. It was supposed the continuous presence, in the house, of two people in standing relaxed. Regarding the control of environmental conditions, the heating system's set-point was fixed at 20°C, while the cooling's one at 25°C.

The peculiarity of this study is the particular attention paid to the characterization of the external finishing layers, consisting of white lime-wash, and its surface properties. Because of this, as regards lime-wash, spectrophotometric parameters were obtained from the study of D. Kolokotsa et al. [20]. In particular, data concerning the so called NHL1-MP (natural hydraulic lime-lime wash mixed with natural mineral earths) coating were used. Thus, it was considered an emittance equal to 0.88 and solar and visible absorbance equal to 0.09.

In order to obtain a wider cognitive framework, simulations were performed both in the state of fact and in "modified" conditions, created to analyze and to compare variations of the considered parameters.

Besides, in order to assess the influence of the color on microclimatic conditions, two other typologies of walls' external coatings, with different colors and so different properties, were chosen. The first is that called, in the already quoted work of D. Kolokotsa et al. [20], NHL1-LRW (hydraulic and hydrated lime with sands of grain size lower than 120 µm, with an emittance of 0.86 and solar and visible absorbance equal to 0.30). The second variant involves the choice of red bricks as finishing layer. The data were obtained from the study of Jian Yao and Chengwen Yan [21]: this coating has an emittance of 0.87 and solar and visual absorbance equal to 0.75.

Finally, in order to demonstrate how the choice of the finishing color is not random, but strictly connected to climatic conditions and to the specific context where architecture arises, it was decided to simulate the building in a climate completely different from that of Ostuni. Thus, it was chosen the city of Bolzano, where the highest dry bulb temperature, 26.87°C, is registered on the 2nd July and the lowest one, about -8°C, on the 14th January.

Simulations were performed with reference to the hottest and the coldest week of the year in Ostuni (17-23 August; 13-19 January) and in Bolzano (29 June-5 July; 13-19 January). Moreover, to value differences in the various cases, both the conditions without air conditioning, as it actually is today, and with air conditioning were analyzed. Then, studies were extended to yearly period.

The second part of the study is focused on the analysis of the outdoor daylight and on the influence of the color on the visual comfort in the analyzed place.

In order to perform these analyses, two software, Ecotect and Daysim, were used. These allow getting detailed information for daylight analysis and, in particular, for calculation of daylight factor. By using Ecotect, a new model of the case study was built, with the same data quoted before. In this case, in addition to the model of the actual building, another one was realized, changing only the external finishing layer with red bricks. This strategy was adopted to assess the influence of the outer color on external visual comfort and, in particular, on the daylight factor. Soon after, these two models were implemented in Daysim to generate an annual illuminance profile and to calculate the daylight parameters in both scenarios. Daysim is a software based on Radiance [22], validated for complex calculations of daylight. The Radiance simulations parameters are assumed according to "scene complexity 1": 5 ambient bounces, 1000 ambient divisions and 300 ambient accuracy. The chosen grid of points, which are the lighting sensors among the buildings, was of 20×24 m and cells dimension of 0.2×0.2 m. The plan of analysis was 1.5 m above ground.

3. Results and discussion

The obtained results were analyzed with reference to some parameters, such as temperature, heat flux through the walls, cooling/heating loads and daylight factor.

3.1. Dynamic thermal simulations in Ostuni

Analyzing the actual building, with the white lime-wash NHL1-MP, and focusing on temperatures and thermal loads exchanged through the walls, it comes out a perfect phase opposition between the two trends. This is a direct consequence of the high thermal inertia of the walls. If the color of the external finishing layer is darker, the walls heat flux increases slightly: in particular, in the case of the dark color of the red bricks, it rises of 0.04 kW compared with the case of NHL1-MP and of 0.02 kW compared with that of NHL1-LRW (Fig. 3a).

As regards indoor air temperature, Figure 3b shows an increase in the case of red bricks, while the values of NHL1-MP are lower with a maximum deviation equal to 0.38°C respect to the Red Bricks.

