Study and analysis of the climate in Greek cities with the aid of climatic data: Climate analysis as a design tool in undergraduate students' projects

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Study and analysis of the climate in Greek cities with the aid of climatic data: Climate analysis as a design tool in undergraduate students' projects

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Abstract. The analysis of the climate and the microclimatic conditions of a place is directly linked with the principles of bioclimatic architecture and thus provides an insight for the first stages of the design or redesign of buildings. The aim of this article is to provide a methodology for the first stages of building design which as far as bioclimatic and sustainable parameters are concerned, involves the analysis and the comprehension of the climate. Climatic analysis can be done with a combination of different sources, data and software, with the primary aim being the identification of the basic climatic parameters and their effect on comfort and energy consumption. After that, and with the use of psychrometric diagrams, climatic data can be directly linked to bioclimatic design strategies that can be introduced from the very beginning of a design project. The proposed methodology has been developed within the framework of undergraduate architectural technology courses and could be applied not only to undergraduate and postgraduate students' design projects, but also to professional work, such as architectural competitions around the world and actual projects.

1. Introduction

Climate constitutes an integral part of nature and the environment and is the first and most important step in the bioclimatic design of buildings. It comprises of separate scales, the macroclimate, the mesoclimate and the microclimate, each one of which has different characteristics and is affected by a variety of elements. The macrolimate scale provides information on the general climatic characteristics of a given area, whereas the mesoclimate scale is useful for smaller geographical areas, moving on to the microclimate scale that involves their direct natural and built surroundings. [1]

The basic climatic parameters that interact with buildings and open spaces, affecting thermal and visual comfort conditions, as well as the consumption of conventional energy for heating, cooling and lighting are dry bulb air temperature, relative humidity, direct and diffuse solar radiation, wind, as well as cloudiness and precipitation. [1] The comprehension and deciphering of these elements and their link to the theory of bioclimatic architecture and passive heating and cooling strategies can produce a broad base of knowledge that can form the background to the design of sustainable buildings and the redesign and refurbishment of existing ones. The methodology that is presented in this article has been developed within the framework of one compulsory and one elective undergraduate building technology courses with emphasis on bioclimatic and sustainable design. It has also been applied, at a smaller extent, to undergraduate architectural diploma projects.

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Climatic analysis can provide a basis towards the selection of the bioclimatic strategies that can be utilized as a critical tool to the design and redesign of buildings. It should be assessed as an integral part of the analysis stage, along with the identification of the existing geometry and elements of the built and natural environment surrounding the project plot. Within the framework of the increased environmental awareness, in combination with the European Directives (EPBD Directive 2002/91/EC [2], EPBD Recast, Directive 2002/91/EC [3], Directive 2012/27/EU [4] and Directive 2018/844/EU [5]) and the national legislation [6] on the energy performance and efficiency of buildings, the need for comprehension of the basic climatic characteristics is of utmost importance.

The link between climate and bioclimatic design strategies is usually provided by psychrometric or bioclimatic diagrams and charts. Psychrometric charts (Figure 1) represent various properties of moist air, namely dry bulb temperature and relative humidity, as well as wet bulb temperature, moisture content, dew point temperature, etc. in a graphical way. [1] Bioclimatic charts (Figure 3) are based on standard psychrometric charts, on which combinations of dry bulb temperature and relative humidity values for a given location are plotted. [1] The primary aim is to see how many of them fall within the "comfort zone", which *"is defined as the range of climatic conditions within which the majority of persons would not feel thermal discomfort, either heat or cold"* [7]. Through the years, the bioclimatic chart has been frequently used to specify bioclimatic strategies that will help broaden the comfort zone in buildings without the use of active, mechanical (HVAC) systems. [7]

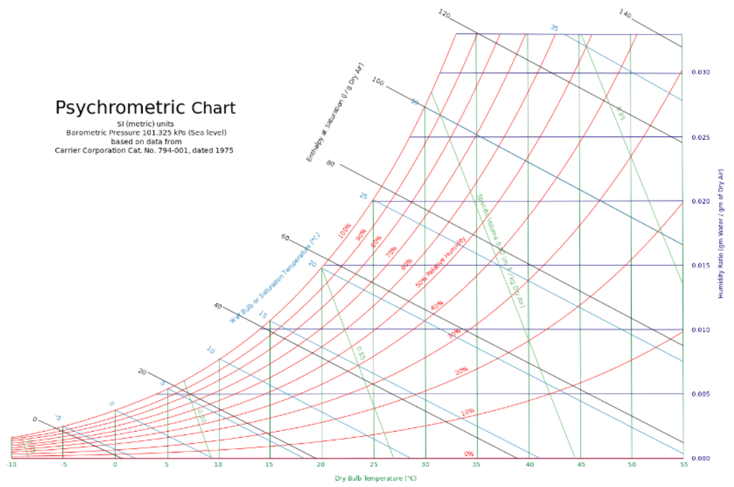

Figure 1. Psychrometric chart. [8]

The bioclimatic design strategies that are applied to the bioclimatic chart involve:

- the winter, namely the heating period, e.g. passive solar heating systems (direct and indirect solar gain)
- the summer, namely the cooling period, e.g. passive cooling systems (shading, natural ventilation, direct and indirect evaporative cooling, etc.)
- the whole year

