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Architectural spatiality and thermal performance for tropical contemporary Brazilian houses

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Abstract

This paper presents a study, through simulation tools, of the relation between thermal comfort (on EnergyPlus) and spatial patterns (on Depthmap). The sample of dwellings analysed, representative of the contemporary architecture from Natal-Brazil, was chosen in order to study how room distribution within a residence can be related to natural ventilation performance, a common bioclimatic strategy for tropical regions. Main results show that it was identified a tendency, which relates high integration, as well as connectivity, to low costs on refrigeration.

Keywords: *space syntax, bioclimatic architecture, thermal performance in residential buildings, natural ventilation, spatiality*

Theme: *Building Morphology and Performativity*

Introduction

It is a well-established fact that the energy saving in buildings is an essential requisite nowadays, considering the need for a more sustainable world, and a better natural balance. By this means, contemporary buildings emphasize their relations with the natural environment, aiming for the saving of energy and natural resources.

The research is motivated by the lack of studies in thermal performance which also consider the matter of spatiality in buildings. Spatiality, in this case, is understood as the relation between physical and visual permeability and the envelope, as well as the consequences to the integration, legibility and appropriation of the internal spaces. It will be considered the matter of space visibility analysis, as commented by Turner (2003, p. 657): “We might use visibility analysis to talk about morphological properties of the built environment, or to talk about how people can move or interact within the visible space, or to discover the significance of objects placed within that space.”

The analysis of those spatial aspects could provide a deeper understanding of “socialization” which has a precise meaning in spatial syntax: “co presence of people in a space, respectively by physical or visual accessibility made possible by the nature of interspaces frontiers which could be more/less permeable to the movement, and more/less transparent to the visibility” (Holanda, 2011, p. 179). Hanson (1988) also explains that the manipulation of the spatial form could enrich the architectural experience by providing a multifaceted socialization; or impoverish it, articulating a point of view of determined actor or nobody at all.

The research was conducted using available software in the area of space syntax, Depthmap, and in the area of energy simulation, EnergyPlus. The sample of dwellings analyzed in the research, representative of the contemporary architecture of Natal/RN, was submitted to both spatial and thermal analyses with the aim of identifying if there are recognizable spatial patterns and how these patterns would relate to the number of hours of physical thermal comfort obtained during the whole year, considering only the use of natural ventilation. It is a very common bioclimatic strategy for building thermal comfort in hot and humid climates.

The authors of the research expect then to identify types of spatiality which would lead to better solutions for bioclimatic dwellings, considering both social (spatial) and thermal performance matters.

In this perspective it is intended to use morphological analyses procedures, giving emphasis to the space syntax analysis of the space through the Social Logic of Space theory (Hillier & Hanson, 1984), as well as the visibility analysis of space (Turner et al, 2001). All combined to the procedures of thermal performance simulation of the selected examples.

Some studies in the area of space syntax considering visible integration in internal spaces were identified by the authors (Beck & Turkienicz, 2009; Lu, Peponis & Zimring 2009), as well as in the area of thermal performance of natural ventilated buildings in Brazil (Sorgato, 2009; Versage, 2009). However, it is unknown the existence of studies which combine both lines of research.

It is expected that by the end of this study it could provide a better understanding of the mutual influences between the spatial distribution and thermal performance of natural ventilated dwellings, as well as improving the knowledge for the designing of new buildings.

Methods and samples

The spatial analyses were divided in visibility analysis and physical accessibility, or permeability, analysis, both held through the software Depthmap and presented as VGA Maps. Space syntax measures such as connectivity (visibility analysis), integration [HH][1] (permeability analysis) and visual integration [HH] (visibility analysis) were analyzed. The average values for each of the specific measures were extracted by zones in order to make it easier to interpret the data generated by the maps.

Each building analyzed had its design simplified in terms of internal possible movements and visibility. The visibility analysis only considered the opaque barriers at the observer's height of vision (h ≈ 1,60m). Windows and doors were considered open for the visibility analysis. However, for the accessibility analysis only the doors were not considered as barriers. Everything else which hindered internal movement was considered as barriers in the accessibility analysis. It is also important to mention that the different types of spatial analysis held in the research only considered the internal spaces of the buildings and their relations.

