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# An Overview of the Architectural Methods Used to Manage the Variable Environmental Influences on Buildings in the Mediterranean Region

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**Abstract**

Most of the environmental influences on buildings are variable by their very nature. This fact creates a need for diverse solutions in energy and environmental design and construction that can facilitate optimum building performance throughout the changing periods. Such solutions, in order to be successful, should be compatible with the climatic, and more generally environmental, conditions that prevail in the region where they are applied. Solutions that satisfy these requirements can come from a wide variety of fields, ranging from vernacular architecture to applications of smart materials and technologies. This paper presents an overview of conventional design and construction measures and practices for managing the variable environmental influences on buildings in the Mediterranean region. To that end, it identifies the environmental factors whose variable behaviour influences the energy and environmental performance of the buildings that are subject to them, and it also evaluates their impact. The study goes on to describe and evaluate the design and construction choices and practices that are implemented in buildings in the region to manage these influences. The aim of this work is to report on the main characteristics of these methods and investigate any ways in which they might be improved.

**Keywords:** Building; Environmental influence; Mediterranean region; Sustainable design

## Introduction

The adaptation of buildings to the climatic and; more generally; environmental conditions of the area in which they are situated can be regarded as having two dimensions:

- The first concerns the adaptation to the climate and the environment in general; defined in terms of statistics; i.e. the climatic and environmental conditions expressed in terms of the mean values of meteorological and environmental measurements in the given region over long periods; while
- The second dimension concerns the adaptation to the changes that the environmental parameters present during the periods in which they occur (e.g. day; year).

Buildings; in general; have characteristics of design; construction and equipment that reflect both types of adaptation. The characteristics that represent their adaptation to the mean conditions are inert; although some of them behave differently under different conditions (e.g. the role of thermal insulation is not the same both in winter and summer). A second category of characteristics corresponds to dynamic and usually more sophisticated systems that can be adjusted in accordance with the prevailing environmental conditions (e.g. movable shading devices). The design and construction of buildings; generally; places more emphasis on features included in the first of the above two categories. This is not sufficient; however; since a building's inability to respond adequately to changing environmental influences has a significant negative impact on its energy and environmental behaviour. This applies more to regions of the planet with climates that are characterized by wide variations in meteorological conditions during the year.

The temperate zones of the planet correspond to geographical areas of mean latitudes in both hemispheres which lie roughly between the 20°C and 10°C isotherms. In these areas; the heights of the sun change considerably; with the result that the solar radiation that reaches the surface and the heat gain vary within broad limits. Moreover; in these areas; air masses of different origins; with large temperature differences which are reinforced by the variety of the terrain and the land-sea distribution; collide. Within temperate zones there are many climate types characterized by mild mean climate values and the increased variability of weather parameters. One such climate type is the Mediterranean climate; which is characterized mainly by hot; dry summers and cool; wet (rainy) winters [1].

Mediterranean-climate regions are found; roughly speaking; between the 30 and 45 degree latitudes north and south of the equator; on the western sides of the continents. The seasonality of these regions differs profoundly from that of more northerly and southerly latitudes. The largest area with a Mediterranean climate is the Mediterranean Basin; which has given the climate its name; although stretches of the Mediterranean coast (in Egypt; Libya and part of Tunisia) are too dry to be thus classified. The Mediterranean Basin roughly includes the southern parts of Portugal; Spain and France; nearly the whole of Italy; the Western Balkans; the whole of Greece; Western Turkey; Western Syria; Lebanon and Israel as well as the north-western coastal area of Africa; stretching from Morocco to Tunisia. The population in these areas exceeds 100 million [2]. Based on data from the World bank climatic database [3] the graphs in Figure 1 show the average monthly values of mean daily air temperature in the areas of large cities that can be considered as being representatives of Mediterranean climate conditions. A key conclusion that emerges from these figures is that the buildings in the respective cities should be heated during the cold period and cooled during the warm period to achieve comfortable indoor conditions. This fact in itself serves to confirm the very

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important influence that the variability of environmental conditions has on the environmental and energy performance of the buildings in these areas and highlights the challenges that this fact entails for their design and construction (Figure 1).

