The Thermal Influence of Envelopment in Naturally Ventilated Environments

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ABSTRACT: Motivated by the increase of 42% on average in Brazilian demand for electricity in the period 2003-2013, due to population growth that reached 12.3% since the year 2000, it has become a priority the adoption of improvements in construction, especially seeking thermal efficiency. More efficient buildings have as targets the intervention and identification of solutions on the project stage, such as the choice of materials with different thermal characteristics and direct relationship in thermal performance. The study aimed to analyze the influence of envelopment materials for the thermal performance of university educational building located in a tropical and humid climate, with the prerogative of the use of natural ventilation as a strategy to improve the comfort, according parameters of Frequency Thermal Discomfort (FDT-%) and Degrees hours of Thermal Discomfort (GhDT-°C.h), seeking the least energy expenditure and promote buildings suitable for the environment. There were made three methodological steps with the 1st on the review of the key concepts work; the 2nd descriptive experimental research simulation with DesignBuilder software; and 3rd of results analysis. Among the results, it was observed that the analyzed environments are all uncomfortable especially the located on the upper floor, with an increase in rates of FDT and GhDT, pointing great interference in thermal gains through the roof, intensified by the impossibility of heat exchange ventilation by night, due to the frames models, which did not allow air circulation, so being required artificial conditioning and required specification of more efficient materials.

Keywords: *Thermal performance; Envelopment; Computer simulation; DesignBuilder.*

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1. INTRODUCTION

Motivated by the 42% average increase in Brazilian demand for electricity in the period 2003-2013 and due to the growth of its population which reached 12.3% since the year 2000, has become a priority the adoption of improvements in construction, in order to get a higher thermal efficiency (IBGE, 2010; ONS, 2014). At the same time, the construction industry is in a evolution period, where is given a growing importance to benefits imposed by materials of less environmental impact and directly linked to the concepts of sustainability (Carvajal, 2004).

It is important to note that in the search for satisfactory thermal behavior, whenever possible, the use of local natural resources, such as natural ventilation, and the use of materials with better thermal performance, in order to increase comfort and reduce electricity consumption, mainly in artificial conditioning environments. In this sense must be intentional the development of solutions that allow the user to enjoy a designed environment integrated to the local climate, providing well being, and adequate spaces for human occupation. Whereas the tropical and humid climate, it should be noted especially the control of heat gains, removal of heat energy and excess moisture from inside of the building (Corbella & Yannas, 2009; Frota & Chiffer, 2009).

An important factor of influence on thermal comfort of buildings is related to the local climate. Due to its large extension the Brazilian territory is covered by various climates and numerous particularities that characterizes them. Given this diversity, it has always been evident the need for definition of climatic groups. Thus the division of the country in bioclimatic zones allows to guide project solutions and constructive guidelines that help in thermal comfort for each region (Roriz et al., 2001).

In tropical and humid climates whereas the absorption of solar thermal energy which focuses on the envelopment, the roof system is the main element of influence on the internal thermal conditioning once is the most exposed to solar radiation in the case of horizontal buildings. The transmission or blocking of thermal load transmitted to the adjacent environments besides influence on thermal comfort also interferes with the energy consumption from forced ventilation equipment and artificial conditioning, demonstrating the importance of heat gains through control of thermal energy dissipation (Corbella & Yannas, 2009; ABNT, 2013).

The specifying materials step during the preliminary design phase fundamental importance on the development of projects with greater thermal efficiency, given the significant influence of those choices on the economic, environmental and social context (Bissoli-Dalvi et al., 2011).

Among the elements of the building envelopment, also stands out as an important factor of influence the side openings. On his historical synthesis Nico-Rodrigues (2008) describes the windows and its influence on ventilation, on his historical synthesis Nico-Rodrigues (2008) describes about windows and its influence on ventilation, demonstrating solutions over time through the adoption of opening protections against solar incidence and allowing natural ventilation permeability, adjusting the comfort temperature. However, these solutions were being forgotten in favor of guidelines and contemporary trends, leading to questionable performance elements.

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One of the processes to the dissipation of the inner thermal load of the environments is the use of ventilation, which occurs exchanging the indoor air by renewed air in search for better air quality and more acceptable comfort temperatures. This process becomes more efficient when there is natural ventilation made by conventional air distribution (Costa, 2005; Liping & Hien, 2007).

