Building Simulation

Seventh International IBPSA Conference
Rio de Janeiro, Brazil
August 13-15, 2001

URBAN CLIMATE AND ITS INFLUENCE ON ENERGY CONSUMPTION

A CASE STUDY IN TWO BRAZILIAN CITIES

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ABSTRACT

Two prototype office buildings with low internal gains were simulated using DOE2 software to evaluate its energy consumption in different urban microclimates. Weather data from two weather stations were used: in Rio de Janeiro – Santos Dumont local airport and Antônio Carlos Jobim International Airport – and in Florianópolis – Hercílio Luz International Airport and LABSOLAR at Federal University of Santa Catarina.

One prototype was designed to be more sensitive to the external environment and the other, less sensitive. The weather files of 3 stations did not have solar radiation data. Solar radiation was estimated from cloud cover based in a different model than that used by DOE 2.1-E that was calibrated with satellite data. This paper presents the comparison of the results of total building electric energy consumption for the two different climatic data files in each city. It presents also the differences in some weather data variables, dry bulb temperature, solar radiation and wind speed, found in each city. Site characteristics, such as urban occupation or location into the city, are factors that affected simulation results. Also, building components characteristics modify consumption according to the site where the prototype is simulated.

INTRODUCTION

Buildings located at dense urban areas tend to consume more electric energy on air conditioning systems than buildings located at less urbanized areas in the same city. This was demonstrated by SANTAMOURIS (1997), who mapped areas of high energy consumption near Athens industrial districts and downtown. To evaluate the effects of urban densification on energy consumption, it is necessary to have access to microclimatic information for a better evaluation. Unfortunately, in Brazil, hourly climatic data files are usually from airports, which does not provide correct microclimatic information due to its location usualy far from the urbanized area. Also, these files often have incomplete data, due to equipment maintenance or humans faults. Nevertheless, this data is the only one generally available for energy and thermal simulation, and therefore, must be used with caution. The aim of this paper is to analyze some errors that can be caused in annual energy consumption simulation due to differences in the microclimate inside two cities, Rio de Janeiro and Florianópolis.

METHODOLOGY

Two prototype office buildings were simulated using DOE 2.1-E software to evaluate its energy consumption in different urban microclimates. Weather data from two weather stations were used in each city. Rio de Janeiro, 22.54° S 43.12° O, with an atlantic tropical climate and Florianópolis, 27.5° S 48.5° O, with a subtropical climate. The weather stations in Rio de Janeiro are located in two airports: Santos Dumont local airport and Antônio Carlos Jobim International Airport. Florianópolis weather stations are located at the Hercílio Luz International Airport and at LABSOLAR, Laboratório de Energia Solar, located in the mechanical engineering building at the Federal University of Santa Catarina, UFSC.

Santos Dumont occupies a small peninsula close to downtown and close to Guanabara Bay opening to the Atlantic Ocean. Downtown has 6,40 km^2 of predominantly high rise commercial buildings. A. C. Jobim airport is located at Ilha do Governador, an island with 42,23 km^2, with 99% of its area occupied (www.rio.rj.gov.br) by low rise buildings, with no more than four floors, in average. It is also located in Guanabara bay, but more distant from the Ocean.

Hercílio Luz International Airport is located in the south of Santa Catarina Island. The city of Florianópolis is located in the middle of the island. Low vegetation or swamps surround the airport. On its turn, UFSC campus is at the center of the island, separated from downtown by a hill called Morro da

Cruz, a natural barrier that protects the campus west side. Some other small hills surround the campus, where trees and shrubs surround buildings of less than five floors.

Two prototype office buildings based on SIGNOR (1999) simulations for the city of Florianópolis were chosen: prototype 49, less sensitive to outdoor temperatures and protected from radiation, and prototype 79, more sensitive to climatic changes.