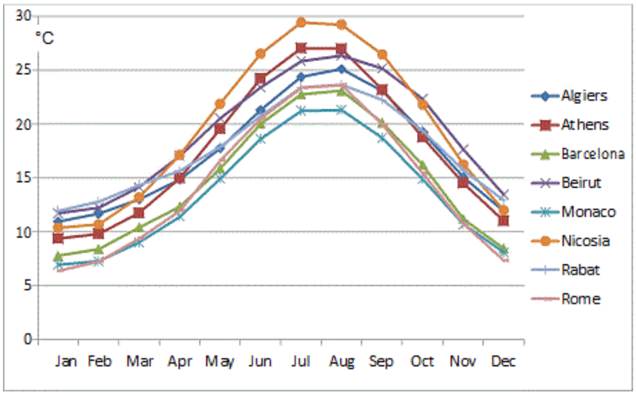


**Figure 1:** Fluctuations in the average monthly values of mean daily air temperature in the areas of eight Mediterranean cities.

This paper explores the potential of architecture; in terms of design and technological issues; to successfully manage the variable environmental influences on buildings in temperate climates. To that end; it analyzes the fluctuating characteristics of the environmental factors and the way they affect the built environment and then it goes on to examine different solutions that are suitable for managing these fluctuations. Emphasis is placed on areas of the Mediterranean where the similarities of building design and construction that have been formed by the similar climatic and; more generally environmental; conditions facilitate the research and development of methods and practices to respond in the most efficient way to the changing; in intensity and effect; environmental impact on buildings.

## Variable Environmental Influences on Buildings

The environment; both natural and anthropogenic; is in a constant state of change. The changes that are observed can be classified as:

(a) those that are closely related to earth's evolutionary progress and

(b) those that reflect the variability of the factors that shape it.

For the second category of changes; it may be observed that those environmental factors which have an impact on buildings are all variable [4]. Such factors include air temperature; solar radiation; moisture; wind; precipitation; air pollution; noise; and so on (Figure 2). More specifically; their physical values; of either scalar or vector type; display fluctuations in many of their aspects. These fluctuations; in the case of some of the above factors; show a wide range of values that may occasionally vary between negative and positive effects; such as air temperature; humidity; solar radiation and wind speed. In the case of other factors; the fluctuations range from insignificant ones to those that are (usually) negative in their effects; such as pollution and environmental noise. Beyond their intensity aspect; the frequency with which the environmental factors affecting buildings vary is also of importance. Periodicity is an attribute that characterizes almost all meteorological factors. Also; it is common to observe many levels of periodic cycles for the same phenomenon (daily or yearly cycles etc.). The same is true for air pollution; especially over urban areas. Nevertheless; randomness is not excluded; according to which some factors emerge in a random fashion. A common example is a storm or a pollution event. It is important at this point to emphasize the fact that the environmental factors affect the built environment on different levels through different processes. The wind; for example; can act as a medium for ventilation; for natural cooling; for pollution dispersion; for thermal exchange at the building shell surface and also as a factor involved in structural integrity. It is obvious that such a factor with such a great variety of effects can be beneficial at some levels and adverse at others. This characteristic makes the efficient management of that factor quite a challenge.

