DesignBuilder used to Improve Passive Design and Reduce Risk of Overheating in Residential Developments in Brazil

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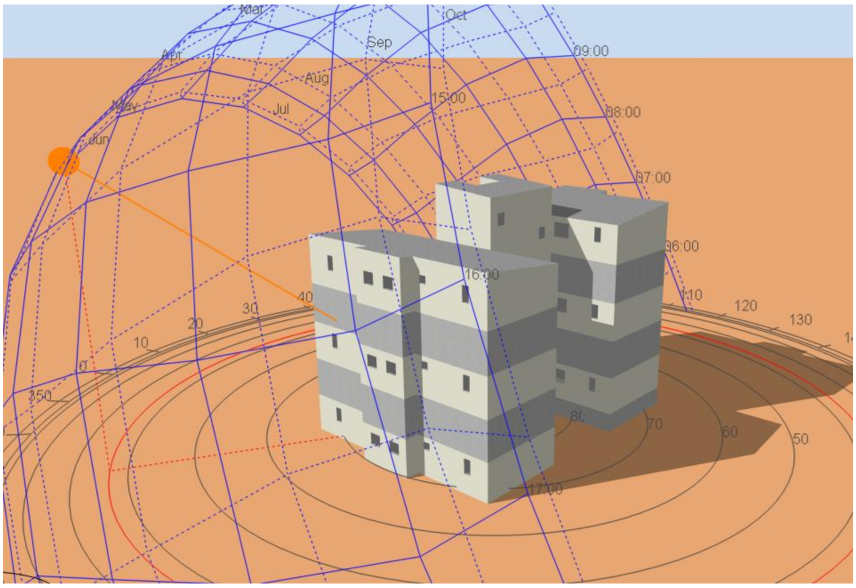
Introduction

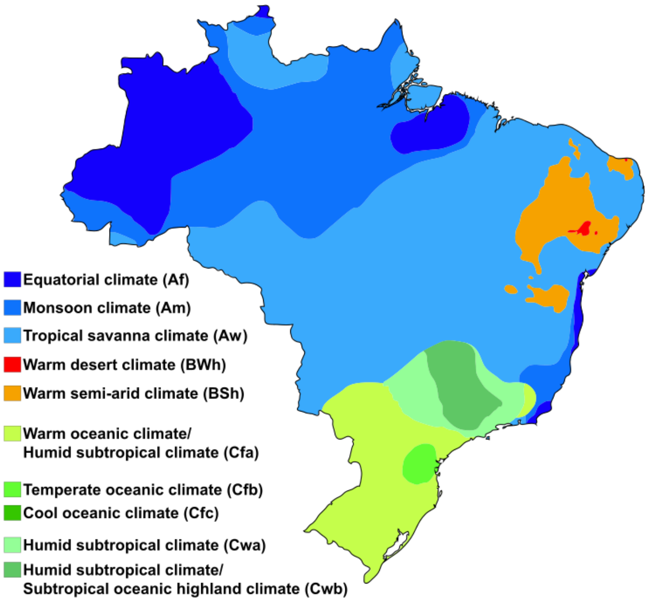
This case study provides an overview about the application of thermal simulation on a typical Brazilian social housing development. The objective is to compare its performance with the national performance standards and international regulation parameters.



Recently, the construction industry in Brazil has seen a short unprecedented period of development. Whilst people were excited about the opportunity of acquiring their home, architects and engineers were concerned about the quality of these developments as there was insufficient regulation for building performance to drive the quality of parameters such as thermal and visual comfort.

In 2013, to fill this gap, the Brazilian building performance standard NBR 15575 was released. The standard proposes minimum parameters in residential buildings for issues such as the structure, flooring, façades and roofs. Among these parameters, thermal comfort is one of the most important items perceived by potential buyers of a housing unit, according to a research carried out by the University of Sao Paulo (DOUEK, FREITAS and MORRONE, 2017). Therefore, within this context, the present analysis was carried out in order to evaluate the performance of residential buildings in Brazil in comparison to the national standard.

To move forward, a description of the Brazilian climate is necessary beforehand. The country is divided into eight bioclimatic zones. Due to its continental proportions, climate zones are significantly different as can be seen in the following image:



As a consequence, the first step to conducting a thermal analysis in Brazil is to select the appropriate bioclimatic zone as the mandatory requirements are different in each zone. The standard[1] also describes three possible levels, which varies according to the level of performance achieved:

- minimum (obligatory);
- intermediate (voluntary);
- superior (voluntary).

The results are highly dependent on the specifications of the outdoor walls and roofs materials. Other requirements include minimum opening areas in order to provide the rooms with natural ventilation. Within the Brazilian context, the main goal is to remove heat, mainly in summer time, by means of cross ventilation.