In the considered winter week, instead, the differences seem to be canceled out. This is due to the predominant role played by the thermal inertia of the walls in comparison with that of the color. Besides, in winter, sunrays penetrate less into the so dense built environment of the old town. When the cooling system is on, in the considered summer week, cooling needs are minimal in all cases, even if there is a slight increase in the case of red bricks. As for winter week, instead, energy requirements for heating are higher in the case of the white external finishing layer.

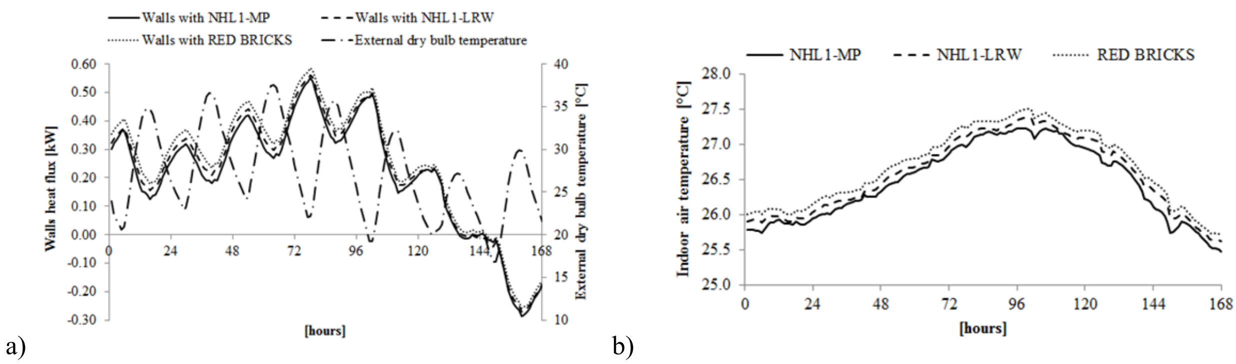


Fig. 3. Simulation of summer week, in Ostuni: comparison between walls heat flux (a) and indoor temperatures (b) in the three configurations.

3.2. Dynamic thermal simulations in Bolzano

Results from simulations in Bolzano reveal how much a different climate influences them.

Even in this case, in the summer week, as the external finishing layer varies, the wall heat flux increases as the color becomes darker (Fig. 4a). In particular, the average increase is equal to 0.015 kW in NHL1-LRW case compared to NHL1-MP and 0.023 kW in red bricks case compared to that of NHL1-LRW.

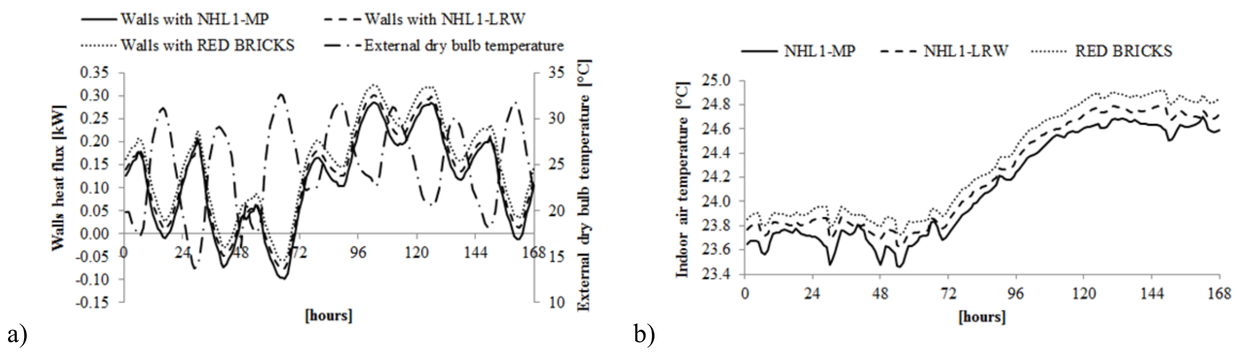


Fig. 4. Simulation of summer week, in Bolzano: comparison between walls heat flux (a) and indoor temperatures (b) in the three configurations.