Depending on the climate of a certain location, the cloud of hourly data points representing dry bulb and relative humidity may fall within a certain area / strategy or not. This way, the applicable bioclimatic design strategies for the climate under consideration can be pointed out. Their actual application or not to the design or redesign of a certain building mainly depends on architectural design parameters and the elements of the surrounding environment. Nevertheless, the specific characteristics of the plot, namely the topography, the location within or outside the urban fabric, the direct built and natural environment, etc., which affect microclimatic and insolation conditions, greatly affect their potential in being used as design tools. For example, a plot situated on a steep north-facing slope will receive little or no desirable solar radiation for passive heating during the winter, so inevitably this proposed design strategy will be omitted. The same applies to an urban plot, where additionally overshadowing for the summer period maybe provided by adjacent buildings, depending on their geometry and orientation.

2. Climate analysis

The proposed methodology aims at acquainting the students with the process of, first of all, searching for, finding and after that, collecting and assessing climatic data. For years, climatic data mean values were given in tabular form, which in a plain form are not readily understood and evaluated. For Greece, tables of the main climatic data are provided in the Technical Note TOTEE 20701-3 [9] for a large number of cities and towns. Nevertheless, mean values only give an indicative idea on climatic conditions. Today, data collection can be achieved through different internet sources, depending on the location of the project. (Table 1)

Table 1. Climatic data collection and analysis from different sources.

Steps	Sources / Retrieval	Resolution
1_Online data	National Weather or Meteorological Services and other websites	Mean monthly values
2_Data files	EnergyPlus weather [10] Climate.OneBuilding.org [11]	Hourly values
3_Data analysis	Climate Consultant [12] AndrewMarsh.com [13]	Monthly, daily and hourly values
4_Bioclimatic strategies	Psychrometric charts from Climate Consultant [12] AndrewMarsh.com [14]	Monthly, daily and hourly values

2.1. Online data

Online data usually involves mean values (mean minimum, mean and mean maximum) of the basic climate data. Data can be retrieved online from various sites, both national and international, starting from the country's national meteorological service (HNMS – Hellenic National Meteorological Service) [15] or other national agencies (NOA – National Observatory of Athens [16]), where the data is available in tables, diagrams or a combination of both. Other, relevant international websites such as [17, 18, 19], etc. offer a variety of representations, such as formatted tables, combined diagrams, and other custom formats. (Figure 2)

This first step is very important, as the students get the opportunity to fully comprehend the difference between weather and climate, as stated by famous quotes, such as "The climate is what you expect; The weather is what you get" by Robert A. Henlein (1973) and "Climate lasts all the time, and weather only a few days" by Mark Twain (1887). [20] They also comprehend that even if weather forecast data is usually available for multiple sites, climatic data is not. Consequently, when an area within a city or another location (town or village) do not have a weather station, data from nearby cities (stations) have to be selected. Nevertheless, there are sites, which offer both recorded and modelled climatic data. The latter "*are based on 30 years of hourly weather model simulations and (...) give good indications of typical climate patterns and expected conditions (temperature, precipitation, sunshine and wind). The simulated weather data have a spatial resolution of approximately 30 km and may not reproduce all local weather effects, such as thunderstorms, local winds, or tornadoes, and local differences as they occur in urban, mountainous, or coastal areas".* [21]