The parameters in table 01 define a building with ten floors, 12 x 30 m, with its largest facades oriented to North and South. Prototype 79, more sensitive to external changes, has windows on 80% of its facade, shading coefficient of 1 and no solar protection, while prototype 49, less sensitive, has 20% of window on its facade, shading coefficient of 0.29 and an horizontal protection of 1 m. The prototypes were divided on five zones, each zone with an independent HVAC system - packaged terminal air conditioner - in order to optimize the energy consumption according to thermal loads. Hot water and fuel use were disabled and air supply rate was default.

	49	**79**
A_{roof}/A_{tot}	0.10	0.10
A_{facade}/A_{floor}	0.70	0.70
WWR	0.20	0.80
PF	1.00	0.00
SC	0.29	1.00
U_{roof} (W/m^2K)	0.952	0.545
U_{wall}(W/m^2K)[1]	1.923	4.348
α_{roof}	0.30	0.70
α_{wall}	0.30	0.70
Sensitivity to external weather	Less	More

Table 01: Characteristics of SIGNOR models.

CLIMATIC DATA FILES

The airports climatic data files had 14% of missing data, in average. For completing this, up to five hours of missing data were interpolated linearly. More than five hours of missing data required an analysis of the climactic data variables (dry bulb temperature, DBT, wet bulb temperature, WBT, solar radiation, wind speed) tendency curve, and copying one of the three preceding or following days to fill missing hours. DBT was adopted as the main factor of the analysis due to its significance on thermal loads (HENSEN, 1999).

Measured solar radiation data was solely available at Lab Solar station. Solar radiation estimated from cloud cover. DOE 2 used one correlation that presented bad results for Floriamópolis, as shown by KRUGER & LAMBERS (1999). To have better estimation of solar data, PITTA (2001) equation (equation 01) was used for Hercílio Luz station Its coefficients are presented in table 02.

PITTA (2001) equation can be expressed as:

$$H/H_0= a(N^2/10)+b(N/10)+c, \qquad \text{(equation 01)}$$

H – daily total radiation

H_0 – daily extraterrestrial total radiation

N – cloud cover (0 – 10, clear to overcast sky)

a, b, c – regression coefficients (table 02)

Since the equations were calculated for daily total radiation, it was necessary to evaluate its use on hourly total radiation. Hourly cloud cover data was converted to daily data and daily total radiation calculated with PITTA (2001) equations. Then the results were applied at Collares-Pereira and Rabl algorithms (DUFFIE & BECKMAN, 1991) to convert the daily total radiation into hourly total radiation. This method was named as method 01. Also, the hourly total radiation was estimated directly from hourly cloud cover using PITTA (2001) equations, which was named as method 02.

Figure 01 shows the differences frequencies between method 01 and method 02. The highest difference is 630 W/m^2, but there are no significant differences above 250 W/m^2. In average, these differences are around 12%, with a standard deviation of 8.5%. This confirmed the validity of using PITTA (2001) equations for hourly total calculations. The number of samples used in each year was the number of possible hours with sun in an year, 4737 hours. Then, a total of 14211 samples for the 3 years.

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[1] Signor (1999) models had U_{wall} of 2.632 W/m^2K

	Florianópolis (PITTA 2001 coefficients)			Rio de Janeiro adjusted coefficient
	a	b	c	c
January	-1.01	0.78	0.48	0.53
February	-0.85	0.62	0.52	0.63
March	-0.50	0.10	0.67	0.59
April	-0.39	-0.04	0.71	0.57
May	-0.26	-0.08	0.69	0.54
June	-0.46	0.03	0.69	0.58
July	-0.64	0.14	0.70	0.48
August	-0.66	0.23	0.68	0.60
September	-0.58	0.15	0.68	0.51
October	-0.77	0.29	0.70	0.52
November	-0.60	0.20	0.68	0.52
December	-0.40	-0.10	0.75	0.59

Table 02: PITTA (2001) coefficients for each month in Florianópolis and adjusted coefficients for Rio de Janeiro.