Include regulations which deal with the thermal performance of buildings and of thermal variables involved, such as the use of natural ventilation as a passive thermal factor, influencing the increased amount of studies mainly in tropical climates, demonstrating a growing interest on thermally suitable environments (Santo et al., 2013).

The study by Armelin and Cherry (2004), about facilities with several levels of solar radiation barrier; different levels of ventilation; use of tiles with different colors, types and materials; it was verified the possibility of achieving a reduction in the flow of heat through the roof of about 80% when the cover system is designed to use solar radiation barriers, ventilation and under blankets of aluminium base.

In this way, the regulation ASHRAE Standard 55 addresses the environmental thermal conditions comfortable theme of the interior of buildings for the human occupation which would be acceptable to the majority of occupants in naturally ventilated environments. Through its adaptive method of analysis is set a relationship between temperature range indoor comfort to the users and the outside air temperature. Variations of 2.5% and 3.5% - more or less - in relation to the limits of comfort presented by regulation, establish comfort of 90% and to 80% respectively of individuals in the environment (Silveira & Labaki, 2012; ANSI & ASHRAE, 2014).

The survey aimed to analyze the influence of components of the envelopment of the building of classrooms - DCAB/DCS of the Center University North of Espírito Santo/UFES, in the city of São Mateus, ES, with the condition to the thermal comfort natural ventilation. The results allow to extrapolating the solutions for similar situations, mainly, to the campus of São Mateus which is in process of deployment. In this sense, the objective of the survey is also to seek appropriate solutions to maximum comfort with minimal energy expenditure, as well to promote school buildings that serve as example of appropriate architecture to the place.

2. MATERIALS AND METHODS

The study was carried out in three main methodological steps being the first on the review of the key concepts guiding work, as well as documentary and survey data. The second stage is characterized by experimental descriptive research, conducted through the software DesignBuilder, object modeling and relevant settings the characteristics of the materials of the building envelopment. The third stage was devoted to the analysis of the results found.

2.1 SCENARIO OF CHARACTERIZATION

The study was conducted in the city of São Mateus, ES, approximately 217 km from the city of Vitoria, ES. The municipality is located in the northern territory of the State, along

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the coast, (Figs 1-3), characterized as zone 8 (Z8) as the Brazilian Bioclimatic Zoning (ABNT, 2005b; INCAPER, 2011).

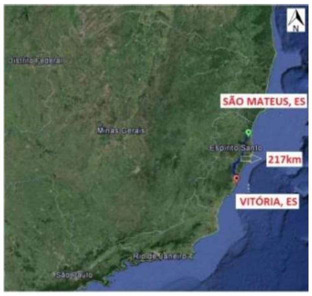

Figure 1. State, ES. Source: Adapted from Google Earth, 2016

Figure 2. CEUNES-UFES. Source: Adapted from Google Earth, 2016

Figure 3. Building analyzed. Source: Adapted from Google Earth, 2016

The municipality of São Mateus, ES has a tropical and humid climate, with incidence of the wind northeast (NE). Has a range of average maximum temperatures for the summer period of approximately 31°C in December to 33°C in February and March for the period 1984 to 2014. The annual average precipitation accumulated is 1,313 mm, with a range of relative humidity for the summer period of approximately 60% to 90%, and is considered a negative factor for comfort when related to high temperatures (INCAPER, 2011; INCAPER, 2014; INMET, 2014).

The model studied was the building of classrooms of the departments of Agricultural and Biological Sciences and Health Sciences of the Center University North of Espírito Santo (CEUNES) of the Federal University of Espírito Santo (UFES). Was chosen for being a standard unit that tends to be repeated elsewhere. Has a horizontal rectangular prismatic architectural typology, composed of four blocks of rooms, distributed in two floors – ground floor and above - with 1,162 m² and 900 m² respectively, totaling 2,062 m² of constructed area. Consists of two blocks of bathrooms, two computer labs and twelve classrooms. Horizontal circulation is established in galleries covered lengthwise and vertical circulation occurs through an external metal stairs and a ramp (Figs 4-5).


Figure 4. Building of classrooms - Longitudinal northeast facade, 2014


Figure 5. Building of classrooms - Longitudinal southwest facade, 2014

For the simulated model (Figs 6-7) were adopted the reference values of the thermal properties of building envelopment elements (Table 1). Your roofing system is lightweight, with aluminium trapezoidal tile of little mass, embedded by parapets, supported on pre-cast concrete slab of 10 cm and PVC liner. The walls are in masonry of ceramic slabs with 8 holes, plaster on both sides and painting with latex paint PVA and coated with white ceramic, totaling approximately 15 cm thick, with the structural system in concrete. The frames are aluminium with colorless glass of 6 mm, with opening system maxim-ar.

