Passive architecture design strategies for hot arid climate

Lessons of vernacular architecture in Almeria and considerations for the urban, building and material level

Pablo Miguel Gómez Ceelen
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

Abstract

Mechanical acclimatisation systems for heating and cooling in buildings require high energy consumption. In a context with non-renewable energy sources, mechanical installations generate C02 emissions and promote the greenhouse effect. On the other hand, in Spain, the high dependence on mechanical installations in buildings to acclimatise indoor spaces translates into energy costs that are difficult to assume for low-income social groups. Passive architectural design strategies can contribute to the creation of climatically comfortable spaces while minimising dependence on energy consumption. In the current climatic context of Almeria, which is locally arid hot and desertic, the vernacular architecture of this territory reflects popular practices for the climatic adaptation of buildings. The vernacular practices of this territory, in conjunction with strategies developed and tested for the planet's arid hot desert climate, provide a framework for action at urban, building and material scales to achieve comfortable and healthy spaces with minimum energy consumption.

Keywords

Passive climate design, Arid hot desert climate, Almeria, Vernacular architecture

1. Introduction

In the province of Almeria (Spain), the lack of passive adaptation of housing to the local climate translates in high dependance on mechanical installations to achieve comfortable interior climates. To cope with the cold and warm temperatures, mechanical installations such as air conditioners are often implemented to acclimatise indoor spaces to comfortable levels, while promoting energy consumption. The energy need of dwellings translates into high costs for the inhabitants. In the case of social groups with low incomes or unemployed, energy costs can be unaffordable. Around 15% of the Spanish population suffers currently from energy poverty (Tirado Herrero et al., 2020). In Andalusia, for 18% of the population, energy costs are disproportionately high in relation to their income, 12% of the population consumes less energy than necessary and 12% live in dwellings with indoor temperatures unsuitable for human health (Tirado Herrero et al., 2020). The high levels of residential energy consumption in Andalusia are also responsible for a significant part of the total C02 emissions, promoting the greenhouse effect that drives climate change (Junta de Andalucía & Unión Europea, 2021). Worldwide, the construction sector, due to energy consumption and industrial processes, is responsible for 40% of the total C02 emissions generated (Ménard & Souviron, 2020).

This thematic research paper is part of the development of an architectural design proposal for a graduation studio project of architecture. The proposed project consists of the design of housing for migrant workers atracted by the agricultural sector of the province of Almeria. Migrant workers in Almeria, particularly African migrants, are a social group suffering and at risk of energy poverty due to their low purchasing power and high levels of unemployment. This research seeks to nourish the architectural project with low tech strategies for the passive design of housing on the following levels: spatial distribution of the architectural volumes and the inbetween spaces, morphological characteristics of the volumes and materialisation.

With this objective in mind, the following question is formulated: ***How could low-tech passive urban and housing design achieve comfortable exterior and indoor climates in the arid hot desert clime of Almeria?*** To answer the main question, the following sub-questions are defined:

- What are the climate characteristics of the region of Almeria, Spain?

- What are the desirable climatic conditions for housing interiors?

- What lessons can be learned from passive climate design of vernacular architecture in the region of Almeria, Spain?

- Which passive climate design strategies could achieve a comfotable interior climate in the region of Almeria?

1.1 Methods

The information analysed in this paper has been obtained through quantitative and qualitative research. The subject matter of the study belongs to the epistemes of morphology and ecology. Each sub-question formulated in this paper constitutes a different section.

For the formulation of the third and fourth points, we obtained quantitative data that provide reliable knowledge about the climatic characteristics of the province of Almeria and the recommended climatic levels for the different conventional domestic spaces. The parameters are obtaines from databases and studies carried out on the subject.

Under point four, the information has been collected by combining the following qualitative methods: a visit to the context to observe and compile graphic documentation, and the research of published literature on the subject to substantiate the results.

In the fifth point, a synthesis is made of architectural design strategies for the design of passive houses in the analysed climatic context. The information presented in this section is qualitative & quantitative and has been obtained from literature.

The information collected in section 5 and 6 is structured in relation to the objective of the study. The results are grouped on urban level (relationship between volumes and intermediate spaces), architectural level (the volume) and material level.

2. Key terms

Vernacular architecture
Vernacular architecture can be understood as the traditional architecture of a geographical context (Schittich, 2019). It is also academically defined as architecture without an architect, buildings built with popular knowledge and methods (García Sanchez, 2010). Vernacular

architecture of a historical moment, usually represents the evolution and transmission of popular building knowledge, including adaptation to the climate of the place. It is generally built with materials from the local context.

Passive architecture design
Passive architectural design consists of making use of the natural resources and renewable energies of a context to maximise the thermal comfort of a building and minimise the energy consumption of the construction (Valladares-Rendón et al., 2017). Lower energy consumption translates into a reduced requirement for mechanical installations, reduced energy costs, reduced environmental impact of the building and improved thermal comfort and healthiness of buildings (Valladares-Rendón et al., 2017).

3. Climate of Almeria

The province of Almería is located on the European continent at latitude 36.83814 and longitude -2.45974. The orography of the province of Almería is mainly made up of valleys and in the inland areas there are mountainous zones with higher altitudes. The territory borders the Mediterranean Sea in the south and east.

In the coastal areas of Almeria, where the greenhouse agriculture activity is concentrated, three climate classes prevailed between 1980 and 2016 (Appendix A). This climate zones according to the Köppen-Geiger climate classification model are: cold arid steppe, cold arid desertic and hot arid desertic (Beck et al., 2018).

According to the evolution of temperatures and precipitation from the data used in the creation of the Köppen-Geiger climate map between 1980 and 2016, a climate scenario for the years 2071-2100 is proposed (Appendix A-1). This climate scenario shows the dominance of a warm arid desert climate in the province of Almeria, as a result of an increase in average temperature and a decrease in average precipitation.

As for the parameters presented below, the climatic measurements were carried out at the state meteorological station located at the Almeria airport in the city of Almeria.

Temperatures
The city of Almeria has an average annual temperature of 18ºC. The average annual maximum temperature is 23ºC and the average minimum temperature is 16ºC as can be seen in the table (Appendix A-2).

Wind
In terms of wind direction, in the cold season between November and April, winds blow predominantly from the N - NW and partly from the SW (Appendix A-6). May is the transition month between the cold and warm season, with winds mainly from the SW direction and to a lesser extent from the E direction (Appendix A-7). In the warm season, between the months of June and September, the wind blows generally from the coast, from SW and E directions (Appendix A-7). In the month of October, the weather transitions from the warm to the cold season, the wind blows mainly from the W-S and NW-E directions (Appendix A-6).

Humidity
Relative humidity generally ranges between 50% and 80% during the year (Appendix A-9).

Sun chart and sunpath
The annual sunchart and sunpath of Almeria are displayed in (Appendix A-3 & A-4).

Sky cover
Almeria is dominated by clear skyes and sunny days. (Appendix A-5) shows the annual sky cover of Almeria.

Rainfall
The arid climate of Almeria is characterised by dry summers. Between 1981 and 2010 the meteorological station recorded an average annual rainfall of 200mm (Appendix A-8).
It is remarkable to point out that occasional meteorological phenomena caused by an isolated depression at high levels generate locally torrential rains (Cañas & Martín, 2004).

4. Interior climate: Health and Comfort

Minimum temperature
The recommended minimum temperature in order to avoid physical and mental health problems related to cold indoor temperatures is 18°C (WHO, 2018). The WHO also highlights the possible requirement for minimum indoor temperatures above 18°C for children, adults and people with cardiovascular pathologies.

Maximum temperature
According to the WHO, high outdoor temperatures are associated with health problems in humans. But there are not enough studies to establish a direct relationship between indoor temperature maxima and increased risks to human health. Depending on the climatic context, local populations tolerate different maximum temperatures (WHO, 2018). Despite the lack of correlation between high indoor temperatures and health problems, the WHO recommends reducing maximum indoor temperatures.

Humidity
Low relative humidity between 5% and 30% in indoor spaces can generate sensory irritation problems in the human body, such as eye and throat irritation (Wolkoff, 2018). On the other hand, high relative humidity levels promote the proliferation of biological pathogens such as bacteria, fungi, viruses and others (Baughman & Arens, 1996).

Climatic comfort
Climate comfort is a conscious, sensory and subjective perception that defines the level of sensory well-being in relation to specific climatic conditions (Nagashima et al., 2018). A person's level of climatic comfort is influenced by metabolic processes of the organism and by factors external to the body (SILVA, 2009). The variables external to the human body that influence climatic comfort include the thermal conductivity of the clothing, the surface of the clothing, the external temperature, the mean radiant temperature, the air velocity, the water partial pressure and the surface temperature of the clothing (SILVA, 2009).

In order to define the appropriate climatic values for comfort, it would be necessary, firstly, to define the typology of the building and the activities carried out in the interior spaces, in order to specify the metabolic rhythms of the users. Secondly, it is necessary to define the parameters external to the human body mentioned above. Knowing these parameters, it is possible to calculate the climatic comfort and discomfort scenarios with comfort models such as ASHRAE-55 or EN-16798. These models take into account the typology of the buildings, the climatic and social context to define the appropriate climatic parameters for the climatic comfort of the users of a building (Zhao, 2021).

The climate consultant software allows to analyse the climatic variables of a geographical location and to develop a psychonometric table. This table defines the dry temperature values in relation to the absolute humidity and relative humidity. The software allows to analyse the impact of passive and mechanical acclimatisation strategies according to a climate comfort model (Appendix A-11).

5. Adaptation to climate of vernacular architecture in the region of Almeria

The vernacular architecture of Almeria made it possible for humans to adapt to a context of scarcity, at the mercy of the region's arid desert climate (Garcia-Sanchez, 2010). In this section we describe construction strategies used historically in the desert context to adapt habitable spaces to comfortable climatic levels.

Survival in the arid desert climate of Almeria was historically linked to accessibility to water sources. The Muslims, who inhabited these lands between 955-1147 and 1157 and 1489, developed a constructive method for the collection, filtering by decanting and storage of rainwater (Figure 1). This construction called Aljibe (water cistern) was replicated and popularly used until the implementation of the water supply system (Figure 2). The cisterns were positioned in the natural watercourses, in wadis and gorges to collect the water from the sporadic rains. The vernacular constructions of Almeria was located in the same places, next to temporary watercourses or in places with underground water flows, accessible by wells (Martínez-Martínez et al., 2018).

Figure 1: Water cister "Aljibe" in the Alcazaba of Almeria

Figure 2: Water cistern "Aljibe" in Cabo de Gata (Almeria).

Among the vernacular typologies in the desert of Almeria, the “cortijo”(farmhouse) and the popular houses stand out. The “cortijos” were buildings dedicated to agricultural and farming activity, constructions that housed all the necessities for subsistence, where workers and livestock lived together (Figure 3 & Figure 4).


Figure 3: Old farmhouse “Cortijo del Fraile” in Nijar (Almeria).


Figure 4: Cortijo in cabo de Gata (Almeria).

5.1 Urban climate adaptive design strategies

In order to minimise the absorption of the sun’s rays, the popular houses of Almeria were covered with lime mortar, giving the exteriors a white finish. The white colour maximises the reflection of sun rays avoiding the thermal gain of the facades (Cañas & Martín, 2004).

The buildings were also protected from solar radiation by the vegetation of the context, positioning the buildings next to existing trees. In some cases water cisterns were protected with evergreen trees such as olive trees. Dwelling rooms were protected with deciduous trees such as vines (Martínez-Martínez et al., 2018).


Figure 5: Vine plants covering a pergola of a popular house in Cabo de Gata (Almeria).


Figure 6: Garden of the Alcazaba of Almeria.

The external spaces of the buildings have historically been designed to control the external temperature and favour the circulation of air through overhead spaces (Cañas & Martín, 2004). Constructions such as the Alcazaba of Almeria or the Cortijo del Fraile had exterior courtyards with vegetation, which were positioned to the north and sheltered by the buildings. In the case of the

Figure 7: Courtyard in Cortijo del Fraile, Nijar (Almeria).

Alcazaba, the courtyard was provided with ponds with moving water to cool the air through evaporative cooling (Figure 6).

In villages with a higher density of dwellings, buildings were arranged in close proximity, minimising the space between dwellings in order to create shaded spaces (Figure 8).

5.2 Building climate adaptive design

Cooling & Ventilation
The cortijos were built on uncovered land, outside from urban settlements, exposed to the sun and the wind. The cortijos were generally rectangular in shape (Figure 9 & 10). In the different cortijos of Almeria, the orientation of the main and long façade towards the south-east prevails. This arrangement allowed maximising the hours of light in the interior rooms and minimising the direct incidence of cold winds coming from the north (Garcia-Sanchez, 2010). Although other cortijos opted for a south and south-west orientation, such as the cortijo del Fraile (Figure 3). The elongated and narrow morphology of the “cortijos” promoted cross ventilation of interior spaces though windows posicioned on opposing sides (Figure 9).

The facades of the vernacular houses are characterised by the predominance of white as a consequence of the lime mortar finishes, as mentioned in the previous section. The dwellings generally consist of austere facades, white planes occasionally interrupted by

Figure 8: Street in the old town of Nijar (Almeria).

Figure 9: South facade of an old farmhouse in Nijar (Almeria).

