Bioclimatic Analysis and Proposal of Bioclimatic Strategies for Buildings: Case Studies in Santo André, São Paulo, Brazil

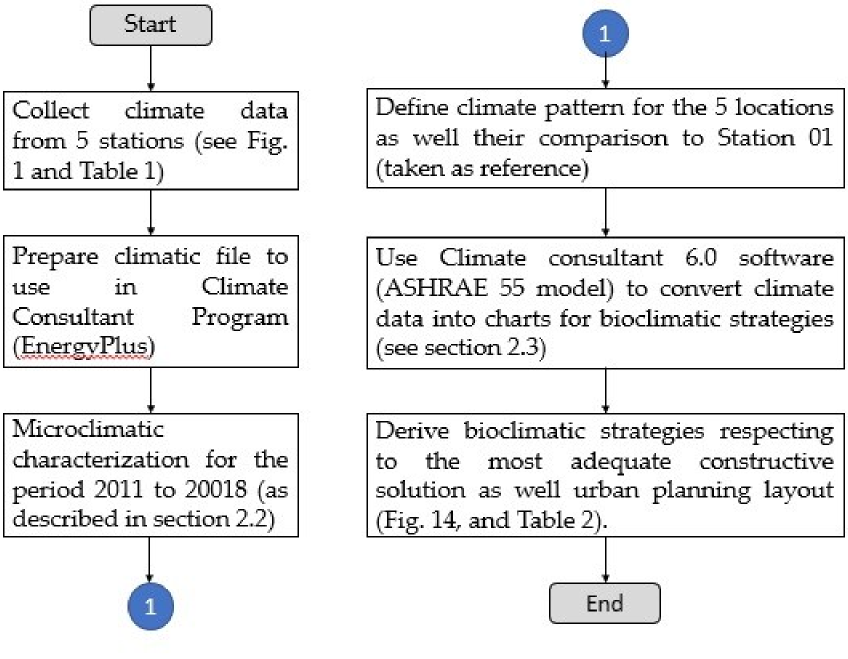
Helenice Maria Sacht [1], Andrea Oliveira Cardoso [2] and Herlander Mata-Lima [1, 2,*]

[1]ILATIT-UNILA, Federal University of Latin American Integration, Parana, Brazil; helenice.sacht@unila.edu.br

[2]UFABC, Federal University of ABC, São Paulo, Brazil

*Correspondence: helenice.sacht@unila.edu.br; helima@tecnico.ulisboa.pt

Graphical Abstract



Abstract

Santo André city is located in the region called *ABC Paulista*, in the southeast of the Metropolitan Region of São Paulo and it is an important city, considering its industrial and economic role. There are few attempts to develop projects that fit the local climate in order to save energy consumption. The study aims to use weather data to define the parameters of normal climate of Santo André that are essential for the thermal comfort project, considering urban planning, new buildings, and retrofit of existing solutions. Data were obtained from meteorological stations in Santo André, regarding five different points of the city to evaluate different microclimates and the influence of the surroundings areas in microclimates, and a climate file was created to predict bioclimatic strategies for buildings. The results reveal spatial variations of temperature (T) and relative humidity (RH) among the five microclimates analyzed (minimum and maximum T and RH were respectively found for stations 04 Paraiso with 17 °C, 01 Camilópolis with 52% and stations 01 Camilópolis with 24,5 °C, 04 Paraiso with 84%), as a result of the following actions: replacement of vegetation by constructions (e.g., asphalt, concrete) and other impermeable surfaces. For the climate pattern of the area, the results reveal that adaptive comfort requires active strategies. If only passive strategies are applied, no more than 32% of the thermal comfort is achieved. This study allows architects and engineers to choose solutions suitable to the climate of the Santo André Urban Qualification Zone, during the process of designing new interventions in urban area.

Keywords: Urban climate; Building strategies; Housing; Urban design; Energy saving.

1. Introduction

Reducing urban energy consumption for buildings cooling and heating require a holistic approach that combine climate, land planning, and architecture [1, 2, 3]. Sustainable projects consider climate variables to constrain the designing and materials options both for a single building and urban planning. Nazarian et al. [4] stress that thermal comfort in indoor and outdoor built environment exerts influence on health, well-being, and productivity of urban dwellers. At present, building represents 45% of primary energy resources consumed globally, 40% of which is due to Heating, Ventilation and Air-conditioning (HVAC) demand [5]. Hence, optimum design of buildings and urban environment depend on climatic characterization which guide land and environmental planning [6] in line with sustainable development goals. Though, climate ought to be used to constrains urban and building thermal comfort by adopting appropriate land planning, architectural conceptions, and materials choice [7, 8]. Such procedure avoids higher temperatures in urban spaces [4, 9].

Manzano-Agugliaro et al. [10] presented a review of bioclimatic architecture strategies for achieving thermal comfort. The authors highlighted the relevance of studying, analysing and implementing bioclimatic architectural systems to learn how the climate behaves in different locations in a city in order to define strategies to reduce energy consumption while considering the possible construction solutions offered at both passive and active levels.This study refers to municipality of Santo André which is part of São Paulo State (Brazil). The ABC region (**Figure 1**) is of great importance for Brazilian Gross Domestic Product (GDP).

In this study the objectives have been made to describe the average pattern of the climate characteristics of Santo André city which is a key contribution to design scenarios of urban comfort. To do so, five different points of the Santo André city were considered to analyse the microclimate to evaluate the impact of the surrounding areas and draw bioclimatic strategies for buildings. This work is strongly related to the goals 9 (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), and 13 (Take urgent action to combat climate change and its impacts) of sustainable development for 2030, which in turn contribute for household energy- and water-saving.

2. Materials and Methods

2.1 Study Area – Climate Data for Different Locations in Santo Andre City

The climate data comes from the five stations available in the study area as described in **Table 1**. **Figure 1** presents the stations, location of Santo André city in relation to Brazil, São Paulo Station and the ABC Paulista Region (**Figure 1 a-c**), and the position of the stations (**Figure 1d**). The climate data analyzed include daily precipitation, temperature, relative air humidity, direction and wind speed, atmospheric pressure, and solar radiation measured in each station from 2011 to 2018, as highlighted by WMO [16] and Mata-Lima et al. [17]. The stations and their data are presented in **Table 1**.

Table 1 - Meteorological Stations of SEMASA – Municipal Service for Environmental Sanitation of Santo André.

Number	Station	Address	Latitude	Longitude	Altitude
01	Camilópolis (Utinga)	218 Olegário Mariano St, Jardim Utinga, Santo André – SP	-23.622800°	-46.521900°	814 m
02	Erasmo Assunção	297 Miguel Guillen St, Jardim Rina, Santo André – SP	-23.647700°	-46.494900°	810 m
03	Tanque de Detenção (RM 9)	Grã Betânia St, Piscinão Rm9, Santo André – SP	-23.664100°	-46.552800°	751 m
04	Paraiso	99 Osvaldo Cruz St, Paraiso, Santo André – SP	-23.679400°	-46.533600°	823 m
05	Vila Vitória	59 Batuíra St, Vila Vitoria, Santo André – SP.	-23.686300°	-46.512300°	813 m

The automatic urban stations used have the longest and most up-to-date data records. Stations with longer series (reaching 30 or more years) are located only in the city of São Paulo which is far from Santo Andre municipality. The closest station with a long record is the IAG station (Lat -23.6512°, Long -46.6224°), which is located in a vegetated area (different from the reality of Santo André) in *Fontes do Ipiranga* State Park, at about 10 km from the Camilópolis station. Previous studies show differences between the variables of the IAG station with others from ABC Paulista [11]. In addition, this station shows positive long-term trends regarding temperature and precipitation, as well as other stations located in the Metropolitan Region of São Paulo [12]. Hence, data from urban meteorological stations in Santo André is more suitable to represent the region.