To show compliance with the minimum requirements, there are three different approaches: prescriptive, computer simulation and onsite measurements. The goal is to prove that internal temperatures are higher in winter and lower in summer than outside air temperatures

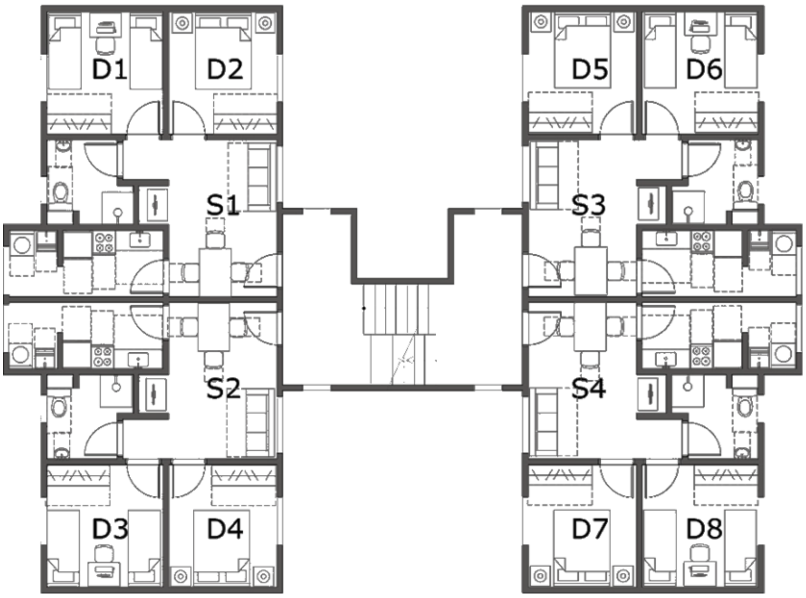
This case study addresses the computer simulation approach.

[1] NBR 15220 – Desempenho Térmico de Edificações Parte 3: Zoneamento bioclimático brasileiro e diretrizes construtivas para habitações unifamiliares de interesse social.

Case Study

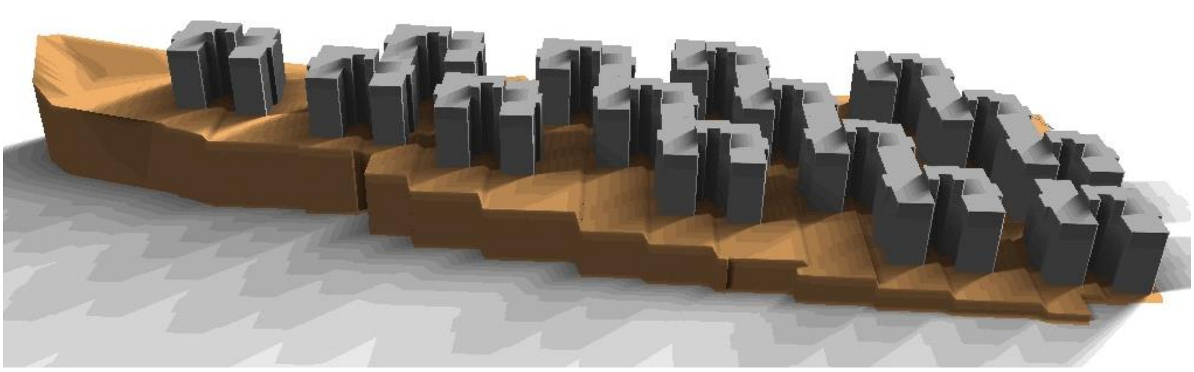
The buildings under analysis are located in Sao Paulo, the capital of the richest state of the country, in the southeast region of Brazil. The development is composed by a group of fifteen "H" shaped identical buildings. The architecture is defined by: five floors, four apartments per floor and a central staircase. Each 42m2 apartment has two bedrooms, one bathroom, a living room and a kitchen/laundry combo.

The construction was built with self-supporting concrete blocks and precast concrete slabs. Windows are standardized and made out PVC. They are divided in three sheets with identical dimensions: 1.2m x 1.2m. The opening area is limited to 50% of the window size.



