Chapter 23
Tools and Strategies for Microclimatic Analysis of the Built Environment

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Abstract There are several important challenges facing the construction sector and among them, achieving low energy buildings is the first step towards the attainment of "nearly Net Zero Energy Buildings." For this purpose it is necessary that architects and designers use adequate design strategies especially in early stages of the project. Without a correct interpretation of climatic, geographic and location parameters, meeting the goals in a project a posteriori would be very difficult. For decades, climogramas (or bioclimatic charts) and sun charts have been widely used for the microclimatic analysis of the built environment. However, the interpretation of results, the definition of strategies and design-integration is still the most difficult issue. For this purpose, this chapter aims to provide valuable design strategies and architectural solutions for the case of temperate climates. Furthermore, 21 cities in 10 countries will be studied in more detail.

23.1 Introduction

One of the most relevant issues that the construction sector is currently facing is the achievement of "very low energy buildings." For this purpose, it is necessary for architects and designers to use adequate design strategies, especially in the early stages, either for new construction or for refurbishment. Without a correct interpretation of the climatic, geographic, and localization factors, it would be very difficult to meet the energy savings and efficiency targets.

Energy simulation software tools, such as EnergyPlus, ESPr, TRNSYS, etc., are powerful software programs oriented to predict the energy performance of buildings (heating and cooling demand, artificial lighting needs, etc.). Thanks to them,

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it is possible to evaluate and implement some strategies to improve the energy performance of buildings before their construction. However, the use of these tools requires specific knowledge, the modeling process is not immediate, and the modification of parameters (especially those related to geometry) is complex and presents difficulties for their users (Attia et al. 2013). In addition, the amount of information demanded for modeling requires a very advanced stage of design. For all these reasons, these types of software are oriented to final design phases, when the decisions that most affect the energy performance of buildings have been already made.

The main goal of this chapter is to highlight the importance of using highly efficient design strategies in the preliminary design stages. The orientation, amount, and size of windows, the use and design of shading elements, and thermal mass are some of the parameters that most affect the energy performance of buildings. Furthermore, those simple, yet highly efficient solutions, should be decided on during the inception phases (Hausladen et al. 2006).

The strategies should be the result of a detailed analysis of the exterior microclimate, use of the building's interior, and definition of comfort conditions. The higher the comfort, the lower the heating and cooling demand and the lower the energy bills. The goal is not only about energy but also about the well-being of their occupants.

Nowadays, there are some useful and user-friendly information technology programs and methodologies (Lin and Jason Gerber 2014; Asadi et al. 2014; Nembrini et al. 2014) oriented to defining a set of design strategies based on climate data and comfort models, such as ESSAT-EM (Santos et al. 2014), Climate Consultant 5.5, Weather Tool^{TM}:: 2011, and Solar Tool^{TM}:: 2011.

This chapter tries to study, in detail, the case of temperate climates by analyzing the cases of 21 cities in 10 countries with Mediterranean climates. It is important to stress that despite the fact that all these cities are framed by the Mediterranean climate, it is essential to avoid generalities and conduct detailed studies. With this aim, a list of the most relevant strategies for each city is provided at the end of the chapter. Among them, sun shading of windows, natural ventilation, fan-forced ventilation cooling, internal heat gains, and passive solar direct heat gain, etc., are listed and their suitability quantified.

23.2 Köppen-Geiger Climate Classification

Identifying general climate characteristics of a certain place should be one of the first steps in the design of "low energy buildings." The climate and sub-climate classification allows a first approximation in the microclimate study (Olgyay 2006). However, a building in Venice (Italy) should not look like a building in Tel Aviv (Israel). It is evident from a theoretical point of view, but it is still difficult to be integrated in the professional practice of architecture. Low energy building cannot be achieved by adding hi-tech gadgets and sophisticated systems once the building has been completely designed.