Figure 10: West facade of an old farmhouse in Nijar (Almeria).

small windows. Popular house envelopes have a small window wall ratio, the construction shun the sun's rays with small windows to keep interior spaces cool and minimally lit and ventilated (Figure 11).

Generally, the popular houses of Almeria have flat roofs covered with lime mortar, this morphology counteracts the refraction of the sun's rays and minimises the heating of the construction (Figure 12)


Figure 11: Popular house in pozo de los Frailes (Almeria).


Figure 12: Facade in Nijar (Almeria).

It is common for traditional buildings to have patios, an open space to the outside in the centre of the ground floor (Figure 14). Inner courtyards are spaces protected from the sun that accumulate fresh air and ventilate the interior of the building (Cañas & Martín, 2004).

Some Cortijos, but not as a general rule, were equipped with exterior porches. Spaces protected from the sun and well ventilated for comfort on hot days (Garcia-Sanchez, 2010).

The popular dwellings of the wealthier social classes were provided with an intermediate space at the entrance, which served as a hall (Figure 15). This buffer zone acts as an insulating airtight space that minimises air flow and thermal variation in the interior when entering or leaving the dwelling.


Figure 13: Town of Nijar (Almeria)


Figure 14: Interior patio in Almeria.

In the vernacular architecture of Almeria we find various methods of minimising the filtration of sunlight through the windows. Some popular dwellings used thin reeds lined up to block the sun (Cañas & Martín, 2004).

Figure 15: Buffer zone house entrace in Nijar (Almeria).

Figure 16: Manual blinds made from rush mats in El pozo de los Frailes (Almeria).

Others opted for the use of rush mattings that functioned as manual blinds (Figure 16). In some cases, the dwellings were fitted with wooden windows, without glass, only to ventilate the interior spaces (Figure 17). It is also common to find shutters, which allow the sun's rays to be regulated. Muslim dwellings were equiped with mashrabiyas, window shutters with geometric motifs that partially blocked out light, creating an interplay between the light and shade of the window (Figure 18).

Many vernacular dwellings have small movable openings in the doors, giving the door the ability to ventilate and illuminate interior spaces (Figure 19 & 20).

We also find the implementation of vertical clearstory in the flat roof to permit the illumination and ventilation while avoiding solar rays (Cañas & Martín, 2004).

Figure 17: Window in Mojacar (Almeria).

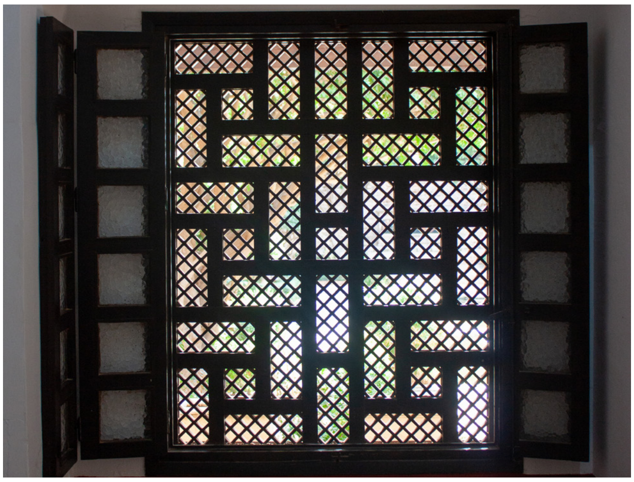


Figure 18: Mashrabiyas, window shutters in the Alcazaba of Almeria.

Figure 19: Front door in Mojacar (Almeria).

Figure 20: Front door in Nijar (Almeria).

Heating

The walls of the vernacular constructions of Almeria were built with stone and mud from the surrounding area. In the weakest parts of the structure, plaster was used to reinforce the construction (Garcia-Sanchez, 2010). Finishes were made with lime mortar, when there was a source nearby, or with mud (Figure 12 & 23). The walls were very thick for structural reasons and to minimise thermal conductivity. Stone walls have a large thermal mass, which allowed the capture of the sun's energy for prolonged transmission in the cool hours of the night.

Generally the large windows were located on the main façade facing south in order to maximise the capture of light for the internal spaces (Cañas & Martín, 2004). Consequently, this arrangement favoured the capture of solar radiation in the cold season.

Most vernacular buildings used non passive heating chimneys to raise temperatures in interiors during the winter (Figure 21).

Figure 21: Chimney in an old Cortijo in Nijar (Almeria).

Figure 22: Stone walls of an cortijo in Nijar (Almeria).

Figure 23: Stone wall of a popular house in Nijar (Almeria).

5.3 Material level

The lack of knowledge of the population on thermal insulation translated in the construction of thick building walls. The stone walls functioned as thermal accumulators but did not possess the necessary insulating capacity for the hot summer conditions and winter cold (Figure 22 & 23).

As mentioned before, the finishing of the facades with lime mortar minimised the thermal absorption of the buildings, contributing to comfort in interior spaces during hot days (Cañas & Martín, 2004).

5.4 Observations

The homogeneous materialisation of buildings in an urban environment with materials reflective to solar radiation can create unwanted energy gains between buildings.

High relative humidity during warm months can be conditioned by increased water vapour concentration in the air as a result of water evaporation. This can lead to excessive levels of relative humidity that are uncomfortable and dangerous for the spread of biological pathogens.

Air circulation is essential to achieve climate comfort levels when temperatures are high. The planning of urban areas with cramped outdoor spaces can impede air circulation and may be a handicap to achieve comfortable climates in urban contexts.

The positioning of windows on the south façades of the farmhouses was beneficial during the cold season for the collection of solar radiation, but could be counterproductive during the warm season if they were not equipped with a system for blocking solar radiation.

6. Passive design strategies for arid hot desert climate in the northern hemisphere

In this section we will analyse different passive design strategies with potential for implementation in the hot arid climate of Almeria.

6.1 Urban passive design

Cooling
The spaces outside buildings play a fundamental role in regulating the internal climate of constructions. Passive design strategies that favour the creation of microclimates in outdoor spaces enhance the cooling capacity of buildings (Valladares-Rendón et al., 2016). The morphology and relationship of buildings in urban environments should favour air circulation for passive ventilation of intermediate spaces and in buildings. In order to avoid the urban heat island effect, the materialisation of outdoor spaces should have a low thermal mass to reduce heat absorption and heat emission in the warm season. To reduce the temperature in outdoor spaces, vegetation can be implemented to create shaded spaces. In the spaces surrounding buildings, light-reflective materials should be avoided to prevent the incidence of unwanted solar radiation (Valladares-Rendón et al., 2016).

Based on the thermal-physical behaviour of the ¨botijo¨, a traditional clay container used for the preservation of liquids, which regulates the interior temperature through evaporation of the liquid on the clay surface, the following cooling systems have been developed. The channelling of water through a clay façade, reducing the temperature of the façade in the project Casa patio 2.12 (Terrados-Cepeda et al., 2015). A ceramic panel has also been developed, which integrates hydrogel, reducing the surrounding temperature by up to 6 degrees at hot times (Millán et al., 2016).

Heating
The composition of the intermediate spaces between buildings must guarantee the incidence of solar radiation on the facades during the cold season for the passive heating of the buildings (Ménard & Souviron, 2020). The outdoor spaces can incorporate deciduous vegetation, which allows the sun to shine in the cold months and provides protection in the hot months. In these spaces, a thermal mass materialisation can be incorporated to buffer night-time temperatures.

6.2 Building passive design

Heating
During the cold season, between the months of November and May, the day and night temperatures on the coast of Almeria are below 20 degrees Celsius (Appendix A2). During this period, buildings can be passively heated by harnessing solar radiation. In order to capture sufficient solar energy, the building must have a suitable morphology. In the climate of Almeria, energy consumption is minimised in buildings with long south-facing facades and narrow east- and west-facing facades (Ford et al., 2007; Fernandez-Antolin, 2019) In order to maximise the absorption of solar radiation, buildings should orient their main facades towards the south with a maximum range of 20 to 30 degrees (Fernandez-Antolin, 2019). Since the south façade receives the most hours of sunlight during the day, it should host the highest percentage of windows for solar energy capture. In order to minimise energy loss through the building envelope, the ratio between wall and windows should be around 20% (Fernandez-Antolin, 2019). It is also essential to minimise the area of openings in the north façade in order to diminish energy loss.

The application of insulating materials throughout the building envelope helps to retain internal heat gains, including that produced by the building's users, light bulbs, appliances and others (Manzano-Agugliaro, 2015).

The application of materials and colours with a low reflectivity index in façades contributes to the absorption of solar radiation, reducing energy consumption (Fernandez-Antolin, 2019).

Cooling
Between the months of May and October is the hot season in the climate of Almeria. During this period, temperatures regularly exceed 25 degrees Celsius, decreasing the comfort in outdoor spaces (Appendix A-2). To acclimatise buildings to comfortable temperatures between 20 and 25 degrees Celsius, it is recommended that the following strategies be applied in building design.

Preventing overheating
During the warm season it is essential to keep the interior spaces protected from solar radiation. The rectangular morphology of a building and the orientation of the short facades towards the east and west reduces the insolation of the interior spaces during peak hours and reduces energy costs (Manzano-Agugliaro, 2015; Fernandez-Antolin, 2019).

To avoid heat gain, it is essential to protect windows on facades exposed to solar gain with window overhangs or operable sunshades (Valladares-Rendón et al., 2016). It is important to avoid positioning unprotected openings on the east and west facades to prevent heat gain when the sun's inclination is low. Windows on the south façade make it easier to control the influx of solar radiation into the interior spaces thanks to the high angle of incidence of sun rays.

Buildings with a wall-to-window ratio of 20% or less require fewer energy consumption for cooling the interior spaces (Fernandez-Antolin, 2019).

Ventilation
The following passive ventilation systems can be applied to dissipate heat in interior spaces. By positioning shaded windows in prevailing wind directions it is possible to ventilate spaces by convection. By designing narrow floor plans and placing openings at opposite ends of the building, cross ventilation of interiors is possible (Ford et al., 2007). For efficient ventilation it is preferable to implement ventilation openings in the upper areas of the house where warm air is concentrated and in the lower parts where cool air is located.

Stack ventilation helps to evacuate warm air and ventilation of spaces with fresh air (Ford et al., 2007). The release of warm air can be accelerated with the integration of solar chimneys, structures exposed to solar radiation that encourage airflow in an upward direction.

Ventilation of the interior spaces during the cooler hours of the night (night flushing) allows the heat accumulated during the previous day to be dissipated and the spaces to be brought to a comfortable temperature. The combination of this strategy with PCM's makes it possible to maintain comfortable temperatures during the day.
Indoor ventilation is also possible with the installation of wind catchers, vernacular structures originating from Iran. These constructions capture the prevailing winds and direct the air through an insulated duct, reducing the temperature of the fluid, towards the interior of the dwelling (Maleki, 2011).

Groud-coupled heat exchange
Due to the change of temperatures during the seasons Almería and because the heat retaining capacity subsoil has a large thermal mass, it retains the ambient heat during the seasons.

This condition translates into temperatures in the subsoil that are lower than the ambient temperature during the warm season and vice versa during the cold season (Appendix A-10). Through the conduction of fluids in earth tubes in the subsoil it is possible to harness energy for cooling or heating of interior spaces in buildings (Ford et al., 2007).

6.3 Material level passive design strategies

Insulation
For the design of a passive building it is necessary to insulate the dividing membrane between the interior spaces and the exterior. A façade with a low thermal transmittance (U) will insulate the interior spaces from the outside climate and retain energy in the house. Floor insulation is not necessary in the warm climate of Almeria and its implementation may make it difficult to harness the energy stored in the subsoil (Ford et al., 2007). Wall insulation should have a maximum energy transmittance of 0.3 W/(m2K) (Ford et al., 2007). For roofs, these surfaces should have a minimum transmittance of 0.3 W/(m2K) (Ford et al., 2007).

Thermal mass
The implementation of PCM's (phase changing materials) on walls and floors in interiors exposed to solar radiation contributes to the temperature regulation of spaces (Manzano-Agugliaro, 2015). PCMs have the ability to retain the energy of daytime solar radiation and emit heat for hours. PCMs also retain cold and therefore play an important role in temperature regulation during the warm season. The energy retention and transmission capacity depends on thermophysical characteristics, density, thermal conductivity, specific heat and thermal storage (Kamal, 2011).

Infiltration and airtightness
When buildings are equipped with mechanical ventilation systems, such as heat recovery systems, a high level of airtightness is required. In climates with non-extreme minimum temperatures, a heat recovery system can be dispensed with and therefore it is not necessary to maximise the control of airflow through a building's membrane (Ford et al., 2007).

Thermal bridges
Proper thermal insulation implies the correct design of the building envelope membrane. The insulation layer should be continuous and should eliminate weak points where thermal bridging can occur to allow thermal flow between inside and outside (Ford et al., 2007).

Windows/glazing
In order to use solar radiation for passive heating of a building, it is necessary to calculate the appropriate values of thermal conductivity U and solar transmittance g of the glazing. Since a lower energy conductivity of a glazing translates into a lower transmittance of solar radiation, it is important to weight the required values according to the solar radiation of the context and the outside temperatures in order to ensure the necessary energy gain for comfortable climatic levels (Ménard & Souviron, 2020).

