INVESTIGATING THE EFFECTS OF CLIMATE DATA TYPOLOGY ON THE RESULTING BIOCLIMATIC STRATEGIES: APPLICATION OF BCCHART TOOL

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ABSTRACT

The recent study aims to investigate the bioclimatic potential of three Brazilian cities: Florianópolis-SC, Curitiba-PR and São Paulo-SP, using the BcChart tool. Hence, the bioclimatic potential is determined using Olgyay's charts to define appropriate passive building design strategies. The study compares the results obtained by two different climate file types: TMY and TRY. The results show that the climatic behavior between the different files is similar, with average differences in average temperatures around 1.0°C in Florianópolis and São Paulo. However, in Curitiba, these differences reach 4.0°C in October and December. Concerning the bioclimatic potential, the natural ventilation duration in the warmer months is longer when using the TMY and shorter when applying the TRY file. Using different climate files resulted in higher differences between the needed shading, demonstrating that the TMY includes higher temperatures than the TRY. In particular, in São Paulo, the shading should be used for differently long periods, namely 56.10% when using the TMY and 42.20% when the TRY. It was confirmed that BcChart could be used for bioclimatic potential in Brazilian temperate climates. However, applying different climate file types may result in different bioclimatic potential, especially on the monthly level. The results suggest that climate file types must be chosen thoughtfully in order to analyze thermal performance and design climate-adapted buildings precisely.

Key words: Bioclimatic Potential, Olgyay's Charts, Climate Files, Temperate Climate.

1. INTRODUCTION

With a constant need to design thermally comfortable and energy-efficient buildings, the bioclimatic design could support designers with the best strategies for a specific location. Using passive strategies, such as shading, passive solar heating and natural ventilation, could increase the indoor comfort level of non-conditioned buildings and simultaneously reduce energy demand. The bioclimatic design applies basic architectonic concepts to take advantage of the climate and ensure minimal comfort levels in the built environment (MACIEL; FORD; LAMBERTS, 2007).

The bioclimatic architecture, which is often overlooked in the early design phases, has been an object of study in numerous recent analyses. Examples, where bioclimatic charts were used in basic investigations are presented by Austin et al. (2020) in Panama-PR in Brasil, Widera (2021) in sub-Saharan Africa and Santy et al. (2017) in Indonesia. The bioclimatic charts suit to analyze if the region and its climate could reach an adequate thermal comfort level and which strategies fit better in these conditions (GIVONI, 1992; AL-AZRI; ZURIGAT; AL-RAWAHI, 2013; MARTINEZ; FREIXANET, 2014).

The discussion of the suitable bioclimatic strategies for a particular location can initiate the analysis of the bioclimatic charts developed by Olgyay (OLGYAY, 1963) and Givoni (GIVONI, 1992). The bioclimatic charts are used to graphically and quantitatively demonstrate the strategies that should be used for a region in each month to achieve human thermal comfort. The first attempt to work with bioclimatic charts was the Olgyay chart back in the 1960s. This method considers the outdoor conditions with a fixed level of clothing and body metabolism (AL-AZRI; ZURIGAT; AL-RAWAHI, 2012; PAJEK; KOSIR, 2017). The comfort range is constant at 20-30°C (WIDERA, 2021).

Givoni's charts were developed to address the limitations associated with Olgyay's, as the indoor temperature considerations, making possible climatic charts in arid and hot regions. For these climate patterns, unconditioned building's indoor temperature is generally higher than outdoors at night and the opposite during the day, which explains Olgyay's method limitations (GIVONI, 1992). Givoni based his chart on the linear relationship between vapor pressure and temperature amplitude of outdoor air to identify the appropriate cooling strategy (AL-AZRI; ZURIGAT; AL-RAWAHI, 2012). Many papers focused on comparing and discussing the two methods to obtain bioclimatic charts (SANTY *et al.*, 201; WIDERA, 2021). Nevertheless, when correctly applied, Olgyay's charts present similar results to Givoni's (PAJEK; KOSIR, 2017).

Pajek and Kosir (2017) evaluated bioclimatic potential in 21 locations in the Alpine-Adriatic region. The authors used basic climatic information to plot Olgyay charts, concluding that solar irradiance has an important influence on the results. Then, energy simulations were performed in five different locations, which corroborate that the method facilitates the design of energy-efficient buildings. Therefore, it is necessary to incorporate bioclimatic design and study ways to determine energy efficiency strategies in early design phases. By bioclimatic potential, the period when passive building design strategies can assure indoor comfort is determined (PAJEK; KOSIR, 2017; GUARDA *et al.*, 2019; PAJEK *et al.*, 2019).