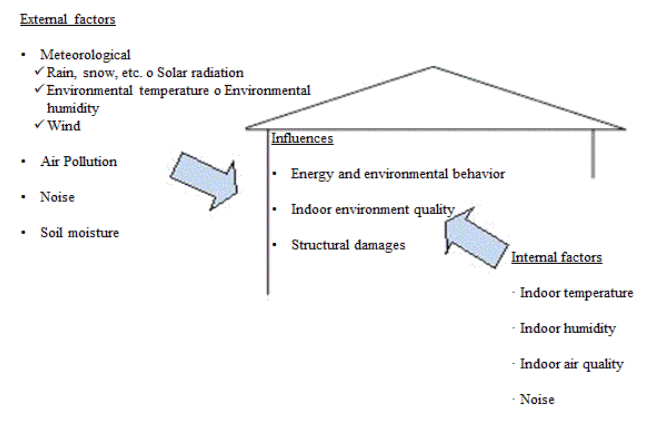


**Figure 2:** A graphic representation of the main environmental factors affecting buildings.

The fluctuations in the values of the environmental factors directly affect the way in which the systems installed in the buildings function in order to control their impact. On the other hand; the way in which the systems respond to variable conditions is critical for their efficiency. Passive systems are efficient if they are adapted to address the effects of the prevailing factors. Active systems; on the other hand; show more flexibility in their response to the fluidity of the environmental impact. Their actions are reflective to the conditions and can be expressed in many different ways; such as changing form; geometry or qualitative characteristics. Dynamic louvers are a good example of a system that "behaves" according to the prevailing conditions; reacting to them in order to optimize control of daylight and solar heat gains. The more adaptable these systems are to a variety of conditions; the more effective they are.

The systems that support the environmental and energy behaviour of buildings are designed to prevent adverse environmental influences and to promote favourable ones. This criterion determines the peculiarities of sustainable design in temperate climates where important environmental factors present variations that have considerably different impacts on buildings. Indeed; while in cold and warm climates the management of these factors is more or less one-dimensional; in temperate climates this is not so as sometimes these factors are positive in their effects and should be favored and sometimes negative and should be prevented. As an example; mention may be made of solar heat gain which; in general; is welcome in cold climates and unwelcome in warm climates; while in temperate climates it is welcome in the winter and unwelcome in the summer.

The above comments indicate the expediency of a separate category of tools for the sustainable design and construction of buildings in temperate climate regions with common characteristic the management of the variable environmental influences. These tools can be either passive or active; with the former being simpler and more elegant in their operation. However; in buildings in temperate climates it is common to find more than one system and also; more generally; architectural practices that are intended to manage different (often contradictory) effects of the same environmental factor. For example; solar gain and solar shading systems can coexist in the same building. This phenomenon; as a consequence of the wide variability of environmental effects; does not exist in other climate zones.

## Methods for Controlling the Fluctuating Environmental Influences on Buildings in the Mediterranean

The building technology of local architecture in the Mediterranean region; as observed in both traditional and more sophisticated modern architectural examples; is directly affected by two main factors: (a) the climatic conditions and (b) the availability of building materials. The basic characteristics that these two factors entail for buildings in the region can be summarized as follows: a) extroverted (i.e. open to the environment) forms intended to exploit the favourable climatic conditions; and b) building shells with high thermal inertia due to the relatively large density of the building materials that are used (stones; ceramics; cement etc.). Consequently; the practices employed to control the environmental influences are; by default; adapted to the characteristics of those factors.

The environmental effects which; on the basis of climatic data in the Mediterranean region; deserve attention because of the variability of the factors that activate and support them are related to solar radiation; air temperature and; to a lesser extent; the wind.

Buildings in the Mediterranean have their openings fitted with sun protection devices in the form of fixed or mobile shadings.

Fixed shadings consist mainly of rigid overhangs. These generally take the form of projections of ceiling slabs (cantilever slabs). Given that balconies are typical features of the facades of above-ground storeys of residential buildings in the Mediterranean region; a practice that is very widely applied in these buildings is the use of the balcony of the storey directly above to provide solar protection for the balcony and balcony door or window immediately beneath it (Figure 3). The design of projections; be these projections providing solar protection or the balconies of apartments on the overlying storey; is based on a calculation of the vertical shadow angle (VSA); in such a way as to ensure that the sun's rays can enter the opening in winter but not in summer. Indeed; the calculations are usually those which are valid for the 21 June (the summer solstice); so that when the sun is at its highest on this particular day its rays only just reach the lower level of the opening. According to this particular method; for the latitude of 35ºN; a projection of approx. 0.6 m in width is required to provide solar protection for a 3 m-long zone on the façade of the building beneath the projection. In other words; such a projection covers all of the openings in the underlying façade of an apartment with an average ceiling height. For functional reasons; the width of projections and; more particularly; balconies is usually greater; an average balcony width in multi-storey buildings in Mediterranean cities is between 1 and 2 m. Consequently; it seems that the fixed shading devices on the south-facing facades of buildings in the Mediterranean region satisfactorily cover the need to manage the variable characteristics of solar radiation; to the extent that they permit the sun's rays to enter the openings in winter but not in summer. More detailed sun control studies that also calculate the effects of solar radiation on indoor lighting conditions and heat gains - studies which are now easier to conduct with the aid of digital design tools - are implemented in the design and construction of the most modern buildings in the region.