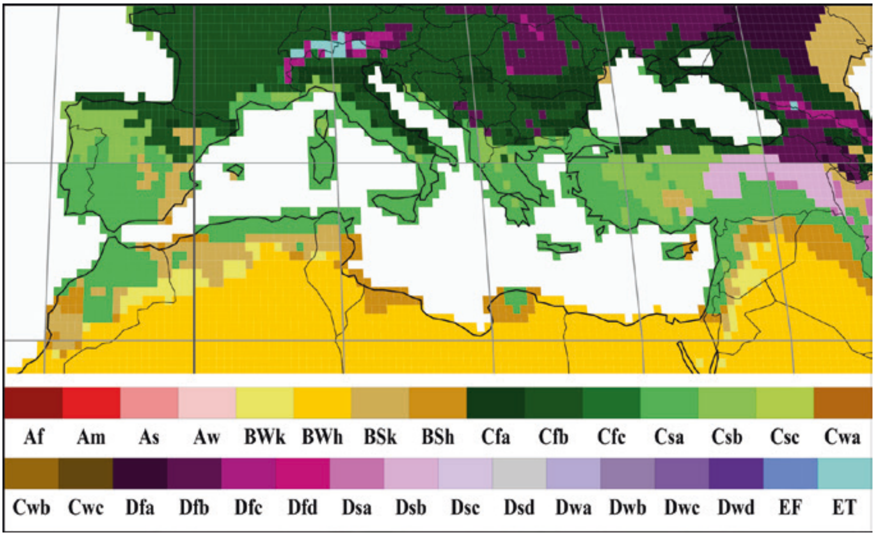

Fig. 23.1 Köppen-Geiger classification for the Mediterranean area. Observed data for 1976–2000 (Rubel 2010)

There are no universal solutions for every building and use—thus, low energy buildings do not follow a determined "style." The design should respond to the microclimatic characteristics of the location and its particular energy potential. For this reason, it would not be correct to define a list of ideal solutions for buildings located in temperate climates; every case is different and should be considered in its complexity and particularity.

Historically, Greeks were the first to develop climate zoning in global terms. Tropical, temperate and polar climates were defined in the early nineteenth century, yet it was not until 1884 when W. Köppen presented his well-known climate classification in which up to five other different climates were identified. The first global climate classification map was published in 1900, and its last review was conducted in 1961 by R. Geiger.

In Kottek et al. (2006) presented an updated and digitized version of the Köppen-Geiger Map. An excerpt for the Mediterranean region is shown in Fig. 23.1. New maps were also published, based on recent climate data recorded by the Climatic Research Unit (CRU) of the University of East Anglia and Global Precipitation Climate Center of the Meteorological Service in Germany. Furthermore, Rubel and Kottek have published maps of future climate scenarios where the impact of global warming is represented.[1] One of the newest visualization options of the digitized maps is that they can be read by Google Earth. Thanks to this, it is possible to identify the climate zone for a specific location by introducing the geographical coordinates.

[1]http://koeppen-geiger.vu-wien.ac.at.

Table 23.1 Köppen-Geiger climate classification for the Mediterranean climate

Climate	Description	Cities
Csa	Warm temperate, summer dry, hot summer	Nicosia (CYP), Barcelona (ESP), Malaga (ESP), Marseille (FRA), Athens (GRC), Thessalonika (GRC), Tel Aviv (ISR), Cagliari (ITA), Lisbon (PRT), Istanbul (TUR), Izmir (TUR)
Csb	Warm temperate, summer dry, warm summer	Nice (FRA), Genoa (ITA), Naples (ITA), Porto (PRT), Ankara (TUR)
Cfa	Warm temperate, fully humid, hot summer	Venice (ITA), Belgrade (SRB)
Cfb	Warm temperate, fully humid, warm summer	Gerona (ESP), Ljubljana (SVN)
BSk	Arid, steppe, cold arid	Alicante (ESP)

The Mediterranean climate is characterized as having a temperate climate, but it is necessary to highlight the importance of its sub-climates. There are main five sub-climates: Csa, Csb, Cfa, Cfb, BSk (Table 23.1). Barcelona (Spain), for example, is characterized by a warm, temperate climate with dry, hot summers that correspond to Csa. On the other hand, Ljubljana (Slovenia) is characterized by a warm, temperate, and very humid climate with warm summers, which corresponds to Cfb. Buildings located in both cities should, therefore, respond differently to their microclimatic conditions.

23.3 Orientation Analysis

Apart from exterior climate factors, one of the parameters that most affects the energy performance of a building is its "orientation." The analysis of the orientation allows minimizing overheating problems and maximizing energy gains in under-heated periods. Depending on the climate and localization characteristics of a given city, shading needs and solar exposure vary significantly. Furthermore, it is important to remember that incident radiation is directly related to the geographical emplacement and that it varies during the year.

The Weather Tool™ 2011 software calculates the incident radiation on a vertical surface by reading climate data[2] and proposes a best orientation. Best orientation for a vertical surface is when there is the most solar radiation during the underheated period and the least during the overheated period. Figure 23.2 shows the calculation for Istanbul and Athens; the red line indicates average daily incident radiation in summer (July, August, September), and the blue line indicates average daily incident radiation in winter (January, February, March)[3].