Another, more traditional type of spatial analysis, using graphs was also used for comparison with past works on the subject. Those are known as justified graphs and are presented along the paper. Graphs were built considering spaces as nodes and direct access between them as links. The initial point at the house's front door and the spaces were labeled according to its use as social, service, intimate, hallway and garden. The closing index was also used. It is described by Hanson (1988) as the percentage of the closed spaces over the total number of convex units of the building. Closed spaces are defined as spaces for intimacy such as bedrooms, bathrooms, suites and restrooms.

Thermal simulations held through the EnergyPlus software were used to verify the number of thermal comfort hours during the whole year (Degrees-hour/year) obtained by the use of natural ventilation, the most common bioclimatic cooling strategy for tropical hot and humid climates. It was also analyzed the annual air changes rate per hour (ach) for each house analyzed.

Virtual designs in 3-D were built for each dwelling selected. All the constructive aspects used in the thermal simulations such as openings, walls, ceiling, sheds, floor, ceiling height and shading devices were standardized, since our concern was the form itself, and its consequences on spatiality and thermal comfort (Table 1). The openings dimensions were established following the minimum requested by Municipal Legislation (Secretaria Municipal de Natal, 2009).

[1] Hillier & Hanson, 1984.

Parameters	Envelope's Adopted Values
Climate	Natal/RN/Brazil
Percentage of ventilated area related to the floor (%) – area of prolonged permanence[2]	16
Percentage of ventilated area related to the floor (%) – area of temporary permanence[3]	13
Wall's absorptance	0,40
Wall's thermal transmittance (W/m²K)	2,59
Roof's absorptance	0,40
Roof's thermal transmittance (W/m²K)	1,79
Glass' Solar Transmittance	0,84
Windows shading device absorptance	0,50

Table 1: Parameters used in the simulations and its respective values.

The annual weather data of Natal/RN (www.labee.ufsc.br) was used for the thermal simulations of all the models. The windows were considered constantly opened during the whole simulation time (24h per day), considering it is a common way to ventilate homes at the specific region.

The thermal performance analysis of each one of the houses intended to verify the number of annual degrees-hour for refrigeration (GHr) and the annual air changes rate per hour (ach), considering the natural ventilation as a bioclimatic strategy very common in the region where the designs were made for. Annual degrees-hour, as it is used in the Brazilian building labeling procedures, is intended to be: "The indicator of the building envelope's thermal performance as being naturally ventilated. It is based on the degrees-hour method which uses the base temperature, not considering comfort temperatures, consisting on a reference temperature for comparing. In this RTQ, the indicator represents the annual degrees-hour sum calculated for the 26ºC base temperature for refrigeration. The calculations are made through the environment operative temperature." (Eletrobras/Procel, 2009).

The internal loads generated by occupants, domestic appliances and lightning were not considered on the simulations in order to observe the building's own capacity of maintaining acceptable annual degrees-hour (GHr) and also considering the innumerous possible patterns for a house operation, from which it would be difficult to settle a representative one. The free-floating simulations, when the ventilation is considered constantly on, were made considering both situations, external windows opened and closed. All the external windows received shading devices in order to improve its performance considering the high solar radiation.

All the designs were oriented following the original designs.

The sample consists of dwellings designed for the city of Natal/RN, and its surroundings. The buildings have total floor area between 150,00m² and 300,00m², placing them in medium-to-high class of construction. The greater typological variety of this range as well as the accessibility to the designs determined the choice. Moreover, the designs belong to a contemporary architectural production, having been designed from 2002 ahead.

Ten houses were selected for the research. Four of the houses, House 01, 02, 04, 05 and 08, were designed for the city of Natal/RN whereas House 03, 07 and House 09 were designed for

[2] Spaces such as bedrooms, kitchens, living rooms, dining rooms and offices.
[3] Spaces such as deposits, hallways and bathrooms.

the city of Parnamirim/RN. House 06 was designed for Extremoz/RN and House 10 was designed for Tibau do Sul/RN. All of them were intended to serve as the official family's house.

All the selected houses have the basic characteristics of a regular Brazilian home. They are all formed by living room, dining room, open kitchen, home office, TV room, bedrooms, suites, social bathroom, private bathrooms, and an area for heavy services (cleaning, washing, etc). Some of the houses have social areas for receiving outside visitors like the House 05 (workshop area).

All the houses were designed by professional architects, not necessarily aiming low environment impact.

The final conclusions will divide the houses' analysis according to its number or floors, considering that the sample is composed of one and two stories. It is important to notice that the second story houses are analyzed in a single linked identity, considering the stair cases as the linking elements between stories.