Standard Floor plan

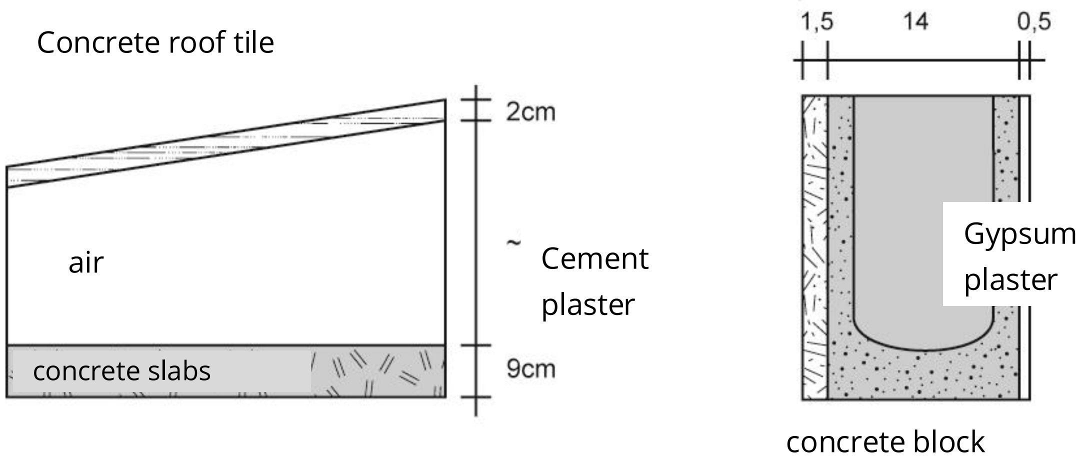
One peculiarity of the set of buildings is that to fit the sloped site, the buildings were stepped with a level difference of 1.25 meters, as it is shown in the following 3D image:



Shading simulation at summer solstice (Ecotect and Radiance software)

Standard Criteria

To comply with the NBR 15575, first of all, the envelop materials characteristics are compared to the minimum requirements. The limit of thermal transmittance (U) and thermal capacity (CT) are defined based on the external solar absorption (α) of the finishing material. Since the construction is located in bioclimatic zone number 3, the applicable comparative analysis table is as follows:



	Walls		Roof		Comply?
	calculated	**required**	**calculated**	**required**	
CT	132.1	≥130	-	-	YES
U	2.6	≤3.7	2.28	≤2.3	YES
α	0.3	≤0.6	0.3	≤0.6	

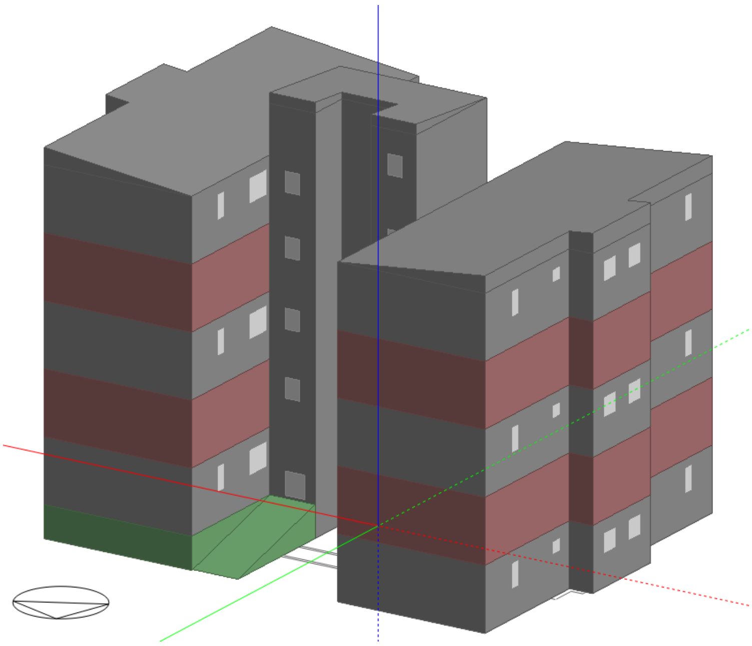
The minimum window floor area ratio (WFR) is also verified in accordance to the standard:

Space	Floor area sqm	Window area sqm	Window opening %	WFR %	Comply WFR ≥7%?
D1	8.9	1.46	50%	8.2	YES
D2	8.3	1.46	50%	8.8	YES
S	10.6	1.71	50%	8.05	YES
kitchen	6.4	0.73	50%	9.2	YES

The primary conclusion is that the building envelope does comply with minimum prescriptive requirements. However, in order to better understand the performance of the building, a series of thermal simulations were carried out. As required by the Brazilian standard, the upper floor was simulated in a typical summer and winter day. This must be done in order to compare external and internal (operative) temperatures. The performance levels are evaluated in relation to the maximum and minimum internal temperatures (Ti) reached in the typical days as follows:

São Paulo NBR temps.	**Summer**	**Winter**
Minimum	Ti max. ≤ 31.9°C	Ti min. ≥ 9.2°C
Intermediate	Ti max. ≤ 29.9°C	Ti min. ≥ 11.2°C
Superior	Ti max. ≤ 27.9°C	Ti min. ≥ 12.2°C

The computer simulation was performed with DesignBuilder software. The tools allow the 3D virtual construction of the building geometry, thermal zoning, definition of the openings and the internal gains parameters to be simulated using the EnergyPlus engine.