7. Conclusion

The coast of Almeria currently has three climatic zones, cold arid steppe, cold arid desertic and hot arid desertic. As a consequence of climate change, the climate of the coast of Almeria will become homogeneously, hot arid desertic. This development will have negative repercussions on the climatic comfort of citizens in outdoor and indoor spaces. And for the population living in non-climatically adapted dwellings, acclimatisation will suppose an increase of energy consumption and the corresponding CO2 emissions as well an increase in their energy costs for the inhabitants

The vernacular architecture in the hot arid and desert areas of Almeria, described in section 5, shows the evolution of popular knowledge and practice for adaptation to the local climate. These strategies can be accurate, but also contradictory to an adequate planning for climatic comfort in outdoor and indoor spaces. It is therefore necessary to reconsider practices and implement new strategies.

In order to minimise energy consumption as a consequence of mechanical installations, proper urban planning is necessary. Urban design must adapt its form and composition to allow for solar radiation on all buildings and the necessary airflow in outdoor spaces. Housing should maximise passive design through orientation, morphology and appropriate materialisation. The conditions described in section 6 would significantly reduce energy consumption and improve the climate comfort of the inhabitants.

The selective combination of the described vernacular and design strategies for the hot arid desert climate can significantly reduce the energy consumption of a building. The implementation of passive design on the urban, building and material scale can contribute significantly to the reduction of energy consumption, but it does not guarantee comfortable levels throughout the year. Passive house design may therefore require reinforced mechanical heating and cooling systems. To minimise environmental impact, these systems should prioritise the use of renewable energy.

As for the methods applied to the study of vernacular and passive strategies for climate adaptation, these may limit the actual range of results. The sections have tried to provide a comprehensive synthesis, but it is possible that some aspects may have been left out.

The passive design approaches analysed are relevant to the hot arid desert climate of Almeria, but are relevant to different geographical contexts with a similar climate. Similarly, cooling, heating and ventilation strategies can be applied for these purposes in different climates.

To understand the quantitative impact of the described passive strategies on climate levels, it is necessary to carry out further design research. The specific approach and simulation of a design with software that allows the quantification of climate levels, climate comfort levels and energy consumption at different scales would help to define the real impact of the different passive strategies.

Literature

Baughman, A.L., & Arens, E.A. (1996). Indoor humidity and human health. Part 1: Literature review of health effects of humidity-influenced indoor pollutants. Ashrae Transactions, 192-211.

Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018).

Cañas, I. & Martín, S.. (2004). Recovery of Spanish vernacular construction as a model of bioclimatic architecture. Building and Environment. 39. 1477-1495. 10.1016/j.buildenv.2004.04.007.

Fernandez-Antolin, M.-M., del Río, J., Costanzo, V., Nocera, F., & Gonzalez-Lezcano, R.-A. (2019). Passive Design Strategies for Residential Buildings in Different Spanish Climate Zones. Sustainability, 11(18), 4816. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su11184816

Ford, B., Schiano-Phan, R., & Zhongcheng, D. (Eds.). (2007). Passive-On project, Comfort, Climate and Passive Strategies. The Passivhaus Standard in European Warm Climates: Design Guidelines for comfortable Low Energy Homes.

Garcia-Sanchez, J.F. (2010). La escasez en el desierto. P+C: Proyecto y ciudad: revista de temas de Arquitectura. 83-96.

Junta de Andalucía & Unión Europea. (2021, mayo). Plan Andaluz de Acción por el clima. https://www.juntadeandalucia.es/medioambiente/portal/documents/20151/27181420/PAAC.pdf/e4761b37-e5ea-1204-9364-3f25bbd39be3?t=1635167310439

Kamal, M. A. (2011). The Study of Thermal Mass as a Passive Design Technique for Building Comfort and Energy Efficiency. Journal of Civil Engineering and Architecture.

Kastner, P., & Dogan, T. (2021). Eddy3D: A toolkit for decoupled outdoor thermal comfort simulations in urban areas. Building and Environment, 108639.

Maleki, B.A. (2011). WIND CATCHER : PASSIVE AND LOW ENERGY COOLING SYSTEM IN IRANIAN VERNACULAR ARCHITECTURE.

Manzano-Agugliaro, F., Montoya, F.G., Sabio-Ortega, A., & García-Cruz, A. (2015). Review of bioclimatic architecture strategies for achieving thermal comfort. Renewable & Sustainable Energy Reviews, 49, 736-755.

Martínez-Martínez, J., Casas Ripoll, D., & Varón Barón, D. (2018). Los cortijos del pasado reciente en el campo de Níjar (Almería, España). Segunda parte: Desde el interiorismo de las casas-vivienda hasta las formas de vida.

Ménard, R., & Souviron, J. (2020). Passive solar heating through glazing: the limits and potential for climate change mitigation in the european building stock. Energy & Buildings, 228. https://doi.org/10.1016/j.enbuild.2020.110400

Millán, M.I., Pacios, R.T., García, A.C., & Picó, A.S. (2016). Energy performance improvement and cultural enhancement of the Andalusian rural heritage: case study – "El Cortijo del Fraile". ARC 2016.

Nagashima, K., Tokizawa, K., & Marui, S. (2018). Thermal comfort. En A. A. Romanovsky (Ed.), Handbook of Clinical Neurology (1.a ed., pp. 249–260). Elsevier.
Problematic

Schittich, C. (Ed.). (2019). Vernacular architecture : atlas for living throughout the world. (H. Busch, Trans.). Birkhäuser.

Silva, M.C. (2009). SPREADSHEETS FOR THE CALCULATION OF THERMAL COMFORT INDICES PMV AND PPD.

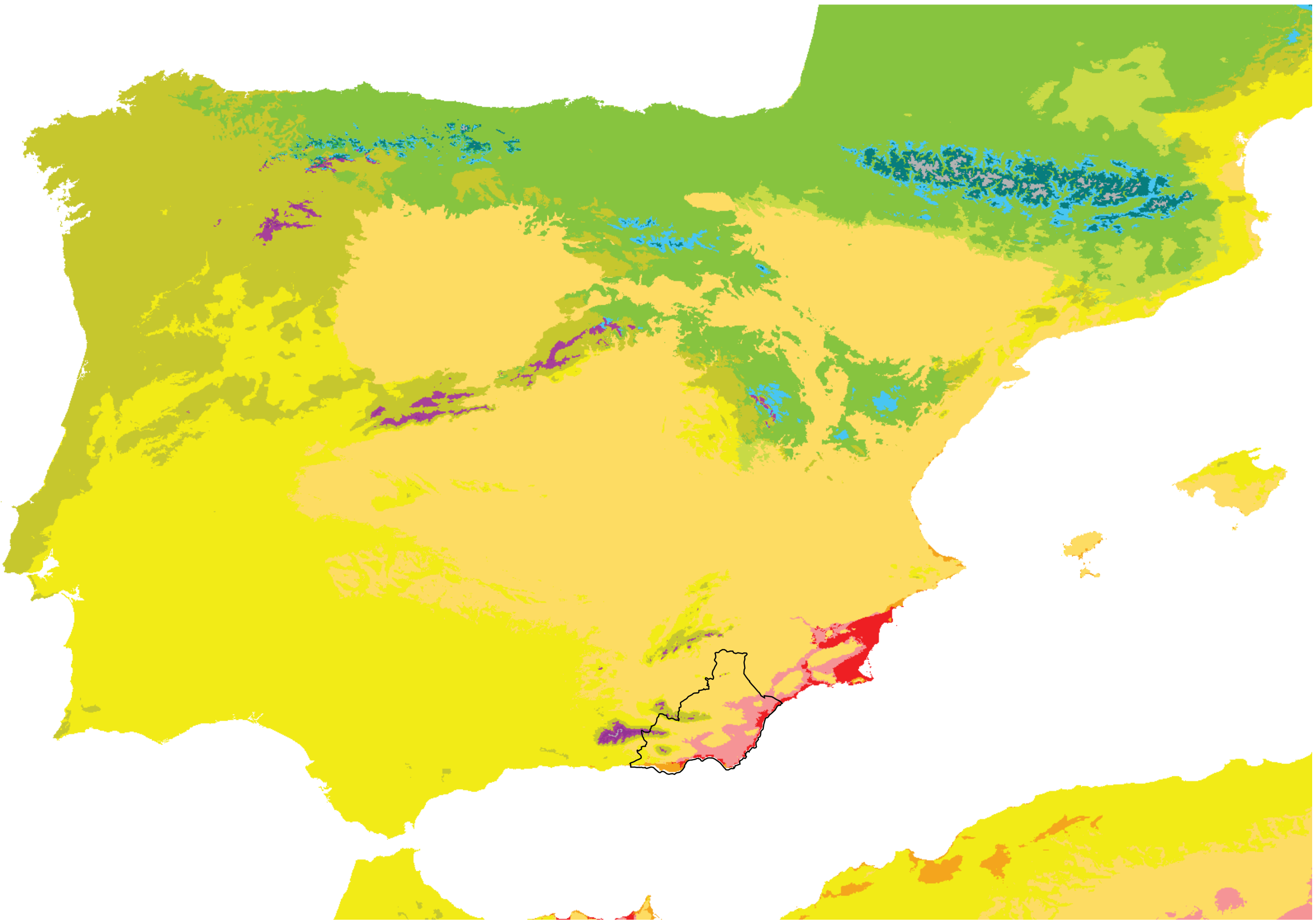
Terrados-Cepeda, F. J., Baco-Castro, L., Moreno-Rangel, D. (2015). Patio 2.12: Vivienda prefabricada, sostenible, autosuficiente y energéticamente eficiente. Participación en la competición Solar Decathlon Europe 2012. Informes de la Construcción, 67(538): e088, doi: http://dx.doi.org/10.3989/ic.13.138.

Tirado Herrero., S., Jiménez Meneses, L., López Fernández, J.L., Irigoyen Hidalgo, V.M.,2018. Pobreza energética en España. Hacia un sistema de indicadores y una estrategia de actuación estatales. Asociación de Ciencias Ambientales, Madrid.
WHO Housing and Health Guidelines. (2018). World Health Organization.

Wolkoff P. (2018). Indoor air humidity, air quality, and health - An overview. International journal of hygiene and environmental health, 221(3), 376–390. https://doi.org/10.1016/j.ijheh.2018.01.015

Zhao, Q., Lian, Z., & Lai, D. (2021). Thermal comfort models and their developments: A review.

Appendix A - Climatic zones - Iberian peninsula



Legend

🟥 Arid - Desert hot

🟥 Arid - Desert cold

🟧 Arid - Steppe hot

🟨 Arid - Steppe cold

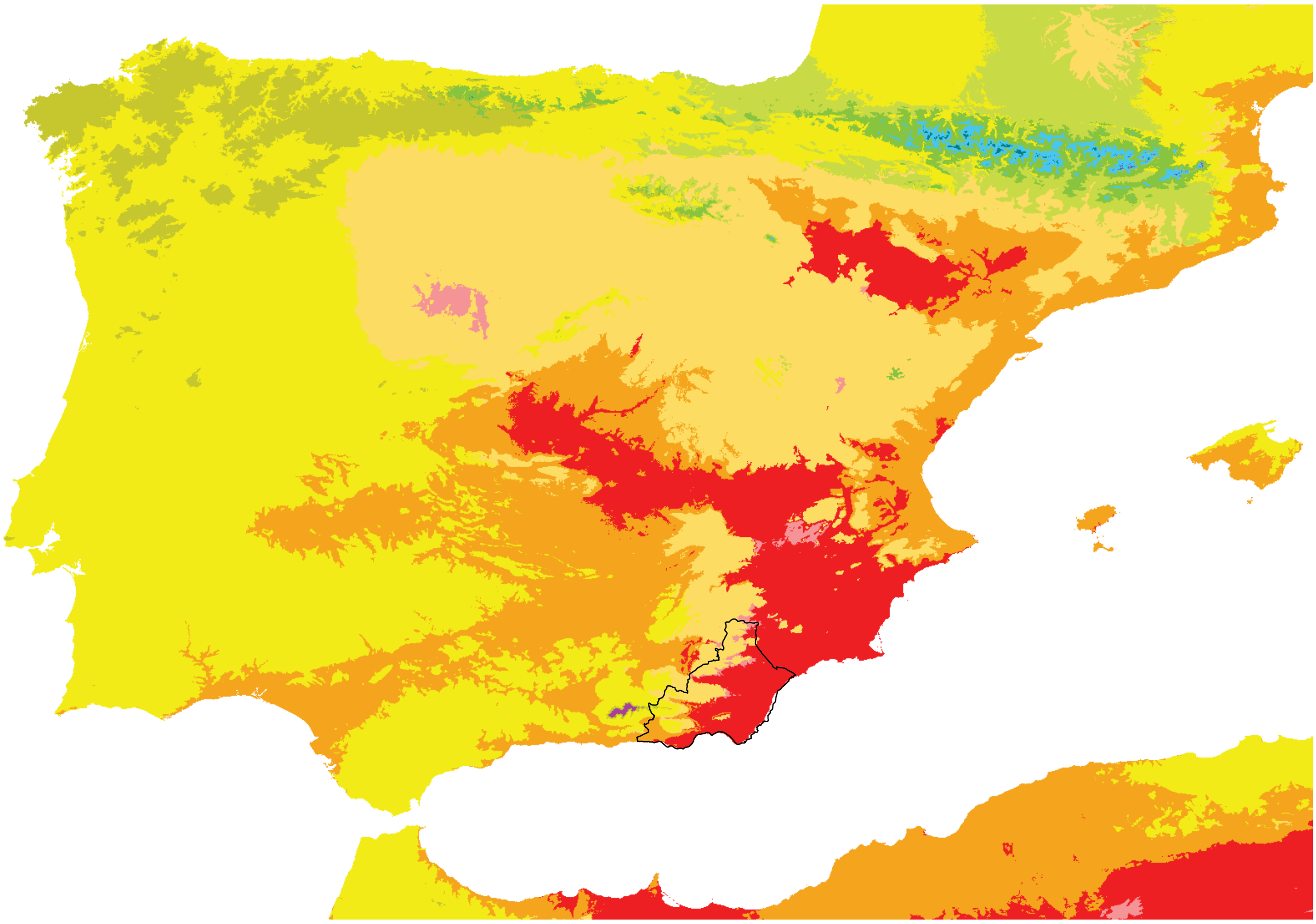
🟨 Temperate - Dry hot summer

🟨 Temperate Dry warm summer

🟩 Temperate - Warm summer without dry season

Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018).

