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FREE COOLING POTENTIAL FOR DATA CENTERS IN BRAZIL

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Abstract. *Data Centers energy consumption has been increasing in alarming rates all around the world. The cooling system is responsible for about 40% of this electricity demand. An effective solution for this problem is the free cooling operation. This paper has analyzed the Data Center free cooling potential of 14 capitals cities from Brazil based on ASHRAE Thermal Guidelines climate ranges using Test Reference Year (TRY) weather data. Two climate parameters have been selected to define the free cooling zones on a psychrometric chart: upper Dry-bulb temperature and upper Dew-point temperature. The results have shown that cities such as Curitiba, São Paulo, Porto Alegre and Brasília have high potential to free cooling usage being able to operate in a compressor-less cooling for more than 3000 hours in a year, even when considering the most restrictive operation range. The North and Northeast region of the country have only presented viability of free cooling usage when considering the most flexible ranges. Furthermore, results have shown that the critical parameter to assess free cooling potential in Brazilian capitals is the Dew-point temperature.*

Keywords: *Data Center, Free cooling, Brazilian capitals, ASHRAE Thermal Guidelines.*

1. INTRODUCTION

Data Centers (DC) are facilities that houses computer systems and associated components, such as telecommunications, data storage systems and all kinds of Information Technology (IT) equipment. During the last years, many countries are experiencing rapid expansions in both the number and size of these facilities to meet their demands for Internet and cloud computing services (Ni and Bai, 2017).

Data Centers energy consumption has been increasing in alarming rates all around the world. Between 2000 and 2005 this value has doubled, from 2005 to 2010 it has got a new increase of 56%, even though the world has been facing an economical crisis. In 2010 Data Centers were estimated as responsible for about 1.8% of electricity use of the entire world (Zhang *et al.*, 2014), and it keeps growing. It is expected an increase of 15-20% per year in the near future (Amoabeng and Choi, 2016). In Latin America the DC market generated a turnover of US\$ 2.87 billion in 2017 where Brazil single-handed was responsible for 47.6% of this amount, which is expected to increase to US\$ 4.37 billion until 2021 (Exame, 2018).

The cooling system of a Data Center facility is indispensable to a proper operation of the IT equipment. In another hand, its consumption represents 30 to 50% of the entire facility energy demand as shown in Fig. 1. Free cooling is defined as the use of natural climate to cool the data center, which means a compressor-less operation commonly known as air-side economizer cycle. Free cooling is considered an effective solution for reducing the energy consumption of cooling systems when its operation is viable for a high number of hours in a year (Zhang *et al.*, 2014).

This work aims to provide a free cooling potential analysis in several capitals cities in Brazil. In order to do that, one has to define the required climate conditions to achieve free cooling. For that purpose, a research mainly based on ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) guidelines for Data Centers has been performed and thereafter free cooling zones have been defined on a psychrometric chart. Weather data from 14 Brazilian capitals has been retrieved to assess their hourly climate condition over a year.

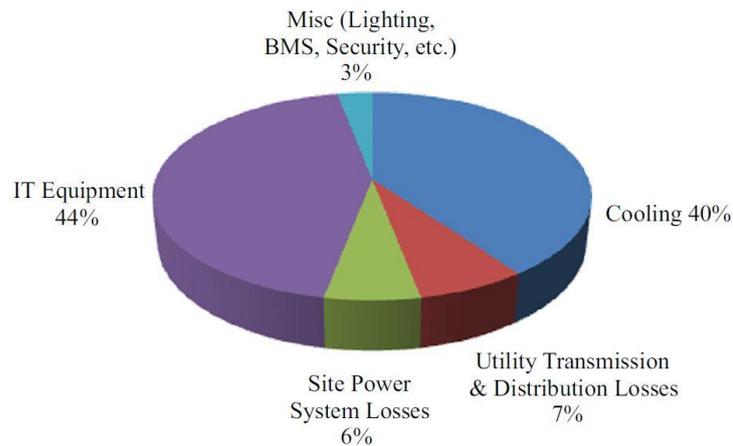


Figure 1. Example of Data Center energy split (Zhang *et al.*, 2014). Adapted from (Johnson and Marker, 2009).

2. METHODOLOGY

Figure 2 summarizes the entire procedure performed by this work in a flowchart. The following sections of this chapter detail each of these steps.