Pajek and Kosir (2018) also investigated the climate change impacts on the bioclimatic design, using future climatic files to evaluate the building behavior. As expected, buildings in Slovenia's temperate climate are more likely to increase the cooling demand, making the actual bioclimatic solution less relevant. Guarda, Kramer e Ordenes (2020) applied a similar approach to analyze the bioclimatic potential in future scenarios for the southern Brazilian city Florianópolis. The results also indicate the increased need for active strategies, mainly by using mechanical cooling.

Both methods, Olgyay's and Givoni's, use the studied location's meteorological data as a necessary input to bioclimatic charts. Because the data may vary concerning the period and the weather station location, the results could be different for each climate file type and should be considered. The most commonly used climate files are the Test Reference Year (TRY) and the Typical Meteorological Year (TMY). TRY represents one single year selected to be the most representative of a specific location (SCHELLER *et al.*, 2015). TMY represents data sets for typical year behavior, including hourly values of solar radiation and meteorological elements. Therefore, investigating the different climate file types is important to understand the specific region's bioclimatic potential.

Within this context, discussions on bioclimatic potential, mainly using the Olgyay's method, have been resumed recently, and the complexity of the method could become a limitation for investigations in different regions and climates. This research introduces the demonstration and the optimization of the method. The BcChart tool (PAJEK; KOSIR, 2017) is used to build the bioclimatic charts and analyze the indicated strategies, considering the temperate climate zone. This tool allows designers to quantify the bioclimatic potential and plan passive strategies in the early stages of the project. Besides, it could contribute to environmental comfort teaching activities, which allows exploring the impact of climate on design strategies.

2. OBJECTIVE

The purpose of this paper is to investigate the bioclimatic potential for Florianópolis-SC, Curitiba-PR and São Paulo Brazilian cities belonging to the temperate climate through Olgyay charts using two types of climatic files: TMY and TRY. The differences between climate file types could directly impact the bioclimatic potential results and the corresponding comfort zone duration. Also, the research aims to apply the BcChart tool for the Brazilian climate to demonstrate the method's optimization while using it.

3. METHOD

3.1. Elaboration of Bioclimatic Potential Through Olgyay Method

Olgyay (1963) proposed a bioclimatic chart to investigate strategies to adapt building to climate using climate data. In order to optimize and facilitate the use of the method, the tool presented and validated in the works developed by Pajek and Kosir (2017 and 2018) is adopted.

Version 2.2 of BcChart software developed at the University of Ljubljana in Slovenia was used to investigate the bioclimatic potential and translate it into design strategies. The software uses Olgyay's bioclimatic charts as the fundamental theory (Olgyay, 1963). Its interface was developed in an MS Excel environment, optimizing the methodological process of the Olgyay method.

As an input, the studied region's climate file in the form of EnergyPlus Weather (EPW) file is needed. Mainly, the average daily maximum dry bulb temperature (°C), average daily minimum dry bulb temperature (°C), average daily minimum relative humidity (%), average daily maximum relative humidity (%), average global daily irradiance on the horizontal plane (W/m²) and maximum global daily irradiance on the horizontal plane (W/m²) are considered. In addition to these parameters, the bioclimatic chart considers human comfort, which is calculated for an average person, with regular clothes (1clo), with sedentary or light muscular metabolic activity (126W) and the air movement is considered to be 0.45-0.90 m/s.

In general, the bioclimatic chart features three zones: Comfort Zone (Cz), Shading Needed (Sh) and Sun Needed (Sn). The Comfort Zone, according to Olgyay's method (1963), has an air temperature range from 21°C to 27°C and relative humidity of 18% to 77%. If these limits are exceeded, the comfort may be reached by applying strategies, such as external shading (comfort achieved with shading - Csh) and/or direct solar gains (comfort achieved with solar irradiation - Csn).

Consequently, temperatures and humidity above this limit will result in Shading Needed (Sh) and, if below, Sun Needed (Sn). Alternatively, thermal comfort may be achieved by mechanical cooling and/or dehumidification (Q), passive solutions for hot arid climates (A), natural ventilation and/or high thermal mass (M) and only natural ventilation (V) for Sh. For Sn, the necessary strategies are passive solar heating (R) and conventional heating, focus on heat retention (H).