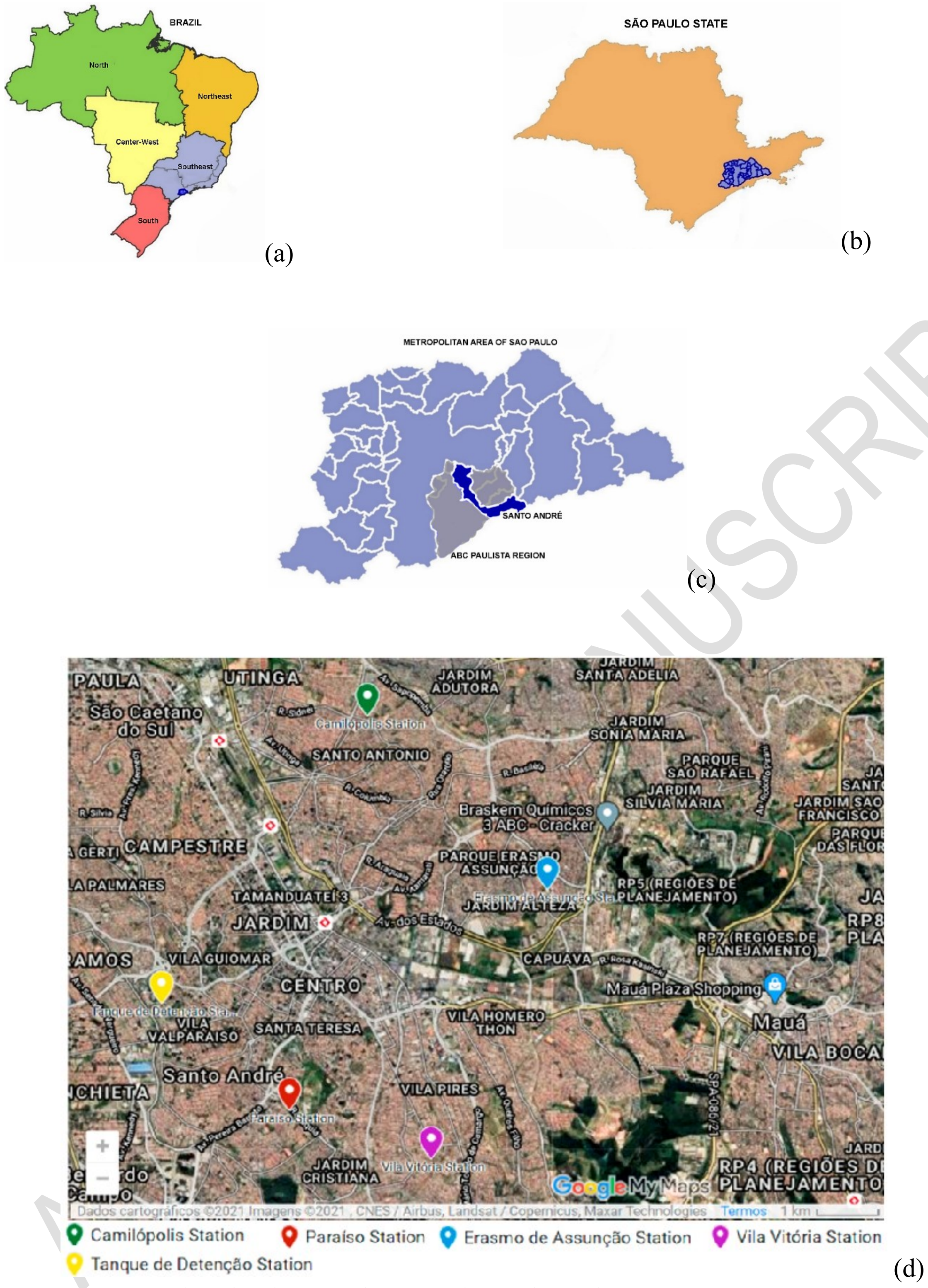


Figure 1a-d - Location of study area and Santo André weather stations.
Source: Based on MSBC [13], EMPLASA [14], and Sacht [15]. Note: Refer to Table 1 to obtain full description of weather stations.

In sequence, a climatic file was elaborated in the epw format to be used in the Climate Consultant Program, as explained in next paragraph. The .epw file is a weather data file saved in the standard EnergyPlus program format; used by EnergyPlus energy simulation software, developed by the U.S. Department of Energy (DOE), and it contains weather data that is used for running building simulations.

After a general analysis of the data and filling of typical records gaps respecting to radiation, the reference climatic year for the locality was evaluated. To fill a few gaps detected, the nearest database is used as a reference because the values are relatively valid for wider regions, since the incident radiation does not present relevant differences. Among the various concepts and methods on the subject [18] it was considered the adoption of a real year (complete with all 12 months) selected by the successive exclusion of the warmer and colder years (see NCDC [19] and HAND et al. [20] for detailed procedure of Test Reference Year – TRY method), leaving only one, to be considered as the typical of the place, in this case the year 2016 (see figure 3 and related description). **Figure 2** synthesizes the entire procedure adopted in this study.

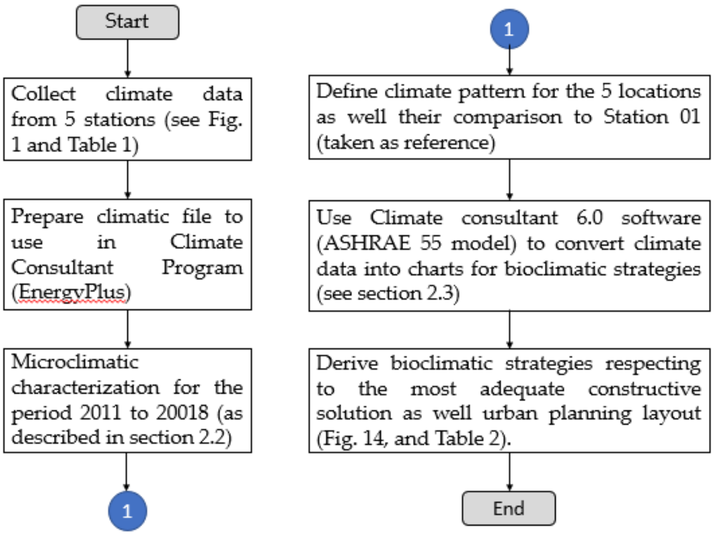


Figure 2 - Flowchart depicting the entire procedure do derive bioclimatic strategy for the study area.

2.2 Procedure for Microclimatic Characterization

The characterization of seasonal cycle of temperature and relative humidity result from the analysis of hourly data. The average values were obtained for each month across the 8 years (2011 to 2018).

The maximum, average and minimum daily values of air temperature were extracted for the period as well the monthly averages for values of air temperature (T) and relative humidity (RH) which depict the seasonal cycle for both variables. Additionally, Station 01 – Camilópolis (Utinga) was taken as reference to calculate the variation of T and RH for all stations (monthly average and diurnal cycle) because it is located in a denser urban area (i.e., it exhibits more buildings per square meters). Finally, the average diurnal cycle of T and RH was obtained for each station, including the variation when compared to Station 01-Camilópolis (Utinga).