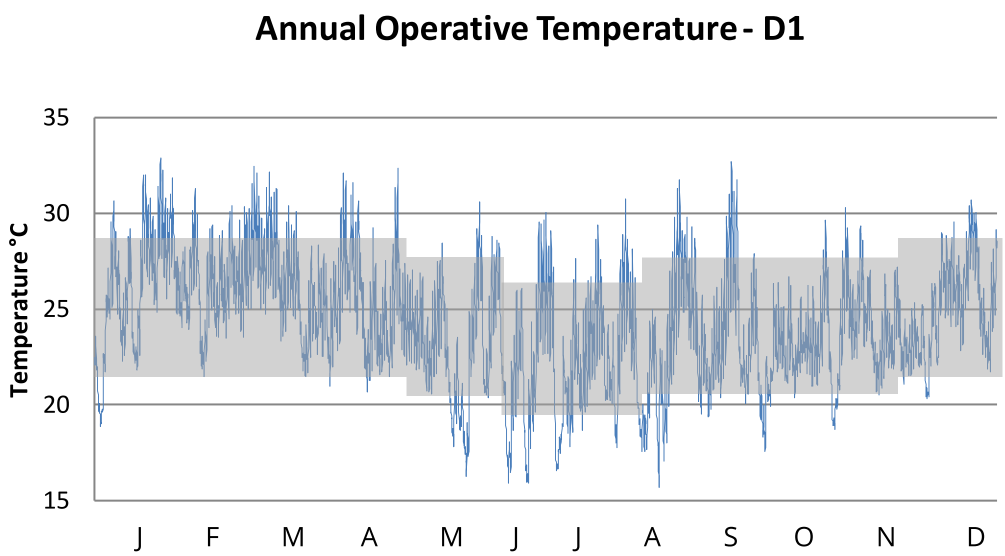
DesignBuilder simulation model

With the hourly internal operative temperatures of the typical day the compliance was analyzed:

Summer 25/01	BEDROOMS								LIVING ROOMS			
	D1	D2	D3	D4	D5	D6	D7	D8	S1	S2	S3	S4
M ≤31.9	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
I ≤29.9	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
S ≤27.9	NO	NO	YES	NO	NO	NO	YES	NO	YES	YES	YES	YES

As shown, in summer, the building achieves intermediate thermal performance since some bedrooms achieve higher temperatures than the maximum defined for superior performance. In winter, the analysis indicated the building compliance to Superior performance level. According to the results, the building performed better than minimum required by the standard. However, the performance can be improved.

To propose modifications, it is important to understand the annual temperature variations in order to avoid improving a few days at the expense of most of the year. To achieve this goal, the same energy model was used to carry out an annual simulation.



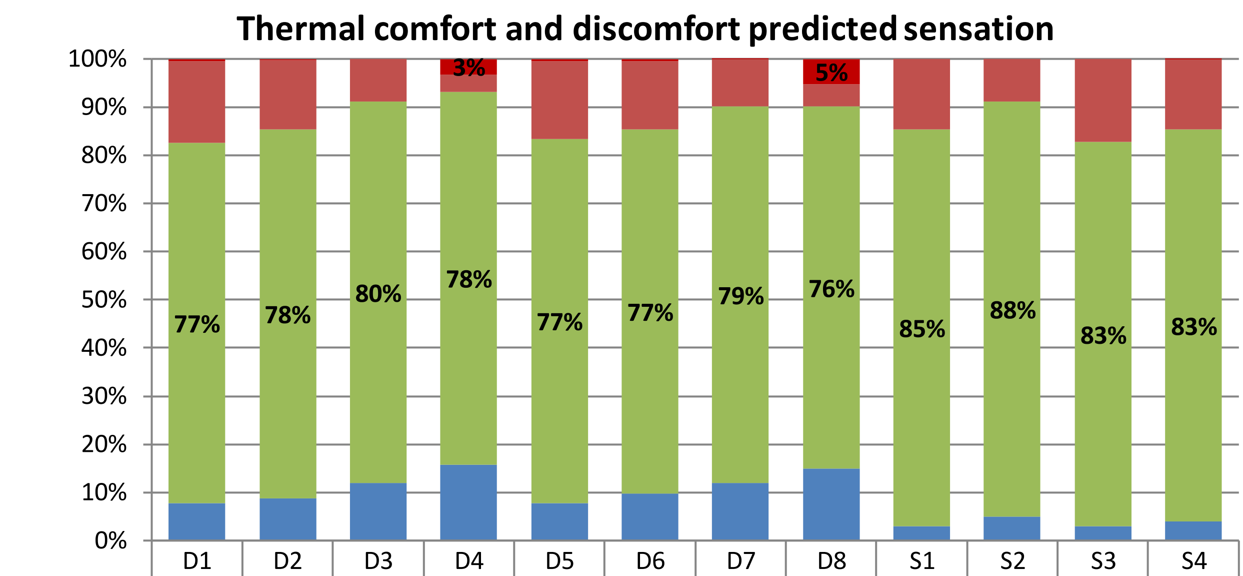
To analyze the annual performance, another methodology was used. The North American standard ASHRAE[2] 55 defines that for naturally ventilated spaces the adaptive thermal comfort methodology should be applied to verify the thermal performance based on predicted user's thermal comfort. The methodology is based on the calculation of annual percentage of internal temperatures within the