[2]The results have been obtained with Weather Tool™ 2011 (observed data for 1961–1990 obtained from Meteornorm 7).

[3]Note that the values in each diagram vary. The scale of values is different in Athens and in Istanbul.

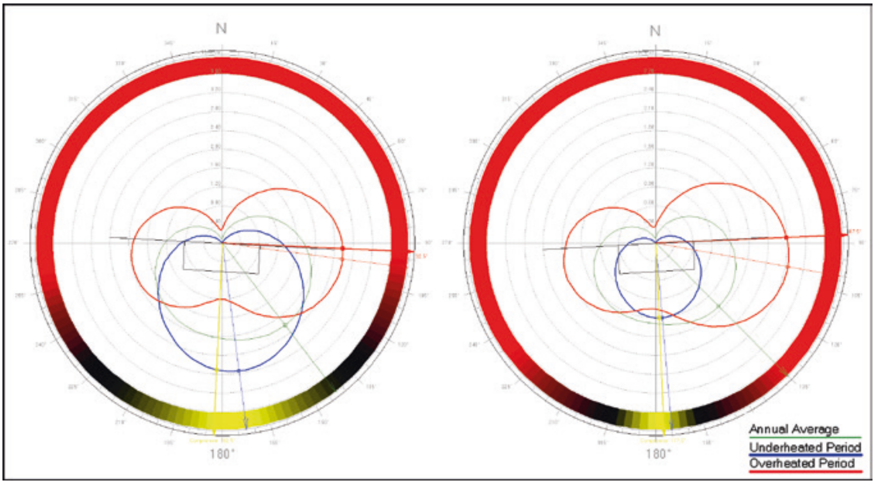

Fig. 23.2 Istanbul's and Athen's optimum orientation calculation

The graphics represent incident radiation values displayed in concentric circles. In Athens, the daily average radiation is 2.69 kWh/m^2 in summer and 1.19 kWh/m^2 in winter. In Istanbul, the daily average radiation is 1.19 kWh/m^2 in summer and 1.08 kWh/m^2 in winter. Therefore in Athens, sun shading is an important passive strategy. In addition, window openings should be minimized in overexposed orientation, e.g., east and west.

In Table 23.2, a summary of the calculation of incident radiation for 21 cities with Mediterranean climate is shown. It shows that incident radiation in the summer varies from 0.81 kWh/m^2 in Nicosia to 1.76 kWh/m^2 in Alicante. In the winter, the values vary from 1.19 kWh/m^2 in Istanbul to 2.89 kWh/m^2 in Gerona. Therefore, the shading need and potential of direct solar heat gain vary significantly within the Mediterranean cities.

Furthermore, the table shows the calculated best orientation for the 21 study cases. In general, the best orientation is towards the south, with light rotation to the east or west (±10º).

23.4 Passive Design Strategies for Mediterranean Climate

Climograms are psychometric charts (with a double entry of values: temperature and humidity) that help to define a number of bioclimatic strategies to counteract discomfort conditions. Climograms are tools to be used in the preliminary design stages, i.e., when the orientation, size, and position of windows, materials, and volume are not yet determined.

Table 23.2 Best orientations for each city

City	Best orientation[a]	Radiation in winter[b]	Radiation in summer[b]
CYP_Nicosia	180.0	2.25	0.81
ESP_Alicante	195.0	2.89	1.76
ESP_Barcelona	186.0	2.65	1.50
ESP_Gerona	182.5	2.89	1.16
ESP_Malaga	190.5	2.79	1.40
FRA_Marseille	182.5	2.47	1.39
FRA_Nice	187.5	2.35	1.74
GRC_Athens	177.5	2.69	1.19
GRC_Thessalonika	180.0	1.99	1.17
ISR_Tel Aviv	192.0	2.35	1.40
ITA_Cagliari	192.5	2.27	1.35
ITA_Genoa	187.5	1.90	1.45
ITA_Naples	190.0	2.06	1.56
ITA_Venice	177.5	1.65	1.19
PRT_Lisbon	187.5	2.35	1.58
PRT_Porto	187.5	2.09	1.59
SRB_Belgrade	180.0	1.63	1.08
SVN_Ljubljana	175.0	1.50	1.00
TUR_Ankara	175.0	1.42	0.93
TUR_Istanbul	177.5	1.19	1.08
TUR_Izmir	182.5	2.38	1.33