The category of mobile elements for solar radiation control that can be found in residential buildings in the Mediterranean region includes adjustable shutters on the exteriors of buildings and curtains in the interiors. Furthermore; on the sides of the building facing the sun's trajectory there are; usually at the top of the openings; light frame canopies; trellises or operable awnings to further control the rays of the sun (Figure 3). Reflective or absorbent glass is rarely used and only in commercial buildings; where internal blinds are the most common type of devices used to control incoming solar radiation.

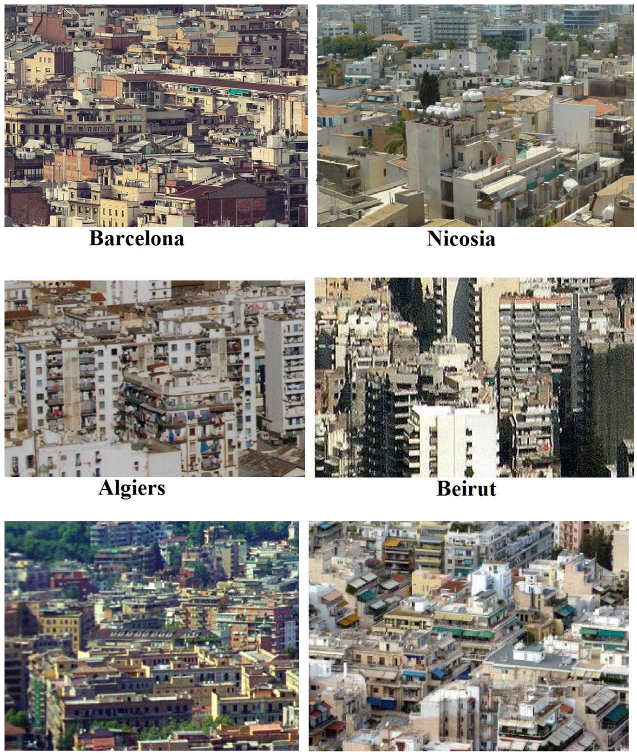


**Figure 3:** Photographs of typical Mediterranean cities. Their common features are high building density, buildings constructed with "heavy" building materials, numerous and large openings on the facades and sun shading devices for openings.

Solar protection measures; as a basic tool for managing the varying levels of solar radiation that strike building shells; also help shape indoor air temperature conditions. Indoor air temperature control is also achieved in buildings in the Mediterranean region through architectural and technical solutions that focus on ventilation control and the use of insulating materials within a building's shell.

Ventilation systems enable the control of air flow inside a building and through that the control of the indoor temperature. Generally;

buildings in the Mediterranean region meet the requirements for sufficient natural ventilation. The main reasons for this are (a) their small scale and (b) the usually extensive openings that are available for user operation (Figure 3). This capacity (for natural ventilation) is widely used by people every time the environmental air temperature conditions are more favourable than those indoors. In this way; natural cooling conditions can also be achieved. Even so; it is interesting that during the year there is considerable variation in the opening and closing of openings in building shells. In the summer; in buildings and apartments where the air conditioning is not functioning and there are no restrictions for security reasons; many openings in the shell remain open around the clock.