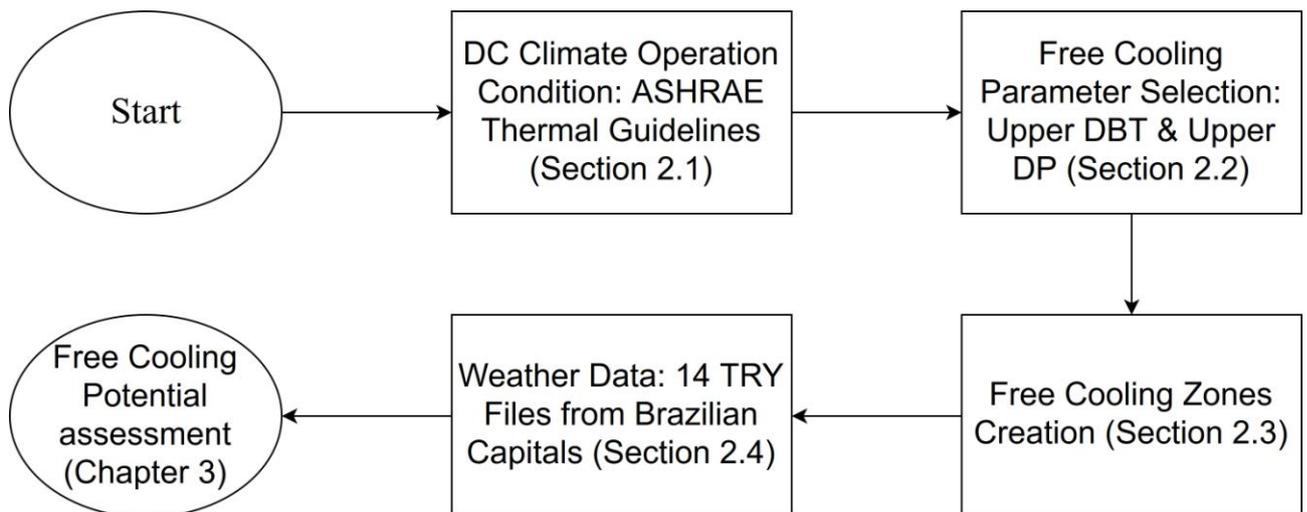


Figure 2. Methodology flowchart for the free cooling potential assessment.

2.1 DC Climate Operation Conditions

To evaluate the free cooling potential of a Data Center, one must specify the required climate conditions to achieve an acceptable and efficient operation. These conditions may vary depending of different classes of IT equipment. Nowadays the ASHRAE Thermal Guidelines are the most important reference for DC management and operation. In their most recent guidelines (ASHRAE TC9.9, 2015), it was featured thresholds of Dry-bulb temperature (DBT), Dew-point temperature (DP) and Relative Humidity (RH) for different classes of IT equipment as shown in Tab.1.

There are four different allowable classes presented in Tab. 1 and also the Recommended range. When it was first created, the Recommended range was intended to be the most reliable, acceptable and reasonable power-efficient operation zone. It was never meant to be the absolute limits of operation (ASHRAE TC9.9, 2011). As a result of the growing need to be more energy efficient, and consequently the interest to utilize economizers as much as possible during a year, the Allowable classes have been developed, reinforcing the idea that it is acceptable to operate outside the Recommended range but within the Allowable boundaries for short periods of time without affecting the overall reliability in the operation of the IT equipment (ASHRAE TC9.9, 2011). It is important to notice that the newer the equipment is, its climate operation zone tend to be more flexible and hence it should suit a broader class such as A3 or A4, while the older ones are more suited to operate within the A1 and A2 classes. It is also stated that this required

climate condition should be measured in the cold face of the IT equipment, *i.e.*, at the supplied air intake (ASHRAE TC9.9, 2015).

Table 1. Recommended and Allowable climate ranges for Data Center operation. Adapted from (ASHRAE TC9.9, 2015).

Range	DBT (°C)	DP (°C)	RH (%)
Recommended	18 to 27	-9 to 15	8 to 60
Allowable A1	15 to 32	-12 to 17	8 to 80
Allowable A2	10 to 35	-12 to 21	8 to 80
Allowable A3	5 to 40	-12 to 24	8 to 85
Allowable A4	5 to 45	-12 to 24	8 to 90

With the classes and limits defined by the Tab. 1, it is possible to plot that information on a psychrometric chart creating the operation envelopes. Figure 3 illustrates these envelopes of the Allowable and Recommended boundaries on a psychrometric chart.

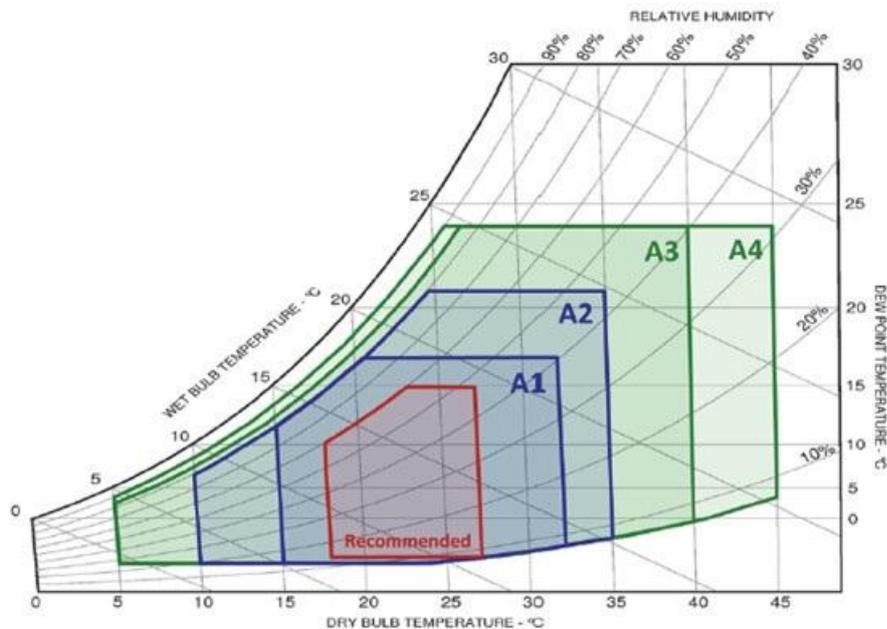


Figure 3. Allowable and Recommended operation envelopes on a psychrometric chart (Kontoyanis, 2016).