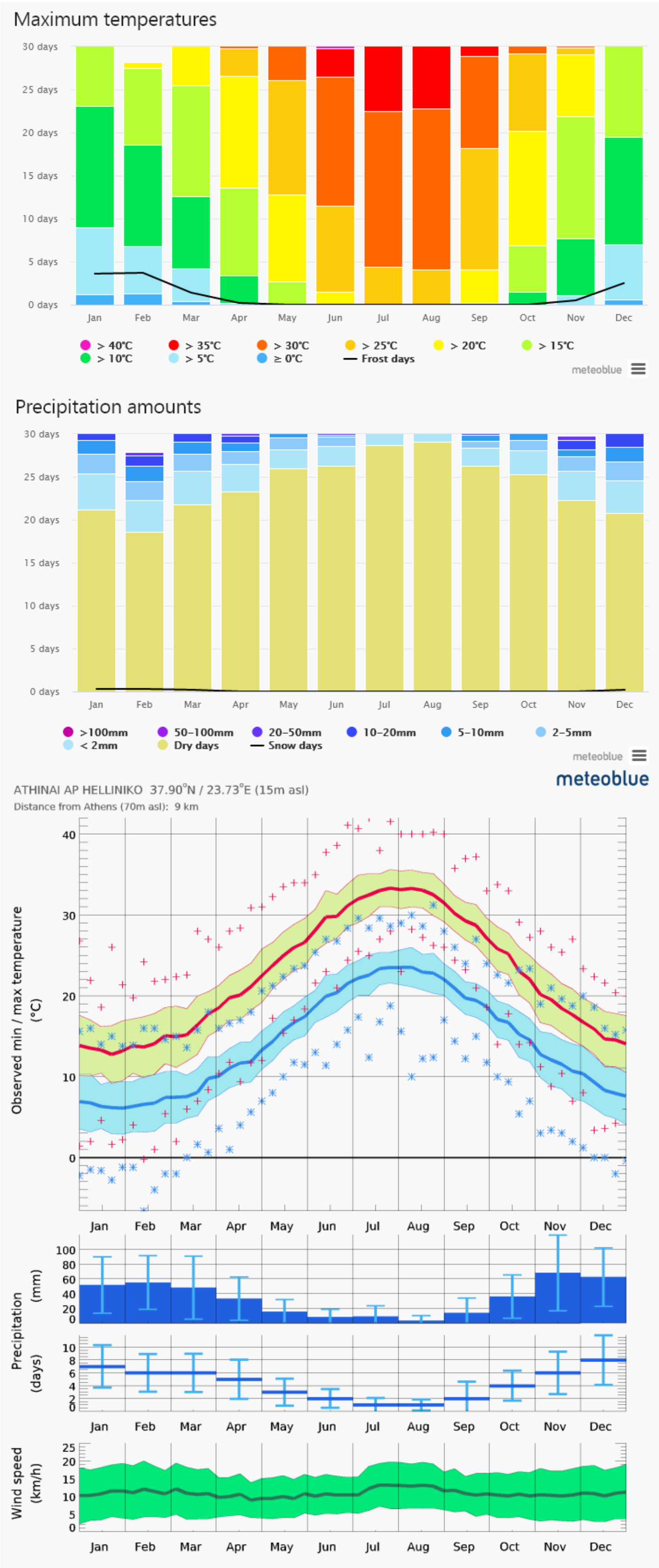

Figure 2. Graphical representation of observed (recorded) and modelled climatic data for Athens, Greece provided by [17].

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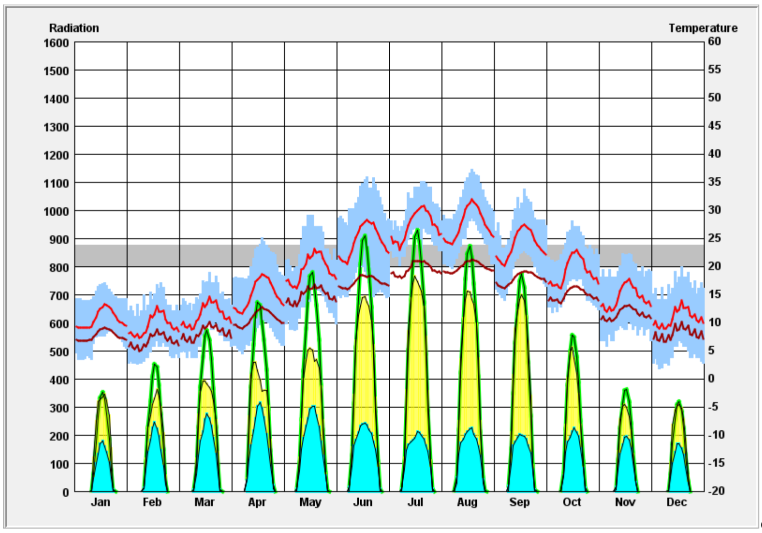
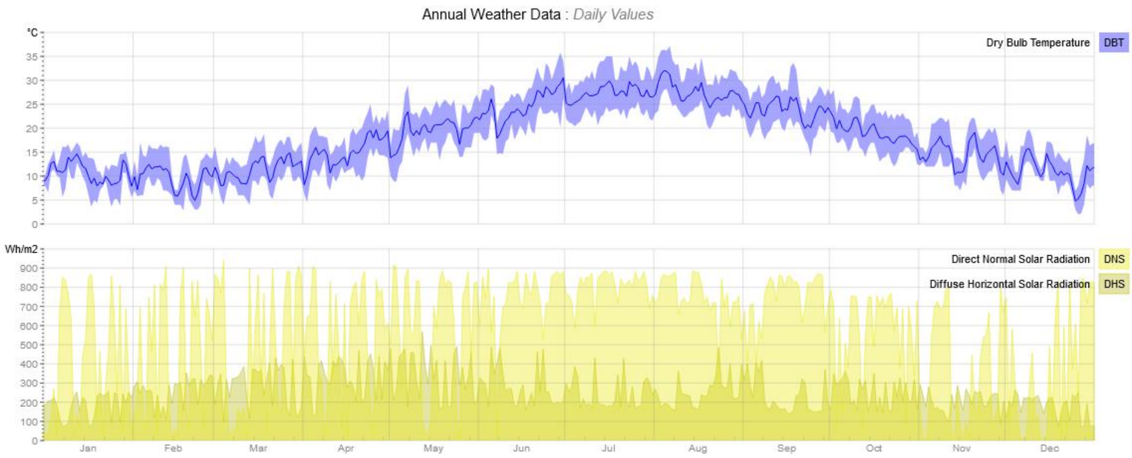
2.2. *Climate analysis software*

Apart from online data, there are various commercial or free software available to use for the task (or that can be employed for the task). The advantage of performing climate analysis with the use of software is that it offers a more accurate representation of the climate, as apart from mean monthly values, daily up to hourly values are also available. (Figure 3) As the proposed methodology is applied by a large number of students, the option of freeware was somewhat a one-way street. Free software such as Climate Consultant® [12], can be downloaded, while other, such as AndrewMarsh.com [13, 14] is available online.



a.



b.