The main result of BcChart is the bioclimatic potential expressed in percentages of hours required to reach the comfort zone. Finally, the Olgyay's method and that of BcChart have limitations because the bioclimatic chart is directly applicable to the temperate climatic zone and elevations not exceeding 300 m. However, in order to apply the tool in the Brazilian context, locations higher than 300m were used. It was verified that this criterion had no significant impact on the bioclimatic potential results.

3.2. Climate context

Three Brazilian cities were selected to perform the Olgyay's method: Florianópolis-SC, Curitiba-PR and São Paulo-SP. All of them are located in the Atlantic Forest Biome, distributed among the regions South (Florianópolis and Curitiba) and Southeast (São Paulo). The altitudes are 15m, 935m and 745m, respectively. According to the Koppen-Geiger classification, Florianópolis and São Paulo belong to the hot humid temperate climate type, with hot summer (Cfa). Curitiba is located in a temperate oceanic climate (Cfb) (KOTTEK et al., 2006).

The climatic data were obtained from the Repository of free climate data for building performance simulation in EPW extension to all locations analyzed (CRAWLEY; LAWRIE, 2021). The chosen climate files belong to the Typical Meteorological Year (TMY) data set, and the Test Reference Year (TRY), with periods considered from 2004 to 2018 and the year 2005, respectively. The intention is to investigate the different periods for the data sets.

4. RESULTS

4.1 Climate profile analysis for the climate files TMY and TRY

The climatic profile of Florianópolis consists of mild temperatures in May, June, July and August, with minimum average temperatures around 14.7°C for TMY and 13.8°C for TRY. Hot temperatures are more common in January, February and March, with maximum average temperatures of 28.4°C for TMY and 28.6°C for TRY. However, it is observed that the most significant differences between the climatic files are in the thermal amplitudes, namely in June 6.7°C for TRY and 9.9°C for TMY, a difference of 3.2°C (Figure 1-A).

Likewise, Curitiba presents a climate profile with mild temperatures, despite the colder temperatures in May, June, July and August. The minimum average temperatures are 9.9°C for the TMY file and 8.8°C for the TRY file. The hotter temperatures prevail from November to April, especially January and February, with a maximum average temperature of 26.3°C for the TMY file and 26.3°C for the TRY file. The climate files are similar, though the difference peak of 4°C in October. The more significant differences occur because of the thermal amplitude, which exceeds 10°C for July, August, September and January in the TRY file. For the TMY file, only August present 11.80°C as maximum thermal amplitude (Figure 1-B). The minimal and maximal temperatures presented in Figure 1 represent the average temperatures between the TRY and the TMY files.