Daily average radiation on a vertical surface for the summer and winter periods
[a]Best orientation for a vertical surface when there is the most solar radiation during the underheated period and the least during the overheated period. Weather Tool™ 2011. Clockwise from north
[b]Daily average radiation on a vertical surface (kWh/m^2)

Since B. Givoni and V. Olgyay presented their well-known climograms, some computer applications have been developed. Among them, Climate Consultant, developed by the University of California, Los Angeles, is perhaps one of the most powerful. The software is free for downloading: http://www.energy-design-tools.aud.ucla.edu. One of the greatest advantages of this application is that it uses EPW climate data (Energy Plus Weather Data), and it allows selecting various comfort models (among them ASHRAE 55-2004 PMV,[4] where clothing and activity levels can be defined).

In the Climate Consultant Climogram, a comfort area is plotted in the middle of the graph according to the selected comfort model. Every line in the climogram

[4]ASHRAE Handbook of Fundamentals Comfort Model up through 2005. For people dressed in normal winter clothes, effective temperatures of 20–23.3 °C measured at 50 % relative humidity, which means the temperatures decrease slightly as humidity rises. The upper humidity limit is 17.8 °C) Wet Bulb and a lower Dew Point of 2.2 °C. If people are dressed in light-weight summer clothes, then this comfort zone shifts 2.8 °C warmer.

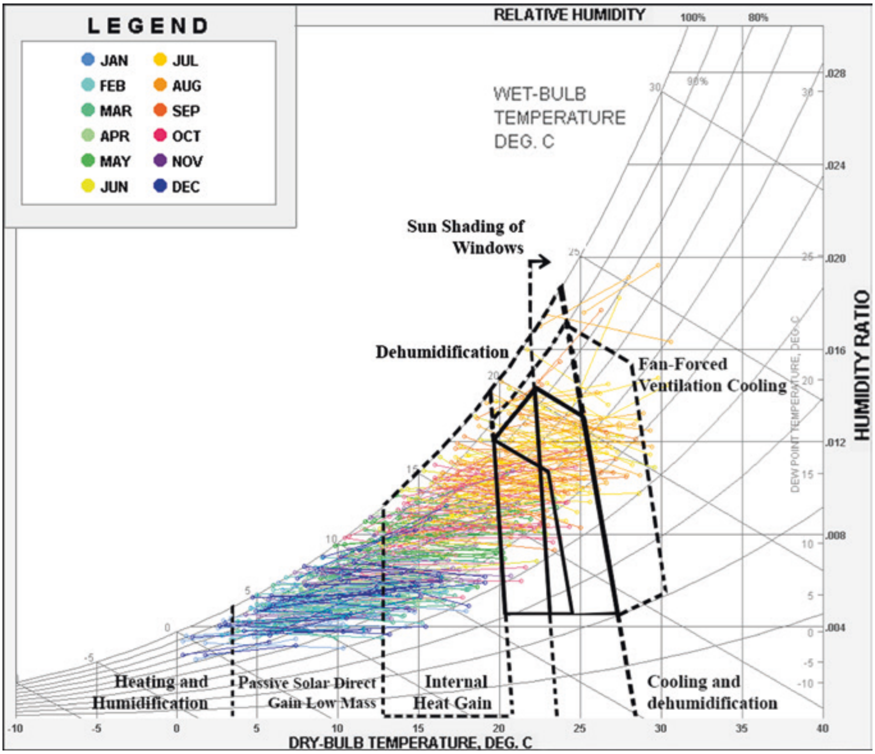

Fig. 23.3 Barcelona's Psychometric Chart. The diagram shows monthly maximum and minimum average values (observed data for 1961–1990 obtained from Meteornorm 7 data)

shows the daily temperature difference, i.e., minimum and maximum hourly values for each day, with a line drawn between them (Fig. 23.3). Climate Consultant uses an algorithm to propose design strategies to counteract discomfort by eliminating the greatest number of heating and cooling hours.

23.5 Passive Design Strategies for Mediterranean Climate

- **Sun shading**

Sun shading is particularly effective in outdoor spaces to control radiant temperatures, and on windows to help prevent indoor dry bulb temperatures from climbing above ambient temperatures.

- **Direct solar gain**

This strategy is very much a function of the building design, but if the building has the right amount of sun-facing glass, then passive solar heating can raise internal temperatures.

- **Internal heat gain**

This strategy represents a rough estimate of the amount of heat that is added to a building by internal loads such as lights, people, and equipment.