Figure 3. Graphic representation of yearly climatic data (source: a. [12] and b. [13])

The data files that are used in both applications, as well as others, are EnergyPlus Weather files (.epw) in SI units, which can be retrieved either from the EnergyPlus website [10], either from the Climate.OneBuilding.org [12]. In the former, data is available in IWEC (International Weather for Energy Calculations) format, whereas in the latter in a .zip containing, apart from the .epw which is actually used, different types of weather data file (.clm, ddy, .pvsyst, .rain, .stat and .wea). Another difference is that in Climate.OneBuilding.org [22] there are different available .TMYx files for different time periods. TMYx files are typical meteorological files derived from US NOAA's Integrated Surface Database (ISD) available years (minimum 5 years) with hourly data through 2021 using the TMY/ISO 15927-4:2005 methodologies. ISD individual year files are created using the

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general principles from the IWEC (International Weather for Energy Calculations) Typical Meteorological Years. Apart from the TMYx files in some cases, there are additional files containing data for the most recent 15 years (2007-2021) and/or for previously published years (2004-2018). [22]

2.3. Psychrometric charts

The final stage of climate analysis involves the visual representation (mapping) of air temperature and relative humidity points on a psychrometric chart in order to define the best bioclimatic design strategies. In the period around the end of the 20th century and prior to the generalized use of software and/or computers, this was done manually by hand on a printed chart (Figure 4). Mean monthly values, sometimes together with mean maximum and mean minimum monthly values were drawn in a psychrometric chart depicting the basic strategies throughout the year and from the resulting diagram conclusions were drawn and consequently decisions were made.

Today, the available software provides this representation not only for monthly, but also for hourly values throughout the year, delivering a much more detailed and closer to real-time conditions figure and analysis. Furthermore, specific periods of the day and within the year can be isolated for more intricate analysis. (Figure 5)

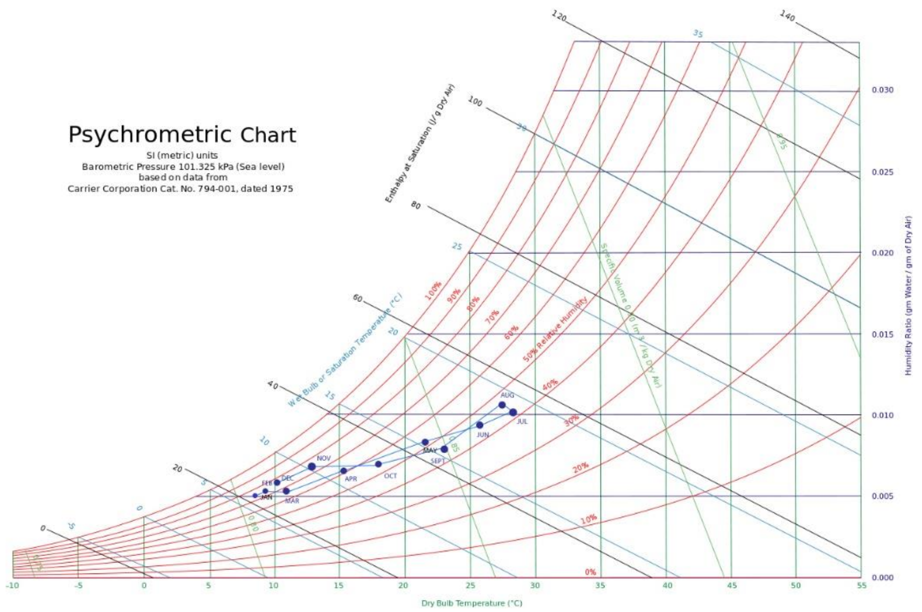
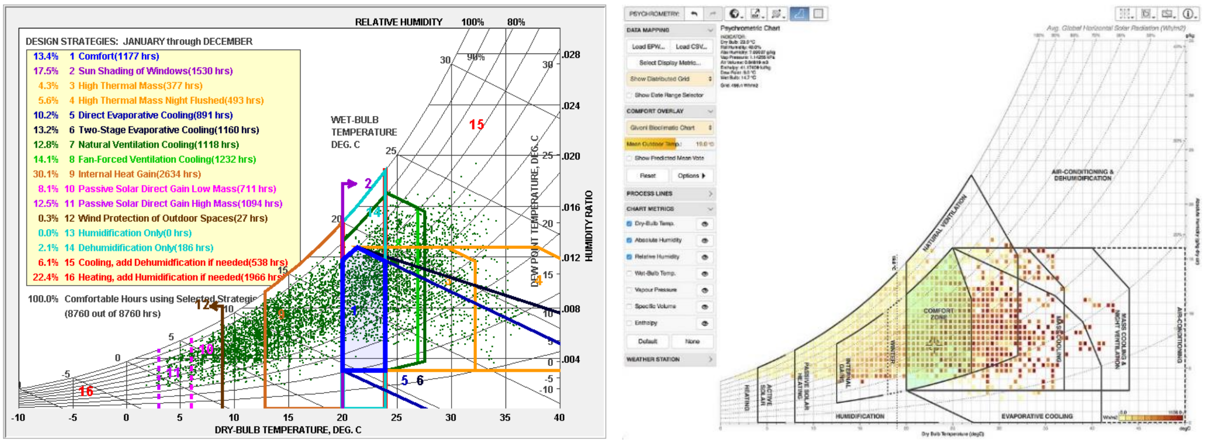


Figure 4. Psychrometric chart [8] with an overlay of mean monthly air temperatures [15] for Athens, Greece. [23]



a. b.