[2] American Society of Heating and Air-Conditioning Engineers (ASHRAE) 55 de 2004: *Thermal environmental Conditions for Human Occupancy*.

thermal comfort range for the location. This range is the comfort zone that varies according to the location average external temperatures. For Sao Paulo, it is calculated based on the weather file[3] average external temperature for each month:

Thermal comfort zone per month by ASHRAE 55 methodology - São Paulo (°C)													
	Jan	Feb	Mar	April	May	Jun	Jul	Ag	Sep	Oct	Nov	Dec	Average
Maximum	27.4	27.5	27.2	26.7	26.0	25.7	25.5	25.8	25.9	26.4	26.7	27.1	26.5
Minimum	22.1	22.2	21.9	21.5	20.8	20.4	20.3	20.5	20.6	21.1	21.5	21.8	21.2

Temperatures higher than the comfort zone maximum limit can be considered to indicate overheating discomfort and lower temperatures, cold discomfort. The high temperatures were also analyzed applying the methodology proposed by the British Chartered Institution of Building Services Engineers (CIBSE)[4] in their guidance document TM52 for overheating situations. Considering the presented methods, the simulated annual internal temperatures were analyzed at each regularly occupied space:



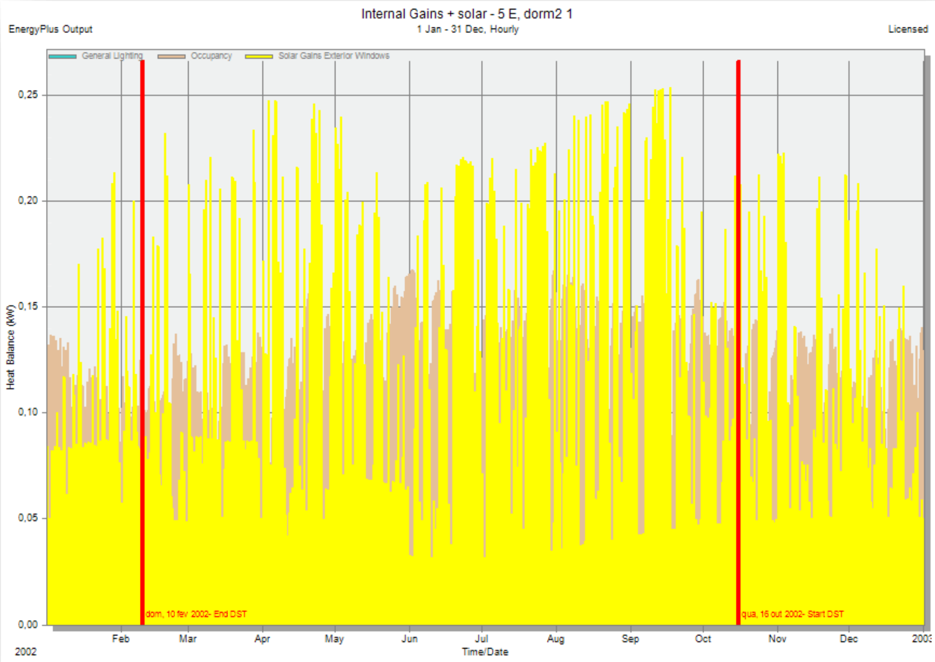
	D1	D2	D3	D4	D5	D6	D7	D8	S1	S2	S3	S4
Over H	0%	0%	0%	3%	0%	0%	0%	5%	0%	0%	0%	0%
heat	18%	15%	9%	4%	17%	15%	10%	5%	15%	9%	18%	15%
comfort	77%	78%	80%	78%	77%	77%	79%	76%	85%	88%	83%	83%
cold	8%	9%	12%	16%	8%	10%	12%	15%	3%	5%	3%	4%