2.3 Bioclimatic Strategies

The aforementioned procedure for microclimatic characterization provides the climate pattern for five locations throughout the study area as well as their comparison to Station 01 - *Camilópolis* (Utinga), as explained above.

The climate assessment was launched by climate Consultant 6.0 software to help performing constructive strategies. The software layouts are user friendly graphics used to extract recommendation concerning bioclimatic strategies. The role of software is to convert the climate data in .epw format file into charts whose interpretations are bioclimatic strategies respecting to the most adequate constructive solution and urban planning [21].

Hereby, one used the Adaptive Comfort Model of the ASHRAE 55 Standard 2010 in Climate Consultant 6.0 since it is a well-known, broadly used and validated model on the area of environmental comfort. ASHRAE 55 considers naturally ventilated spaces, and that occupants can adapt their clothing to thermal conditions. It also verifies if occupants are sedentary, varying the metabolic rate between 1.0 and 1.3 met. For the selected model, the criteria – took into account the natural ventilation and acceptable comfort limit of 80% - adopted for Santo André are: (i) maximum average outdoor monthly temperature of 24.1 °C and (ii) minimum average monthly temperature outdoor of 14.7 °C. For the maximum and minimum operating temperature, 27.8°C and 19.9 °C were respectively considered.

3. Results and Discussion

3.1 Climatic characterization

The study did not consider the climate normal (30 years of data) which is the ideal situation. Though, it is worth mentioning that, in spite of the recommendation of climate normal (30 years of data), the preparation of summaries of climate data for recent and relatively short periods must be encouraged [16, 17].

The average monthly pattern of rainfall and temperature (depicted in **Figure 3**) was characterized using meteorological data from *Camilópolis* Station (Utinga).

A seasonal cycle related to precipitation and temperature is observed, with higher values in summer and lower values in winter. In the case of temperature, there is a high daily thermal amplitude (difference between maximum and minimum temperatures, due to the day cycle) throughout the year, with higher values between winter and summer, reaching maximum in winter with values that exceed 9 °C. The months of August and February show the highest average thermal amplitude of 9.5 ºC and 8.9 °C, respectively. In relation to the average temperature, the annual thermal amplitude (seasonal cycle) is around 6.5 °C, reaching the maximum in February 23.3 °C and the minimum in July of 16.9 °C. The precipitation regime is strongly influenced by the atmospheric systems, with emphasis on the South Atlantic Convergence Zone (ZCAS) as the main cause of persistent and high rainfall in the summer, and convection and transient systems such as cold fronts and cyclones [22]. The circulation of sea breezes also provides the occurrence of precipitation, which may be enhanced by the effects of the urban heat island [23].

Figure 3 also shows the monthly values observed in 2016 for precipitation (in circles) and maximum and minimum temperatures (dashed lines), as it is the year considered as a reference for the indication of construction strategies and the preparation of the file in epw format. As can be seen, in most months, the maximum temperature in 2016 was below the average for the period analyzed, except in the hottest months (February and December), which were practically equal to the average and in the months of April and July. In general, the average monthly minimum temperatures for 2016 were close to the average for the entire period of analysis.

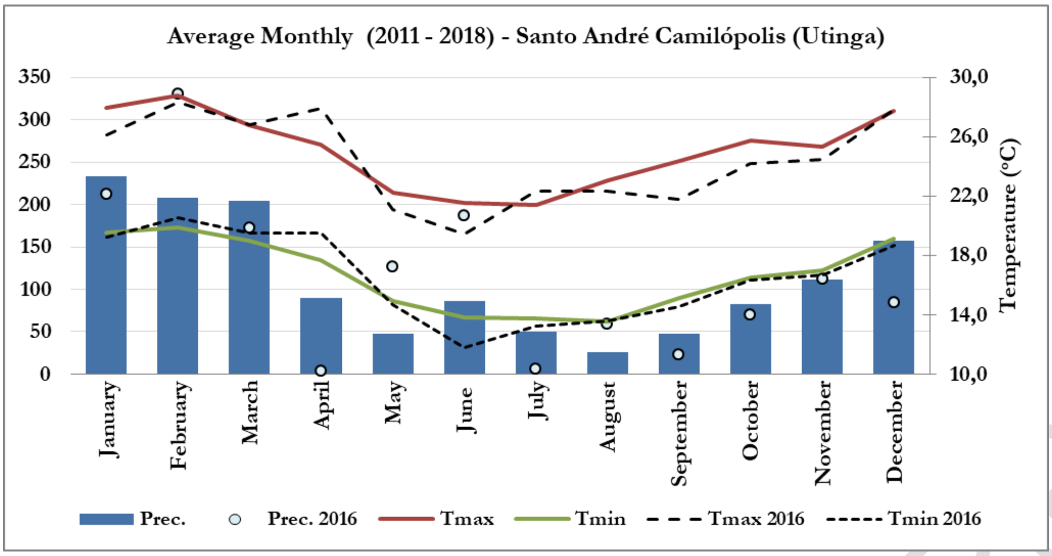


Figure 3 - Average monthly rainfall and temperature standard for the Santo André City – Camilópolis (Utinga). Source: authors based on SEMASA data, as referred on table 1.

Microclimate analysis is essential to understand the climate pattern across different areas of the city. The climatic characterization of the Urban Qualification Zone (Station 01 – *Camilópolis* area) of Santo André is a way to achieve goals such as identification of bioclimatic strategies to reach thermal comfort through passive or minimum active systems (for cooling and heating).

3.2 Microclimatic characterization: Average monthly temperature (T) and Relative humidity (RH)

Climate data was statistically treated to characterize the seasonal cycle of T and RH. The average monthly temperatures for the five weather stations used are exhibited in **Figure 4**. The temperature is generally higher for Station 01 - *Camilópolis (Utinga)*, which the area is densely occupied by vertical buildings and 20.46 °C is the average annual value. Among the infrastructure around Station 01 are buildings, roads, and others (surfaces covered by asphalt and concrete). The absence of vegetation is remarkable in this area.

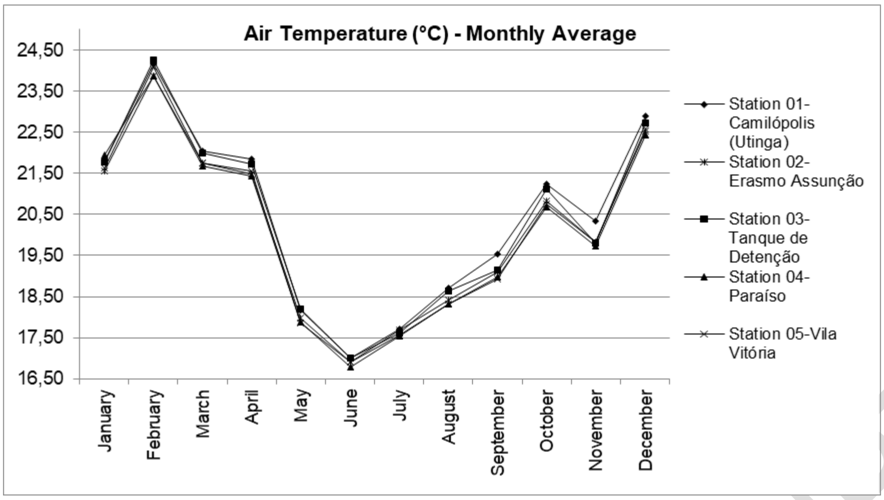


Figure 4 - Average monthly temperature. Source: authors based on SEMASA data, as referred on table 1.