Figure 5. Psychrometric charts with design strategies. (sources: a. [12] and b. [14])

3. Discussion

There is a number of implications that must be taken into consideration when viewing, analysing and assessing climate data, online and/or with the use of software, in order to make initial stage design decisions for a project. These mainly include:

- the location of the station (within the city or metropolitan area and/or at the airport) and
- the recording period.

The location of the station is based on two different parameters: the station itself and the assortment between different stations in relation to the position of the plot or site under investigation. Concerning the station itself, it is very important to note that the location of the station where the data is collected is usually the airport. Airports are situated at some distance from the city centers (Figure 6) in flat, open areas with few buildings (those that serve their functions), no ground vegetation and artificial land cover (concrete and/or tarmac paved runways) [24] (Figure 7). As a result, some climatic data that are predominantly influenced by the terrain and the topography, such as wind speed and direction, may vary compared to urban areas, and this fact must be qualitatively assessed and taken into consideration. Gough & Leung (2022) [24] state that airports generate a microclimate of their own, an "airport" climate. Their findings indicate that airports generate a peri-urban climate [25], even when the surrounding environment can be classified as rural, marine or mountainous. [24]

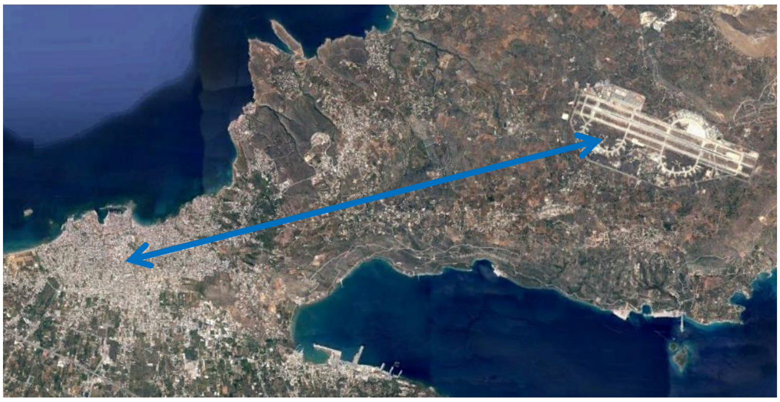
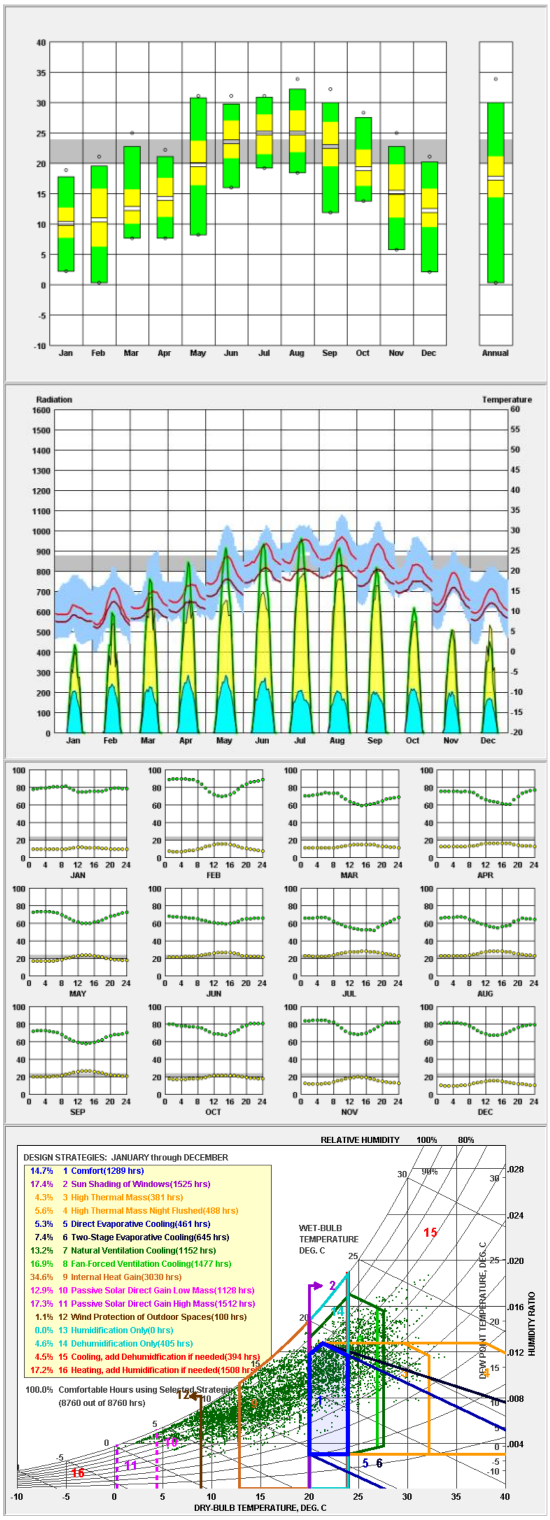
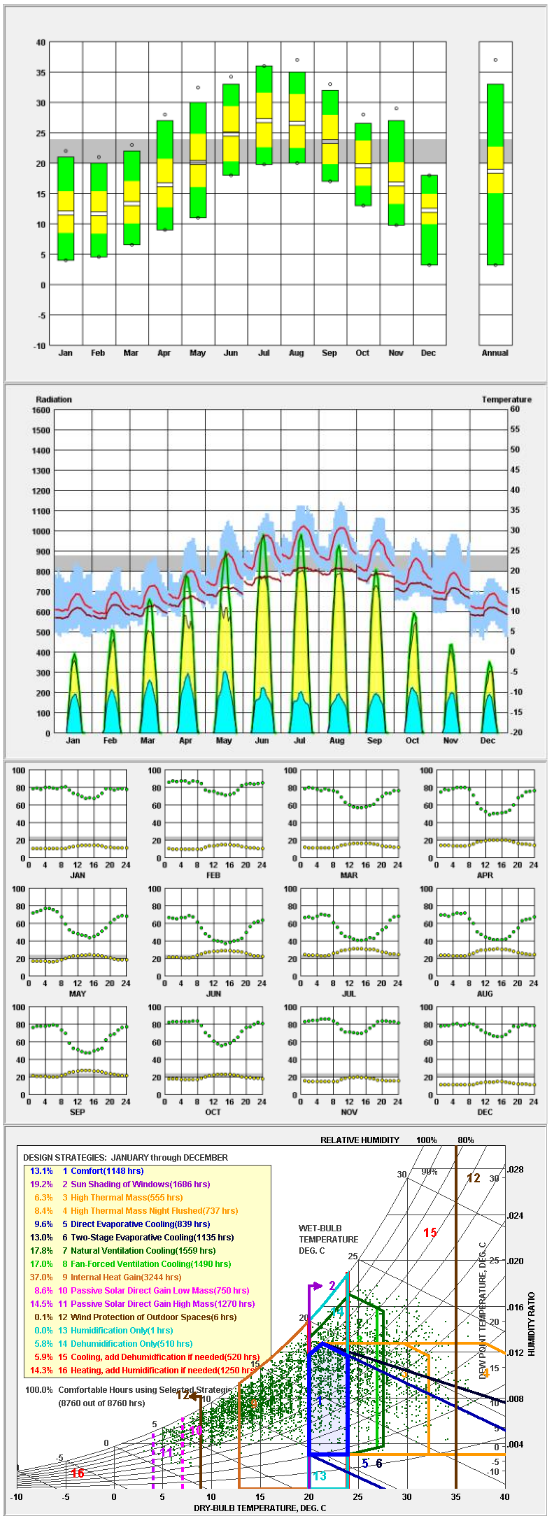