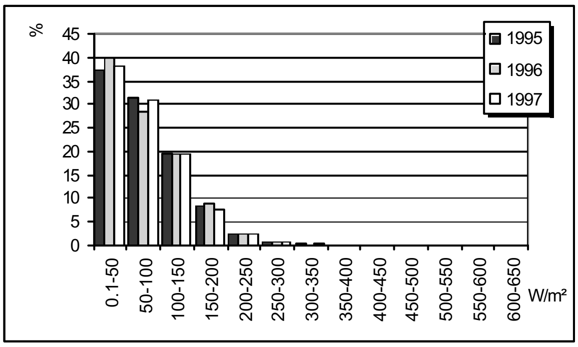

Figure 01: Frequency of occurrence of differences between method 01 and method 02. The maximum difference is 630 W/m^2.

To split total radiation into direct and diffuse, Erbs' algorithm (DUFFIE & BECKMAN, 1991) was used to calculate the fraction of diffuse radiation present at total radiation on a horizontal plane.

Further, wind speed data was not available at Lab Solar. It was necessary to copy wind data from Hercílio Luz station, due to its influence on energy consumption. PEDRINI (1997) has found a difference of 6% in the annual energy consumption when simulating a commercial building in Florianópolis with and without wind velocity data.

Rio de Janeiro also had no solar radiation data such as Hercílio Luz station, and in this case no equations were available too. Equation 01 coefficients were then adapted for Rio de Janeiro, based on mean monthly satellite radiation data from Brazilian Solar Atlas developed by COLLE & PEREIRA (1998, www.labsolar.ufsc.br). The adjusted coefficient is presented in table 02. After elaborating the new equations, hourly total radiation was calculated using method 02 and diffuse radiation calculated with Erbs algorithms (DUFFIE & BECKMAN, 1991). Cloud cover data was only available at Santos Dumont climatic files. Since the distance between the two airports was only 20 km across part of Guanabara Bay, it was assumed that the radiation was similar. So, Santos Dumont calculated total and diffuse data was copied to A. C. Jobim climatic files.

MICROCLIMATIC AND SITE ANALYSIS

In Florianópolis, Hercílio Luz and Lab Solar dry bulb temperature and radiation data correlations were plotted for the three years to analyze microclimatic conditions. Figure 02 presents DBT correlations in 1995. Temperatures above 20^{o} C are higher in Hercílio Luz than in Lab Solar. Also, radiation tends to be more intense in Hercílio Luz, as seen in figure 03. These radiation and temperature patterns are similar to those presented in 1996 and 1997.

Figure 04 presents, in relative terms, cooling degree days (100% = 106) and cooling degree hours (100% = 208) in Florianópolis. The difference between sites is variable: Hercílio Luz has less CDD and CDH than Lab Solar: 13% less in 95 and 37% less in 96, but this behavior has changed in 97 when Hercílio Luz has slightly more CDD and CDH than Lab Solar: 8%.

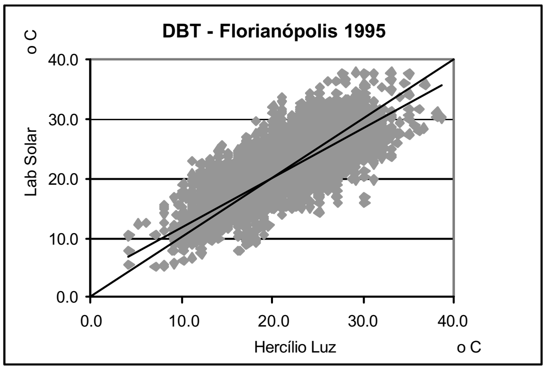

Figure 02: Dry bulb temperature in 1995 at Florianópolis.

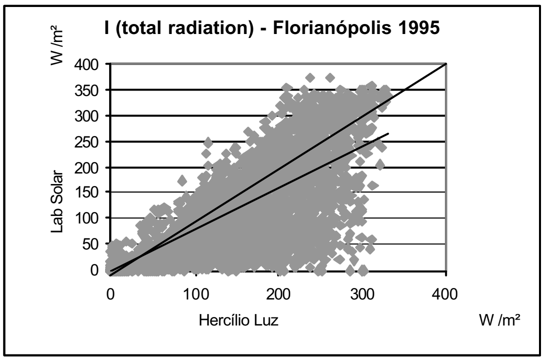

Figure 03: Total radiation in 1995 at Florianópolis.