Figure 1: House 01 to House 05 floor plans with its respective orientations and zones.

Figure 2: House 06 to House 10 floor plans with its respective orientations and zones.

Figure 1 and Figure 2 show how each house is configured and how they were zoned for the simulations. Those were zoned basically into Social (ZS), Intimate (ZI) or Circulation (ZC) zones, according to the type of activity performed. The stair cases which are cloistered and not close to a mezzanine were considered as a Circulation Zone (ZC) and the other ones were integrated to the social or intimate zones.

Results and conclusions

It can be noticed that the House 10, the one with the Social Zone's highest values for integration and connectivity, is also the design which obtained one of the lowest number of degrees-hour over 26ºC. On the other hand, the House 03 has the worst thermal performance. It presents values for integration for the social zone lower to the House 10, and with some other zones presenting even lower values, Figure 3 and Figure 4.

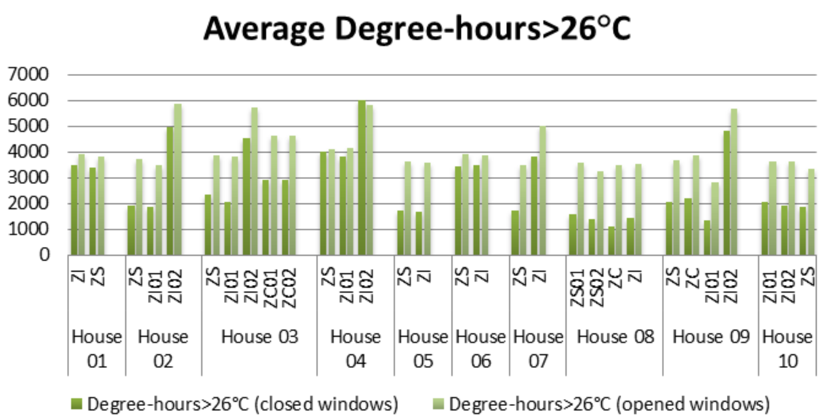


Figure 3: Average Degree-hours >26°C per zone for both closed and opened windows conditions.

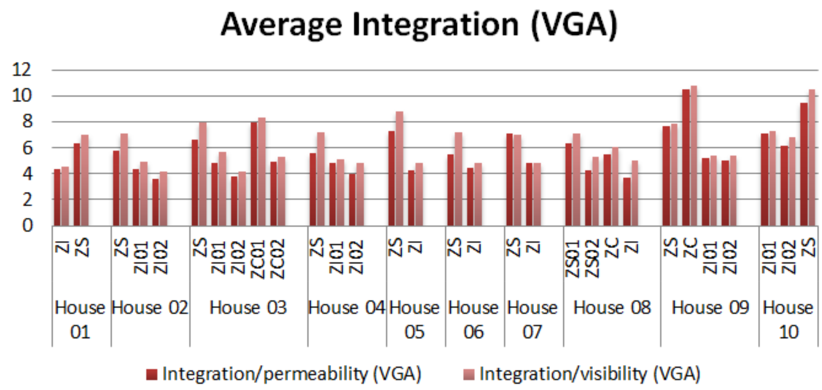


Figure 4: Average Integration values per zone for both permeability and visibility analysis.

While the thermal performance simulations reveal the House 05 and the House 10 as the most comfortable ones they also present the lowest values for the closing index. On the other hand the House 03, the design with the highest number of degree-hours over 26ºC, has the third highest value for the closing index as well as medium average rate for air changes per hour. The House 05 has a more compact design, or less spread out floor plant, however, House 10, has a more spread out design, and both present a good thermal performance. On the other hand, House 10's closing index value is higher than the Houses 05's closing index value.

This pattern identified between low closing index, high compactness, and best thermal performance is interesting because may lead us to conclude that it is possible to have more compact buildings with less internal divisions (and thus lower closing index values) and better thermal performance. And on the other hand, the more spread out designs are those should present even higher closing index values, or being more partitioned, in order to balance the air changes rate distribution through the distinct zones, as observed in House 04 (Figure 5 and Figure 6).