Figure 6. Google Earth image depicting the city and the airport at Chania, Crete, Greece. [27]

Figure 7. Airport layout and buildings. [26]


Radiation
Temperature
RELATIVE HUMIDITY
DESIGN STRATEGIES: JANUARY through DECEMBER
14.7% 1 Comfort(1289 hrs)
17.4% 2 Sun Shading of Windows(1525 hrs)
4.3% 3 High Thermal Mass(381 hrs)
5.6% 4 High Thermal Mass Night Flushed(488 hrs)
5.3% 5 Direct Evaporative Cooling(461 hrs)
7.4% 6 Two-Stage Evaporative Cooling(645 hrs)
13.2% 7 Natural Ventilation Cooling(1152 hrs)
16.9% 8 Fan-Forced Ventilation Cooling(1477 hrs)
34.6% 9 Internal Heat Gain(3030 hrs)
12.9% 10 Passive Solar Direct Gain Low Mass(1128 hrs)
17.3% 11 Passive Solar Direct Gain High Mass(1512 hrs)
1.1% 12 Wind Protection of Outdoor Spaces(100 hrs)
0.0% 13 Humidification Only(0 hrs)
4.6% 14 Dehumidification Only(405 hrs)
4.5% 15 Cooling, add Dehumidfication if needed(394 hrs)
17.2% 16 Heating, add Humidification if needed(1508 hrs)
100.0% Comfortable Hours using Selected Strategies
(8760 out of 8760 hrs)
WET-BULB TEMPERATURE DEG. C
DEW POINT TEMPERATURE, DEG. C
HUMIDITY RATIO
DRY-BULB TEMPERATURE, DEG. C