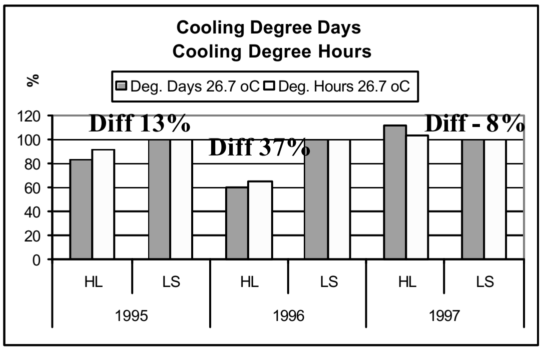

Figure 04: Cooling degree-days and cooling degree hours at Florianópolis.

Figures 05 and 06 show aerial views of Florianópolis sites. Figure 05 shows Lab Solar location at the center of urbanized area, with Morro da Cruz range of hills surrounding it. At northwest and southwest, North and South bays are seen. Figure 06 shows Hercílio Luz site in the same scale of figure 05. At west, part of South Bay is seen. There are no hills between the site and the ocean in both sides, east and west, of the island.

Lab Solar is actually more urbanized than Hercílio Luz site, so it is expected to have higher temperatures. But the sites exposition to South Bay reduces temperature variations as seen in figure 04 in 1997.

According to figure 03, solar radiation is higher in Hercílio Luz, but since this variable was not measured, but calculated with equation 01 - that was developed with Lab Solar data (PITTA, 2001) - it is not possible to analyze Morro da Cruz influence in radiation. Morro da Cruz does not affect Hercílio Luz cloud cover conditions. Nevertheless, Morro da Cruz is expected to have some influence on cloud cover over Lab Solar.

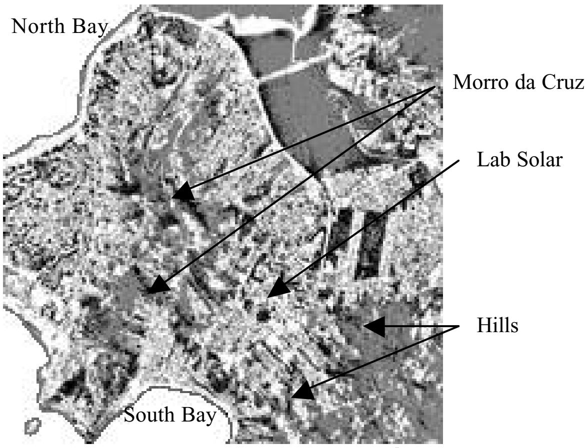

Figure 05: Lab Solar site in Florianópolis.

Legend of figures 05 and 06

■ Dense green area
▨ Green area
░ Built area
☐ Built area

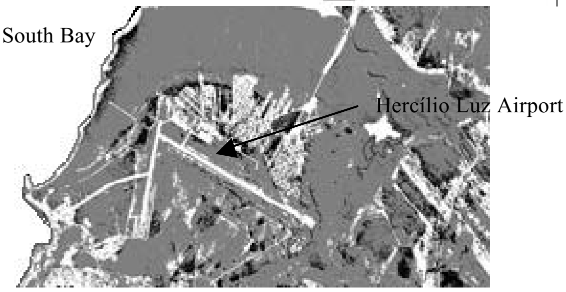

Figure 06: Hercílio Luz site in Florianópolis.

In Rio de Janeiro, radiation was the same for the two locations, then temperature and wind speed were analyzed. Figure 07 shows the correlation of DBT data in 1988 between A. C. Jobim and Santos Dumont. Temperatures above 24° C tend to be higher in A. C. Jobim airport. Figure 08 presents CDD and CDH for both sites in Rio de Janeiro. A. C. Jobim has in average, 53% more cooling degree days and cooling degree hours than Santos Dumont.

Further, figure 09 shows that A. C. Jobim has higher wind speeds in 1998. DBT and wind speed data behavior in 1987 and 1989 are similar to that presented for 1988.