However; the element that plays the most important role in controlling indoor air temperature is the building shell. The specific heat capacities of the structural materials that form the shells of buildings in the Mediterranean region (which are mainly constructed of reinforced concrete; perforated or solid bricks with mortar-cement and plaster) are usually high; with values ranging roughly between 0.80 and 0.90 $kJkg^{-1}K^{-1}$. Moreover; the average thickness of these walls ranges from 20 to 30 cm. According to these data; the lengths of decrement delay that building shells incur in buildings in the Mediterranean region range from approx. 7.8 h (in the case of 20 cm-thick walls of perforated bricks) to approx. 9.7 h (in the case of 30 cm-thick walls of reinforced concrete). Even higher decrement delays (> 12 h) are presented by limestone walls over 40 cm thick that are found in traditional architecture and also in applications still used today in many parts of the Mediterranean [5]. These values show that the thermal mass of building shells makes a satisfactory contribution to the improvement of internal temperature conditions by moderating and delaying diurnal temperature extremes.

Building shells; particularly those of modern buildings in the Mediterranean region; contain thermal insulation. This fact; despite reducing the value of the shell's thermal inertia in the control of internal temperature; entails a considerable saving of energy and improvement in the quality of the internal environment [6-8]. For a 5 cm-thick layer of thermal insulation (with a thermal conductivity; $\lambda$ = 0.035 $Wm^{-1}K^{-1}$); which can be regarded as representative; the values for the overall heat transfer coefficient (U-value) of building shells in the Mediterranean region range from 0.58 $Wm^{-2}K^{-1}$ (for 20 cm-thick masonry of reinforced concrete coated with a 2 cm-thick layer of plaster on both sides) to 0.43 $Wm^{-2}K^{-1}$ (for 30 cm-thick masonry of perforated bricks coated with a 2 cm-thick layer of plaster on both sides).

Standard architectural practices for addressing the variable environmental influences on buildings in the Mediterranean region are occasionally supplemented by building elements relating to attributes other than those pertaining to the environmental behaviour of buildings (e.g.; functionality; aesthetics; statics). Some of these elements often react and behave differently to the varying environmental factors affecting buildings. A typical example of this category of elements is the balcony; which is a common accessory in the majority of buildings in the Mediterranean area. The contribution of balconies to a building's environmental behaviour can vary from beneficial to negative; depending considerably on the fluctuation of the environmental factors observed over time [9].

"Green" elements; such as trees; shrubs and so on; are considered a useful natural design tool to control the fluctuations of the environmental impact. In the Mediterranean region; this potential is exploited mainly in rural areas where the required soil exists; as well as adequate space for the plants to be laid out and grow. In urban environments; on the other hand; where the majority of the built mass is situated; such "green" attributes are restricted by a lack of space. In such environments it is possible for plants to be placed in small strips of soil in front of buildings (if available) and in the non-constructed inner areas of residential blocks. Apart from the other advantages they offer; green roofs and green facades seem to be a good solution for the control of temperature changes in buildings in the Mediterranean region; although at present they have a limited distribution [10,11]. The same is also true of ventilated double-skin roofs and facades; which; on the basis of studies in similar climatic conditions; have been shown to play a positive role in controlling and modulating the effects of outside temperature on indoor thermal comfort conditions [12]. However; in this case too; high cost and increased technical difficulties do not favour their application.

Active (kinetic) systems that can adapt to the changes in the environmental influences affecting conventional buildings in the Mediterranean region commonly require the mediation and care of the residents to deploy and utilize them [13]. Additionally; most of them serve to support standard HVAC systems that form the main tool for regulating indoor environment conditions. It is noteworthy that similar provisions are a necessary complement of passive solar systems (thermal mass walls; sunspaces; solar atriums etc). These systems; even though they are not widespread in the Mediterranean region; are effective only periodically (on a daily or yearly basis). For the rest of the time; their operation is not only ineffective but also harmful to the energy behavior of buildings (e.g.; overheating during the summer) and has to be prevented. Therefore; the users/residents in the region form a critical parameter since their contribution to the energy management and behaviour of their buildings is important. One category of the systems just mentioned includes rows of louvers (horizontal or vertical) that can be pivoted with the aid of a central mechanism; usually an electric motor. These systems cover relatively large flat surfaces; usually those of commercial buildings. The fact that the angle of incline of these louvers can be regulated means that they can be given the most suitable orientation; in accordance with the season and the time; in order to provide shading and optimized daylight and energy control. Examples of such applications in buildings in the Mediterranean region are the "Promálaga Excelencia" Center in Malaga [14]; the Institute Gorgs in Barcelona [15]; the Hotel de Ville in Montpellier [16]; the "Maciachini" Centre in Milano [17]; the Headquarters of "Telecom" in Patra [18]; the "Akter" Business Center in Chania; Crete [19]; the Olympic House in Nicosia [20] etc. More sophisticated control systems; which can follow and respond more efficiently to changes in the environmental conditions; are found only in buildings in the Mediterranean area that have set higher specifications and clearer sustainability goals. These include central control systems (BMS); automatic louvers; automatic windows and ventilation units; automatic shades and shutters; amongst others. Characteristic example of such an application in the Mediterranean region is the Media-TIC building in Barcelona [21].