Appendix A-1. Climatic zones - Iberian peninsula

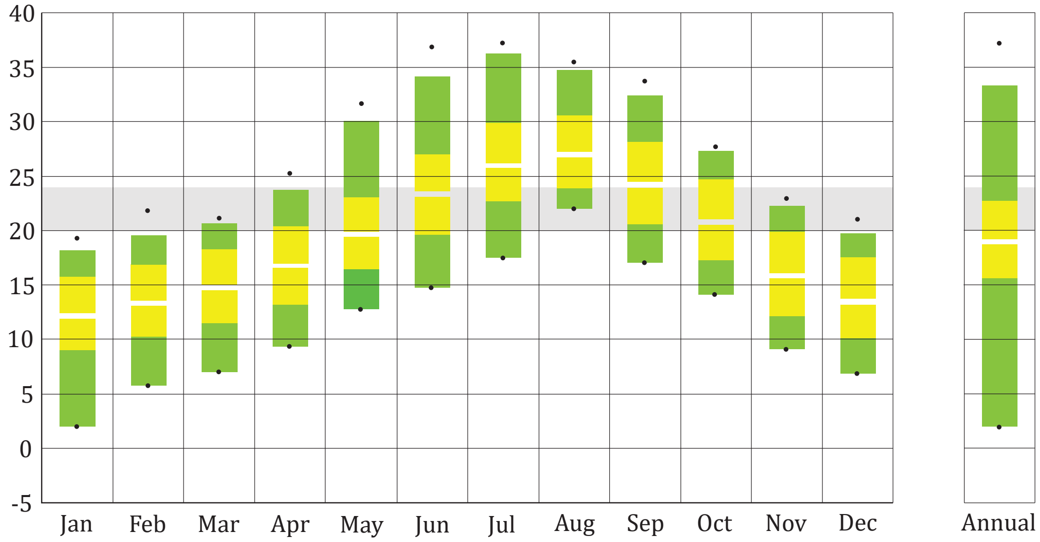


Legend

- 🟥 Arid - Desert hot
- 🟥 Arid - Desert cold
- 🟧 Arid - Steppe hot
- 🟨 Arid - Steppe cold
- 🟨 Temperate - Dry hot summer
- 🟩 Temperate Dry warm summer
- 🟩 Temperate - Warm summer without dry season

Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018).

Appendix A-2. Climate Almeria - Annual hour temperature distribution

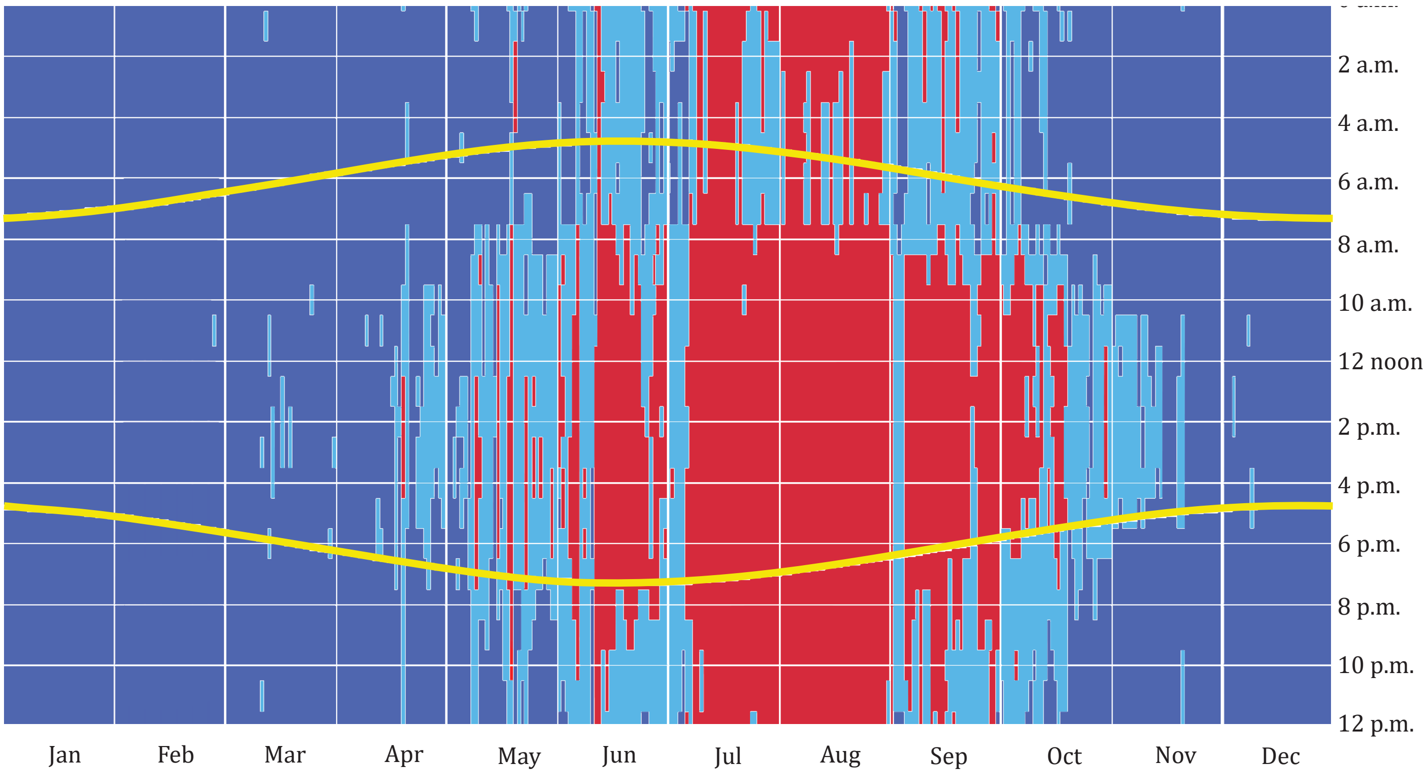


Legend

- • Recorded high
- 🟩 Design high
- 🟨 Average high
- Mean
- 🟨 Average low
- 🟩 Design low
- • Recorded low

Climate Consultant Software ,www.aud.ucla.edu/
energy-design-tools;2014

Climate Almeria - Annual hour temperature distribution

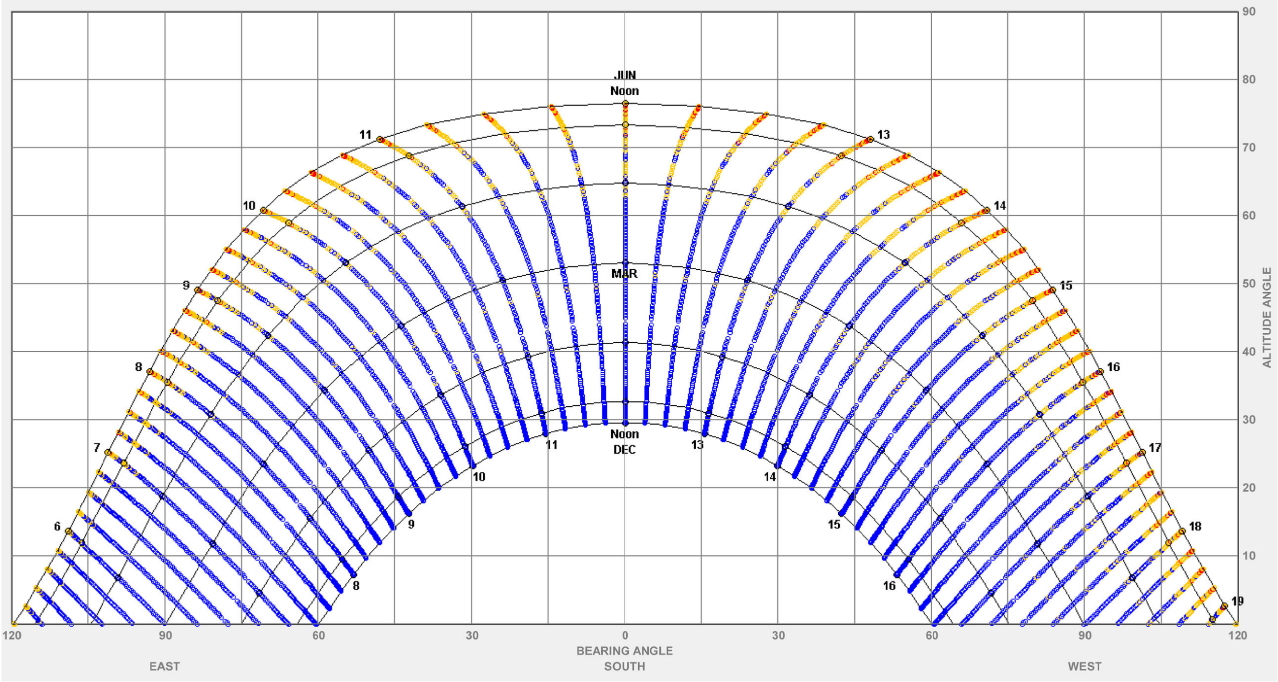


Legend

- 🟥 24 - 38 C
- 🟦 20 - 24 C
- 🟦 0 - 20 C

Climate Consultant Software ,www.aud.ucla.edu/
energy-design-tools;2014

Appendix A-3 . Climate Almeria - Sunchart Almeria



21 December - 21 Juni

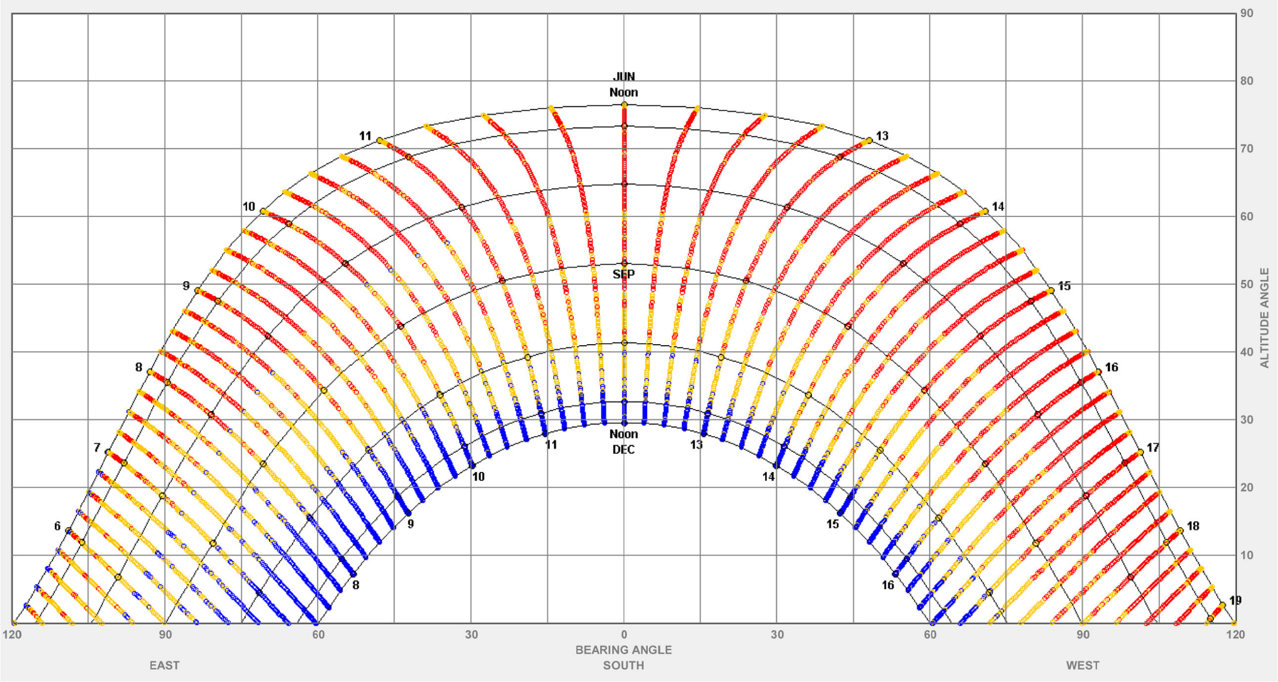
Climate Consultant Software ,www.aud.ucla.edu/ energy-design-tools;2014