- **High thermal mass**

In summer, in hot dry climates, using high thermal mass on the interior is a good cooling design strategy. In winter there is also some positive warming effect of high mass buildings, provided that daytime outdoor temperatures get into the comfort zone.

- **Thermal mass with night flushing**

In summer, in hot dry climates using high thermal mass on the interior is a good cooling design strategy, especially when either natural ventilation or a whole-house fan is used to bring in a lot of cool nighttime air, and then the building is closed up during the heat of the day.

- **Two-stage evaporative cooling**

Evaporative cooling takes place when water is changed from liquid water to gas (taking on the latent heat of fusion); thus the air becomes cooler but more humid. The first stage uses evaporation to cool the outside of a heat exchanger, through which incoming air is drawn into the second stage where it is cooled by direct evaporation.

- **Fan-forced ventilation cooling**

Fan-forced air motion is one of the few ways to produce a cooling effect on the human body. It does this by increasing the rate of perspiration evaporation and giving the psychological sense of cooling (note that ventilation does not actually reduce the dry bulb temperature).

23.6 Climograms—Case Study of Barcelona

In this section, the case of Barcelona is studied in detail in order to show how to define passive design strategies in the early design stages.

According to the Köppen-Geiger classification, Barcelona presents a warm temperate climate with hot, dry summers (Csa, observed period: 1976–2000). In summer, the temperature frequently reaches 30 °C at noon and goes down to 17 °C at night. In winter, the temperature is quite mild and reaches around 17–18 °C at noon and 10 °C at night. For example, shading elements should be correctly designed to avoid overheating problems in summer, but should also allow direct solar gains in colder months. A set of the best strategies for the different seasons is described in Fig. 23.3.

- **Warm months**

During June, July, August, and September, it is common to reach comfort conditions in 50 % of the time (1308 h) without the help of any strategy. Due to this, the efforts should be focused on not disturbing this comfort and solving the discomfort during the rest of the day. At noon, it is common to exceed the upper temperature limit and reach 30 °C. It must be stressed that the thermal lag between diurnal and nocturnal temperature is not very pronounced. In July, for instance, the average minimum temperature is 17 and 29.5 °C maximum. Because of this, in order to reduce overheating problems due to direct solar gains, the building should be correctly oriented, and shading elements should be strategically located in the façade. The use of fan-forced ventilation is also an adequate strategy to improve comfort; it is possible to achieve comfort in an additional 550 h. The use of conventional air conditioning systems could be reduced to occasional moments or unusually hot days (only 99 h). Finally, in order to reduce discomfort at night, the use of internal heat gain is an optimal solution; thanks to it, an extra 869 h in comfort conditions are achievable.

- **Cold months**

In January, February, March, April, November, and December, it is common not to reach comfort conditions either during the day or the night (only 23 h). The average daily temperature fluctuates around 10 °C. Therefore, the building and window openings should be oriented facing the south in order to optimize direct solar gains. Thanks to this strategy, comfort is achievable in an additional 1062 h. The use of internal heat gains is another good strategy that adds an extra 1228 h in comfort. Thanks to these strategies it is possible to postpone and/or reduce the functioning of conventional heating systems.

- **Intermediate months**

In May and June it is common to reach comfort conditions at noon most of the time. For the rest of the day, the use of internal heat gains and solar direct gain add 877 h and 369 h of comfort, and would be the most reasonable passive strategies.

- **Barcelona's "Sun Chart"**

As mentioned, sun control is one of the most important and simplest strategies for improving comfort in Barcelona. The Sun Chart for Barcelona (June 21–December 21) is shown in Fig. 23.4. In the chart, the temperature for every 15-min interval is represented. Red dots indicate temperatures above 27 °C, yellow dots indicate comfort conditions (when sun shading is provided), and blue dots represent temperatures below 21 °C. The chart shows that comfort conditions are achievable with the help of shading devices in 984 h and that in 387 h, overheating problems can occur. Among all the orientations, the western orientation is the most penalized one; thus, in June, July and August—apart from exterior high temperatures—this orientation receives direct solar radiation. Consequently, the size and number of windows in a west-facing façade should be minimized, and vertical shading elements or awnings disposed of in order to avoid overheating problems.