Radiation
Temperature
RELATIVE HUMIDITY
DESIGN STRATEGIES: JANUARY through DECEMBER
13.1% 1 Comfort(1148 hrs)
19.2% 2 Sun Shading of Windows(1686 hrs)
6.3% 3 High Thermal Mass(555 hrs)
8.4% 4 High Thermal Mass Night Flushed(737 hrs)
9.6% 5 Direct Evaporative Cooling(839 hrs)
13.0% 6 Two-Stage Evaporative Cooling(1135 hrs)
17.8% 7 Natural Ventilation Cooling(1559 hrs)
17.0% 8 Fan-Forced Ventilation Cooling(1490 hrs)
37.0% 9 Internal Heat Gain(3244 hrs)
8.6% 10 Passive Solar Direct Gain Low Mass(750 hrs)
14.5% 11 Passive Solar Direct Gain High Mass(1270 hrs)
0.1% 12 Wind Protection of Outdoor Spaces(6 hrs)
0.0% 13 Humidification Only(1 hrs)
5.8% 14 Dehumidification Only(510 hrs)
5.9% 15 Cooling, add Dehumidfication if needed(520 hrs)
14.3% 16 Heating, add Humidification if needed(1250 hrs)
100.0% Comfortable Hours using Selected Strategies
(8760 out of 8760 hrs)
WET-BULB TEMPERATURE DEG. C
DEW POINT TEMPERATURE, DEG. C
HUMIDITY RATIO
DRY-BULB TEMPERATURE, DEG. C

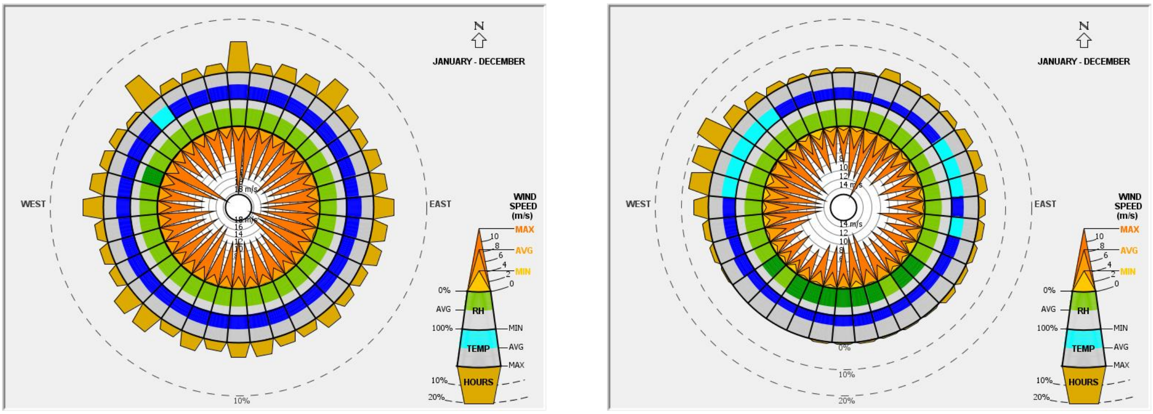


Figure 8. Comparison of the basic climatic data for Chania city (alt. 62 m) (left) and airport (I. Daskalantonakis) (alt. 149 m) (right), with data from [11] and graphic representations from [12].

A preliminary, qualitative comparison of climatic data from city and airport stations around Greece was done with data files from [11] (see for example Figure 8 for Chania, Crete). The observed differences were not at all pronounced, nevertheless, the juxtaposition of the diagrams revealed that in comparison to cities, airports demonstrate:

- relatively higher maximum and lower minimum air temperatures, with a wider seasonal range.
- significantly lower mid-day relative humidity values during the summer period
- relatively higher solar radiation and illumination values..
- more directional winds with higher wind speeds and frequency (hours).

As far as the second parameter is concerned, when an area, a city or a town does not have a weather station, nearby stations have to be selected. In order to choose between more than one nearby stations, certain qualitative criteria must be applied. These criteria should focus on the similarity of the geomorphological and site characteristics. For example, for various sites in the metropolitan area of Athens, Greece, data is available for Ellinikon, Theseon and Nea Philadelphia (Figure 9). From the three sites, the first is situated near the sea front, which influences / attenuates temperature extremes, the second is situated on a hill in the heart of the city thus predominantly urban, whereas the latter is situated in the heart of Attica, and therefore has more “continental” characteristics. Therefore, it is sometimes necessary to compare the inter-seasonal variation of various climatic elements, together with the air temperature, such as wind speed and direction and relative humidity, in order to decide which file will be used for the climatic analysis.

Figure 9. Google Earth image with the available stations / data for Attica, Greece. [27]

Finally, concerning the recording period, available data of .epw files usually include the last 15 to 20 years, whereas online data from websites may include larger periods of time. During the last years, the approach of climate change is emerging and the analysis may include not only recorded climatic data, but also projected, climate change-based ones. Freely available climatic data files to this day involve only typical years described in Section 2.2. Data on climate change in the form of specific diagrams may be found on websites [e.g. 17, 21], while commercial climate analysis software, such as Meteonorm, offers data files that simulate climate change based on IPCC scenarios [28], whereas building energy simulation commercial software, such as Design Builder, also works with design years that can accommodate the impact of future climate scenarios [29].

4. Conclusions

The article proposes the introduction of a number of additional steps involving the analysis and the comprehension of the climate to the first stages of architectural design, which involve:

- The collection of online available data from websites
- The collection and analysis of climate data files
- The use of bioclimatic (psychrometric) diagrams in order to fully comprehend the climate and to point out efficient bioclimatic design strategies.