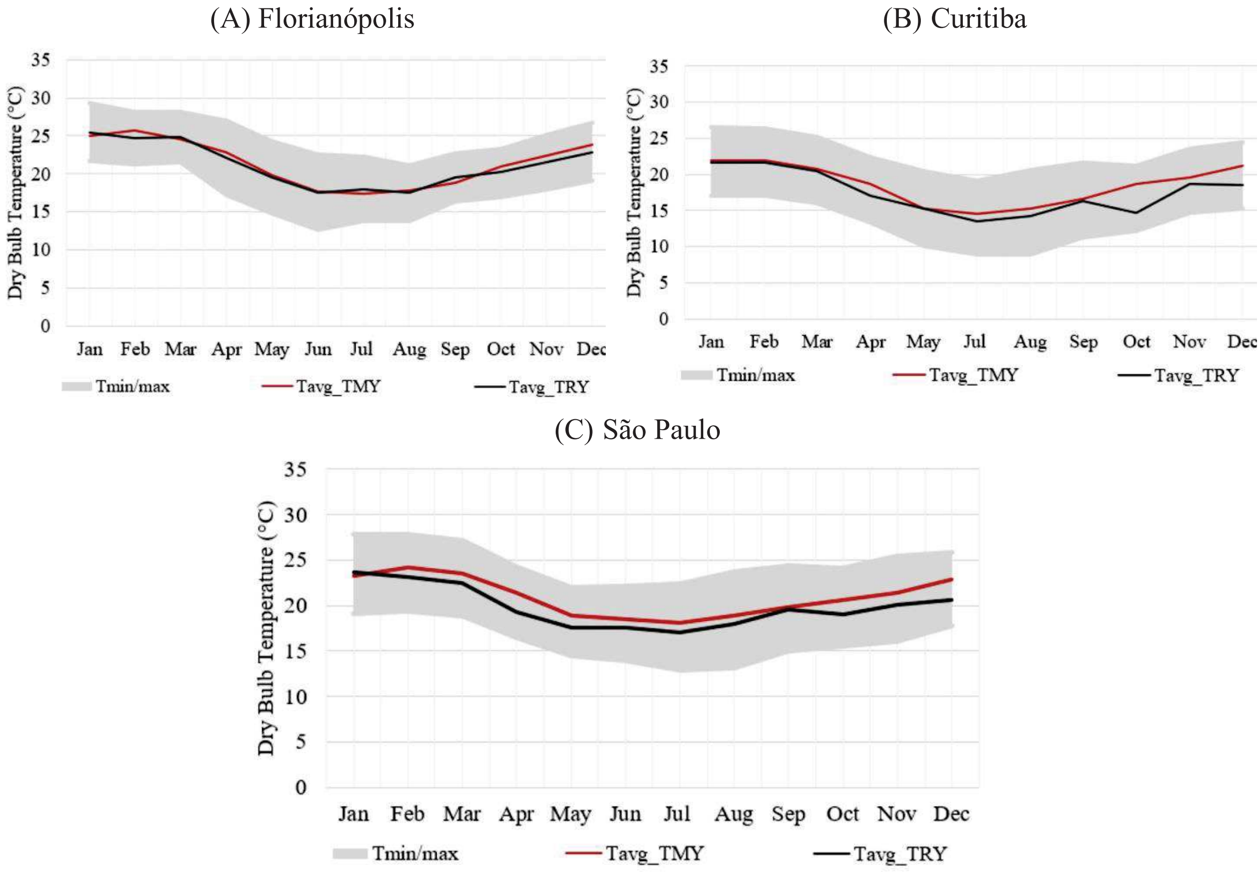

Figure 1 – Climate profile of Florianópolis (A), Curitiba (B) and São Paulo (C)

The climate in São Paulo presents similar characteristics to Florianópolis, with higher average temperatures of 20.8°C and 26.8°C in January and 27.2°C and 28.5°C in February, from TRY and TMY, respectively. July and August show average temperatures of 12.1°C and 13.3°C, concerning the TRY file. The climate files are similar, with average air temperature differences around 1.0°C, except in April, when this difference is 2.1°C (Figure 1-C). Regarding the temperature amplitude, higher values were obtained in the TRY file, mainly in July, August and September, 10.0°C, 11.3°C and 10.3°C, respectively. In the TMY file, the amplitudes did not exceed the 9.5°C.

Therefore, the climate profiles among the cities and analyzed climate files are similar. The average temperature differences between the files were around 1.0°C in Florianópolis and 4.0°C in Curitiba. This average temperature difference in Curitiba impacts in its bioclimatic potencial and passive strategies that should be used, also influenced by the climate file chosen.The same behavior is observed in São Paulo, especially in October, November and December, but with lower differences. It is important to decide which climate file will be used to investigate the bioclimatic strategies, as these differences can directly impact the results.

4.2 Bioclimatic Potential Analysis

In Florianópolis, Curitiba and São Paulo, the strategies of mechanical cooling and/or dehumidification (Q), passive solutions for hot arid climates (A) and conventional heating with heat retention (H), were not considered since their potential to reach the comfort zone obtained was 0%, in both climate file types and all the analyzed months.

In Florianópolis (Figure 2-A), for January, February and March, the results suggest that 100% of the time, natural ventilation is needed (V) concerning both climate file types. The results relate to the fact that the external temperatures are higher in these months, characterizing the summer. In December and April, a 13% and 18% difference, respectively, is noticed between the TRY and TMY climate files (Figure 2-A). The TMY climate file has average temperatures higher than TRY, reaching differences of up to 0.7°C in April and 1.0°C in December. The TMY climate file contains more recent data than TRY, and due to a warming climate, it may include higher air temperatures.

Consequently, the recommended bioclimatic design strategies are affected. The importance of shading is not limited only to the hottest months. There is 100% demand for natural ventilation (V) and the shading strategy (S) in the summer season. The latter occurrence extends to April, May, October and November, with the demand of 90%, 41%, 62% and 82%, respectively, considering the TMY file. For TRY, the demand for this strategy also occurs but with lower values (Figure 2-A). Considering the months with mild temperatures, such as June, July and August, the potential for S strategy was on average 7% for TMY and 15.6% for TRY. In addition, it is observed that in these months, the air temperatures showed higher values in the TRY, significantly for July, where the differences between the files were 0.6 ° C, characterizing a winter less severe in the TRY than in the TMY.