As shown in **Figure 5**, Station 03 (*Tanque de Detenção* - close to an urban void area) and 04 (*Paraiso*) exhibit highest temperature in February (24.26 °C) and January, respectively. This station is located in area of ABC Paulista which was identified as heat island in a recent study [11].

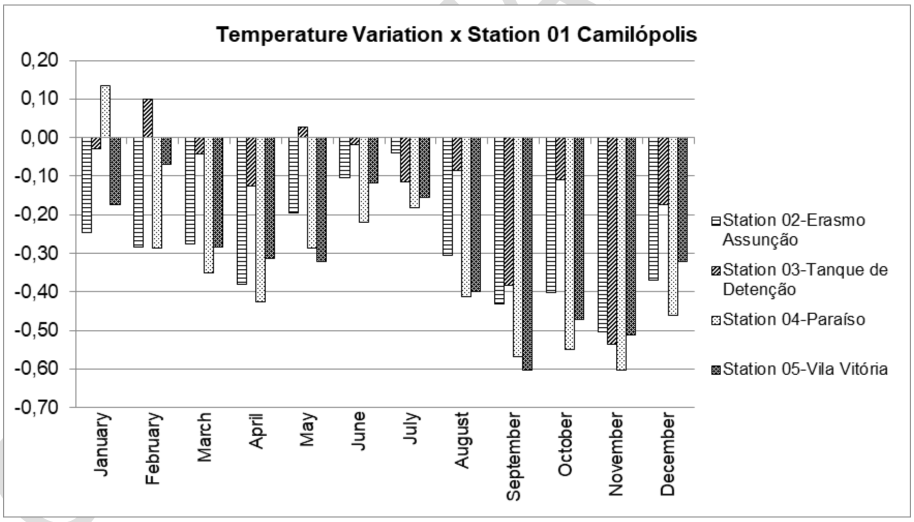


Figure 5 – Monthly Temperature: Difference in Relation to Station 01 – *Camilópolis.* Source: authors based on SEMASA data, as referred on table 1.

The highest monthly averages of relative humidity (RH) was observed in Station 05 from January to July and in Station 04 from August to December. The two stations are surrounded by green areas that contribute to higher humidity. On the other hand, Station 01 showed lowest RH as it is sorrounded by infrastructures (e.g., buildings and roads) (**Figures 6** to 8).

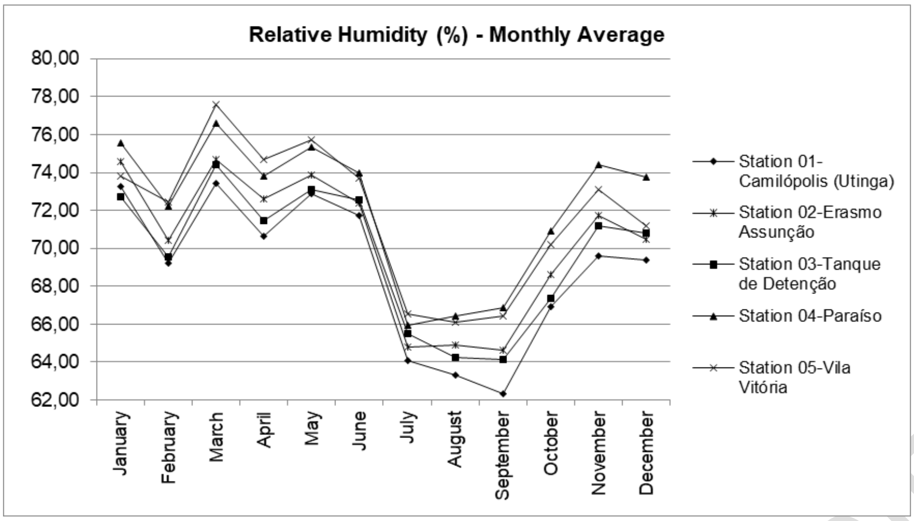


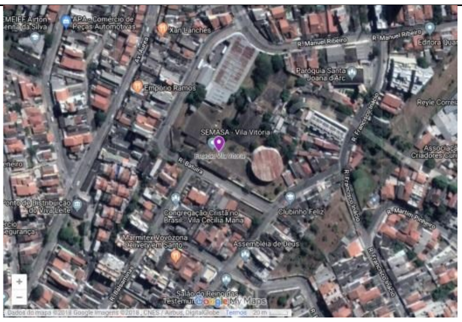
Figure 6 - Average monthly relative humidity. Source: authors based on SEMASA data, as referred on table 1.

Station 01 – *Camilópolis* (Utinga)

Station 02 – *Erasmo de Assunção*

Station 03 – *Tanque de Detenção*

Station 04 – *Paraiso*



Station 05 – *Vila Vitória*

Figure 7 - Weather stations and surrounding areas to illustrate the land occupation near each station. Source:

Based on Google My Maps [15].

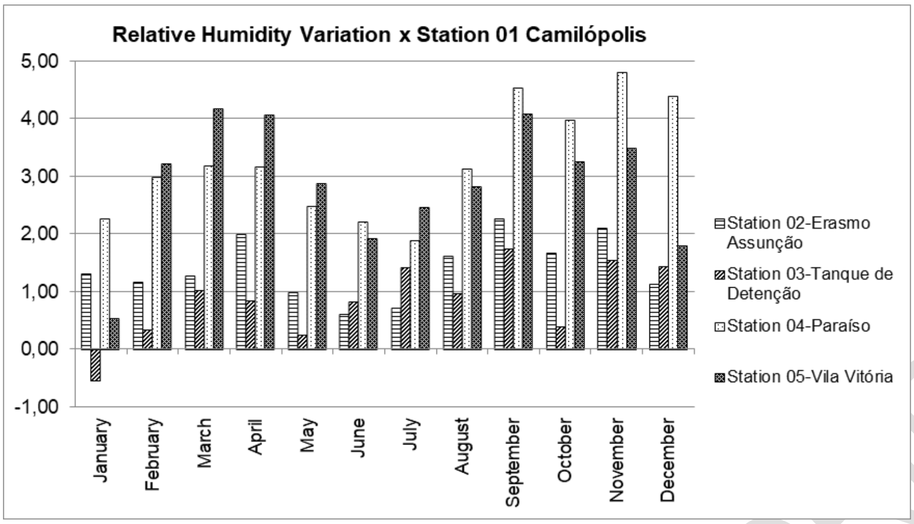


Figure 8 – Monthly Relative humidity difference in relation to Station 01 – *Camilópolis*. Source: authors based on SEMASA data, as referred on table 1.

3.3 Microclimatic characterization: Diurnal cycle average temperature and Relative humidity

The higher differences for temperature of diurnal cycle were found in Station 01, from 11 o'clock (23.54 °C) to 17 o'clock (21.08 °C), with other stations showing very similar temperatures (**Figure 9** and **10**). For the period from 0 to 6 hours, Station 03 shows higher temperatures.