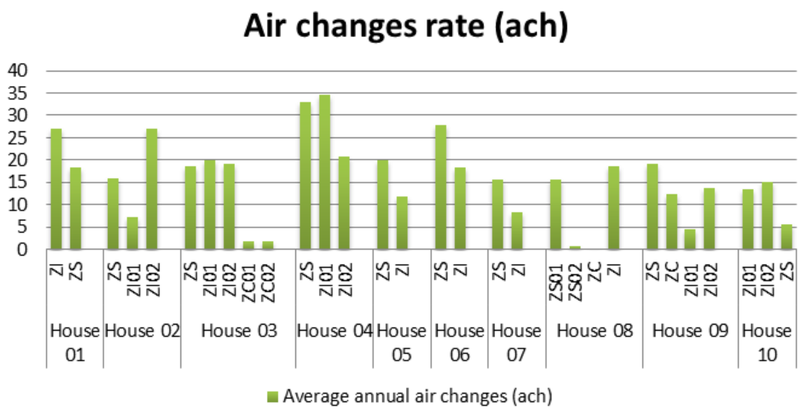
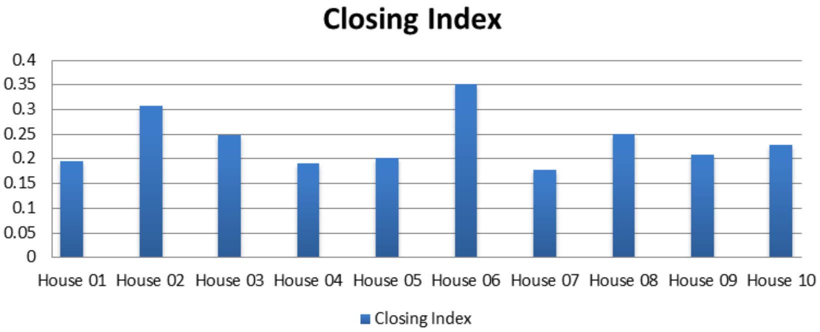


Figure 5: Average Annual air change rate (ach) per zone.



.Figure 6: Closing Index per house.

More compact systems present less outside surface area and less heat exchange with the outside. This pattern is noticed in House 01 which has a similar closing index to House 05 and a reasonable thermal performance, as well as being a compact design compared to others. Figure 9 show this relation (Closing index versus Degree-hours) in more details.

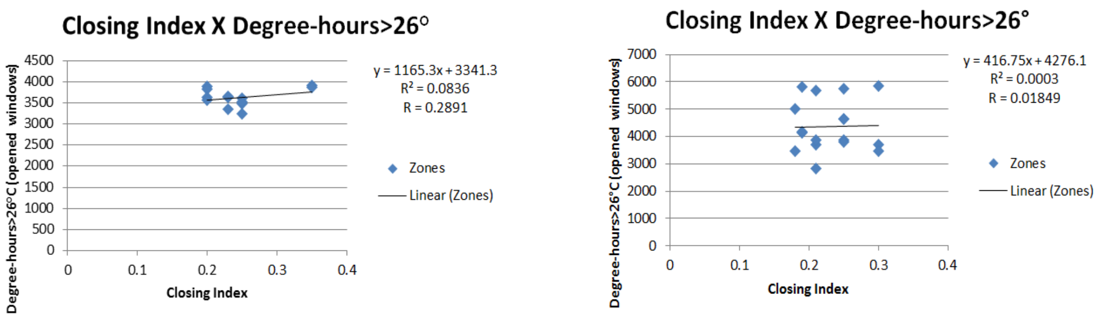


Figure 7: Closing Index values versus Degree-hours >26°C for opened windows condition per zone, single floor houses and two floors houses respectively.

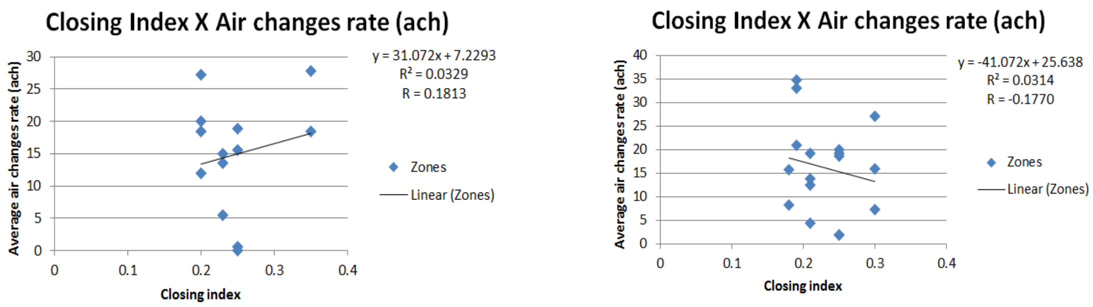


Figure 8: Closing Index values versus annual average air change rate per hour (ach) for each zone, single floor house and two floors houses respectively.