[3] https://energyplus.net/weather-region/south_america_wmo_region_3/BRA

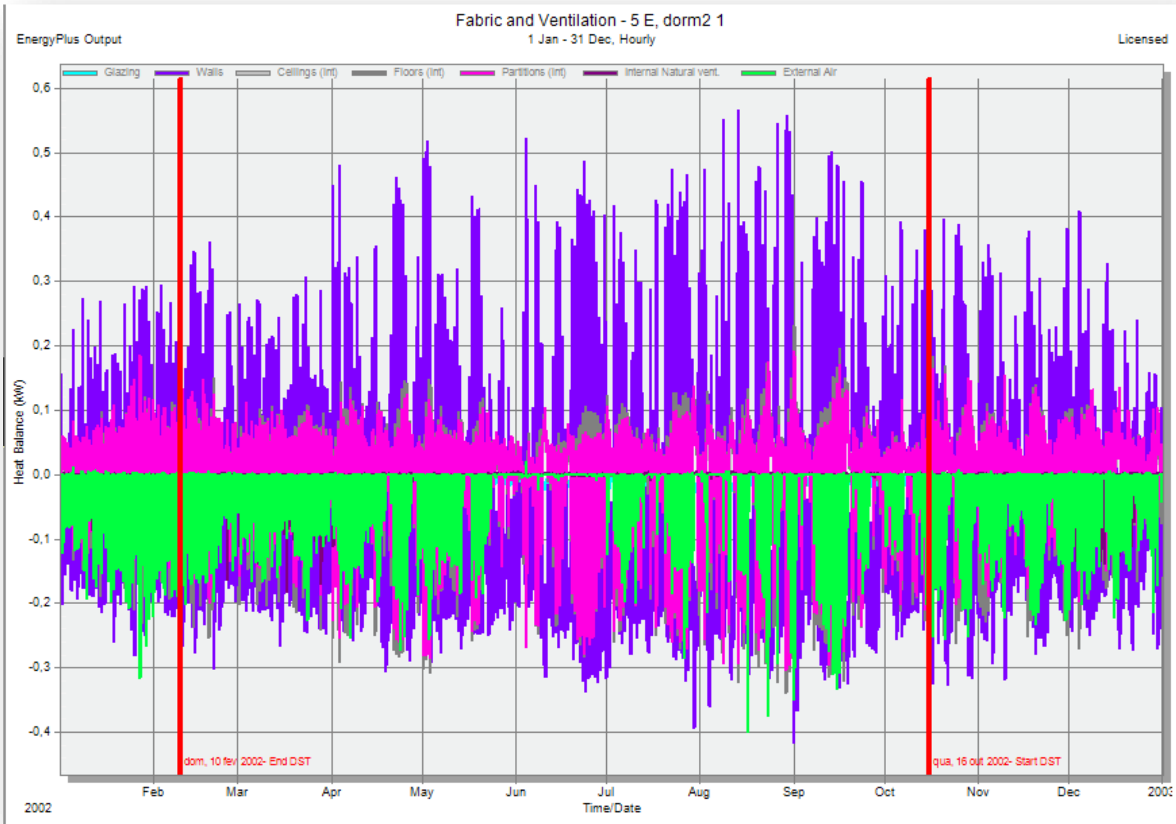
[4] CIBSE (Chartered Institution of Building Services Engineers): TM52 The Limits of Thermal Comfort_ Avoiding Overheating in European Buildings NEW 2013.

At least 80% of annual comfort hours can be considered a good thermal performance for these spaces. As shown in the chart, they show relatively good thermal performance. All the living rooms have more than 80% of annual internal temperatures within the comfort zone range, showing a good performance. However, in the bedrooms the envelope could be improved to get closer to 80% comfort. Also, two bedrooms (D4 and D8) show overheating situations that must be avoided. The diagnostic of discomfort can be expressed by the following diagram:

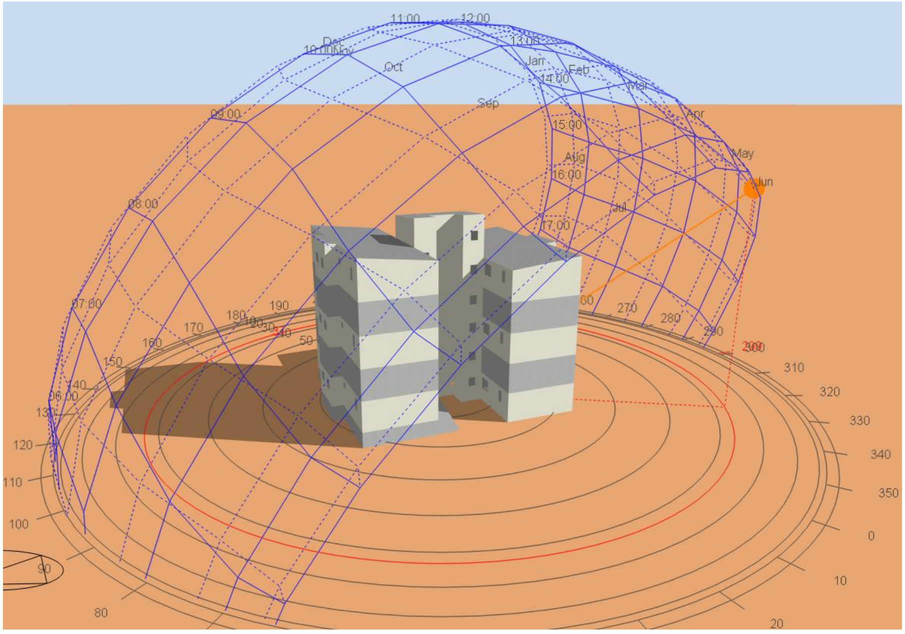
Diagnostic of Thermal performance: Red- Heat discomfort / Blue-Cold discomfort/Overheat.