Research has indicated that there are more advanced active and passive systems that can be used to address environmental adaptation issues and provide solutions that are viable and economically feasible [22]. Well-targeted applications of these systems can be easily adapted to the local socio-economic conditions and can improve the overall environmental and energy behaviour of buildings in temperate climates [23]. The methodologies that support these systems follow two main approaches that can be merged whenever required; since they work best when combined [24]. The first approach involves the use of mechanical systems that enable a building shell to alter its physical geometric characteristics; its structural elements and/or its façade elements in response to environmental changes. This approach includes kinetic systems integrated within a building's structural or cladding elements that are controlled by advanced technological systems and assemblies. Examples of such systems are shading systems that are controlled by shape memory devices or other technologies [25-27]; as well as systems that control the effects of wind on a building's shell [28]. This category also includes systems inspired by nature [29]. The second approach involves the use of smart materials for building surfaces that can responsively change their physical or energy properties according to the prevailing climatic conditions. Typical examples in this category are the Phase Change Materials (PCMs) [30] and the cool pigments. Schemes of this kind; which at present is rare; represent; for the near future; the most promising choices regarding the management of the variable environmental influences on buildings in temperate climates. On the other hand; a number of more specialized research efforts have to be made in order to clarify the details of the integration of these schemes into the overall sustainable design and construction features of buildings. This observation is especially applicable to the Mediterranean EU states where the relevant legislation imposes strict standards on the sustainable performance of buildings; the most characteristic piece of legislation being EU Directive 2010/31/EU; which requires member states to ensure that by 2020 all new buildings are; in the words of the Directive; 'nearly zero-energy buildings' [31].

## Conclusion

The methods used to control the fluctuating environmental impacts on buildings play an important part in the overall design and construction features of buildings that aim to adapt to local climatic and environmental characteristics. Their responsiveness makes a direct contribution to the overall energy and environmental behaviour of the buildings in which they are applied. This is more valid in areas located in temperate climates.

The Mediterranean countries are geographically located in an area where the climatic conditions present significant fluctuations; in such a way as to have a distinct impact on indoor comfort conditions. The application of measures and practices that can manage and regulate this variability is therefore a requirement for the buildings in the region. The present work substantiates this proposition and also presents design and construction methods that are applied to buildings in the region in order to meet this requirement. This presentation has shown that the measures and practices that are generally employed in conventional buildings adopt low-cost and low-tech solutions: the passive measures are based mainly on the installation of fixed shading devices for sun-facing openings; an optimal distribution of openings in building shells; and the utilization of the building shell's thermophysical properties; while the most common measures that actively react to variable environmental influences involve the handling of casements and operable sun shading devices in the shell.

More advanced systems to control the fluctuating environmental impact on buildings; like the ones that take advantage of smart materials and technologies; appear to be absent in contemporary design and construction practices used in the region. Also; no systematic studies have been carried out to evaluate the contribution of such systems or even to establish a framework for their integration. Significant benefits that such systems can bring in enhancing sustainable design of buildings in temperate climates should foster further relevant studies. In fact; conclusions of present work indicate that similar studies should be conducted and evaluated in the Mediterranean region where the environment for exploiting their results seems to be favorable.

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