Despite Santos Dumont high-rise and dense building occupation neighborhood, temperatures are lower due to the airport exposition to Guanabara Bay opening to Atlantic Ocean (figure 10). On its turn, A.C. Jobim airport is located in an horizontal built area in Governador Island located more to the inside of Guanabara Bay.

If temperatures are often higher in A. C. Jobim than in Santos Dumont, buildings are expected to consume more energy in A. C. Jobim. Wind speed is also higher in A. C. Jobim and this increases building envelope thermal transfer and air changes. Then, energy consumption in Rio de Janeiro is influenced by several factors, such as urban occupation and site location and cannot be previewed based on climatic variables solely.

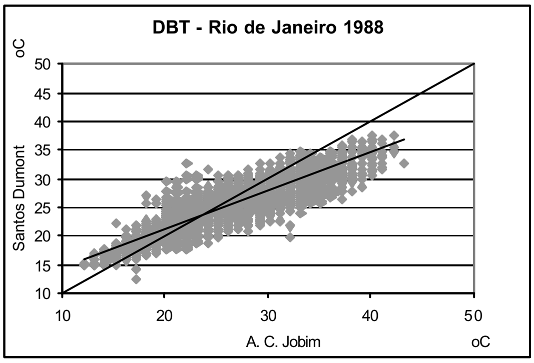

Figure 07: Dry bulb temperature at 1988 at Rio de Janeiro.

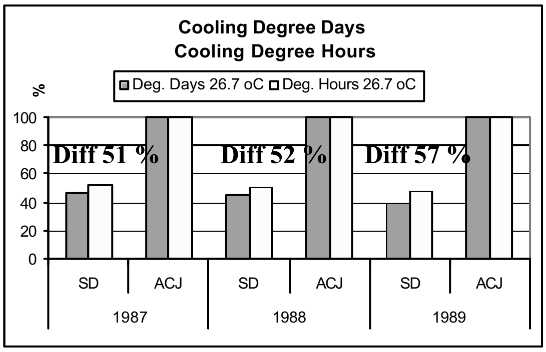

Figure 08: Cooling degree-days and cooling degree-hours at Rio de Janeiro.

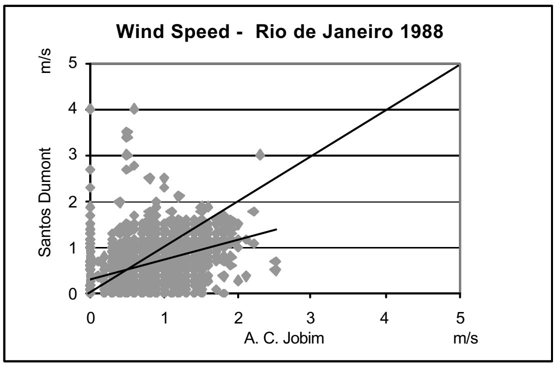

Figure 09: Wind speed at 1988 at Rio de Janeiro.

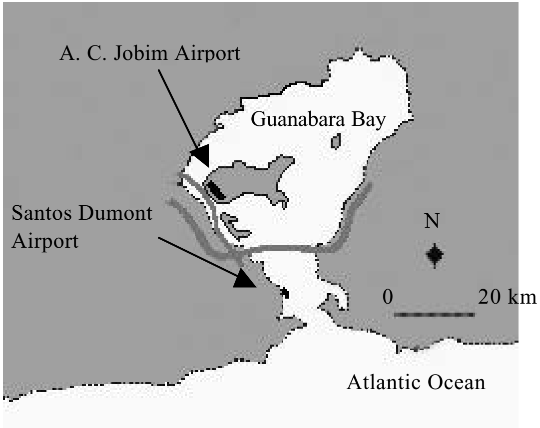

Figure 10: Rio de Janeiro airports location.

RESULTS

After adjusting and compiling the climatic files to DOE 2.1-E format, simulations were performed for both cases: prototypes 49 (less sensitive) and 79 (more sensitive) were simulated using three climatic years for two locations in each city.