Legend

🟥 Warm/Hot > 24 C

🟨 Comfort > 20 C

🟦 Cool/Cold < 20 C



21 Juni - 21 December

Climate Consultant Software ,www.aud.ucla.edu/ energy-design-tools;2014

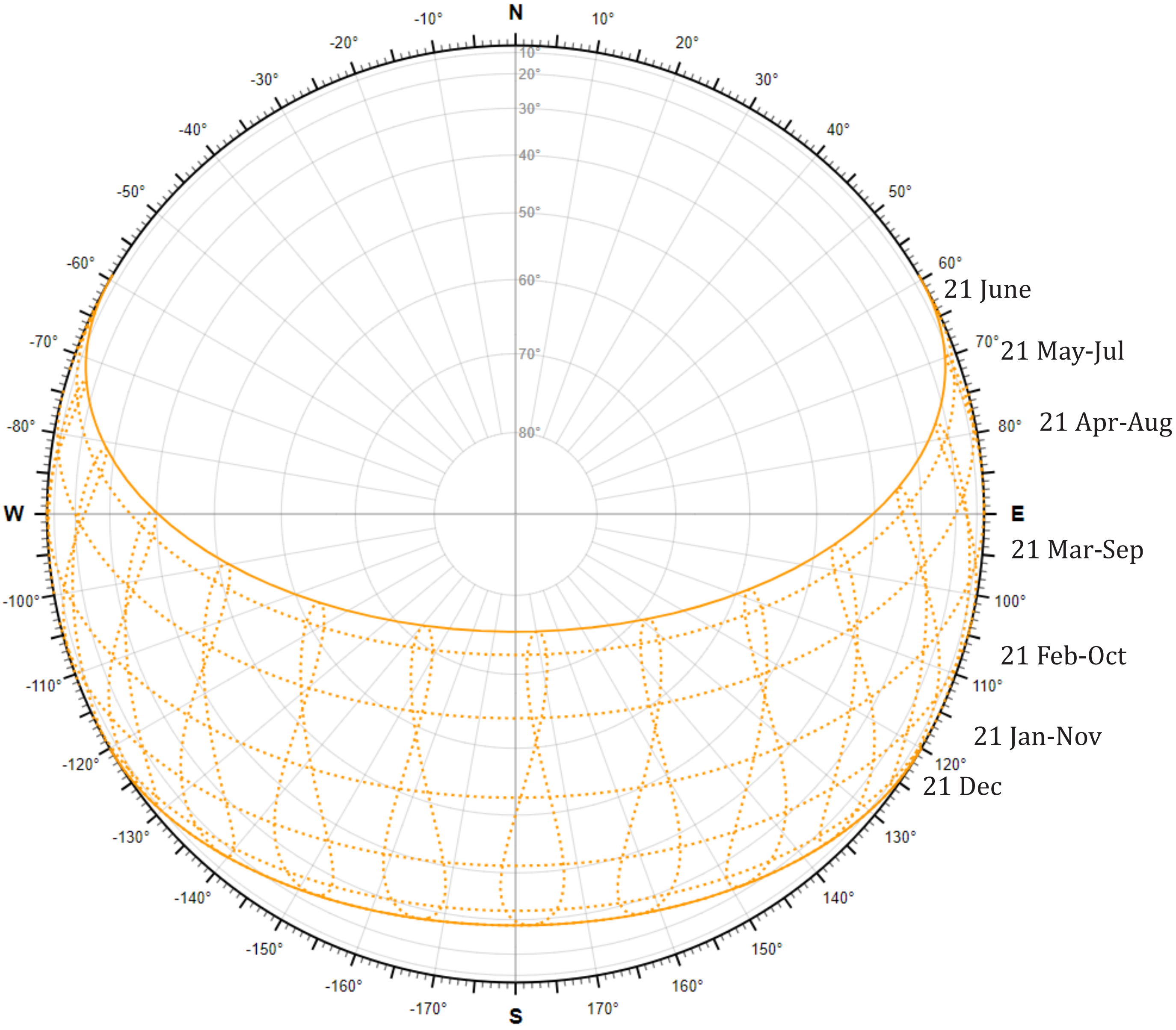
Legend

🟥 Warm/Hot > 24 C

🟨 Comfort > 20 C

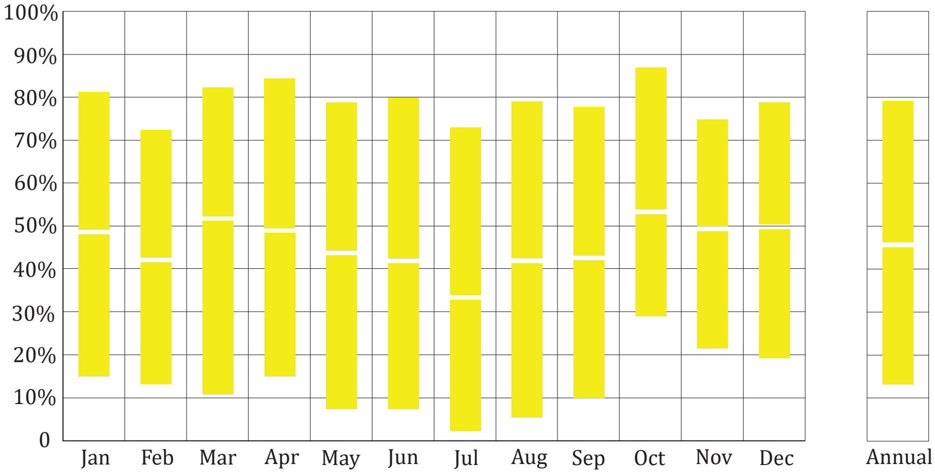
🟦 Cool/Cold < 20 C

Appendix A-4. Climate Almeria - Annual sunpath Almeria



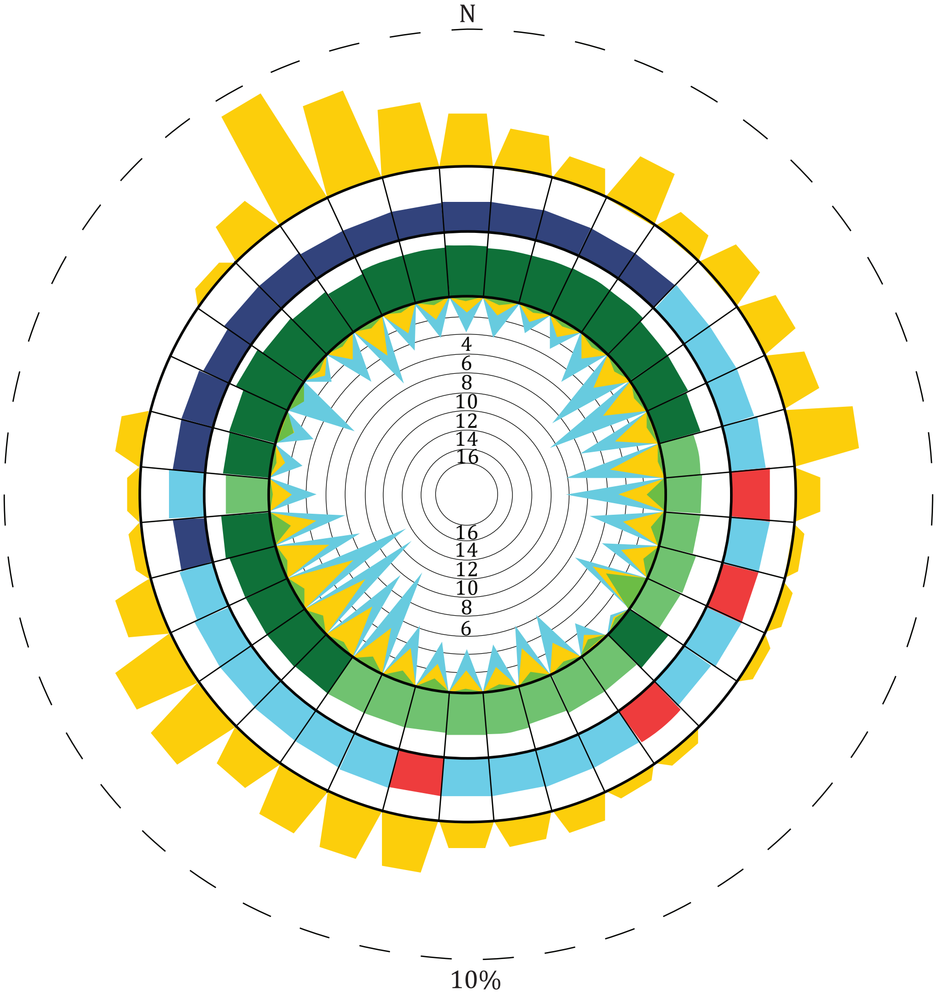
D. (2017). 2D Sun-Path. Andrewmarsh.Com. http://andrewmarsh.com/apps/releases/sunpath2d.html

Appendix A-5 . Climate Almeria - Sky cover

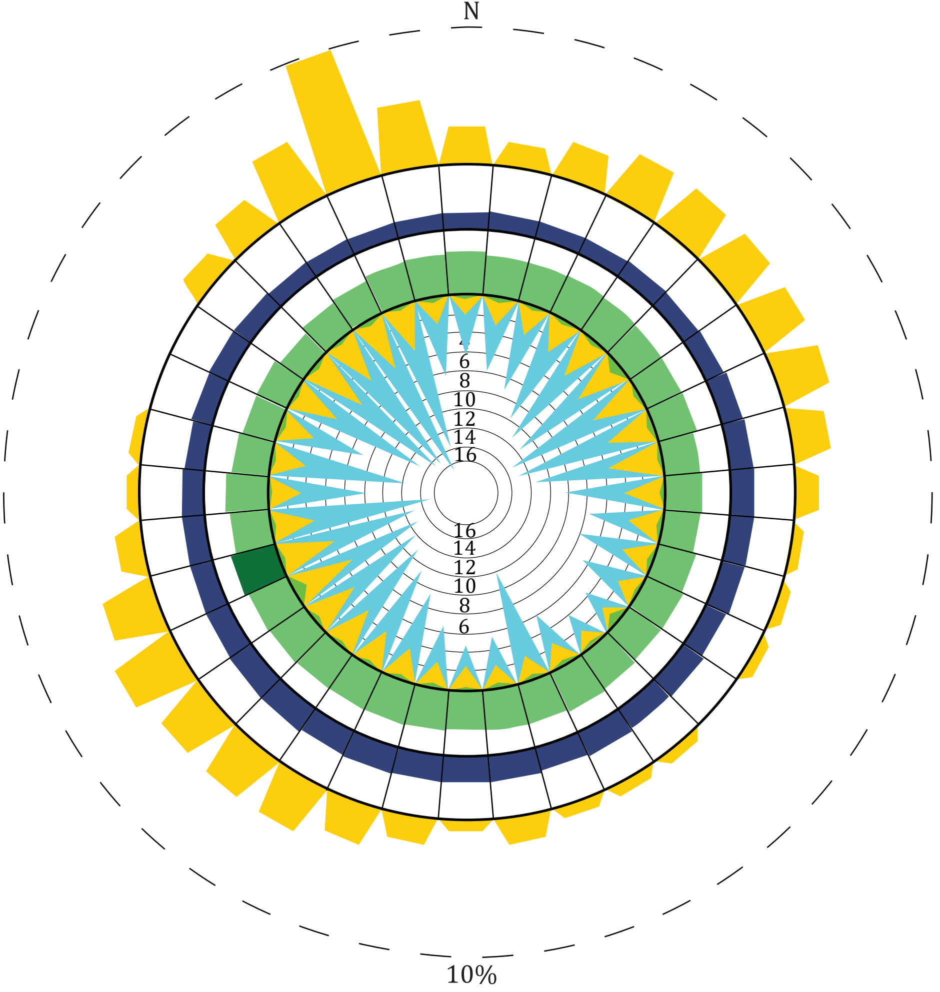


Climate Consultant Software ,www.aud.ucla.edu/energy-design-tools;2014

Appendix A-6. Climate Almeria - Wind wheel



October



November - April

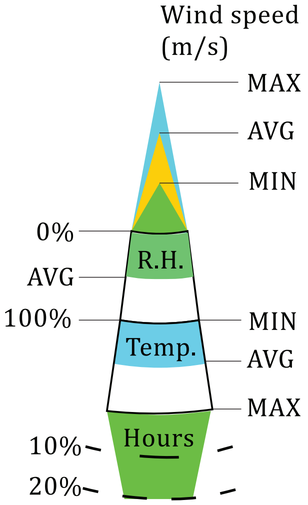
Legend

Temperature (Deg. C)