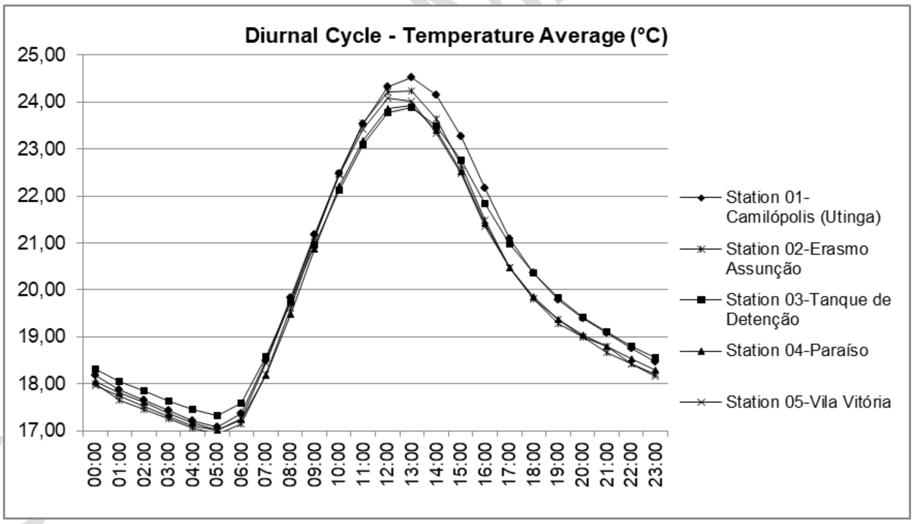


Figure 9 - Diurnal cycle average temperature. Source: authors based on SEMASA data, as referred on table 1.

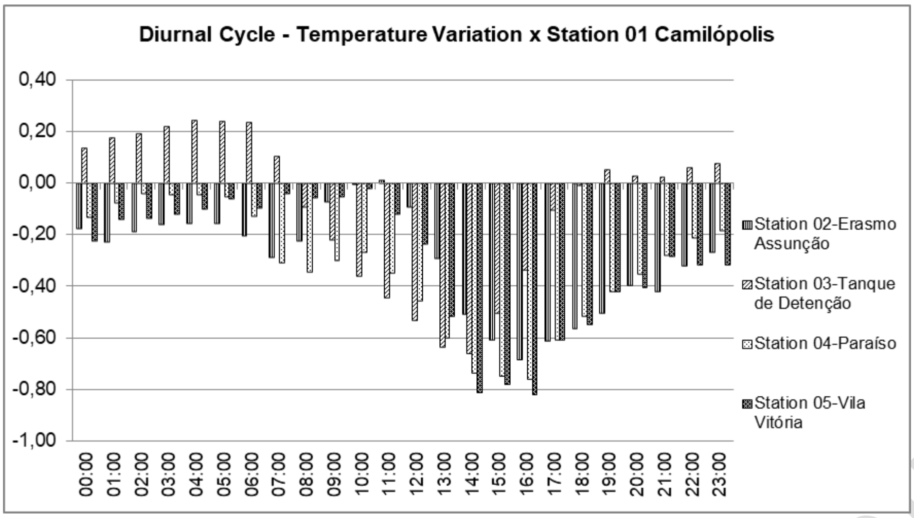


Figure 10 - Diurnal cycle average temperature: Difference in relation to Station 01 – *Camilópolis*. Source: authors based on SEMASA data, as referred on table 1.

Stations 04 and 05 present highest values of RH of diurnal cycle, and the lowest RH is for Station 01 (**Figures 11** and **12**). The highest values of RH when compared to Station 01 begin at 12 o'clock and end at 15 o'clock.

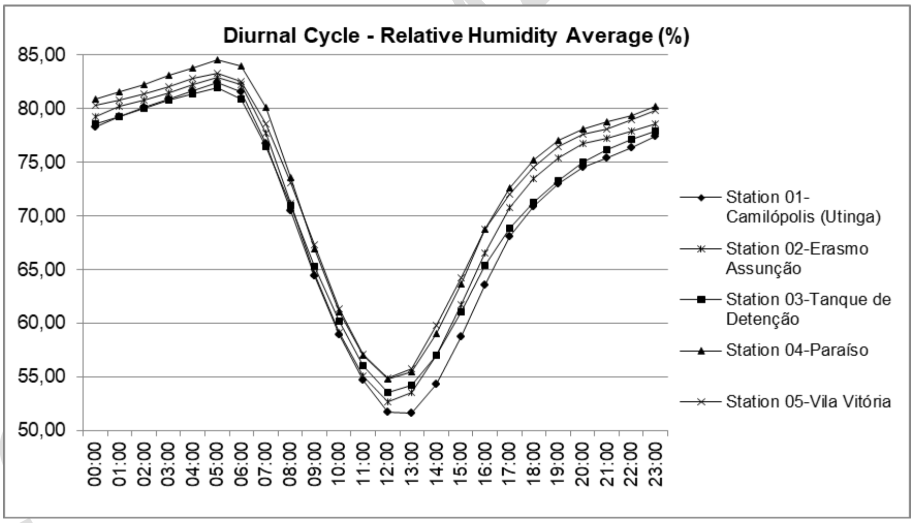


Figure 11 - Diurnal cycle average relative humidity. Source: authors based on SEMASA data, as referred on table 1.

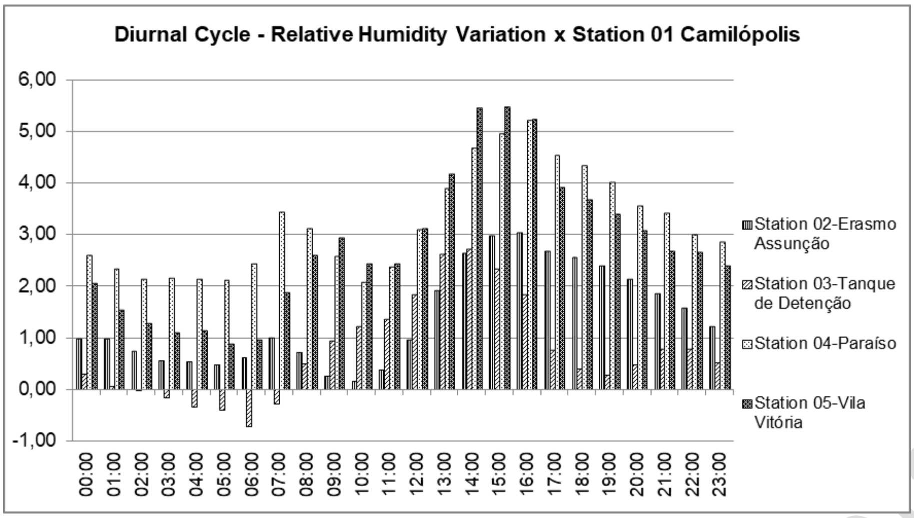


Figure 12 - Diurnal cycle average Relative humidity: Difference in relation to Station 01 – *Camilópolis*. Source: authors based on SEMASA data, as referred on table 1.

3.4 Bioclimatic Strategies for Santo André – SP

Figure 13 synthesizes the average bulb temperature and relative humidity for each month of the year as well as the comfort zone (horizontal gray line).

The temperature is near the comfort zone during only a short period of the year, and the differences to comfort zone are higher in June and July. Other relevant information is that dry bulb temperature is maximum between 12 and 16 o'clock, wereas the dew point temperature is fairly constant during the day.