2.2 Free cooling parameters selection

Considering exclusively the zones inside the envelopes of Fig. 3 would have resulted in an underestimated free cooling potential. Some of the boundaries presented are meant to a compressor-cooling operation and, as a result of that, they should not be considered while assessing the possibility of free cooling. With some common assumptions it is possible to reduce the number of the climate parameters that are being analyzed and, therefore, simplify the analysis. Because of that, an in-depth look in the ASHRAE guidelines and DC climate condition parameters has been made.

The ASHRAE TC9.9 (2015) reduced the Relative Humidity limit (Tab. 1) to 8% as a consequence of different studies that questioned its necessity (Gao *et al.*, 2015; Hydeman and Swenson, 2010; Wan *et al.*, 2013). The main reason it was first considered as an important parameter in the operation was due to its relation with the Electrostatic Discharge (ESD). Gao *et al.* (2015) concluded that reducing the lower RH limit from 25% to 8% has indeed increased the probability of ESD failures but not at high rates, implying that the possible energy saves would be far more relevant than the increase on ESD risk. In Brazil, there are almost no occurrences of Relative Humidity values below 8%, furthermore, according to ASHRAE TC9.9 (2015) the lower RH limit should not be a problem if the Data Center had a decent level of electricity safety. Thus, it was decided to not include the lower RH limit while assessing the free cooling potential of cities in Brazil.

It is also possible to exclude the upper RH limit from the analysis using the assumption that if the Dew-point temperature did not exceed the upper limit of the operation envelope desired it would be possible to mix the inlet air with the one returning from the facility, reducing the RH level. This assumption agrees with the European free cooling maps methodology (The Green Grid, 2012).

For the Dry-bulb temperature, definitely the upper limit is the major issue. However, the lower limit should not be a problem for the operation. As stated in the ASHRAE TC9.9 (2011), the lower boundary of DBT is intended to prevent an extremely inefficient energetic operation while using compressor-cooling. In order to assess the free cooling potential that boundary is also unnecessary.

Therefore, to evaluate the free cooling potential of a Brazilian city just two parameters for the Allowable or Recommended ranges are necessary: upper Dry-bulb temperature limit and upper Dew-point temperature limit (which have been presented in Tab.1).

2.3 Free cooling zones

The two parameters for the free cooling analysis have been selected: upper Dry-bulb temperature and upper Dew-point temperature. If a climate condition had values lower than these two parameters, free cooling potential is considered achievable in that time. If not, it means that compressor-cooling is required or, at least, another auxiliary method of cooling is needed. Figure 4 illustrates the defined free cooling zone on a psychrometric chart considering the Recommended range and all the assumptions described in Section 2.2.

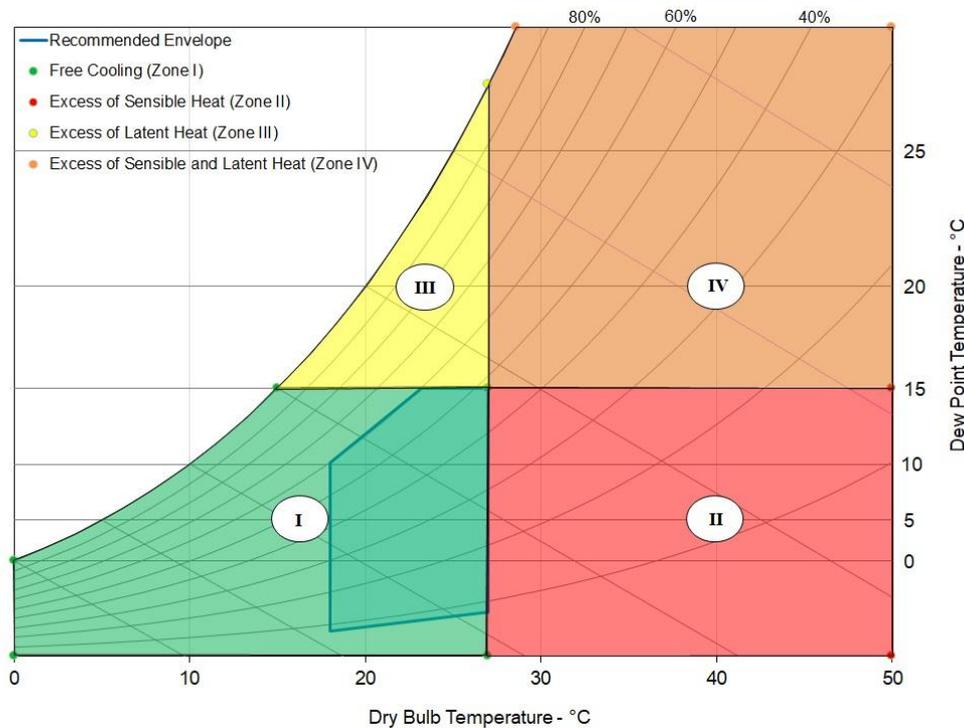


Figure 4. Free cooling zone considering the Recommended range on a psychrometric chart.