- 🟦 0 - 20
- 🟦 20 - 24
- 🟥 24 - 28

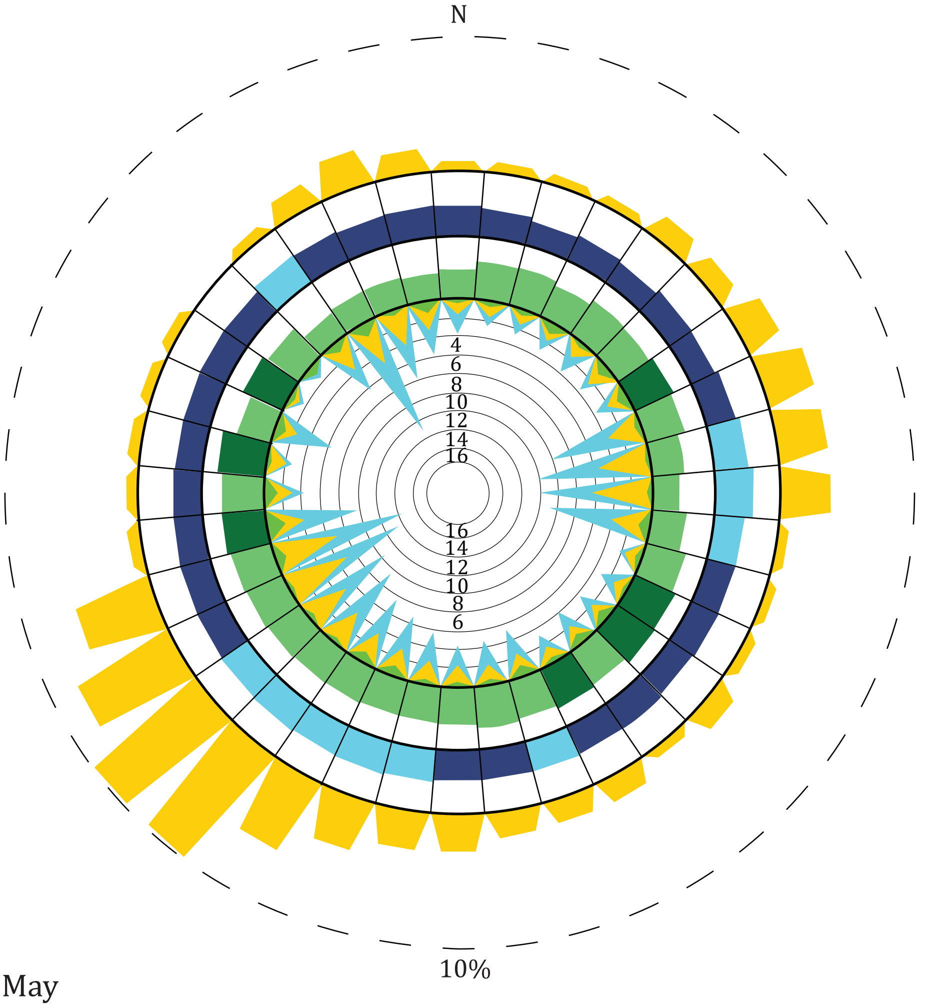
Relative humidity

- 🟨 < 30%
- 🟩 30% - 70%
- 🟩 > 70%

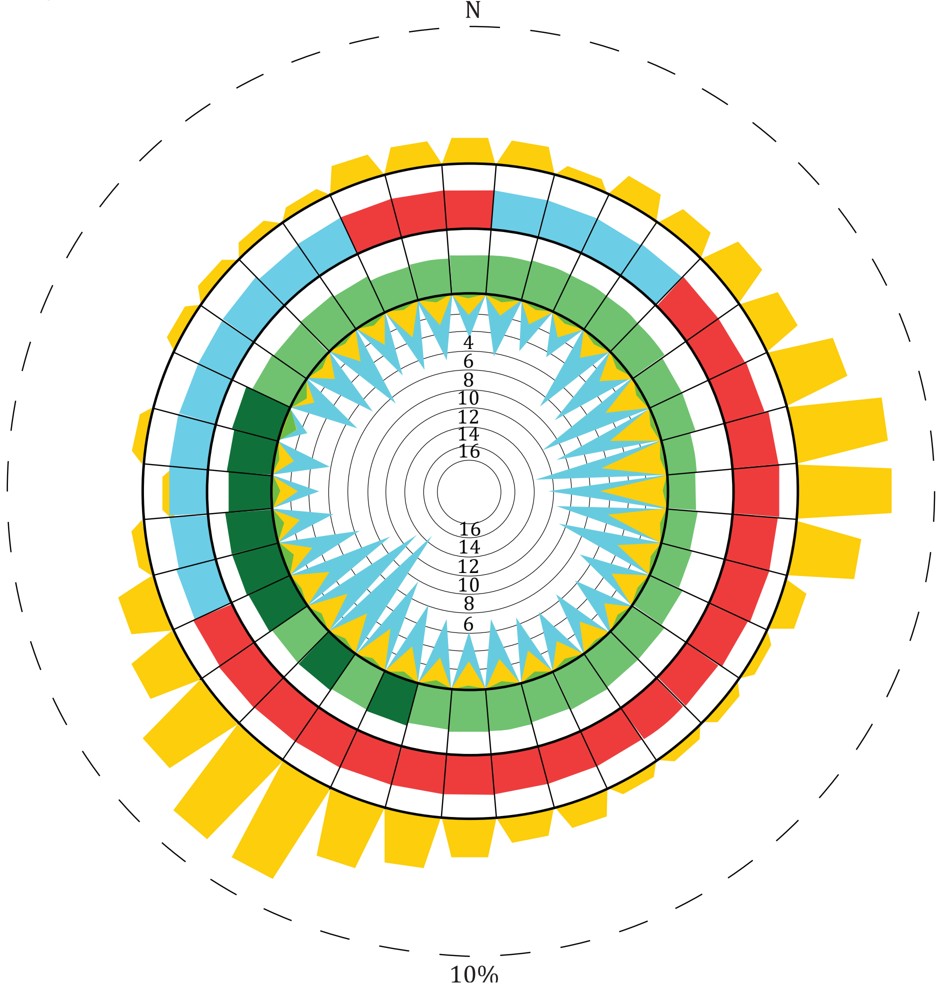


Climate Consultant Software ,www.aud.ucla.edu/energy-design-tools;2014

Appendix A-7. Climate Almeria - Wind wheel



May



June - September

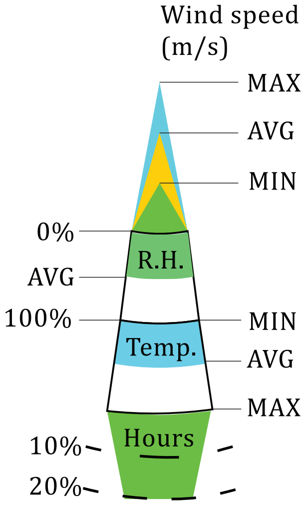
Legend

Temperature (Deg. C)

- 🟦 0 - 20
- 🟦 20 - 24
- 🟥 24 - 28

Relative humidity

- 🟨 < 30%
- 🟩 30% - 70%
- 🟩 > 70%



Climate Consultant Software ,www.aud.ucla.edu/energy-design-tools;2014

Appendix A-8. Climate Almeria - Precipitation between 1981 and 2010

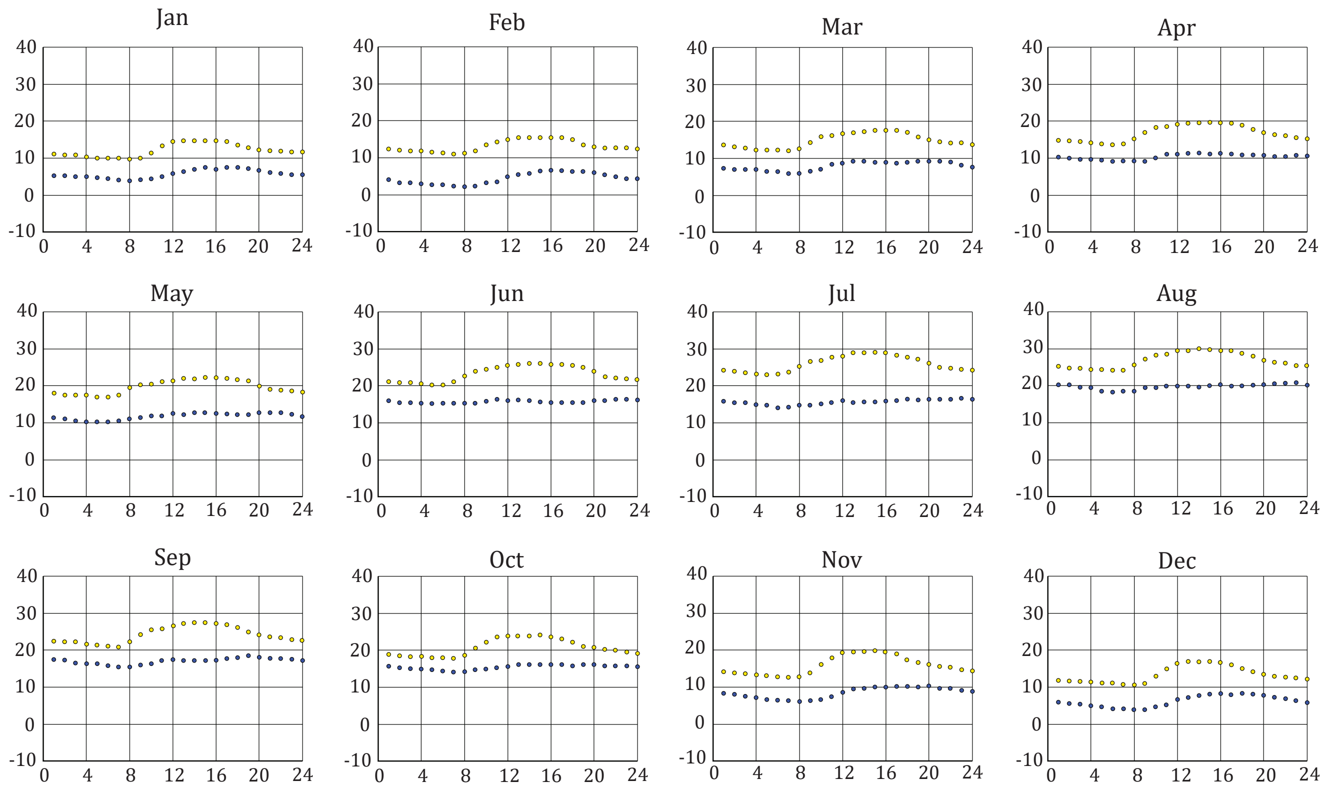
	R	DR
January	24	2.9
February	25	2.9
March	16	2.6
April	17	2.6
May	12	1.9
June	5	0.6
July	1	0.3
August	1	0.3
September	14	1.5
October	27	2.8
November	28	3.6
December	30	3.3
Year	200	25.4

R Monthly precipitation / annual average (mm)

DR Monthly average of days with precipitation higher or equal to 1 mm

Meteorología, A. E. (2021). Almería Aeropuerto: Almería Aeropuerto. Agencia Estatal de Meteorología - AEMET. Gobierno de España. https://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=6325O&k=undefined