The prototypes annual energy consumption are presented in table 03 (Florianópolis) and 06 (Rio de Janeiro). Table 03 presents the difference between annual consumption in both sites in the three years of simulation in Florianópolis. As expected, prototype 49 consumed less energy than prototype 79. Prototype 49 building components such as WWR of 20%, SC of 0.29 and horizontal solar protection on windows reduced thermal gains and so, energy consumption. In average, the difference between prototypes 49 and prototypes 79 was about 59%, with higher differences in Hercílio Luz, 61% in all years. In Lab Solar, it varied from 56% to 58%. As seen in figure 03, radiation is higher in Hercílio Luz, while Lab Solar had more CDD and CDH (figure 04). The temperature results show that under this condition, solar radiation had a higher influence on the difference between prototypes.

The differences between years are shown in table 04. It varies from –2.2% to 7.0% and Lab Solar presented slightly higher differences than Hercílio Luz. Consumption variation between years had shown to be dependent on CDD and CDH variation between years. Consumption increases from 95 to 96 in Lab Solar while it decreases in Hercílio Luz. It also decreases in Lab Solar from 96 to 97 in prototype 49, not varied in prototype 79.

The differences between sites in table 05 vary from –5% to 14%, with the higher differences in 1995 for prototype 79. Curiously, 1995 also has the lowest difference between sites – in fact, no difference- for prototype 49. DBT and total radiation presented in figures 02 and 03 resulted in this consumption increase of 14% in Hercílio Luz. Since 1996 and 1997 total radiation graphs are similar to 1995, prototype 79 consumed, in average 7.7% more energy in Hercílio Luz than in Lab Solar as Hercílio Luz had higher solar radiation data.

Although CDD and CDH differences between sites are more significant in 1996, about 37% (figure 04), prototype 79 consumption difference between sites is not higher in 1996 than in 1995 and 1997 (table 05) nevertheless, prototype 49 consumption difference between sites is higher in 1996. Then, despite of having more cooling degree hours in Hercílio Luz in 1997 (figure 03), this difference does not seem to be sufficient to change prototype 49 higher consumptions in Lab Solar. On its turn, prototype 79 consumption is always higher in Hercílio Luz (table

05), following solar radiation tendency independent of temperature variations between sites.

Prototype	Units	Sensitivity to external weather	1995		1996		1997	
			Hercilio Luz	Lab Solar	Hercilio Luz	Lab Solar	Hercilio Luz	Lab Solar
49	kWh/m^2	Less	65	64	63	66	64	65
79	kWh/m^2	More	165	145	162	156	162	154
Difference between prototypes			61 %	56 %	61 %	57 %	61 %	58 %

Table 03: Annual energy consumption in Florianópolis and percentages of annual energy consumption differences between prototypes. ((P 79 – P 49)/ P 79)

Prototype	Sensitivity to external weather	(96– 95)/96		(97 – 96)/97		Total average in module
		Hercilio Luz	Lab Solar	Hercilio Luz	Lab Solar	
49	Less	-2.2 %	3.0 %	1.2 %	-2.2 %	2.1 %
79	More	-1.9 %	7.0 %	0.0 %	-1.5 %	2.6 %

Table 04: Percentage of annual energy consumption differences between years in Florianópolis.

Prototype	Sensitivity to external weather	1995	1996	1997	Total average in module
49	Less	**0%**	**5 %**	**2 %**	2.3 %
79	More	**-14 %**	**- 4 %**	**- 5 %**	7.7 %

Table 05: Percentage of annual energy consumption differences between sites in Florianópolis. ((LS-HL)/LS)

Rio de Janeiro results also demonstrate a large difference between prototype 79, more sensitive to climatic conditions, and prototype 49, less sensitive, in table 07. In all years and sites, the differences between prototypes 79 and 49 are 59%. No site or year differences were found for the differences between prototypes.

Differences between years, in table 08, vary from –2.9% to 1.2 %, that is a small amplitude if compared to Florianópolis results, in table 05. It should be noted that A.C. Jobim has higher CDD and CDH (51%, 52% and 57%) but both files have the same solar radiation data.