The correlation found between the Closing Index values versus the annual average air change rate (ach) for single floor houses is 0.18, a weak correlation (Figure 8-a). For two floors houses, the correlation found is also -0.18, a weak correlation, however, a negative one (Figure 8-b). Other completely different values were found for the correlation between Closing Index values and Degrees-hour>26°C (Figure 7), those are 0.28 (single floor houses) and 0.02 (two floors houses), both weak correlations. Once we found weak correlations for those variables, it is difficult to make deeper assumptions about it. Perhaps, closing index do not correlate to air changes because this last one also depends on the building’s solar orientation.

Considering the system depth (Figure 12 and Figure 13) of the five houses with one floor (House 01, House 05, House 06, House 08 and House 10) compared to the others with two levels we notice that the deeper the system is, the higher is the number of degree-hours over 26ºC it presents. Maybe the answer for better design methods, aiming to improve thermal performance, would be shallow systems, however with low, or high, closing index (depending on the design’s compactness), and high visual connectivity as well as integration. The relation between visual connectivity, integration and thermal performance is better illustrated through Figure 9 to Figure 11.

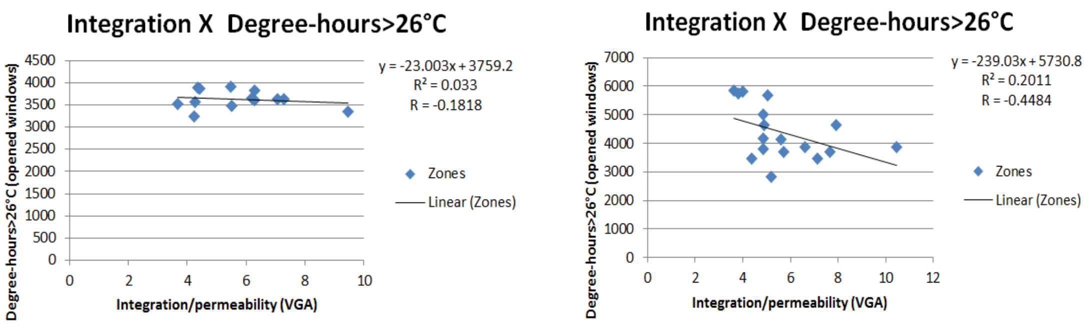


Figure 9: Integration (permeability) versus Degree-hours >26°C for opened windows condition per zone, single floor houses and two floors houses resptctively.

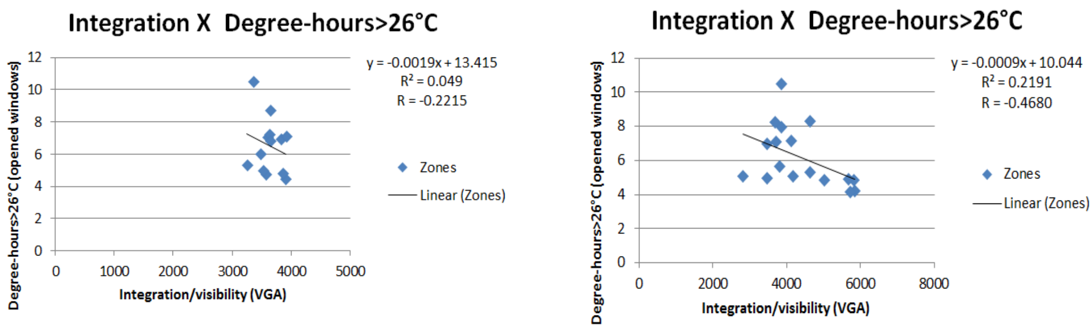


Figure 10: Integration (visibility) versus Degree-hours >26°C for opened windows condition per zone, single floor houses and two floors houses respectively.