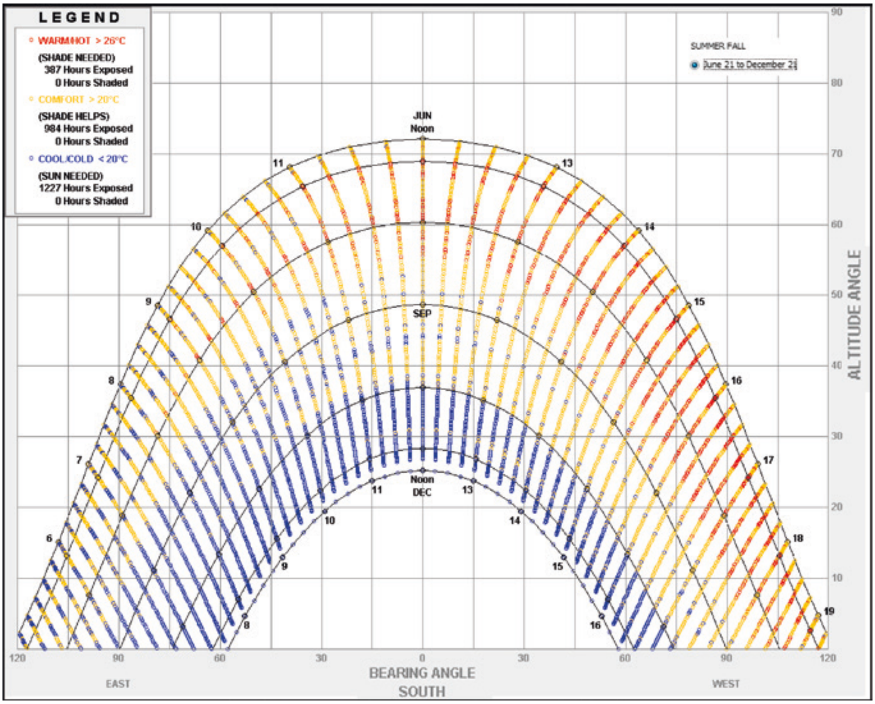

Fig. 23.4 Barcelona's Sun Chart Diagram. Comfort analysis for every 15 min during the summer and fall months (June 21–December 21). The *yellow dots* indicate comfort conditions, *blue dots* indicate under-heated conditions and *red dots* overheated

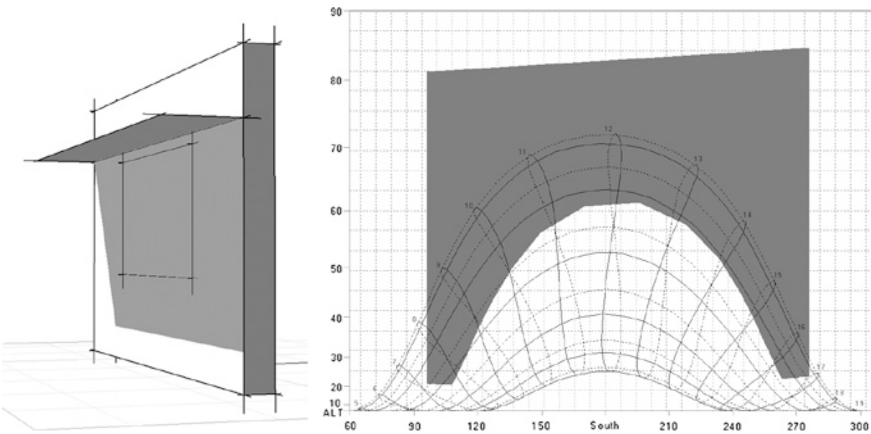

Fig. 23.5 Barcelona's Sun Chart Diagram and shading element optimization

Once the shading need is determined, the software Solar Tool^{TM}:: 2011 allows designing, evaluating, and optimizing the dimensions of a given shading device that best fits the local climate and orientation. Figure 23.5 shows the results of the analysis of a window (1.20 m high and 2.40 m wide) with the best orientation for Barcelona (+186º). The solution is quite simple: with a 0.70 m horizontal element, the window will be protected in the summer and will receive solar radiation during the coldest months. Note that the horizontal element should be wider than the window, as shown in the chart.

23.7 Summary of Design Strategies for Mediterranean Cities

A list of the best strategies for Mediterranean Climate is presented below. Each strategy has been evaluated and its suitability calculated using Climate Consultant 5.5 software. The results are in order, by season and city. The aim of this study is to provide general design ideas to architects and engineers who plan to construct low energy buildings in the Mediterranean climate.