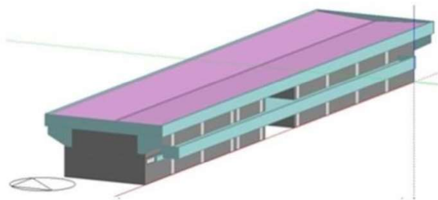

Figure 6. Simulation. Source: DesignBuilder, 2012

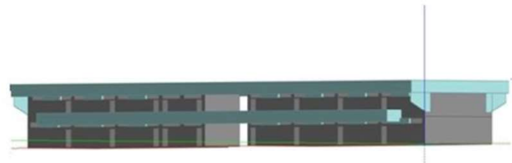

Figure 7. Simulation. Source: DesignBuilder, 2012

Table 1. Thermal characteristics of materials, elements and components of construction

Materials	Apparent bulk density (ρ) kg/m³	Thermal conductivity (λ) W/(m.k)	Specific heat (c) (J/kg.k)
Cement mortar	2000	1.15	1000
Ceramic block	1600	0.90	920
Concrete	2200	1.75	1000
Aluminium miter	2800	160.00	880
Aluminium roofing sheet	2700	230.00	880
Painting	Solar radiation absortivit (α)		0.20
	Emissivity (ε)		0.90
Colorless glass 6mm	Thermal transmittance (U) W/m².k)		5.78

Source: ABNT, 2005a

The study did not consider the possible influence of the surroundings of the building, considering the actual situation of the building on Campus - without elements built nearby, because the studies in Brazil inherent impacts of buildings in the neighborhood are still poorly developed (Scaldo, et al., 2010).

2.2 Processing of data and simulations

With use of DesignBuilder software - 3.1.0.068 Beta - 2012, using calculations for the EnergyPlus 7 algorithm, it was possible to set the monthly average temperature of outside air, following the configuration guidelines established by Venâncio (2009).

Predicting the worst framework of discomfort to the heat, the study was limited to examining the values in "non-compliance" to the maximum of the comfort temperature, for 90% of acceptability, recommended by ASHRAE Standard 55 (2014) for the summer period. Since way, are considered the features of the Z8 and the use of the file Test Reference Year (TRY) the city of Vitória, ES, given the proximity of the city and the consolidation of the climate information (UFSC, 2012; INCAPER, 2013).

For the data analysis process, with the condition the use of natural ventilation for the suitability of temperature in environments, was adopted the analysis model that establishes the relationship between indicators for the heat Frequency of Thermal

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Discomfort (FDT-%) and Degrees hours of Thermal Discomfort (GhDT-°C.h) (Nico-Rodrigues, 2015; Nico-Rodrigues et al., 2015).

The FDT-% indicator is the percentage of time in a specified period, where the operating temperature is in non-compliance with the established range as comfort temperature. Already the GhDT-°C.h indicator is the sum of the difference between hourly operating temperature and the temperature of comfort (Nico-Rodrigues, 2015).

Complementary manner was adopted the buoyancy diagram (Fig. 8), to facilitate the analysis of the studied indicators, measuring the discomfort with the frequency and thermal intensity (Nico-Rodrigues, 2015; Nico-Rodrigues et al., 2015).

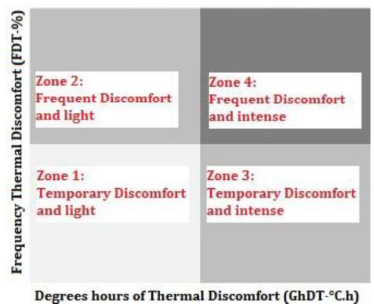

Figure 8. Buoyancy diagram of FDT and GhDT. Source: Adapted from Sicurella et al., 2012

The simulations were carried out to the classrooms 01, 06 and computer lab 01, located on the ground floor and upper floor equivalents for rooms are located at the ends of the building and have larger envelopment area exposed to solar incidence and electronic equipment in the laboratories (Fig. 9).