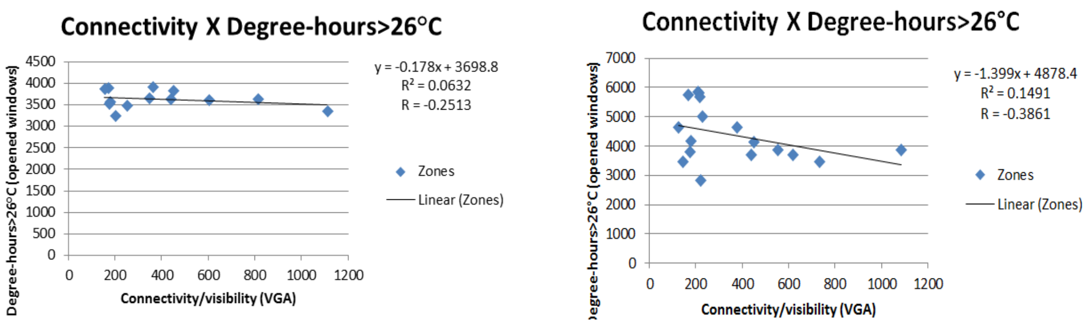


Figure 11: Connectivity (visibility) versus Degree-hours >26°C for opened windows condition per zone, single floor

houses and two floors houses respectively.

The correlations found between Integration (permeability) values and Degrees-hour >26°C values are -0.18 (single floor houses) and -0.45 (two floors houses), weak and moderate correlations, respectively. However, higher correlations were found between Integration (visibility) values and Degrees-hour >26°C values, -0.22 (single floor houses) and -0.47 (two floors houses). For Connectivity (visibility) versus Degrees-hour >26°C it was found a correlation of -0.25 (single floor houses) and -0.39 (two floors houses), weak and moderate correlations, respectively, similar to integration's correlations.

Perhaps, we could assume that there is correlation between connectivity, integration and Degree-hours>26°C because the more integrated or connected a system is less barriers (walls) for ventilation it has and less built mass it has to be cooled down, so it should be easier to keep the inside cool. In addition, differently to the air changes rate variable, the thermal performance (Degree-hours>26°C) do not depends so much on the solar orientation.

It is important to notice that the thermal performance of the houses improved, especially for Houses 05, 08 and 10, when the external windows were considered shut during the whole simulation time, Figure 3. From this result we could conclude that keeping the windows shut, in these cases, is better than what is commonly done in Natal, when the windows remain opened for almost the whole time. However, both analyses (closed and opened windows) follow the same pattern of thermal performance distribution by zone, except for House 08. It is important to notice that internal loads are not considered in the research.

The difference between one story houses and two story houses is more visible when we relate the space syntax measures and thermal performance variables such as Integration, Connectivity and Degree-hours>26°C. That happens because once the houses' second floors are usually more segregated they are also more susceptible to the solar radiance what gives it a worst thermal performance than the one story houses. It is also important to notice that the one story houses present higher thermal inertia because of the direct contact to the soil what avoids higher heat exchanges with the outside and also less heat gain to the inside. That is the reason why the one story houses present better thermal performance than the two story ones.

Through the justified graphs it was possible to observe that House 01, House 05 and House 09 are the shallowest systems and those are distributed in six levels of depth. It is important to notice that the deeper the space is inside the system is, the higher its integration (RRA) values tend to be, Figure 12 and Figure 13.