In Fig. 4, the green color represents the zone where free cooling is achievable (Zone I); the red color means that the free cooling is not possible due to the high Dry-bulb temperature level (Zone II); the yellow color represents that free cooling is not possible due to high Dew-point level (Zone III); and finally, the orange zone is where free cooling is not viable due to both: DBT and DP parameters (Zone IV).

Figure 4 was made using the Recommended range from Tab. 1, however using the same methodology it is possible to create free cooling zones for Allowable classes A1, A2, A3 and A4. In this paper all classes were taken into consideration to assess the free cooling potential aiming to provide greater flexibility to the analysis.

2.4 Weather data

To assess the number of hours that a city has potential to operate a Data Center using free cooling in a year (8760 hours), weather data containing hourly Dry-bulb and Dew-point temperatures were required. These files for Brazilian cities are available at LabEEE website (LabEEE, 2005). It was decided to consider only cities where the Test Reference

Year weather data (TRY) was available. As a result of that, 14 capital cities have been selected for this analysis. They are: Belém (PA), Brasília (DF), Curitiba (PR), Florianópolis (SC), Fortaleza (CE), Maceió (AL), Natal (RN), Porto Alegre (RS), Recife (PE), Rio de Janeiro (RJ), Salvador (BA), São Luís (MA), São Paulo (SP) and Vitória (ES).

3. RESULTS

Table 2 summarizes the free cooling results for all 14 Brazilian capitals analyzed in this paper. All operation ranges (Recommended and Allowable A1, A2, A3, A4) have been considered.

Table 2. Free cooling hours in 14 Brazilian capitals.

City	State	Geocode	Free Cooling (FC) hours considering Recommended range	FC hours considering A1 range	FC hours considering A2 range	FC hours considering A3 range	FC hours considering A4 range
Belém	PA	-1.38,-48.48	0	2	387	7888	7888
Brasília	DF	-15.87,-47.92	3028	5079	8745	8760	8760
Curitiba	PR	-25.52,-49.18	5575	7299	8726	8760	8760
Florianópolis	SC	-27.67,-48.55	1925	3760	7004	8470	8470
Fortaleza	CE	-3.78,-38.53	0	1	221	6657	6657
Maceió	AL	-9.52,-35.78	8	130	5795	8759	8759
Natal	RN	-5.92,-35.25	0	6	3048	8697	8697
Porto Alegre	RS	-30,-51.18	3783	5309	7927	8735	8735
Recife	PE	-8.13,-34.92	0	4	2521	8694	8694
Rio de Janeiro	RJ	-22.83,-43.25	255	1134	5481	8555	8555
Salvador	BA	-12.9,-38.33	17	261	5061	8729	8729
São Luís	MA	-2.58,-44.23	0	1	168	8141	8141
São Paulo	SP	-23.62,-46.65	4259	6418	8665	8760	8760
Vitória	ES	-20.27,-40.28	447	1417	5304	8494	8494

Table 2 shows that Curitiba has the best performance of all cities analyzed being capable to operate inside Zone I (Fig. 4) for 5575 hours considering the Recommended range. Capital cities such as São Paulo, Porto Alegre and Brasília also presented high potential to free cooling usage (~3000+ hours considering Recommended range) in Data Centers.

Most of the cities of the North and Northeast region of Brazil did not have good results in this regard. All of the representative cities of these regions had a negligible amount of hours being able to operate inside Zone I considering Recommended and A1 ranges.

Overall better results have been achieved when considering more flexible ranges (A2, A3 and A4). Curitiba, São Paulo and Brasília have been able to operate in free cooling considering A2 range for almost the entire year (8000+ hours) and all cities aside from Fortaleza have been able to operate inside Zone I for 7800+ hours in a year when A3 or A4 ranges were considered.

Figure 5 is a map made to improve the visualization of the results achieved in Tab. 2. It is important to notice that the results were obtained only for the capital city of each state, however for the sake of a better comprehension of the map the entire state was painted to illustrate the free cooling potential of its capital. Since the Tab. 2 showed that the number of free cooling hours considering Allowable A3 and A4 regions were exactly the same to all cities, they were presented on the same map.