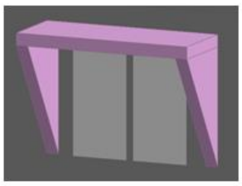
The causes of these high and low temperatures can be identified in internal gains and heat balance graphics produced with DesignBuilder software:



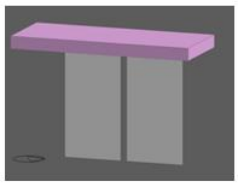
They indicate that the internal gains come mainly from incident solar radiation entering the windows. However, the windows conduction heat gain shown in the second graphic is not significant. The gains indicated in the heat balance are mainly related to the external walls and losses are caused by natural ventilation and external air that creates convection heat losses. These findings lead to the conclusion that window shading, orientation and the external wall materials should be the main envelope aspects to be addressed in order to improve the thermal performance and enhance annual comfort hours.



In view of those conclusions, and also considering the sun path in this location (above), the following comfort improvement strategies are proposed:



Infinite Horizontal shading (blue)



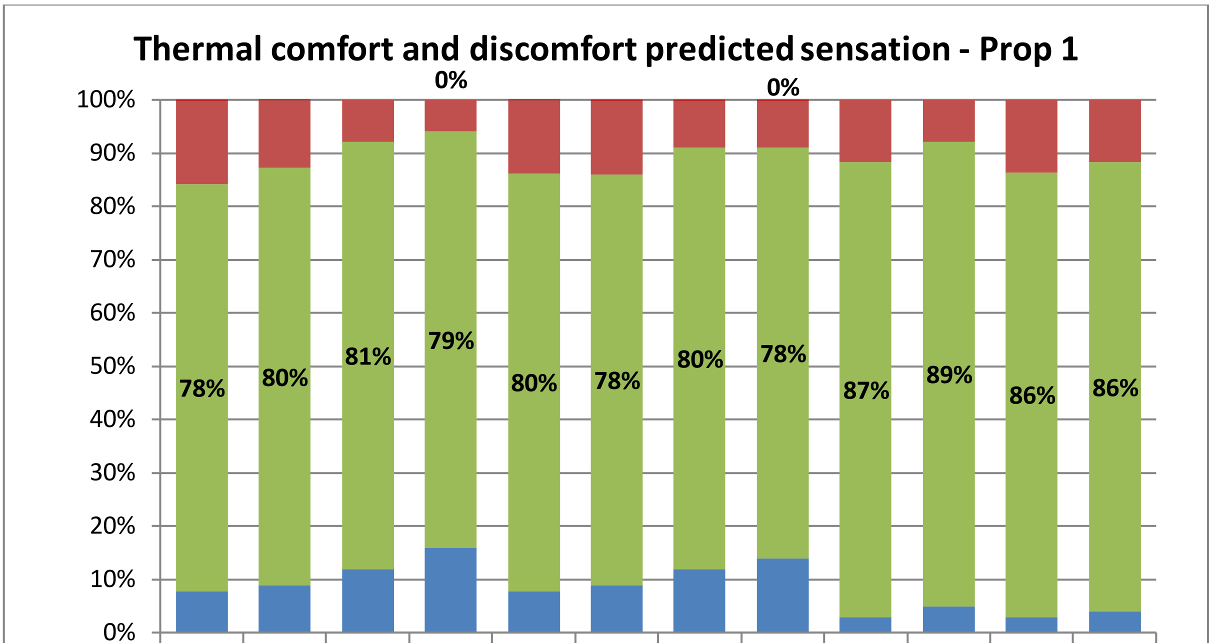
Finite Horizontal shading (orange)

Proposal diagram 1:

- Adding Horizontal Shadings (in blue and orange as indicated);
- Changing the window from the current wall to the one indicated (red);

- Adding a new window (similar to the existing) in the indicated wall.