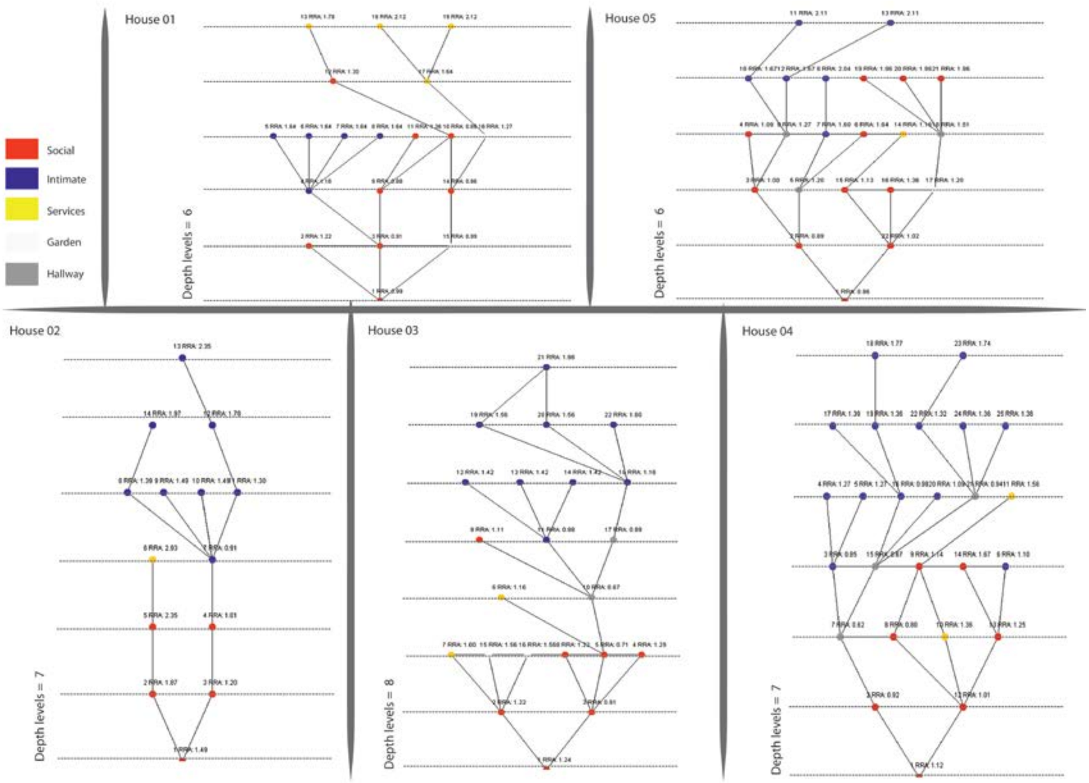


Figure 12: Justified graphs of each house system (house 01 to house 05).

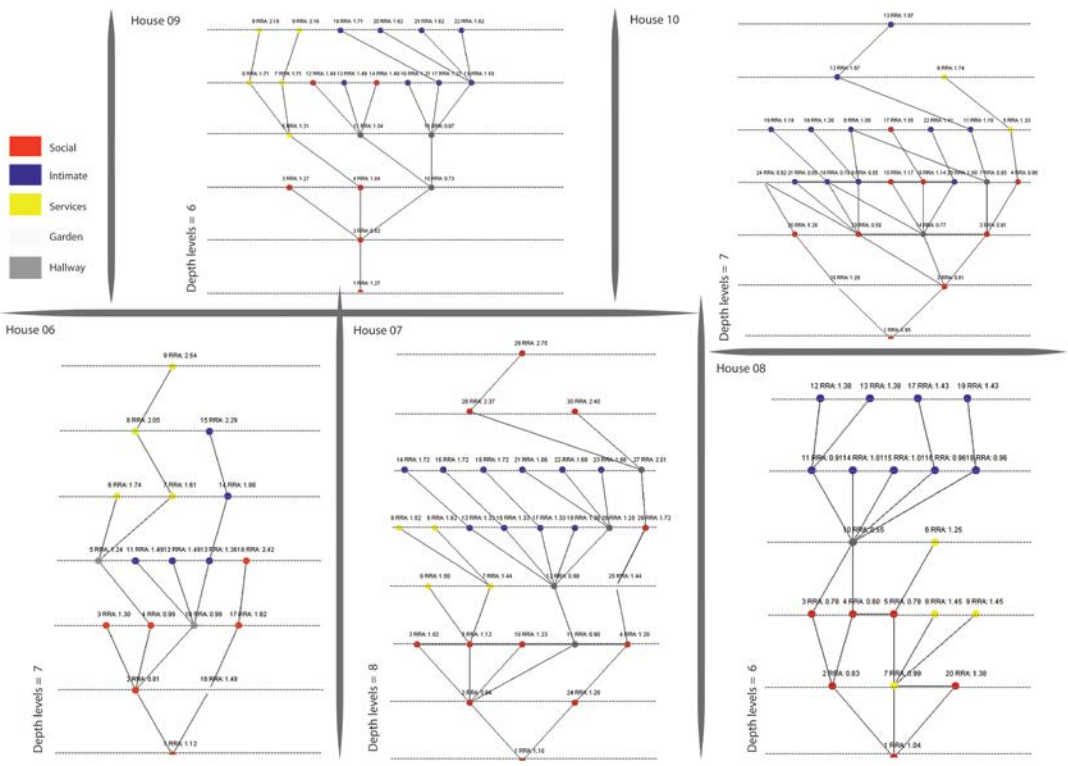


Figure 13: Justified graphs of each house system (house 06 to house 10).