Besides, there is an increase of indoor air temperatures, which, however, are below the temperature threshold for cooling, so it is not necessary to switch the plant system on (Fig. 4b). In this case, there is an average difference of temperature between the red bricks and the state of fact of about 0.2°C. In the winter week, then, the trends of heat flux and indoor air temperature in the different cases are very similar.

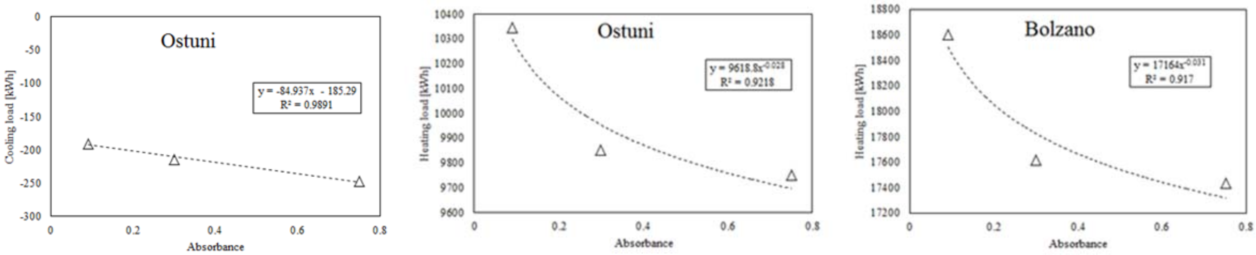
Finally, the cooling system is not necessary in summer thanks to thermal inertia of the walls and the different climate conditions in Bolzano, characterized by summer temperatures lower than those in Ostuni. In the winter week, instead, heating energy requirements are higher when NHL1-MP is used, while in the other two cases, the energy needs have about the same trend, as in the case of Ostuni.

3.3. Annual comparison of dynamic thermal simulations

Simulations were, then, extended to longer periods and show how climate influenced constructive techniques used in these architectures. In particular, the change of external finishing layer influences energy requirements both in summer and in winter. By extending simulations to the whole year with the cooling and heating systems switched on, it is possible to put in relation solar absorbance with yearly energy needs for cooling and heating.

As absorbance increases, cooling energy need increases (Fig. 5a). This means that the light color of the lime-wash can contribute to reduce summer energy consumptions. In particular, there is a decrease of about 30% in the configuration NHL1-MP and of 15% in that of NHL1-LRW compared to the consumption in the case of red bricks.

As regards heating energy needs (Fig. 5b), the situation is reversed and consumptions rise in the case of NHL1-MP, with an increase of 5.7% compared to NHL1-LRW and of 1% compared to red bricks. However, if in summer, the use of white lime-wash allows to save 57 kWh compared to red bricks, in winter, it causes an increase of 592 kWh.



a) b) c)

Fig. 5. Heating (a) and Cooling Load (b) for Ostuni and Heating Load (c) for Bolzano at the three different values of absorbance of the external finishing.

This is a weakness point, because summer savings cannot balance the bigger winter consumption. However, at the time of building construction, in winter, fireplaces were used in it, making up the heating need; while in summer, cooling systems did not exist, so adopted passive strategies contributed to solve the problem of high temperatures.

As regards the city of Bolzano, the use of light colored external finishing layers is not suitable because, during summer, there is no need of cooling energy, while, in winter, the heating consumption increases of 6.3%, from the configuration with red bricks to that with NHL1-MP, with a further requirement of 1167 kWh (Fig. 5c).

3.4. Analysis of the external visual comfort

The analysis in Daysim reveals the significant role of the coatings' color on visual comfort and illuminance level.

Figure 6 shows how the level of illuminance in the street between the buildings is influenced by the different finishing layer of the two configurations. In the case of light color (NHL1-MP), the average value of the Daylight Factor reaches 49.54% with a minimum value of 36.90%, due to the height of buildings that provides shading in the urban canyon. The situation changes in the case of dark color (Red Bricks), where the average Daylight Factor is of 37.45% and the minimum value is of 23.8%. The difference between the two cases is highlighted by the Figure 7 where is shown the trend of the Daylight Factor along the middle of the road between the two buildings.