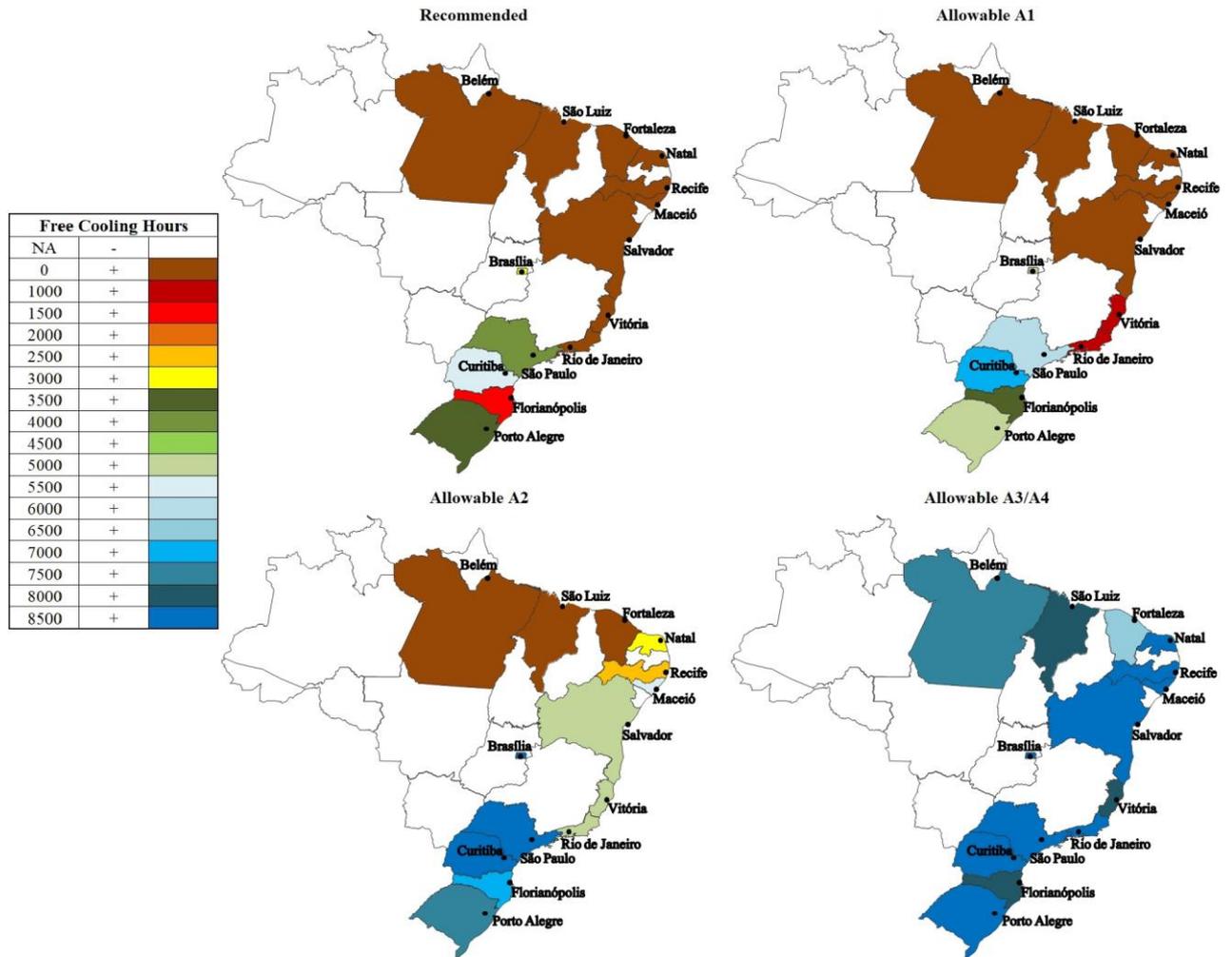


Figure 5. A graphic illustration of the free cooling potential of the capital cities in Brazil considering all operation regions.

As earlier mentioned, the North and Northeast regions have not performed well (as it is indicated by their brown color) even in Allowable A1 and A2 ranges. The South and Southeast regions have presented the overall best results in Brazil as expected while it is not possible to infer anything about the Midwest region since there were no TRY files available for the cities in there.

By looking exclusively to the free cooling hours it is not possible to know if the critical problem of these cities was either the excess of sensible heat expressed by higher Dry-bulb temperatures or the excess of latent heat expressed by higher Dew-point temperatures. Thus, it was decided to further analyze some of these cities, now looking for the reasons why it is not possible to have more hours of free cooling there. The capital cities chosen for this analysis were: Curitiba due to its overall good results, São Paulo due to its economical relevance for the country and Fortaleza as a representative city of the Northeast region. The climate hourly occurrences have been plotted on a psychrometric chart with the indicated zones (as in Fig. 4) to achieve a better understanding of cities climate and its relation with the possibility of free cooling.

3.1 Curitiba detailed results

Figure 6 shows the climate hourly occurrences for Curitiba considering the Recommended range to define the four zones.