In São Paulo, the Shading (S) strategy is required during the entire year, for both climate files, with more significant percentages for the TMY file. The percentages needed in the TMY file were 91%, 97% and 92% for January, February and March, respectively. Considering the TRY file, they were 84%, 85% and 75%, respectively. The natural ventilation strategy is required only in January, February and March, for both climate files and in December for the TMY file. This strategy has greater values than 51% only in February of the TRY file, namely 83% (Figure 2-C).

Unlike the other two cities, the natural ventilation (V) strategy in Curitiba is required only in January and February, for both climate file types and also in December for the TMY file. Compared to the TRY file, the ventilation percentages in January for the TMY are 59% higher. The external temperatures of the TMY are higher than that of the TRY by 0.3°C, in January. This same behavior is observed in shading (S), in which higher percentages are noted in the hottest months: January, February and March. In the TMY file, the percentage of shading need is higher, especially in January with 71%. For the TRY, it occurs at lower values, i.e. 62% for the same month (Figure 1-C).

Unlike ventilation and shading strategies, which are cooling strategies for buildings, the passive solar heating (R) strategy presented higher percentages when using the TRY than the TMY and extended until December in Florianópolis. These differences between the files were more significant in July, with the value of 80% in the TRY and 66% in the TMY (Figure 2-A). This difference extends to September, October, November and December, with an average of 6.75%. The application of passive solar heating strategy becomes important to reach the comfort zone, especially when considering the climate file with older data and that includes lower temperatures, the TRY.

The passive solar heating (R) strategy is required throughout all year for both climate files in Curitiba. The TMY presents lower R values, probably because this file has more recent data. Consequently, the need for cooling is higher than that for heating. The higher values for passive solar heating strategy are noticed in May, June, July, August and September (Figure 2-B).

For São Paulo, a passive solar heating strategy is required in all the months, but with higher percentages only in the colder months, such as April, May and June for the TRY file. Considerable differences are noted among the climate file types, with -35%, -46% and -37%, for the respectively months in the TMY file (Figure 2-C).

(A) Florianópolis - TMY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	100	100	100	90	41	5	4	12	24	62	82	100
V	100	100	100	75	0	0	0	0	0	33	50	100
R	0	0	0	10	59	95	66	88	76	38	18	0
M	0	0	0	15	0	0	0	0	0	28	32	0
Csh	0	0	0	0	41	5	4	12	24	1	0	0
Csn	0	0	0	0	0	0	30	0	0	0	0	0

(A) Florianópolis - TRY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	100	100	100	69	40	19	20	8	37	48	69	87
V	100	100	100	57	0	0	0	0	19	27	69	87
R	0	0	0	31	60	81	80	92	63	52	31	13
M	0	0	0	12	0	0	0	0	18	21	0	0
Csh	0	0	0	0	40	19	20	0	0	0	0	0
Csn	0	0	0	0	0	0	0	0	0	0	0	0

(B) Curitiba - TMY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	71	68	54	30	0	0	0	2	5	31	39	60
V	71	34	0	0	0	0	0	0	0	0	0	34
R	29	32	46	50	62	63	71	64	95	69	61	40
M	0	34	0	0	0	0	0	0	0	0	0	26
Csh	0	0	54	30	0	0	0	2	5	31	39	0
Csn	0	0	0	20	38	37	29	34	0	0	0	0

(B) Curitiba - TRY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	62	66	51	5	0	0	0	0	11	0	29	28
V	12	53	0	0	0	0	0	0	0	0	0	0
R	39	34	49	95	69	78	74	65	89	75	71	72
M	29	13	0	0	0	0	0	0	0	0	0	0
Csh	20	0	51	5	0	0	0	0	11	0	29	28
Csn	0	0	0	0	31	22	26	35	0	25	0	0

(C) São Paulo - TMY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	91	97	92	61	27	20	21	31	40	51	60	85
V	34	51	45	0	0	0	0	0	0	0	0	20
R	10	4	8	30	45	49	52	51	44	39	35	15
M	51	45	45	0	0	0	0	0	0	0	0	33
Csh	5	0	3	61	27	20	21	31	40	51	60	32
Csn	0	0	0	9	28	31	27	18	16	10	5	0