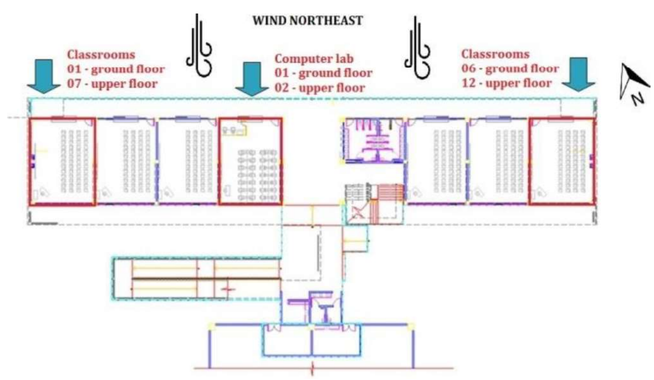

Figure 9. Schematic layout of the analyzed environments. Source: Adapted from UFES, 2006

For the definition of the days analyzed, we used a normal model of probability and statistical interference, based on the use of external air temperatures in summer days, defining the valid days of effective analysis, determining an operational temperature range with 99% confidence, resulting in the final set of 23 days, namely, 552 hours (Table 2). The comfort temperature ranges for the summer months in study were established from the adaptive comfort chart of ASHRAE standard 55, adopting the temperatures obtained through computer simulations (Table 3) (Nico-Rodrigues, 2015; Nico-Rodrigues et al., 2015).

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Table 2. Set of days defined by the confidence interval for the summer period

Months	Analyzed dates									
December	21									
January	5	6	17	22	25					
February	1	5	8	9	10	19	20	21	25	26
March	1	3	6	9	10	11	17			

Table 3. Monthly averages of external air temperature/ Thermal comfort range

Months	Monthly average external air temperature	Comfort temperature range - Adaptive model ASHRAE 55 (Min. - Max.)
December	26.86°C	23.61°C – 28.61°C
January	26,35°C	23.45°C – 28.45°C
February	25,76°C	23.27°C – 28.27°C
March	26,65°C	23.55°C – 28.55°C

3. RESULTS

To the maximum values of the indicators for the season of the summer, were established the FDT-% (100%) = 552 h or 23 days and GhDT-°C.h = 62.75°C, reached on March 17 date for the computer lab 02 in the upper floor.

The study diagnosed the widespread occurrence, uncomfortable environments, demonstrated that the indicators are non-conforming virtually throughout the analysis period. It has an average range of occurrence of GhDT of 14.54°C.h to 39.60°C.h, indicating temperatures above the range of comfort. Similarly, there was an average range of occurrence of FDT 49.68% to 64%, pointing to a daily frequency in occurrence of discomfort (Table 4).

For the month of March, where all the days analyzed showed high temperature and frequency, the day 17, characterized as the largest day FDT, between 18 and 21 hours of the day (Table 5).

Table 4. Results by environments

Environments	Total GhDT (°C.h)	Average GhDT (°C.h)	Average FDT (%)	Total FDT (h)	Average (23 days) FDT (h)
Ground floor					
Classroom - 01	334.42	14.54	49.68	274	12
Classroom - 06	335.97	14.61	50.40	278	12
Computer lab - 01	768.56	33.42	56.93	314	14
Upper floor					
Classroom - 07	435.72	18.94	56.02	309	13
Classroom - 12	437.03	19.00	55.66	307	13
Computer lab - 02	910.75	39.60	64.00	353	15

Table 5. FDT - Extract daily results - march

Dates		1/3	3/3	6/3	9/3	10/3	11/3	17/3
Ground floor								
Classroom - 01	FDT (%)	66.72	66.72	58.38	66.72	66.72	37.53	75.06
	FDT (h)	16	16	14	16	16	9	18
Classroom - 06	FDT (%)	66.72	66.72	66.72	66.72	70.89	41.70	75.06
	FDT (h)	16	16	16	16	17	10	18
Computer lab - 01	FDT (%)	70.89	70.89	66.72	75.06	75.06	45.87	83.40

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	FDT (h)	17	17	16	18	18	11	20
				Upper floor				
Classroom - 07	FDT (%)	66.72	66.72	58.38	70.89	70.89	45.87	79.23
	FDT (h)	16	16	14	17	17	11	19
Classroom - 12	FDT (%)	66.72	66.72	58.38	70.89	70.89	45.87	79.23
	FDT (h)	16	16	14	17	17	11	19
Computer lab - 02	FDT (%)	79.23	75.06	66.72	79.23	79.23	54.21	87.57
	FDT (h)	19	18	16	19	19	13	21

Comparing the indices of classrooms with computer labs, the classrooms present frequent and slight discomfort, with temperatures slightly above the comfort temperature and lower maximum values compared to laboratories (Fig. 10).