The proposed methodology has been developed within the framework of a compulsory and an elective undergraduate architectural technology course, but has also been applied, to a smaller scale to undergraduate and postgraduate students' design projects, diploma projects and student competitions. Apart from that, it could also be integrated to professional work, such as architectural competitions around the world and actual projects.

Depending on the level of knowledge (under-graduate, post-graduate or professional), and, of course, the complexity of the project, the analysis may be more superficial or in-depth. The latter may include the comparison of various sources and files in order to define the climatic characteristics more clearly and reliably. Moreover, special effort should be given in the comprehension of the different climatic parameters and their interrelation with the thermal comfort conditions. Finally, concerning the bioclimatic design strategies that are derived from the use of psychrometric charts for a specific location, their actual application to the project depends on the plot and its characteristics (rural, suburban or urban), the surrounding built and natural environment, the views, the size, the building use and other parameters, that may be even more important and decisive than climate to the project. Nevertheless, the design process of a building of any kind encompasses the synthesis of many parameters that should be equally evaluated and addressed in order to deliver a project that equally addresses all issues interrelated with the construction and function of the built environment. Climate responsive and environmental design tools are among them.

References

[1] Evaggelinos E & Zacharopoulos H 2001 Methodoi kai systimata exoikonomisis energeias me bioklimatiko sxediasmo (Methods and systems of energy conservation with bioclimatic design) ed D Loukopoulos *Bioklimatikos sxediasmos ktirion kai periballontos xorou (Bioclimatic design of buildings and open spaces)* (Patras: Hellenic Open University) pp. 21-154

[2] Directive 2002/91/EU, The Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings *Off. J. Eur. Union, L1* (4.1.2003) http://data.europa.eu/eli/dir/2002/91/oj

[3] Directive 2010/31/EU, The Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings *Off. J. Eur. Union, L153*

(2010) http://data.europa.eu/eli/dir/2010/31/oj
[4] Directive 2012/27/EU, The Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC *Off. J. Eur. Union, L315* (2012) http://data.europa.eu/eli/dir/2012/27/oj
[5] Directive 2018/844/EU, The Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency *Off. J. Eur. Union, L156* (2018) http://data.europa.eu/eli/dir/2018/844/oj
[6] KENAK Kanonismos Energeiakis Apodosis Ktirion (Energy Performance of Buildings Regulation) *FEK 2367 B* (12.07.2017)
[7] Givoni B 1992 *Journal Energy and Buildings* **18** 1 11-23 https://doi.org/10.1016/0378-7788(92)90047-K
[8] Psychrometric chart by ArthurOgawa via Wikimedia Commons, CC BY-SA 3.0
[9] Technical Chamber of Greece (TCG) 2010. *Technical Note TOTEE 20701-3/2010. Climate data of Greek cities*. http://portal.tee.gr/portal/page/portal/tptee/totee/TOTEE-20701-3-Final-TEE%202nd.pdf
[10] EnergyPlus. Weather data. https://energyplus.net/weather
[11] Climate.OneBuilding.Org. https://climate.onebuilding.org
[12] UCLA Energy Design Tools Group 2020 Climate Consultant (Version 6.0) [Computer software]. https://www.sbse.org/resources/climate-consultant
[13] Marsh AJ 2021 Psychrometric Chart [Online software]. http://andrewmarsh.com/software/psychro-chart-web/
[14] Marsh AJ 2021 Data View 2D [Online software]. http://andrewmarsh.com/software/data-view2d-web/
[15] Hellenic Meteorological Service (HNMS) (2017-2021). Climatology. http://www.emy.gr/emy/el/climatology/climatology
[16] National Observatory of Athens (NOA) (n.d.). Climatic data.. https://www.meteo.gr/climatic.cfm
[17] Meteoblue. Weather close to you. https://www.meteoblue.com
[18] ClimaTemps.com. http://www.climatemps.com
[19] CantyMedia. Weatherbase. http://www.weatherbase.com
[20] Quote Investigator. Tracing quotations (2012, June 24). The Climate Is What You Expect; The Weather Is What You Get. https://quoteinvestigator.com/2012/06/24/climate-vs-weather/
[21] Meteoblue. Weather close to you. History & Climate. Climate (modelled). https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/athens_greece_264371
[22] Climate.OneBuilding.Org 2022. Climate / Weather Data Sources. https://climate.onebuilding.org/sources/default.html
[23] Derivative of Psychrometric chart by ArthurOgawa via Wikimedia Commons, CC BY-SA 3.0. Derivative by Flora Bougiatioti, CC BY-SA 3.0
[24] Gough WA and Leung ACW 2022 *Meteorology* **1** 171–182. https://doi.org/10.3390/meteorology1020012
[25] Gough WA 2020 *Journal of Applied Meteorology and Climatology* **59** 9 1443-1452. https://doi.org/10.1175/JAMC-D-19-0292.1
[26] Photo by Skyler Smith on Unsplash
[27] Google Earth. https://earth.google.com/web/
[28] Remund J, Müller S, Schilter C and Rihm B 2010 *EMS Annu. Meet. Abstr.* **7**.
[29] Design Builder. Climate Analytics - Weather and Climate Data for Building Performance Simulation. https://designbuilder.co.uk/software/climate-analytics