(C) São Paulo - TRY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	84	85	75	35	9	14	13	24	40	32	46	52
V	49	83	56	0	0	0	0	0	0	0	0	0
R	16	15	25	65	91	86	57	57	48	68	44	39
M	35	2	19	0	0	0	0	0	0	0	0	0
Csh	0	0	0	35	9	14	13	24	40	32	46	52
Csn	0	0	0	0	0	0	30	19	12	0	10	9

Figure 2 - Bioclimatic Potential for Florianópolis (A), Curitiba (B) and São Paulo (C)

The high thermal mass (M) strategy is only required in some months of the year for the three cities analyzed. In Curitiba, the M value is 29% in January and 13% in February for the TRY and 34% in February and 26% in December for the TMY (Figure 1-B). In Florianópolis, the strategy is required only in April, October and November, with percentages lower than 35% in both climatic files (Figure 1-A). In São Paulo, this strategy has higher percentages using the TMY, reaching a difference of up to 43% compared to the TRY (Figure 1-C). This can be justified by the differences in external air temperatures among the files, where higher temperatures in TMY results in higher percentages of the strategy.

4.3 Analysis of the Comfort Zone Percentages (Cz)

The comfort zone (Cz) can be reached directly through the application of strategies that involve external shading (Sh) and/or direct solar gains (Sn).

In Florianópolis the months from May to October require external shading (Sh), with higher values in May (i.e. 41%) and September (i.e. 24%), considering the TMY. These values are lower if using the TRY, 40% and 8%, respectively. The utilization of direct solar gains (Sn) is only required in June at 31% and only for the TMY.

Therefore, the comfort zone is directly reached only in 10.0% of the time in case of the TMY and in 7.2% in case of the TRY. This condition is achieved when the air temperatures are between 21°C and 27°C and the relative humidity between 18% and 77% (Figure 3-A). In general, the bioclimatic potential presents differences of around two percentage points between the two climate files. The results for the TRY climate file showed higher values for the Sn than in the case of the TMY. The opposite is valid for the Sh value. The external temperatures and, mainly, the period considered in the climate files influence the comfort zone directly and the application of the strategies in buildings.

In Curitiba, on a yearly level, the comfort zone (Cz) is reached in 23.70% of the time for TRY and 26.60% for TMY (Figure 3-B). Involving direct solar gains (Sn), the strategies present higher percentages during the months with milder temperatures. The higher values are noticed in May, i.e. 38%, and June, i.e. 37%, considering the TMY. In the TRY, these values are lower, 31% and 22%, respectively. The external shading (Sh) strategies are required in January and November, with 54% and 39% of percentage hours for the TMY. In the TRY, these percentages are 0% for these months.