- **Passive strategies for the summer period**

The following chart (Fig. 23.6) shows the suitability of various passive strategies for the hottest months in 21 study-cities (from July 1 to September 30). It must be emphasized that in most of the cases, comfort conditions are achievable without

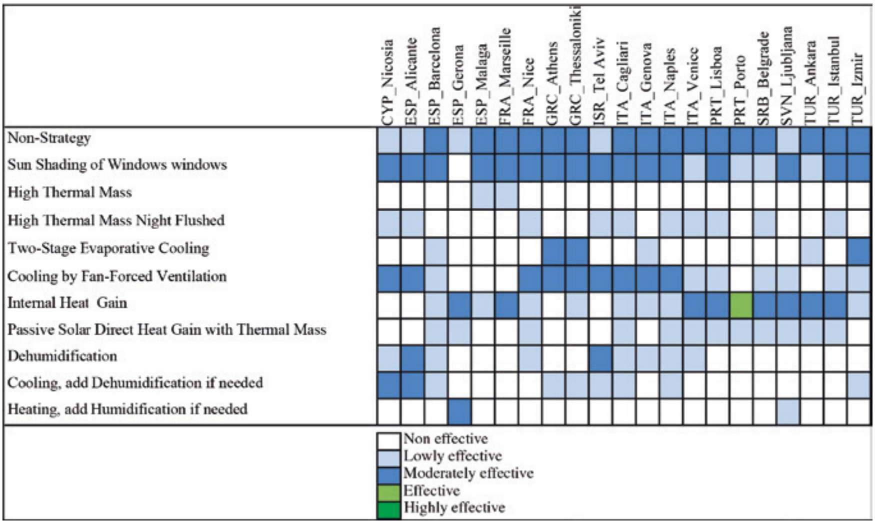

Fig. 23.6 Passive strategies for the July 1–September 30 summer period

the use of any strategy: in 1055 h in Barcelona, 1030 h in Lisbon, and 1002 h in Istanbul. Therefore, a correct design and orientation are key factors for reducing the energy demand. Note that the use of air conditioning systems is not necessary all the time. In addition, it is correct to think that in many cases an incorrect design is the main cause for cooling needs and use of air conditioning in a Mediterranean climate. By reducing the size and number of windows in eastern and western façades, cooling loads could be considerably minimized. When sun shading elements are provided, comfort conditions could be achievable in additional hours: 824 h in Athens, 850 in Tel Aviv and 815 in Nicosia.

Fan-forced ventilation is another good option for cities such as Alicante, Tel Aviv, and Naples, where comfort conditions are achievable in an additional 929 h, 1011 h, and 743 h, respectively. In some cases, such as in Porto and Belgrade using internal heat gains is recommended where comfort is achievable in an extra 1132 and 906 h, respectively.

- **Passive strategies for the spring period**

During the spring (Fig. 23.7), the use of internal heat gains is one of the most effective strategies, particularly in Nice, Genoa, Porto, and Lisbon, with an additional 1261, 1218, 1232, and 1261 h of comfort respectively. In most cases, comfort conditions are achievable without the application of a strategy. The solar direct heat gains accompanied by thermal mass of the building is another good solution, and comfort is achievable in an extra 615 h in Alicante, 537 in Tel Aviv, and 468 in Izmir. The use of conventional heating systems is unavoidable with low nighttime temperatures in all the cities. On the other hand, in some other cities—such as Nicosia, Athens, and Cagliari—sun shading starts to be necessary because the temperature starts to exceed 21 °C.