Appendix A-9. Climate Almeria - Dry bulb

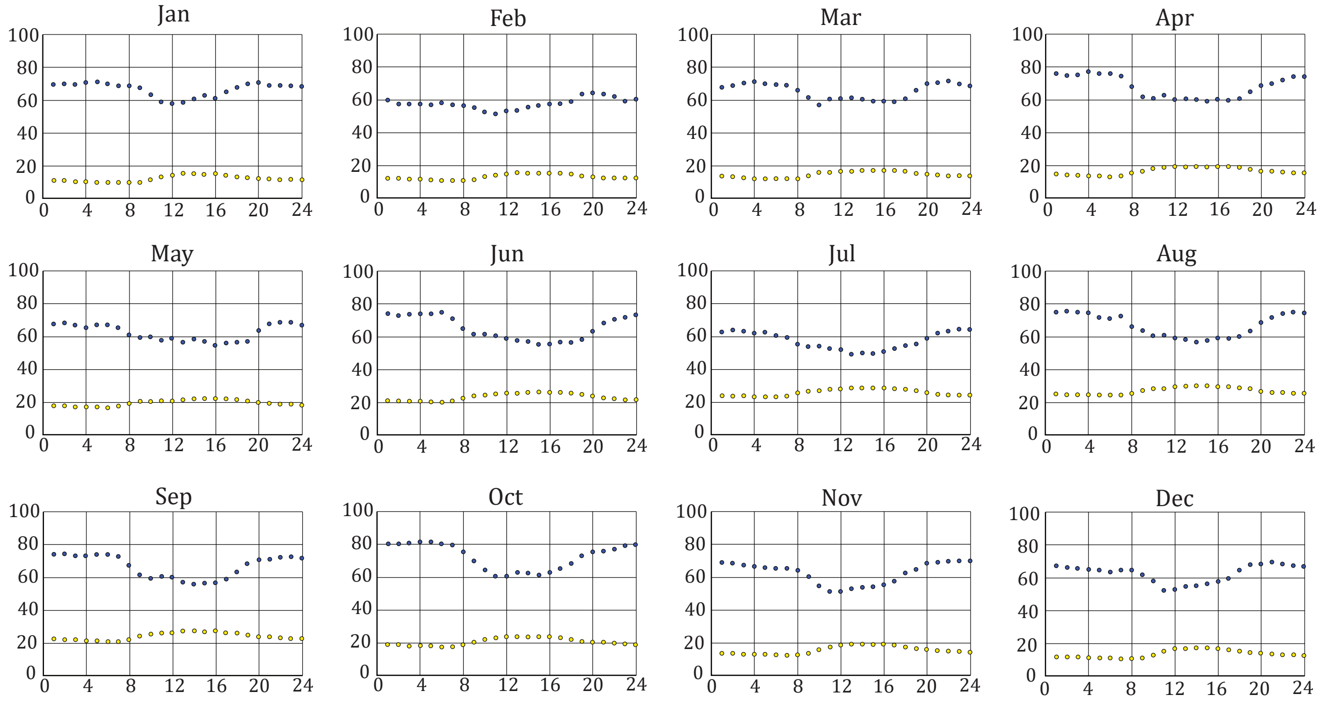


Legend

- ● Dry bulb
- ● Dew point

Climate Consultant Software ,www.aud.ucla.edu/energy-design-tools;2014

Climate Almeria - Humidity

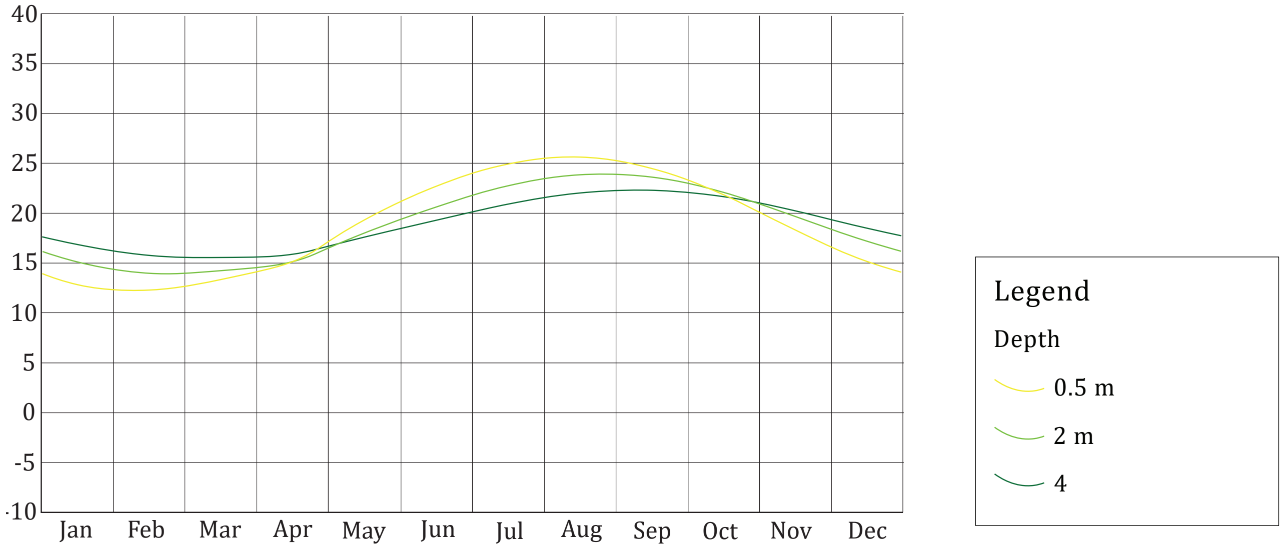


Legend

- ● Dry bulb
- ● Humidity

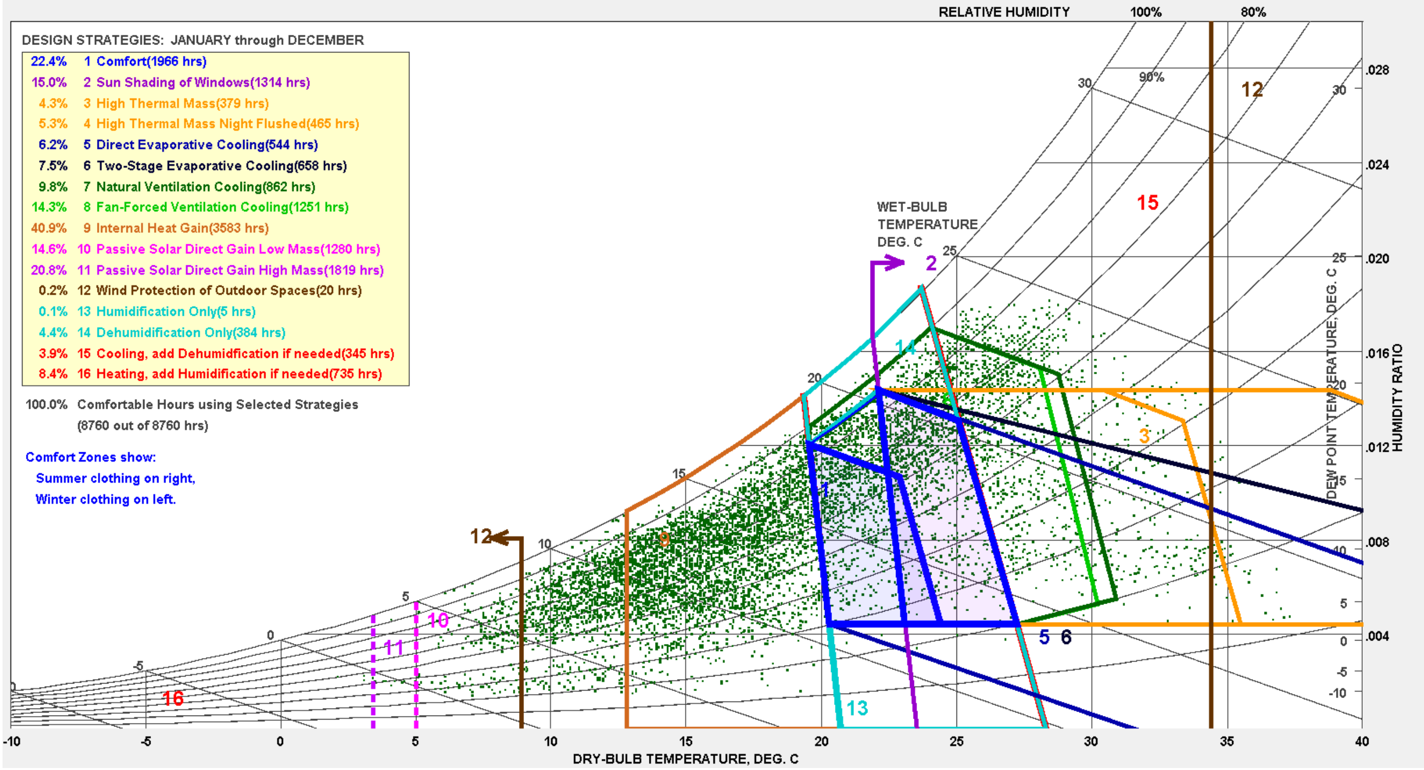
Climate Consultant Software ,www.aud.ucla.edu/energy-design-tools;2014

Appendix A-10. Climate Almeria - Ground temperature



Climate Consultant Software ,www.aud.ucla.edu/
energy-design-tools;2014

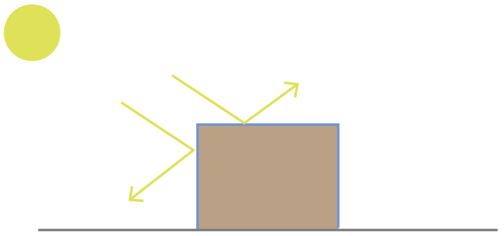
Appendix B. Climate consultant: Psychonometric chart Almeria



Climate Consultant Software ,www.aud.
ucla.edu/energy-design-tools;2014

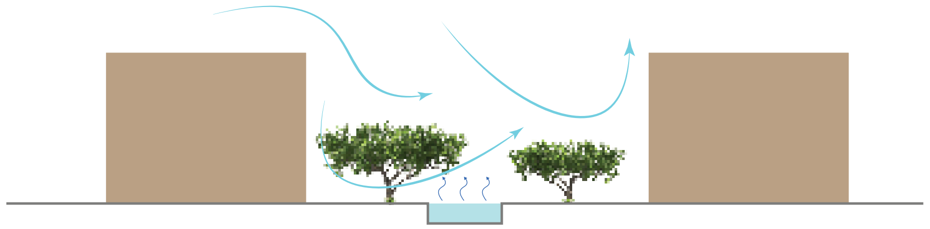
Research results: Urban scale

Vernacular climate adaptation: Cooling

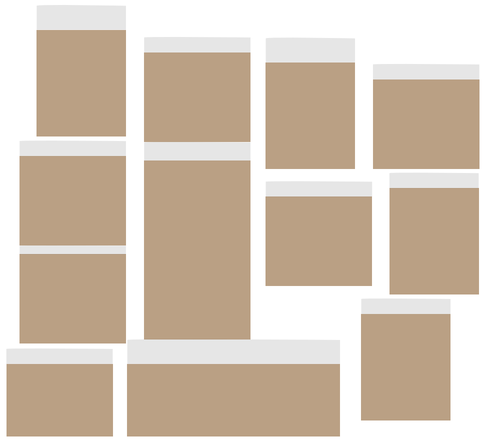


White facades with lime mortar to reflect solar radiation.

Protecting constructions againts solar radiation with vegetation .

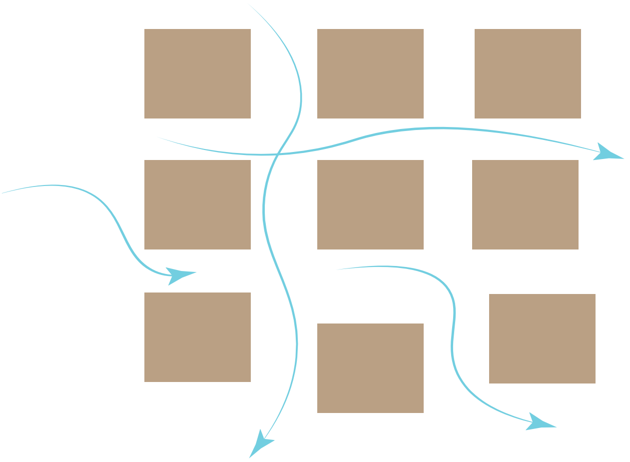


Open courtyards to promote ventilation and water ponds to generate evaporative cooling.

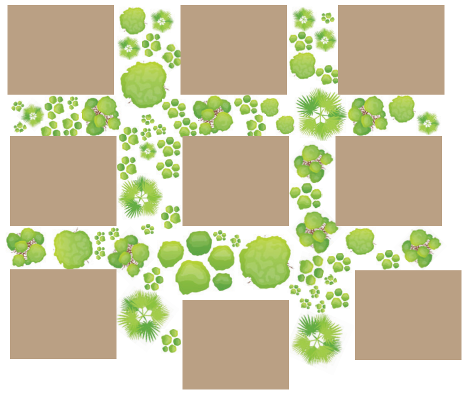


Narrow strees to create shadowed streets.

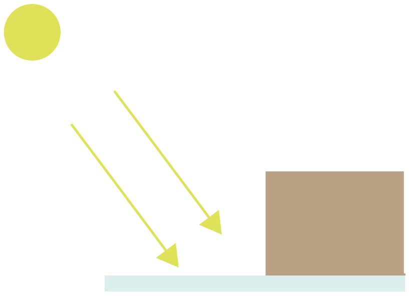
Passive design strategies: Cooling



Generate inbetween spaces for wind circulations.



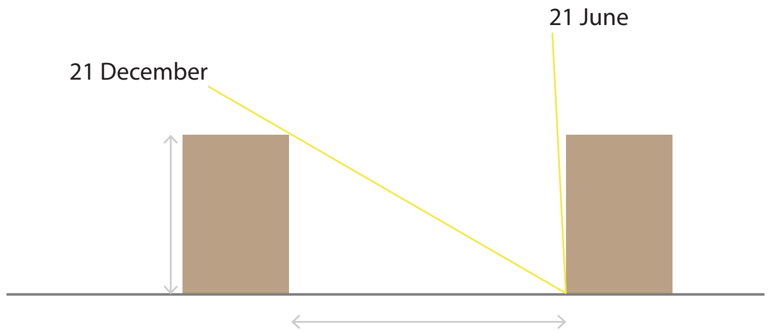
Creating microclimate zones with vegetation.



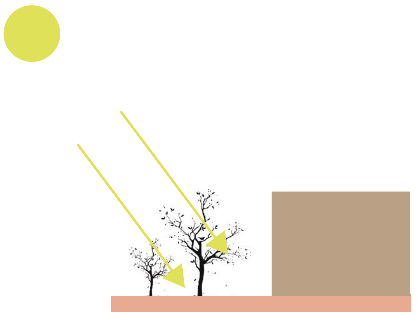
Avoid materializations around buildings with heat absorbing materials.

Generate evaporative cooling with facade systems.

Passive design strategies: Heating



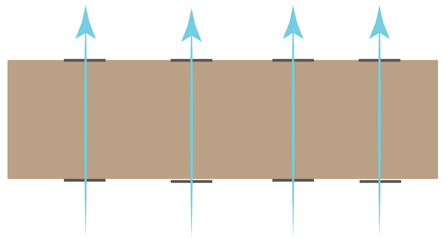
Ensure solar radiation during the winter.



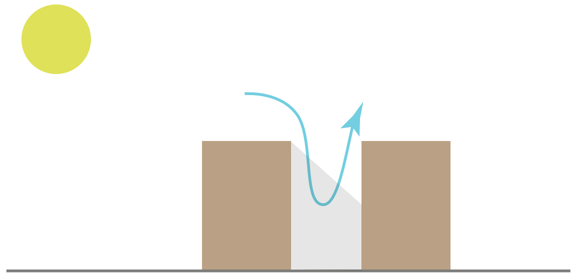
Use of decidious trees to allow solar radiation on buildings during the winter.