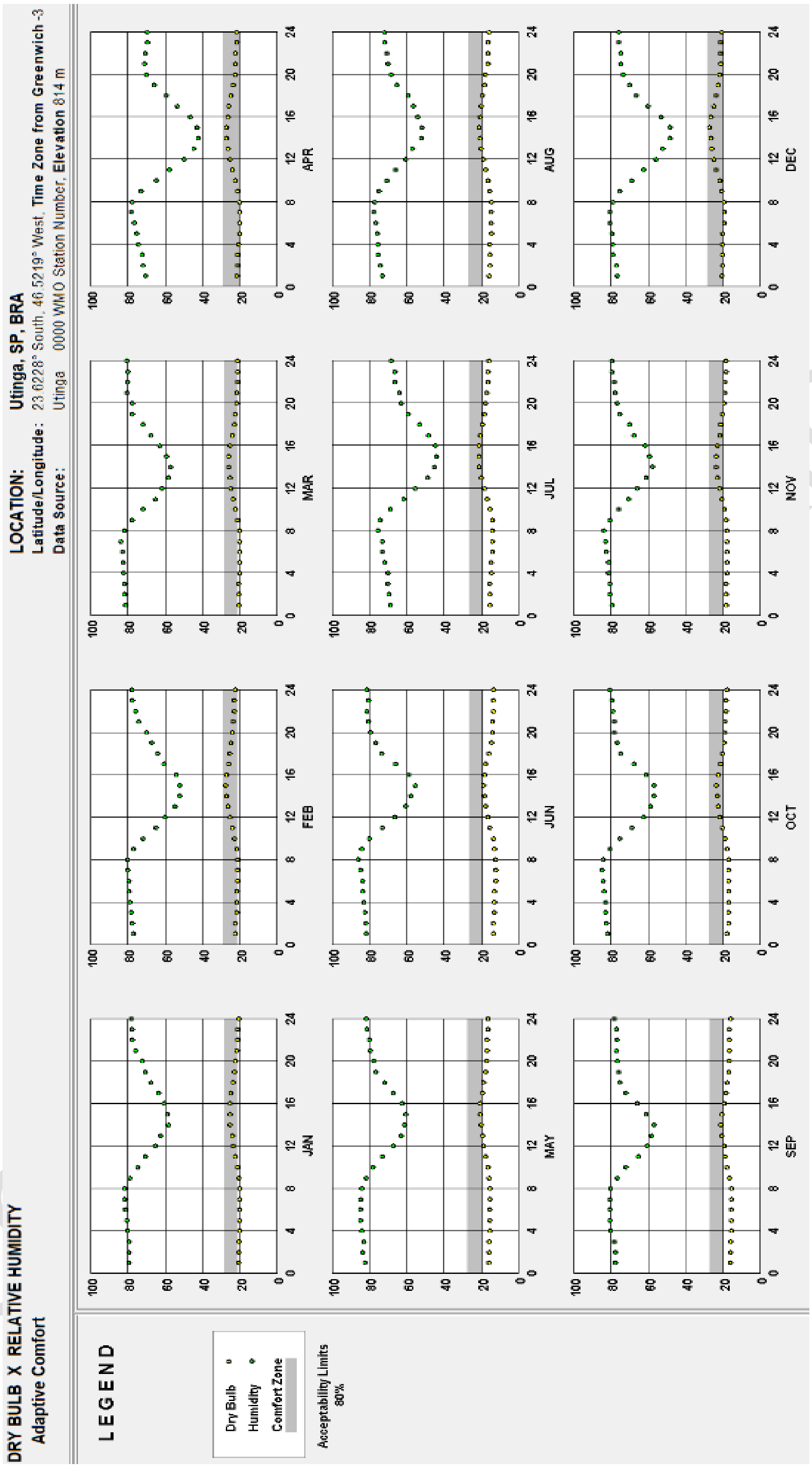


Figure 13 - Average dry bulb temperature and relative humidity graphs for the Station 01-Camilópolis (Utinga) Santo André. Source: authors based on SEMASA data, as referred on table 1.

A bioclimatic diagram (or psychrometric chart) was derived for the Station 01 – *Camilópolis* (**Figure 14**).

The Urban Master Plan classify the area as an urban qualification zone (i.e. areas where the objectives are the maintenance of existing non-residential uses, the promotion of productive activities, and the diversification of uses or moderate population density). In **Figure 14** the x-axis represents the dry bulb temperature and the y-axis shows the fresh air humidity, and the psychrometric curves represent the relative humidity.

The challenge is to define climatic conditions and the related architectural strategies to transform the environmental conditions of the house into the comfort zone, giving priority to passive strategies (zero energy consumption). Strategies will be used to reduce energy consumption to heat or cold the indoors environment (active strategies) when passive solution is not possible. When applied, the design strategies contribute to improve the comfort. Therefore, a set of design guidelines is applied to the area for which the climate file as analyzed. As stressed before, there are low and high temperatures, respectively in winter and summer. For the climate pattern of the area, the results reveal that adaptive comfort requires active strategies. If only passive strategies are applied, no more than 32% of the thermal comfort is achieved.

The analysis performed take into account that there is an Adaptive Comfort model, with naturally ventilated spaces, where the occupants are able to control the openings and their thermal response depend in part on the outdoor climate. Two importants assumptions area considered: (i) the occupants adapt their clothes to the thermal conditions, and (ii) are sedentary (1.0 to 1.3 met). The interval of the comfort zone is between temperatures of 18.9 and 28.8 °C (**Figure 14**).