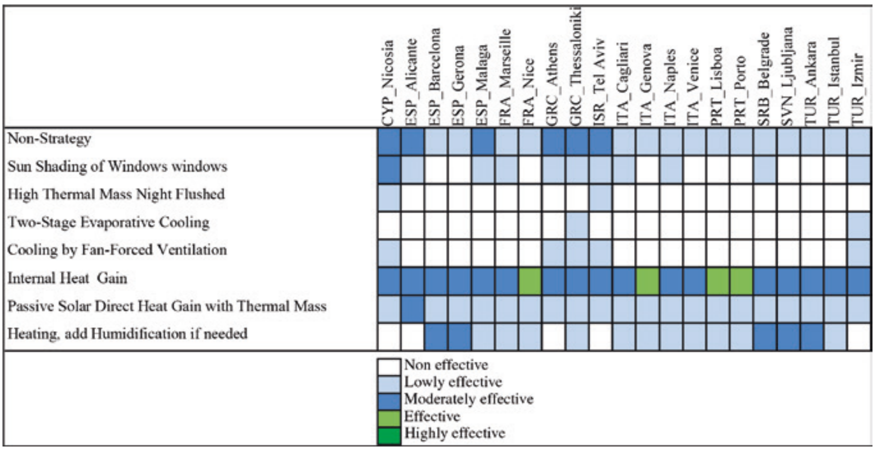

Fig. 23.7 Passive strategies for the April 1–June 30 spring period

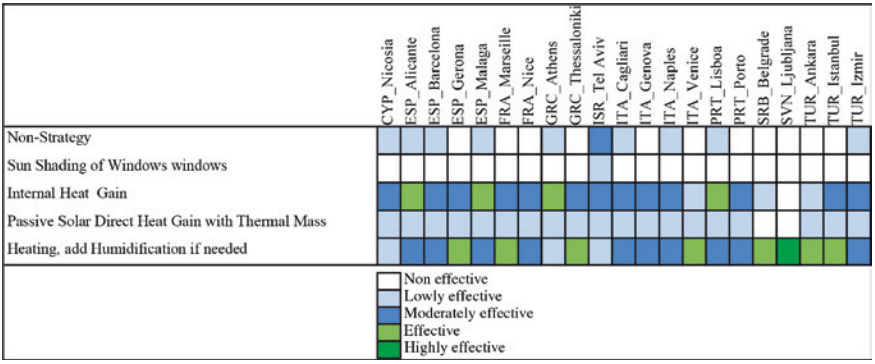

Fig. 23.8 Passive strategies for the October 1st-December 31st autumn period

- **Passive strategies for the autumn**

During the autumn (see Fig. 23.8), the use of internal heat gains is one of the most effective strategies—particularly in Athens, Malaga, Alicante, and Lisbon, where comfort is achievable in additional 1198, 1156, 1112 and 1223 h, respectively. In most of the cases, comfort conditions are achievable with the use of no strategy. The use of solar direct heat gains, accompanied by thermal mass in the building, is another good solution for Gerona (426 h) and Marseille (358 h). The use of conventional heating systems (1908 h) is unavoidable due to low nighttime temperatures in some cities, such as Ljubljana.

23.8 Passive Strategies for Winter

In winter (Fig. 23.9), the use of conventional heating systems is necessary because of low temperatures. At noon, internal heat gains and direct solar gains will help reduce the use of them in cities such as Tel Aviv (an extra 1128 and 273 h, respectively), Cagliari (an extra 624 and 150 h, respectively) and Izmir (an extra 568 and 460 h, respectively).

23.9 Conclusion

There are several important challenges facing the construction sector; among them are achieving low energy buildings, which is the first step towards achieving nearly Net Zero Energy Buildings. For this purpose it is necessary that architects and designers use adequate design strategies, especially in their early design stages, in order to facilitate their decision-making.

To help achieve the main goal of this book, a detailed analysis of 21 cities in 10 countries with Mediterranean climate was conducted. The results show that an

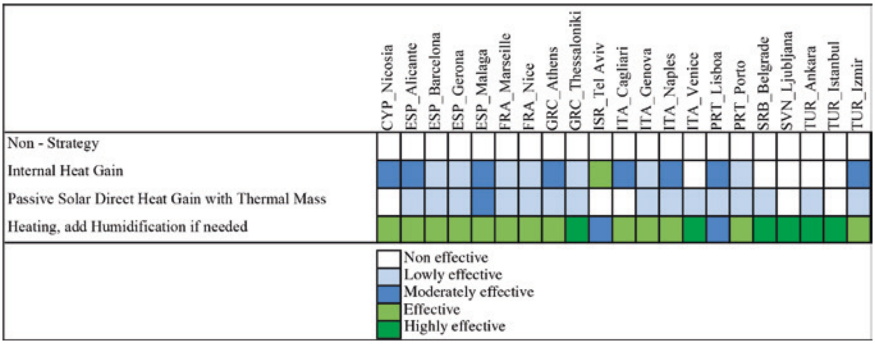

Fig. 23.9 Passive strategies for the January 1–March 30 winter period

incorrect design is, in most cases, the main cause of an unnecessary need for air conditioning in a Mediterranean climate. By minimizing the number and size of windows in eastern and western façades, most overheating problems can be avoided. When a building is correctly oriented (facing south), it is easier to design shading elements that provide shade when necessary and permit solar exposure in underheated months. In any case, it is necessary to conduct a detailed study for each city and use of the building. On the other hand, fan-forced ventilation is another good solution.

For under-heated months, the use of internal heat gains is a good solution to minimize and postpone the use of conventional heating systems.

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