The laboratories present frequent and intense discomfort, with temperatures above the comfort temperature and maximum values higher than the classrooms, with larger and more negative buoyancy, showing high temperatures for longer period of the day, caused by electronic equipment (Fig. 10).

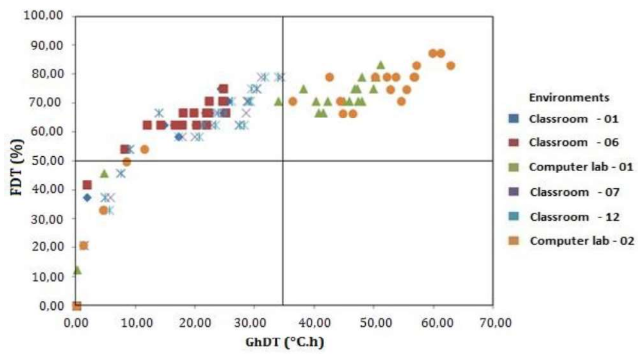

Figure 10. Diagram of buoyancy of environments

The resulting discomfort demonstrates that even the environments having one of the walls protected with a space with porch, which assists in blocking solar incidence, the obtained values still remained above the comfort temperature, a fact noted by the absence of night ventilation, since the window model does not provide constant ventilation and thermal inertia increases the internal temperature overnight. The thermal gain of the equipment and the user, as well as the envelopment and roof increases the internal temperature, increased by the absence of night ventilation.

The comparison of environments between decks pointed to an increase in the indicators of FDT and GhDT, demonstrating an important interference factor in the thermal gains by inefficient roof system (Figs. 11-12).

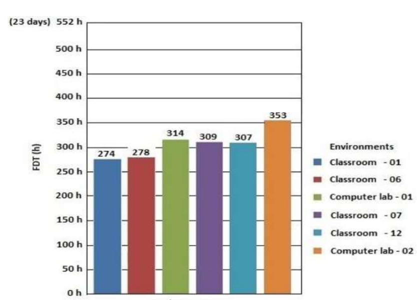

Figure 11. Hours in thermal discomfort equivalent to FDT-% in 23 days analyzed

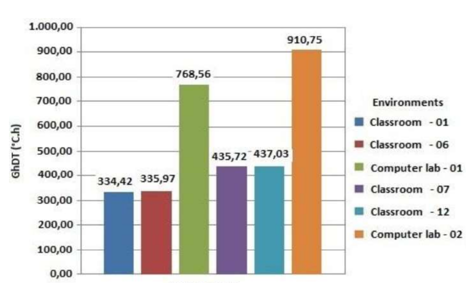

Figure 12. Sum of the GhDT-°C.h in 23 days analyzed

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4. CONCLUSIONS

The results presented by the simulations showed high percentages of FDT and GhDT for all environments. Was evidenced that the configuration of the architectural typology and envelopment elements that are commonly used in buildings of the campus of CEUNES directly influence for the creation of ambiences uncomfortable.

An important factor of increase in the negative performance observed in the study is related to the typology of maxim-ar type windows used in construction and widespread on campus, and its relationship with the night ventilation. Its structure is completely fenced to ventilation, without any element that allows the renewal of the air when closed, requiring the need for manual opening, for only thus allowing natural ventilation and air renewal.

The method of analysis allowed to quantify the disparity between the operative temperature which exceeds the limit of adaptive comfort temperature set for the period. In this way, allow to characterize the environments according to the simulated environmental conditions, making possible performance improvement interventions, even so, allow the establishment of data for the development of future projects for campus and region, with higher quality and thermal efficiency.

The simulations have made it possible to conclude that the materials specified for the envelopment, widespread and found in other buildings on campus, do not offer satisfactory thermal performance for comfort. The results showed the need of intervention actions in order to improve the performance of the environments examined. In accordance with Nico-Rodrigues (2015), there is a need for the adoption of protective envelopment shaders, as well as the need for more efficient materials specification, especially for the system of roof in horizontal buildings cover.

It is observed that in the current reality is indispensable to artificial conditioning prerogative on warmer days and times of the summer, but at the same time it is feasible that by specifying more efficient materials achieve a reduction in the frequency and intensity of the indoor temperature in building environments studied.

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