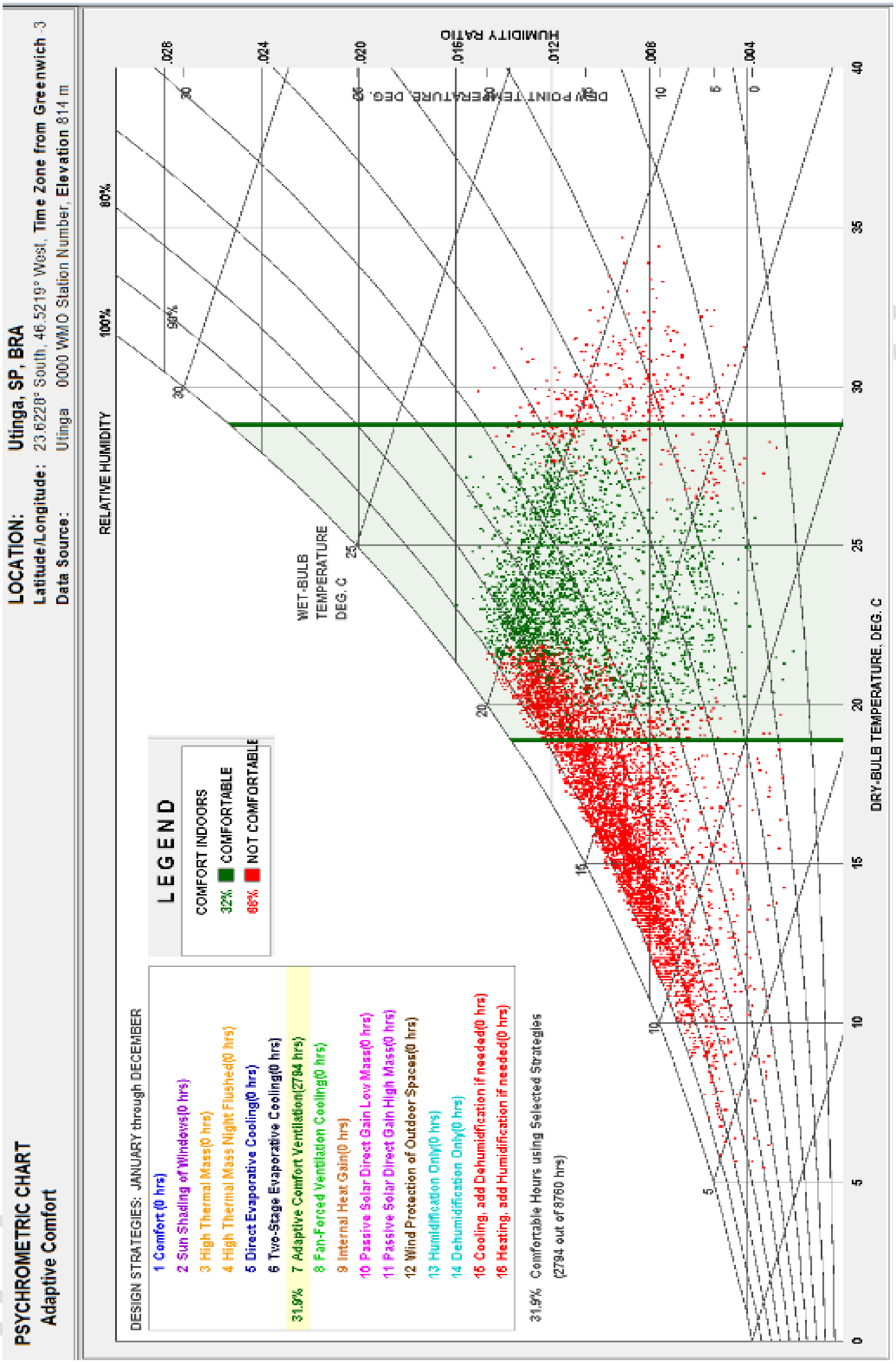


Figure 14 - Psychrometric chart for the Station 01 – *Camilópolis* (Utinga) area, from Santo André with indicated strategies. Source: authors based on SEMASA data, as referred on table 1.

The climate data analysis leads to strategies for the area surrounding Station 01, and comprise guidelines for housing and urban design projects (**Table 2**).

Table 2 - Bioclimatic Strategies for Santo André-SP.

Strategy 17:
Heat should be minimized (mainly on west) by using plant materials (trees, buches, ivy-covered wall).

Strategy 32:
Reduce the heat in the afternoon during summer and fall avoiding west facing glazing.

Strategy 33:
Increase cross ventilation in temperate and hot humid climates using long narrow building floorplan.

Strategy 34:
Use exterior wingwalls and planting to capture natural ventilation by changing wind direction up to 45 degrees toward the building.

Strategy 35:
Shade and oriente windows in such a way that breezes can be captured to improve natural ventilation and reduce or eliminate active system (cooling device)

Strategy 36:
Cross ventilation should be considered by placing door and window on opposite sides of building with larger openings facing up-wind.

Strategy 37:
Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning.

Strategy 42:
On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8 °C) or more, thus less air conditioning is needed.

Strategy 47:
Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.

Strategy 49:
Maximize vertical height between air inlet and outlet (open stairwells, two story spaces, roof monitors) to produce stack ventilation, even when wind speeds are low.

Strategy 53:
Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes can extend living and working areas in warm weather.

Strategy 54:
Provide enough north glazing to balance daylighting and allow cross ventilation (about 5% of floor area).

Strategy 56:
Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems.

Strategy 58:
This is one of the more comfortable climates, so shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter.

There is a correlation between an increase in green areas and a reduction in local temperature [24], suggesting the augmentation of urban vegetation as an appropriate mitigation strategy for the UHI. Residual spaces that can be converted into green areas are scarce in metropolitan areas, so convert traditional black flat roofs into green ones could be a solution. Additionally, the increase of green roofs might lead to a better urban storm-water management, and improvement of air quality.

The strategies on **Table 2** suggest what should be done (some in the stage of project and other in existing building) to improve thermal comfort and minimize the use of active systems. It should be open to allow a range of broad solutions. For a basic description with illustraion of each strategy, reader should refers to Manzano-Agugliaro [10], and Elaouzy and Fadar [25]. Although, such studies do not cover the climate of Santo André-SP, which makes this study important. To complement the strategies in table 2, reader should consider a brazilian online platform to verify bioclimatic strategies, called PROJETEEE "*Projetando Edificações Energeticamente Eficientes*" (Designing Energetically Efficient Buildings), which brings together solutions for an efficient building Project [26].

Another recent works [27, 28], with suggestion for bioclimatic strategies, present tips (including illustration) concerning solutions to minimize the use of active comfort systems in an easy way in order to contribute for more resilient and sustainable environment.

4. Conclusions and Recommendations

Since the appropriate building and urban design can lead to energy conservation, the present study provides information for decision- and policy-makers on sustainability practices (i.e., increase energy efficience and reduce ecological footprint). As heating, ventilation and air conditioning (HVAC) are the main energy consumers in buildings, natural ventilation might be promoted by increasing the surrounding green area to increase the voids between buildings, and reduce high temperatures.

The analysis of each microclimate is necessary to check the effect of the surrounding elements (biophysical characteristics) on thermal comfort in different locations in a city. It was found that the microclimates of the study area require (1) natural ventilation strategies (cross ventilation) for energy saving, (2) adequate orientation of glazed façades; (3) inclusion of balconies and patios as well overhangs in roof, among other strategies able to eliminate (or at least reduce significantly) the use of cooling and heating devices.

Even located near the city of São Paulo, Santo André has different characteristics in terms of climate, which is why it is crucial to obtain climatic data to perform study concerning bioclimatic architectural strategies to guide building and urban development projects instead of using data from nearby climates.

For the climate pattern of the area, the results reveal that adaptive comfort requires active strategies. If only passive strategies are applied, no more than 32% of the thermal comfort is achieved.

Among the main recommendations of this work, the following must be highlighted given their feasibility (low cost) in the study area as well alignment with sustainable development goals:

- Urban vegetation should be used as an appropriate mitigation strategy for the UHI, as well conversion of black flat roofs into green ones
- West facing glazing should be avoided to reduce heat in the afternoon
- Capture of breezes by windows should be increased to improve natural ventilation and reduce or eliminate active system
- Cross ventilation must be promoted by placing door and window on opposite sides of building with larger openings facing up-wind
- Open plan interiors to promote natural cross ventilation (e.g., alternatives include louvered doors or jump ducts if privacy is required) must be used mainly in public and industrial buildings
- North glazing to balance daylighting and allow cross ventilation (about 5% of floor area) must be emphasized
- Providing screened porches and patios to make possible passive comfort cooling by ventilation as well prevent insect problems which is typical in the study area is of utmost importance.

This study allows architects and engineers to choose solutions suitable to the climate of the Santo André Urban Qualification Zone, during the process of designing new interventions in urban area.

Acknowledgment

This research was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Fundação Araucária de Apoio ao Desenvolvimento Científico e Tecnológico do Estado do Paraná, and PRPPG-UNILA.