Table 09 presents differences between sites in Rio de Janeiro. In all cases, the consumption in Santos Dumont is lower than in A. C. Jobim airport, with the highest difference of 8% in 1988.

Prototype	Units	Sensitivity to external weather	1987		1988		1989	
			A. C. Jobim	S. Dumont	A. C. Jobim	S. Dumont	A. C. Jobim	S. Dumont
49	kWh/m^2	Less	83	78	82	76	81	77
79	kWh/m^2	More	200	191	201	186	198	188
Difference between prototypes			59 %	59 %	59 %	59 %	59 %	59 %

Table 07: Annual energy consumption in Rio de Janeiro and percentages of annual energy consumption differences between prototypes. ((P 79 – P 49)/ P 79)

Prototype	Sensitivity to external weather	88 - 87		89 - 88		Total average in module
		A. C. Jobim	S. Dumont	A. C. Jobim	S. Dumont	
49	Less	-1.3 %	-1.6 %	-1.0 %	0.8 %	1.2 %
79	More	0.3 %	-2.9 %	-1.4 %	1.2 %	1.3 %

Table 08: Percentage of annual energy consumption differences between years in Rio de Janeiro. ((88-87)/88 and (89-88)/89)

Prototype	Sensitivity to external weather	1987	1988	1989	Total average
49	Less	6 %	7 %	5 %	6 %
79	More	5 %	8 %	5 %	6 %

Table 09: Percentage of annual energy consumption differences between sites in Rio de Janeiro. ((A. C. Jobim – SD)/A. C. Jobim)

CONCLUSION

The simulated prototypes have building components and architectural characteristics, such as WWR, SC and solar protection, that resulted in less consumption in prototype 49 than in prototype 79. These characteristics, like the others of table 01, are responsible for the prototype 79 higher sensitivity to climatic conditions and so, to microclimatic changes. The average difference between prototypes of 59% is due to this sensitivity. While radiation effects prevail on prototype 79, hiding temperature effects, dry bulb temperature has visible influence on prototype 49 consumption. Nevertheless, as the prototype annual energy consumption is influenced by external air, temperature, wind speed and solar radiation, the conditions effect has shown peculiarities in each city.

Differences between years vary from -2.2% to 7.0% (table 04). This indicates differences that may occur if climatic files are not available for the studied year, as for example when TRY data is used.

The building characteristics also influence consumption differences between sites in the same city, varying from 2.3% to 7.7% in Florianópolis. Consumption differences between sites varied in 19% (5% to –14% in table 05). This shows that simulation with climatic data from a distant site must be executed with caution. Differences found in temperature, solar radiation and wind speed show that topography, in Florianópolis, location and urban occupation, in both cities, may define conditions that change original microclimatic data and so, consumption in buildings with HVAC systems.

The differences between sites found in Florianópolis and that were not found in Rio de Janeiro show that solar radiation is an important variable in energy simulation and as cloud cover is not measured, but based on observations, this information is generally not reliable.

Brazilian climatic data are usually incomplete and need some adjustments to be used for energy simulation. Reaching a stage where microclimatic data is available for simulation into the urban structure is still needed. The simulations processed into this work used climatic data files from airports, which is known to be distinct from data measured among streets. Urban microclimatic data would provide more precise information about buildings consumption and thermal gains. Urban climate research was performed in several Brazilian cities in order to provide climatic information into dense urban areas. It is now necessary to combine this information with the available climatic data files in order to apply more precise microclimatic data in thermal and energy simulations.

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NOMENCLATURE

α	Solar absorption coefficient
A	Area
A. C. JOBIM	Antônio Carlos Jobim Airport
CDD	Cooling degree-days
CDH	Cooling degree hours
DBT	Dry bulb temperature
H	Daily total radiation
H0	Daily total extraterrestrial radiation
HL	Hercílio Luz Airport
I	Hourly total radiation
LS	Lab Solar Station
N	Cloud cover
PF	Projection factor
SC	Shading coefficient
SD	Santos Dumont Airport
WWR	Window wall ratio