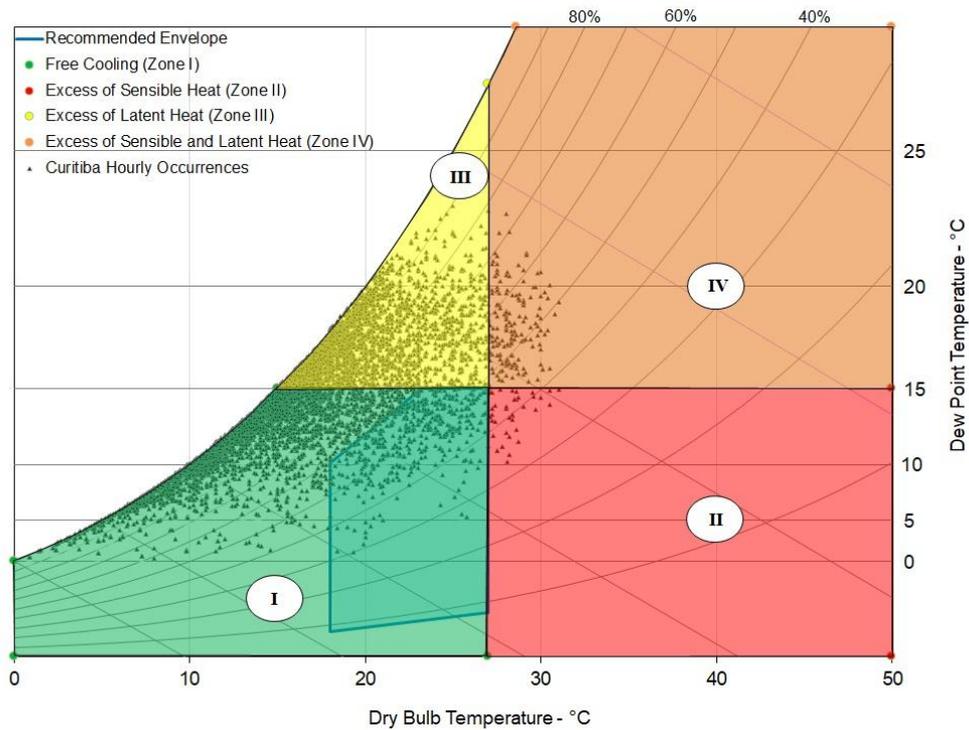


Figure 6. Curitiba hourly occurrences in a year.

The climate hourly occurrences in this city are happening mainly in Zone I (free cooling) and Zone III (free cooling not achieved by excess of latent heat). Zone II (excess of sensible heat) had only a few occurrences in the entire year which indicates that Dry-bulb temperature is not the critical parameter for free cooling potential in Curitiba. The detailed quantitative results are presented in Tab. 3, now considering all ranges.

Table 3. Curitiba climate hourly occurrences in a year.

Range	Zone I (%)	Zone II (%)	Zone III (%)	Zone IV (%)
Recommended	63.64%	0.45%	34.07%	1.83%
A1	83.32%	0.00%	16.68%	0.00%
A2	99.61%	0.00%	0.39%	0.00%
A3	100.00%	0.00%	0.00%	0.00%
A4	100.00%	0.00%	0.00%	0.00%

As shown in Tab. 3, Curitiba has the potential to operate 63.64% of the hours in a year inside Zone I considering the Recommended range, also due to its cool climate there are no hours above the Dry-bulb temperature limit of the Allowable class A1. The main issue in this city is the high humidity rates which deny the free cooling application within the A1 range for 16.68 % of the year (1461 hours). In a more flexible class, such as A2 it is possible to operate in free cooling for almost the entire year (99.61%), moreover considering A3 and A4 ranges all occurrences happens in Zone I.

3.2 São Paulo detailed results

Figure 7 shows the climate hourly occurrences for São Paulo considering the Recommended range to define the four zones.

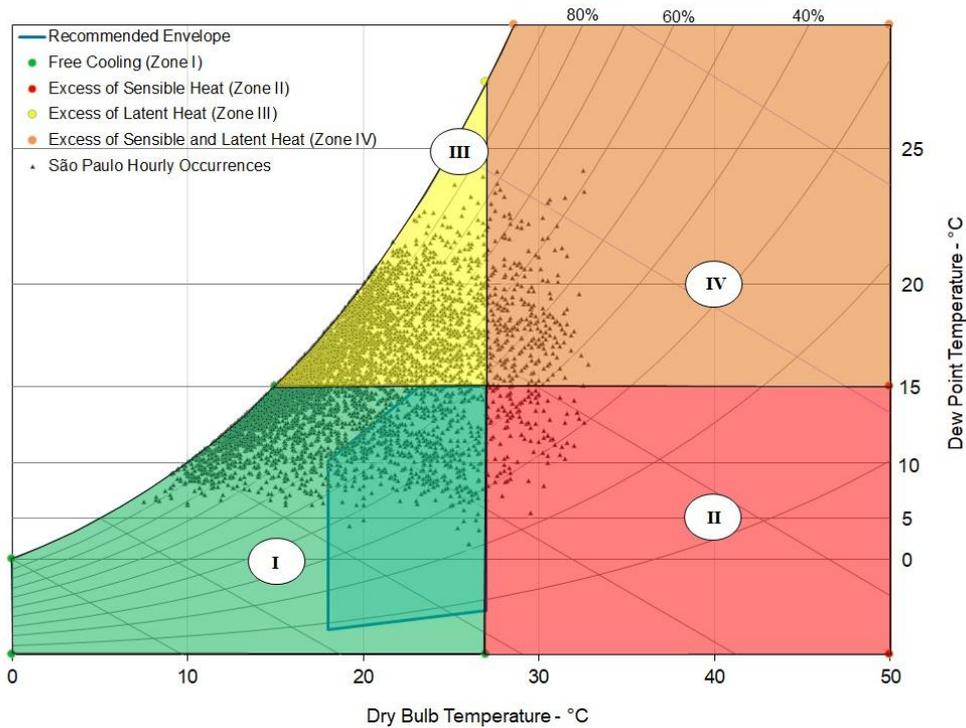


Figure 7. São Paulo hourly occurrences in a year.