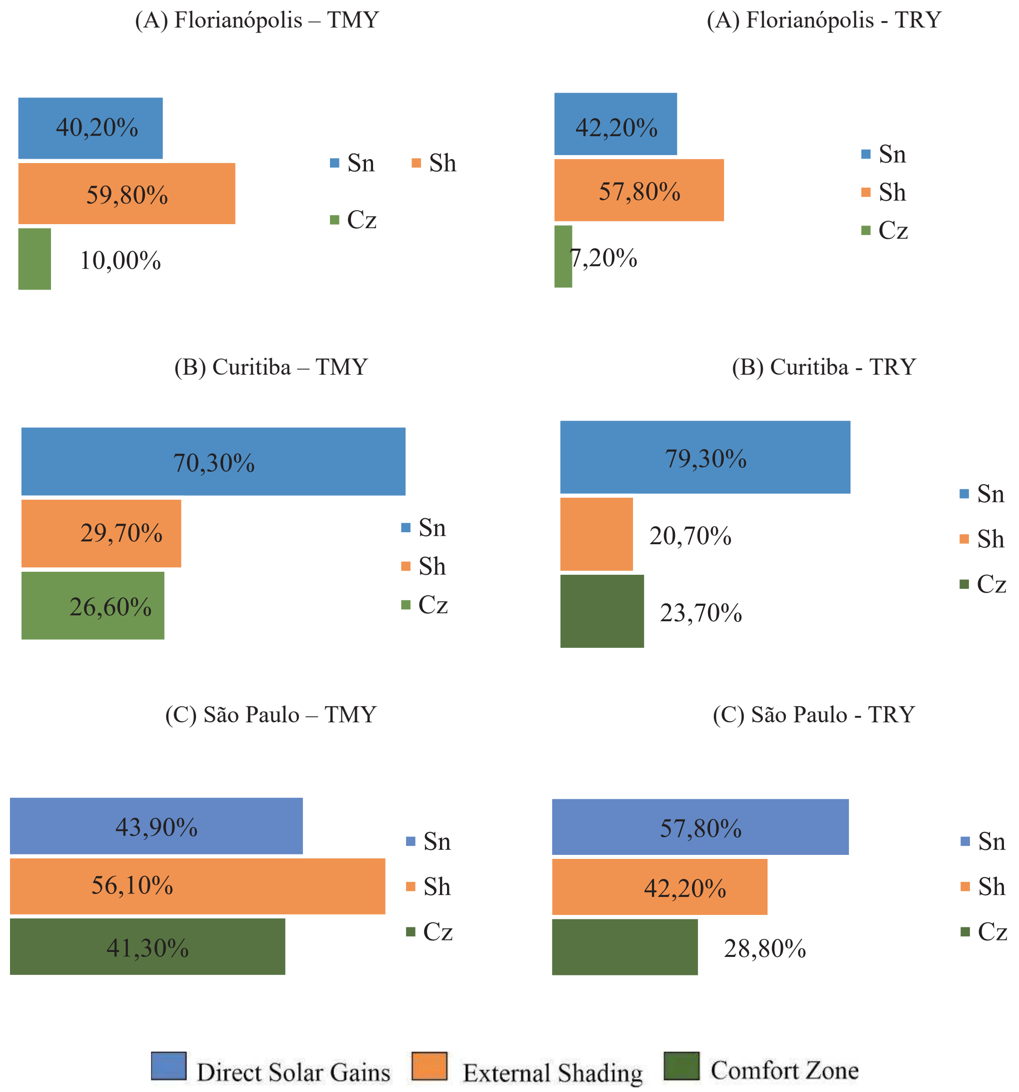

Figure 3 – Yearly profile of the recommended strategies for: (A) Florianópolis, (B) Curitiba and (C) São Paulo

Unlike the other cities, São Paulo presented a higher percentage of comfort hours in the case of TMY. It demonstrates that the need for external shading (Sh) and direct solar gains (Sn) are relatively similar, and the application of each strategy can be sized to be used in specific periods of the year. The strategies that involve direct solar gains (Sn) present higher percentages in the TRY, mainly in the months with milder temperatures. The external shading (Sh) is required in all months but with lower values concerning the TMY. In May, for example, the Sn value is equal to 91% (Figure 3-C). Considering the TMY, the needs for these strategies are different since Sh is required in all months. In this case, there are values greater than 40% from May to September. The Sn is not required only in the winter months, but also in October and November, with 10% and 5%.

Therefore, in cities with milder temperatures during the year, such as Curitiba and São Paulo, longer comfort zone duration may be reached. The balance between external shading (Sh) and/or direct solar gains (Sn) strategies is related to external temperature. In Florianópolis, the hottest temperatures from December to March require the application of external shading (Sh) strategies, reducing the percentages of hours in the comfort zone (Cz).

5. CONCLUSIONS

In the presented study, the BcChart tool was used to analyse the bioclimatic potential of three Brazilian cities. Furthermore, two different climate file types, namely the TMY and the TRY, were used in order to assess the differences and similarities between the two in the resulting bioclimatic potential. It was learned that using any of the climate files resulted in a relatively similar bioclimatic potential throughout the year for all the three cities analyzed.

In Curitiba and São Paulo, more evident differences between the results based on the TMY or the TRY file were noticed in October, November and December, namely spring and summer. However, in the TMY file, higher outside air temperatures are indicated compared to the TRY file. The latter can be justified by the time series (period 2004-2018) considered in the TMY file, while on the other hand, the TRY file refers to the year 2005. The results highlight the importance of considering different climate file types in building design mainly because climate adaptation results from the climate variables, particularly the temperatures.

The presented preliminary analysis of the implications of using different climate file types used to evaluate bioclimatic strategies is necessary. Applying different climate file types may result in different bioclimatic potential, especially on the monthly level. Therefore, the selection of climate file type impacts the bioclimatic potential concerning the thermal performance and climate adaptation of buildings.

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