Important considerations derive from these results. In the narrow streets of the old town of Ostuni, the light color does not give glare problem thanks to the shading provided by surrounding buildings, but, promotes a rather uniform distribution of illuminance levels in the urban context, against the problem of overshadowing. The dark color, instead, causes a reduction of Daylight that could bring to the decrease of the external visual comfort conditions.

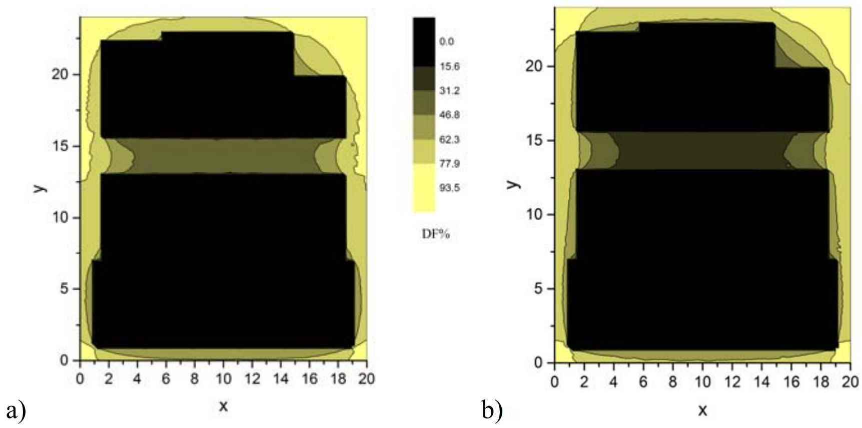


Fig. 6. Daylight factor in NHL1-MP configuration (a) and in Red Bricks configuration (b).

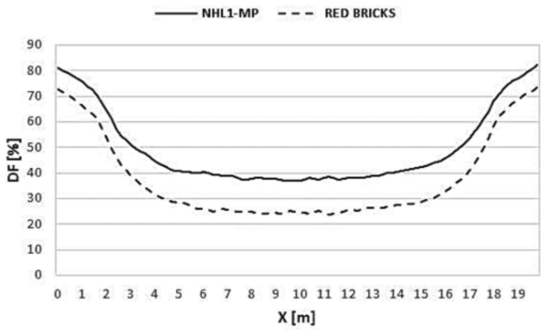


Fig. 7. Comparison between Daylight factor in NHL1-MP and Red Bricks configurations, calculated along the axis of urban canyon.

4. Conclusions

The study of a Mediterranean vernacular architecture shows that nothing was random in choosing building solutions. It is clear the role played by high thermal inertia of the walls, the "heaviness" of these buildings, and so, the consequent thermal wave shift and attenuation combined with moderate envelope's dispersions. The context, in which the studied building is placed, influences, even if slightly, the building's behavior, dampening thermal loads exchanged through the envelope, especially in summer. Chromatic change of the external finishing layer determines a decrease of thermal loads, in summer, passing from a dark color to white.

In terms of cooling and heating loads, it is possible to assert that the existing building (NHL1-MP configuration) involves less cooling energy needs and, so, the optimal solution, in summer conditions, in warm climate, is just the actual one. Besides, it is clear that heating need is far greater than cooling one and it is, also, for this reason that each house in the old town of Ostuni was provided with fireplaces in ancient times. Instead, when these houses were built, active cooling systems were not still known; thus, the only effective solution was the adoption of passive strategies.

The same solution, applied in a completely different climate such as that of Bolzano, is, instead, unsuitable, because heating needs are dominant compared to those of cooling, almost null.

As regards visual comfort in this particular context, the white external buildings layers guarantee, more than the dark ones, adequate levels of illuminance and the risk of glare is averted by the peculiar urban configuration.

Therefore, the reasons of such almost exclusive use of white lime-wash, as external coating, are clear: improvement of thermal and visual comfort, in addition to a better hygiene, inside buildings and urban environment.

Thus, the research demonstrates that it is impossible to think architectures designed regardless of climatic, environmental and traditional peculiarities of places. Such aspects have to be used necessarily as guidelines in a conscious architectural design and in urban choices. Vernacular or traditional architectures are of great help and source of inspiration.

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