São Paulo has overall worse results than Curitiba regarding its free cooling potential as it is shown by the higher amount of climate occurrences outside Zone I. Most of the occurrences are happening in Zone I and Zone III which, once more, indicates that the Dew-point temperature is the critical parameter for the free cooling analysis in this city. The detailed quantitative results are presented in Tab. 4, now considering all ranges.

Table 4. São Paulo climate hourly occurrences in a year.

Range	Zone I (%)	Zone II (%)	Zone III (%)	Zone IV (%)
Recommended	48.62%	1.52%	46.47%	3.39%
A1	73.26%	0.08%	26.63%	0.03%
A2	98.92%	0.00%	1.08%	0.00%
A3	100.00%	0.00%	0.00%	0.00%
A4	100.00%	0.00%	0.00%	0.00%

Table 4 confirms that the Dry-bulb temperature does not represent a problem at all for free cooling in São Paulo, since while considering the recommended threshold only 1.52% of the occurrences happens in Zone II and there are no occurrences of DBT above the A2 class limit. The high humidity levels are the problem once more, but São Paulo has got a decent result for free cooling considering A1 class (73.26%), its climate is almost entirely inside Zone I considering A2 range (98.92%), and 100% of occurrences happens in the free cooling zone for A3 and A4 ranges.

3.3 Fortaleza detailed results

Figure 8 shows the climate hourly occurrences for Fortaleza considering the Recommended range to define the four zones.

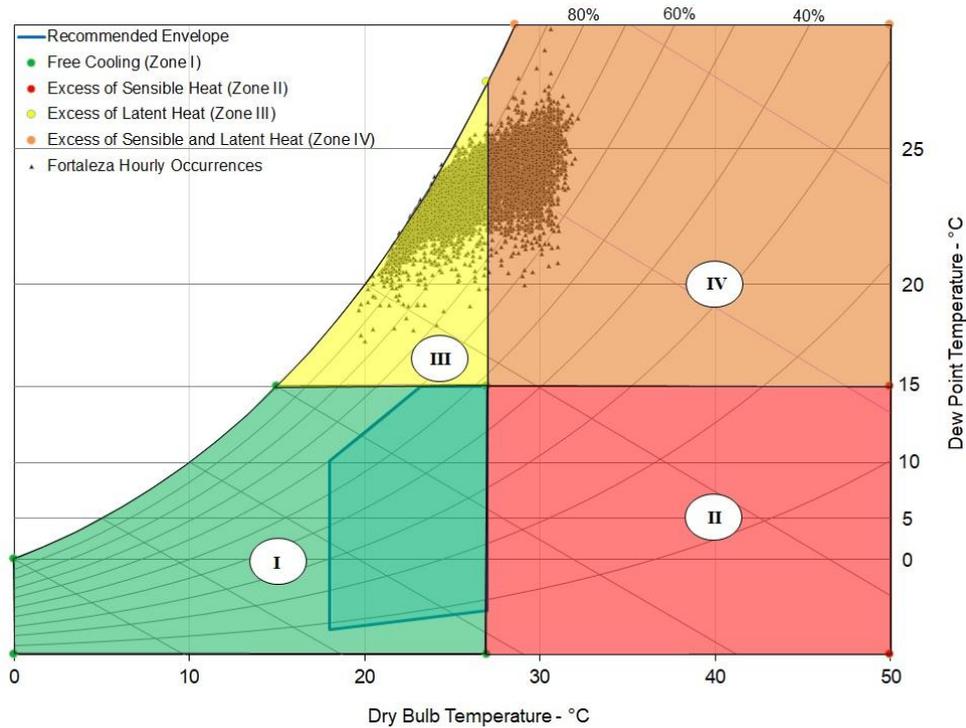


Figure 8. Fortaleza hourly occurrences in a year.

From the three cities further analyzed in this paper, Fortaleza has the worst performance of all. Due to its constant high Dew-point temperature there is no hour in the year that fit inside Zone I or II. The detailed behavior of this city considering also flexible ranges is presented on Tab. 5.

Table 5. Fortaleza climate hourly occurrences in a year.

Range	Zone I (%)	Zone II (%)	Zone III (%)	Zone IV (%)
Recommended	0.00%	0.00%	61.88%	38.12%
A1	0.01%	0.00%	99.98%	0.01%
A2	2.52%	0.00%	97.48%	0.00%
A3	75.99%	0.00%	24.01%	0.00%
A4	75.99%	0.00%	24.01%	0.00%

Table 5 shows that Fortaleza can only achieve good results regarding free cooling potential considering A3 and A4 ranges (75.99%). The critical parameter here is once again the Dew-point temperature since there are not a single hour inside Zone II and from A1 range onwards there is also almost no climate occurrences in Zone IV.