References

1. Bugenings, L.A. and Kamari, A. (2022), Bioclimatic Architecture Strategies in Denmark: A Review of Current and Future Directions, *Buildings*, **12**, 224. https://doi.org/10.3390/buildings12020224

2. Ahangari, M. and Maerefat, M. (2019), An innovative PCM system for thermal comfort improvement and energy demand reduction in building under different climate conditions, *Sustainable Cities and Society,* **44**, 120-129. https://doi.org/10.1016/j.scs.2018.09.008

3. Daemei, A.B., Eghbali, S.R. and Khotbehsara, E.M. (2019), Bioclimatic design strategies: A guideline to enhance human thermal comfort in Cfa climate zones, *Journal of Building Engineering,* **25**, 100758. https://doi.org/10.1016/j.jobe.2019.100758

4. Nazarian, N., Acero, J.A. and Norford, L. (2019), Outdoor thermal comfort autonomy: Performance metrics for climate-conscious urban design, *Building and Environment,* **155**, 145-160. https://doi.org/10.1016/j.buildenv.2019.03.028

5. Li, B., Du, C., Yao, R., Yu, W. and Costanzo, V. (2018), Indoor thermal environments in chinese residential buildings responding to the diversity of climates, *Applied Thermal Engineering,* **129**, 693–708. https://doi.org/10.1016/j.applthermaleng.2017.10.072

6. Ulpiani, G., Di Giuseppe, E., Di Perna, C., D'Orazio, M. and Zinzi, M. Thermal comfort improvement in urban spaces with water spray systems: Field measurements and survey, *Building and Environment,* **156**, 46-61. https://doi.org/10.1016/j.buildenv.2019.04.007

7. Santamouris, M. (2014), Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, *Solar Energy*, **103**, 682-703. https://doi.org/10.1016/j.solener.2012.07.003

8. Latha, P.K., Darshana, Y. and Venugopal, V. (2015), Role of building material in thermal comfort in tropical climates – A review, *Journal of Building Engineering*, **3**, 104-113. https://doi.org/10.1016/j.jobe.2015.06.003

9. Coccolo, S., Pearlmutter, D., Kaempf, J. and Scartezzini, J-L. (2018), Thermal Comfort Maps to estimate the impact of urban greening on the outdoor human comfort, *Urban Forestry & Urban Greening*, **35**, 91-105. https://doi.org/10.1016/j.ufug.2018.08.007

10. Manzano-Agugliaro, F., Montoya, F. G., Sabio-Ortega, A. and García-Cruz, A. (2015), Review of bioclimatic architecture strategies for achieving thermal comfort, *Renewable and Sustainable Energy Reviews*, **49**, 736–755. https://doi.org/10.1016/j.rser.2015.04.095

11. Valverde, M. C. et al. (2020), Urban climate assessment in the ABC Paulista Region of São Paulo, Brazil, *Science of the Total Environment*, **735**, 139303. https://doi.org/10.1016/j.scitotenv.2020.139303

12. Lima, G. N. and Rueda, V. O. M. (2018), The urban growth of the metropolitan area of São Paulo and its impact on the climate, *Weather and Climate Extremes*, **21**, 17–26. https://doi.org/10.1016/j.wace.2018.05.002

13. Município de São Bernardo do Campo (MSBC). (2019), **Capítulo I: Geografia E Meio Ambiente,** [Chapter I: Geography and Environment] Painel Estatístico 2019/ Ano Base 2018. https://www.saobernardo.sp.gov.br/painelestatistico/-/document_library_display/hmqHL6AVBmN8/view_file/975680 May. 30, 2020.

14. Empresa Paulista de Planejamento Metropolitano (EMPLASA). (2019), **Sobre a RMSP** [On the RMSP]. https://www.emplasa.sp.gov.br/RMSP.

15. Sacht, H. M. Meteorological Stations Map - Santo André. Google My Maps, 2021. https://www.google.com/maps/d/u/0/viewer?mid=1bVPTTEDfGwzsyRk4TgIBYui-V9iz59pI&hl=pt-BR&ll=-23.654553853295642%2C-46.52385000000001&z=13

16. World Meteorological Organization, WMO. (1966), **Climatic Change: report of a working group of the Commission for Climatology, Technical Note** Nº 79, WMO - Nº 195.TP100, 79 pp. Available at: https://library.wmo.int/doc_num.php?explnum_id=865

17. Mata-Lima, H., Mata, I.P. and Lima, A.V.F. (2005), Aplicação e validação de um simulador estocástico de variáveis climáticas. O caso da precipitação, ***Ingenieria de*** , **12**, 27–37. https://doi.org/10.4995/ia.2005.2549

18. Pajek, L. and Košir, M. (2019). Implications of present and upcoming changes in bioclimatic potential for energy performance of residential buildings, *Building and Environment*, **127**, 157-172. https://doi.org/10.1016/j.buildenv.2017.10.040

19. NATIONAL CLIMATIC DATA CENTER, NCDC. (1976), **Test Reference Year (TRY):** tape reference manual, TD-9706. Asheville. North Carolina: National Climatic Data Centre, US Department of Commerce. Manual.

20. Hand, J.W., Crawley, D.B.; Donn, M. and Lawrie, L.K. (2005), Improving the Data Available Available in: to Simulation Programs. Ninth International IBPSA Conference Montréal, Canada. August 15-18. Available at: https://publications.ibpsa.org/proceedings/bs/2005/papers/bs2005_0373_380.pdf

21. Milne, M. (2015), Energy Design Tools. Climate Consultant. Department of Architecture and Urban Design –University of California, Los Angeles, UCLA. http://www.energy-design-tools.aud.ucla.edu

22. Reboita, M.S., M. S., GAN, M.A., Rocha, R. P. and Ambrizzi, T. (2010), Regimes de precipitação na América do Sul: uma revisão bibliográfica, *Revista Brasileira de Meteorologia*, **25**, 185-204. https://www.scielo.br/pdf/rbmet/v25n2/a04v25n2.pdf

23. Pereira Filho, A. J., Santos, P.M., Camargo, R.; Festa, M., Funari, F.L., Salum, S.T., Oliveira, C.T. Santos, E. M., Lourenço, P.R., Silva, E. G., Garcia, W., Fialho, M.A. (2007), Impactos antrópicos no clima da Região Metropolitana de São Paulo [Anthropogenic impacts on the climate of the São Paulo Metropolitan Region], *Boletim da Sociedade Brasileira de Meteorologia*, **30**, 48-56. https://nossasaopaulo.org.br/sites/default/files/biblioteca/impactos_antropicos_clima.pdf

24. Takebayashiand, H. and Moriyama, M. (2007), Surface heat budget on green roof and high reflection roof for mitigation of urban heat island, *Building and Environment*, **42**, 2971-2979. https://doi.org/10.1016/j.buildenv.2006.06.017

25. Elaouzy, Y. and Fadar, A. (2022), Impact of key bioclimatic design strategies on buildings' performance in dominant climates worldwide, *Energy for Sustainable Development*, **68**, 532-549, https://doi.org/10.1016/j.esd.2022.05.006

26. BRASIL, Ministério do Meio Ambiente (MMA). (2022), LabEEE - Laboratório de Eficiência Energética em Edificações. Projeteee – Projetando Edificações Energeticamente Eficientes. Available at: http://www.mme.gov.br/projeteee/sobre-o-projeteee/ Accessed on: 31 Out. 2022.

27. Silva, C. and Góes, T. (Org.). (2022), **Dicas bioclimáticas para um projeto mais sustentável** (Bioclimatic tips: to guide sustainable design projects). LaSUS FAU. Brasília: Editora Universidade de Brasília. Available at: https://livros.unb.br/index.php/portal/catalog/book/273 Accessed on: 31 Out. 2022.

28. Santy, Matsumoto, H., Tsuzuki, K. and Susanti, L. (2017), Bioclimatic - Design Stage of Passive House in Indonesia, *Buildings*, *7*, 24. https://doi.org/10.3390/buildings7010024