The shading devices can have a different aesthetic solution, but the goal of blocking incident radiation at noon has to be maintained without preventing entry of natural light. After these modifications, the building was simulated again:

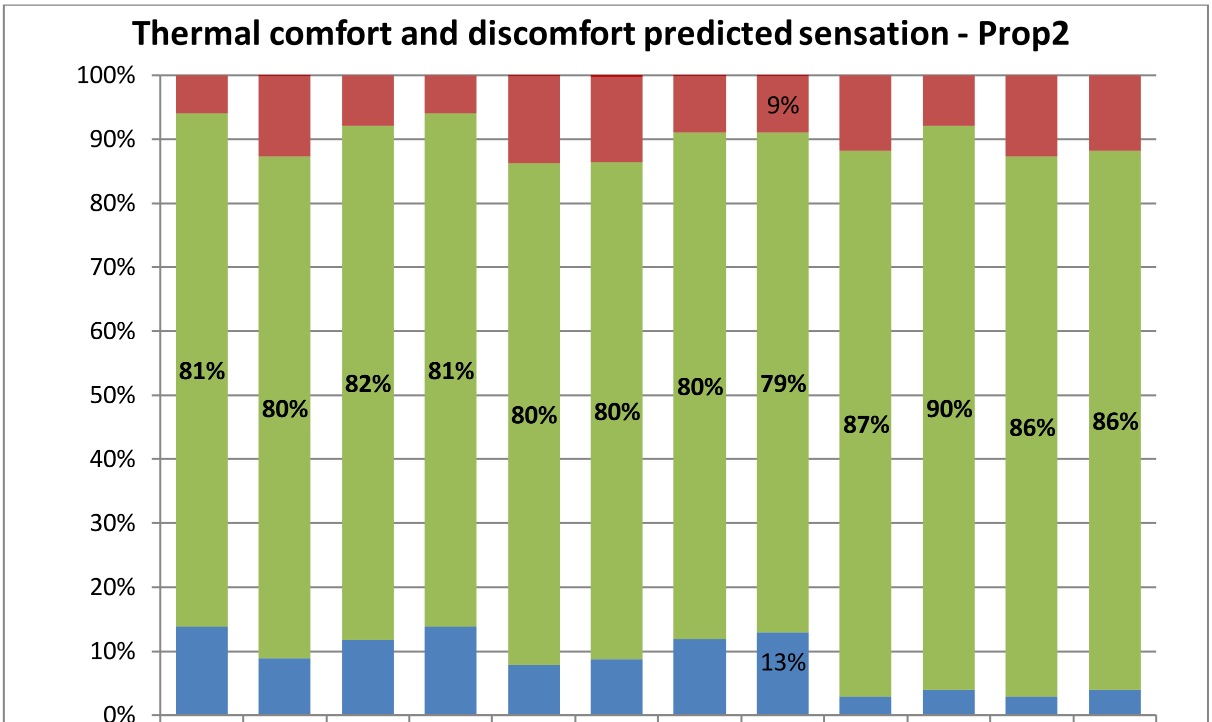


	D1	D2	D3	D4	D5	D6	D7	D8	S1	S2	S3	S4
Over H	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
heat	16%	13%	8%	6%	14%	14%	9%	9%	12%	8%	14%	12%
comfort	78%	80%	81%	79%	80%	78%	80%	78%	87%	89%	86%	86%
cold	8%	9%	12%	16%	8%	9%	12%	14%	3%	5%	3%	4%

The results show that the percent of comfort hours has increased in all the spaces. The overheating problems were solved. On the other hand, some bedrooms still had comfort hours below 80%. This suggests that there are opportunities for improvement. Also, consideration of more thermal mass is highly recommended to reduce peak temperatures.

Proposal Diagram 2

This second proposal considers the highlighted walls to be built with 20cm concrete blocks instead of 15cm blocks. The results of these changes are as follows:



	D1	D2	D3	D4	D5	D6	D7	D8	S1	S2	S3	S4
Over H	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
heat	6%	13%	8%	6%	14%	14%	9%	9%	12%	8%	13%	12%
comfort	81%	80%	82%	81%	80%	80%	80%	79%	87%	90%	86%	86%
cold	14%	9%	12%	14%	8%	9%	12%	13%	3%	4%	3%	4%

The Graphic shows that almost every space achieves 80% of annual comfort hours. The only exception is bedroom D8 that only achieves 79% of comfort hours but very close to the required 80%.

The building performance analysis considered only passive conditioning strategies like natural ventilation, thermal inertia and optimizing passive solar gain in winter without increasing cooling loads. With the use of ceiling fans and/or heaters, it is probable that a higher number of comfort hours would be achieved. However, as demonstrated with simple envelope modifications it was possible to improve the building thermal performance and increase the predicted percentage of annual comfort hours in the main occupied spaces.

Conclusions

Computer simulation is necessary to analyze thermal performance of residential buildings in Brazil. Lawsuits and other legal problems can be avoided when computer models are used to predict performance of buildings, especially in regard of the Brazilian Standard 15.575.

The DesignBuilder software has been successfully used as the main tool to carry out these analyses. By allowing owners and designers to visualize the geometry of the building and analyse the impact of shading systems, thermal mass etc, the decision-making process can be vastly improved.