Research results: Building scale

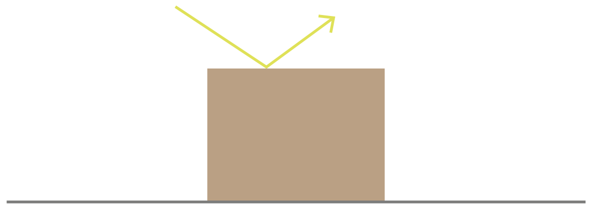
Vernacular climate adaptation: Cooling



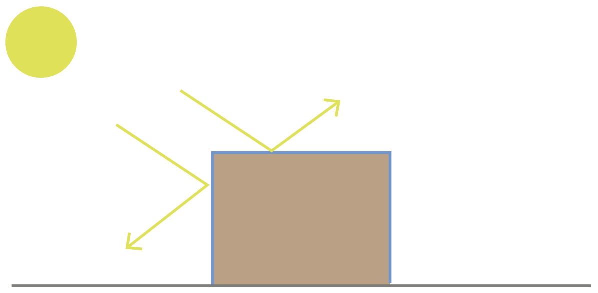
Promote cross ventilation.



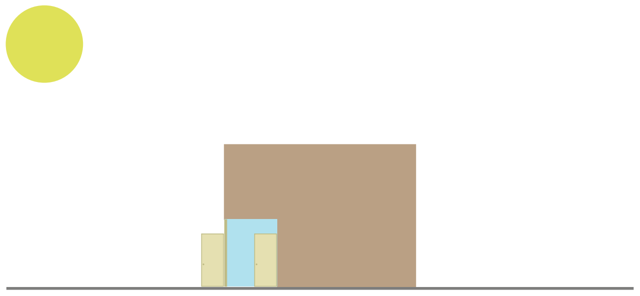
Interior patios for ventilation and entrances of daylight.



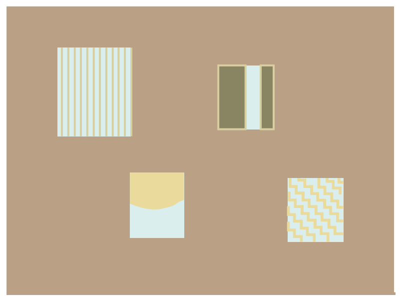
Flat roofs to minimize sun exposure.



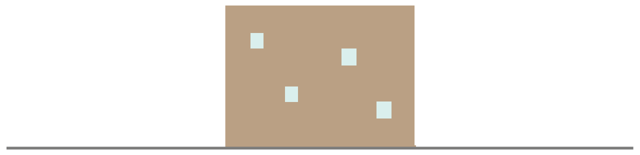
White facades to reflect solar radiation.



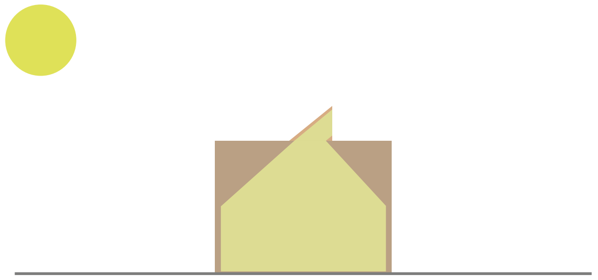
Protected entrance and buffer zones.



Exterior window shuttes from wood and mashrabiyas to create an adaptative crontrol solar radiation.



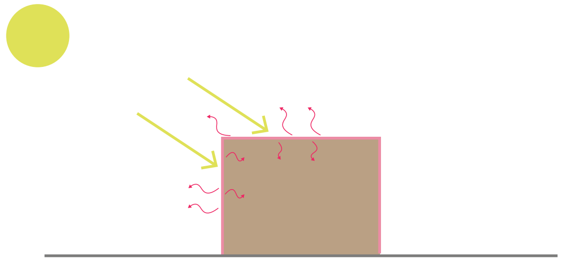
Stereotomic architecture with small window openings.



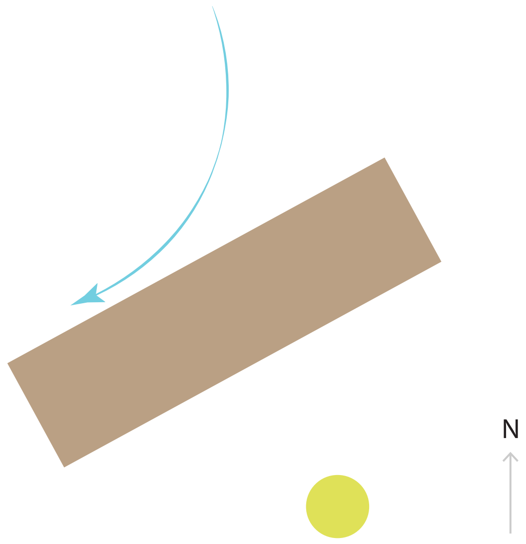
Vertical clearstories to allow the acces of natural daylight while avoiding solar radiation.

Terraces and pergolas to create shaded exterior spaces.

Vernacular climate adaptation: Heating



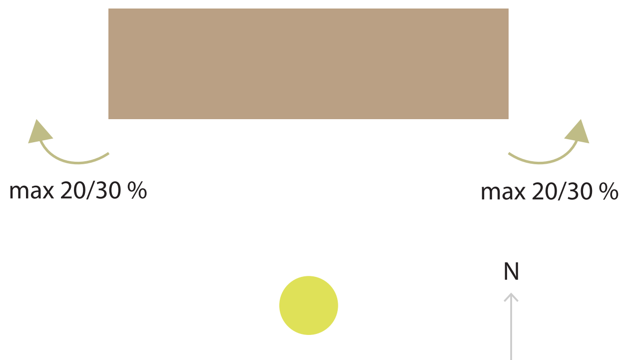
Materialization with stones and earthmortar, creating a thermal mass shell to heat interior spaces.



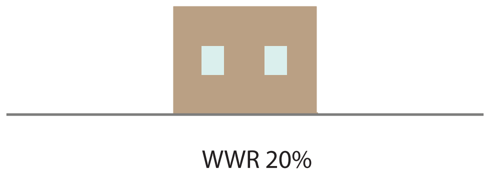
Avoid building orientations towards prevaling winds during winter season.

Research results: Building scale

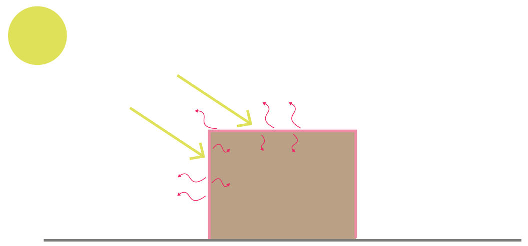
Passive design strategies: Heating



Narrow and long typologies with north south orientation to maximize exposure towards solar radiation

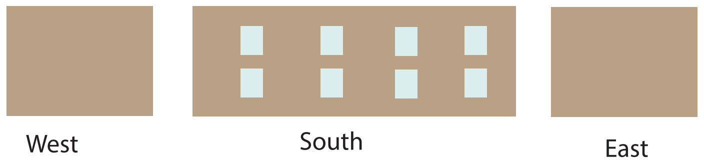


Window wall ration below 20% to reduce heat loss.

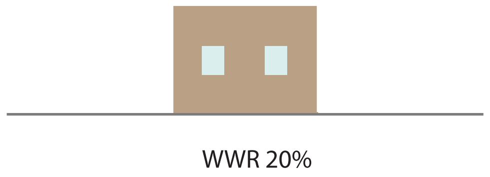


Materialization with stones and earthmortar, creating a thermal mass shell to heat interior spaces.

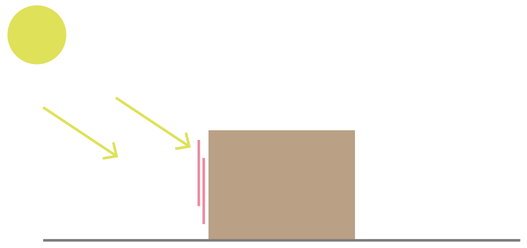
Passive design strategies: Cooling



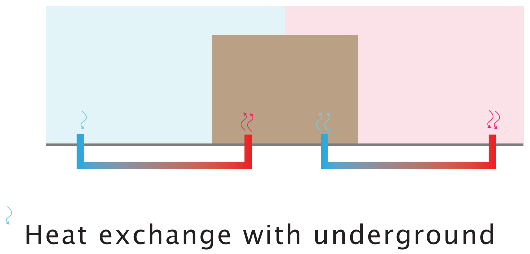
Avoid window openings on east and west facades to minimize uncontrolled heat gain when the sun position is low.



Window wall ration below 20% to avoid heat gain from solar radiation.

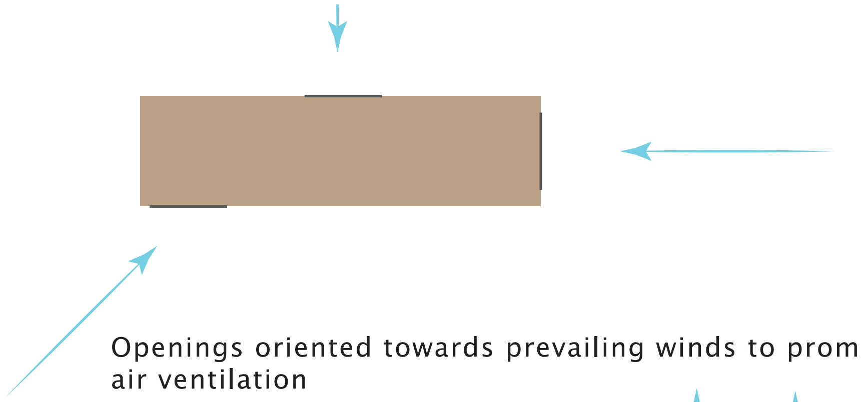


Avoid heat absorbing materials.

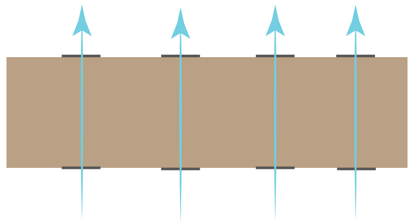


Heat exchange with underground ventilation.

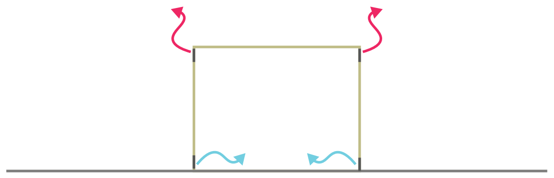
Passive design strategies: Cooling / Ventilation



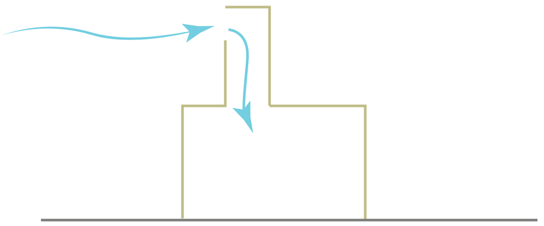
Openings oriented towards prevailing winds to promote air ventilation



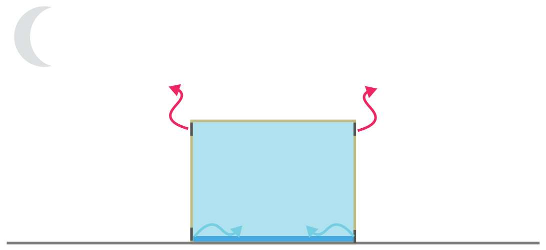
Promote cross ventilation.



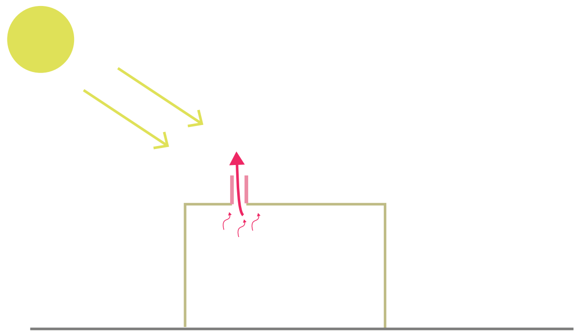
Openings for natural ventilation.



Wind catchers for interior air ventialtion

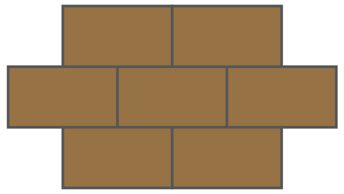


Night flushing: ventilating during night time

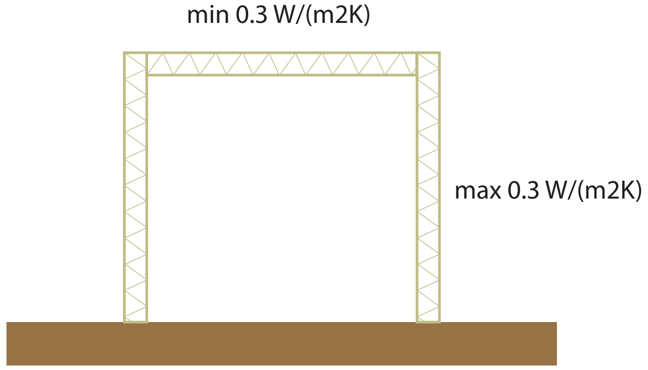


Solar chimneys to exhaust heat in interior spaces.

Research results: Material scale



Materialization with thermal mass materials.



Thermal insulation.