3.4 Parameter analysis

The further analysis has taken into consideration one capital from the South region (Curitiba), one from the Southeast region (São Paulo) and one from the Northeast (Fortaleza). For all of them the critical parameter that denies the free cooling operation is the excess of latent heat expressed by the higher Dew-point temperatures. It is interesting to notice that in these three cities the hours that free cooling is not possible exclusively due to higher Dry-bulb temperatures is almost negligible. Therefore, it was decided to analyze all of the 14 capital cities, this time taking into account only the Dew-point temperature parameter to investigate if the Dry-bulb temperature is really needed. In another words, this new analysis checked if there would have been major differences in the overall free cooling potential results considering a hypothetical situation in which Zone II had been merged with Zone I.

Table 6. Free cooling (Zone I) hours while assessing only the Dew-point temperature parameter and its percentage growth in relation with the analysis considering the two parameters.

City	Free Cooling (FC) hours considering Recommended range	FC hours considering A1 range	FC hours considering A2 range	FC hours considering A3 range	FC hours considering A4 range
Belém	0 (=)	2 (=)	387 (=)	7888 (=)	7888 (=)
Brasília	3329 (+9.94%)	5086 (+0.14%)	8745 (=)	8760 (=)	8760 (=)
Curitiba	5615 (+0.72%)	7299 (=)	8726 (=)	8760 (=)	8760 (=)
Florianópolis	1929 (+0.21%)	3760 (=)	7004 (=)	8470 (=)	8470 (=)
Fortaleza	0 (=)	1 (=)	221 (=)	6657 (=)	6657 (=)
Maceió	13 (+62.50%)	130 (=)	5795 (=)	8759 (=)	8759 (=)
Natal	0 (=)	6 (=)	3048 (=)	8697 (=)	8697 (=)
Porto Alegre	3836 (+1.40%)	5323 (+0.26%)	7939 (+0.15%)	8735 (=)	8735 (=)
Recife	0 (=)	4 (=)	2521 (=)	8694 (=)	8694 (=)
Rio de Janeiro	259 (+1.57%)	1134 (=)	5487 (+0.11%)	8555 (=)	8555 (=)
Salvador	17 (=)	261 (=)	5061 (=)	8729 (=)	8729 (=)
São Luís	0 (=)	1 (=)	168 (=)	8141 (=)	8141 (=)
São Paulo	4392 (+3.12%)	6425 (+0.11%)	8665 (=)	8760 (=)	8760 (=)
Vitória	447 (=)	1417 (=)	5304 (=)	8494 (=)	8494 (=)

The results from Tab. 6 corroborate with the idea that Dew-point temperature is indeed the critical parameter to the free cooling potential analysis in Brazil. Only while assessing the Recommended range (in which upper Dry-bulb temperature limit is 27°C) this parameter has been important for a few cities such as Brasília and São Paulo which have presented increases of 9.94% and 3.12% respectively. Maceió had an increase of 62.50% in its free cooling hours in a year (8760 hours), however the number of hours is negligible since it has grown from 8 to 13 hours. For the Allowable classes all cities have showed slightly increases or even no changes at all in the number of free cooling hours. Thus, at least when considering the Allowable ranges the free cooling analysis could have been done only with the Dew-point temperature without causing major changes in the final result.

4. CONCLUSION

This paper has analyzed the Data Centers free cooling potential from 14 Brazilian capitals using TRY weather files. Based on the ASHRAE Thermal Guidelines two parameters: upper Dry-bulb Temperature limit and upper Dew-point Temperature limit have been selected to define a free cooling zone on a psychrometric chart. With the free cooling zones defined and the hourly climate condition obtained it was possible to count the number of hours in a year that each of the 14 selected Brazilian capitals was capable to operate with compressor-less cooling.

The results have shown that cities such as Curitiba, São Paulo, Porto Alegre and Brasília have the potential to use free cooling in their Data Centers for over than 3000 hours in a year considering the most restrictive operation range (Recommended range). Curitiba has presented the overall best performance from the cities analyzed being able to operate 5575 hours with compressor-less cooling in that range.

All cities from the North and Northeast region from the country have not showed viability to the free cooling application in Data Centers considering the most restrictive ranges. However, while assessing more flexible classes such as A3 and A4 almost all cities analyzed were able to operate with more than 7800 hours of compressor-less cooling. It was not possible to infer anything about the Midwest region of the country since there were no TRY files available for the cities in there.

A further analysis has been made to detail the results of three cities: Curitiba, São Paulo and Fortaleza. As a result of this, it was indicated that the critical parameter to assess free cooling potential to Brazilian capitals was the Dew-point temperature. This suspicion was confirmed by a parameter analysis which has showed that the Dry-bulb parameter is only relevant for a few cities and while considering the Recommended range. For the Allowable classes the analysis could have been done only with the Dew-point temperature without causing major changes in the final result.

5. ACKNOWLEDGEMENTS

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