In general, we could assume that the social zones present better thermal performance than the intimate ones, at the same time that those are also the most connected and integrated ones considering most of the syntax simulations used in the research, Figure 14.

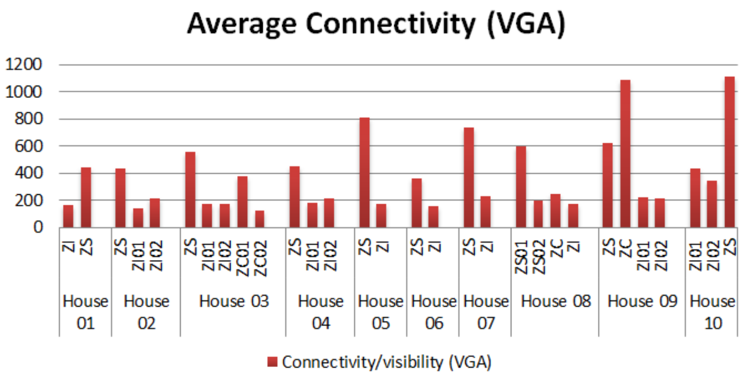


Figure 14: Average Connectivity values per zone for visibility analysis.

Considering the relation between Space Syntax metrics such as connectivity and integration and the air changes rate (ach), it is interesting to notice that the correlations found in the research are weak for both variables (connectivity and integration). Those results are better illustrated through Figure 15 to Figure 17.

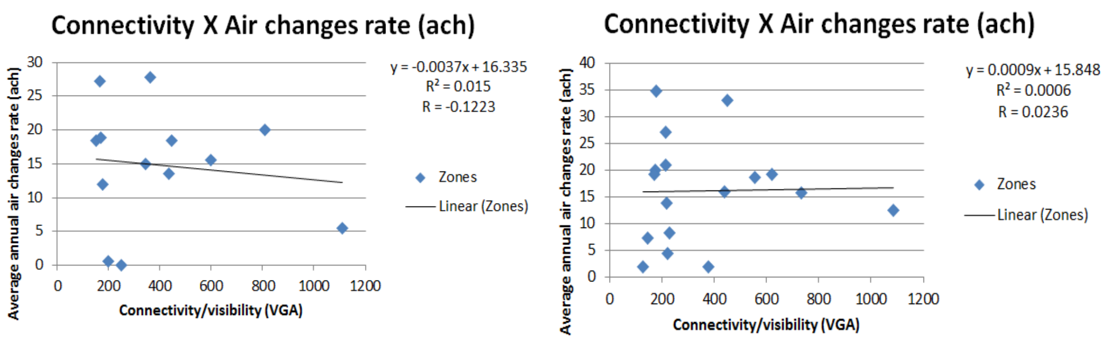


Figure 15: Connectivity (visibility) versus annual average air changes rate per hour (ach) for each zone, single floor houses and two floors houses respectively.

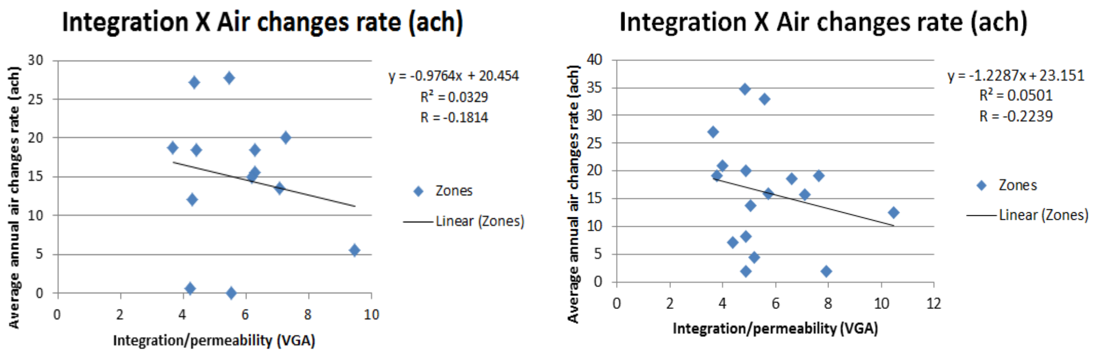


Figure 16: Integration (permeability) versus annual average air changes rate per hour (ach) for each zone, single floor houses and two floors houses respectively.

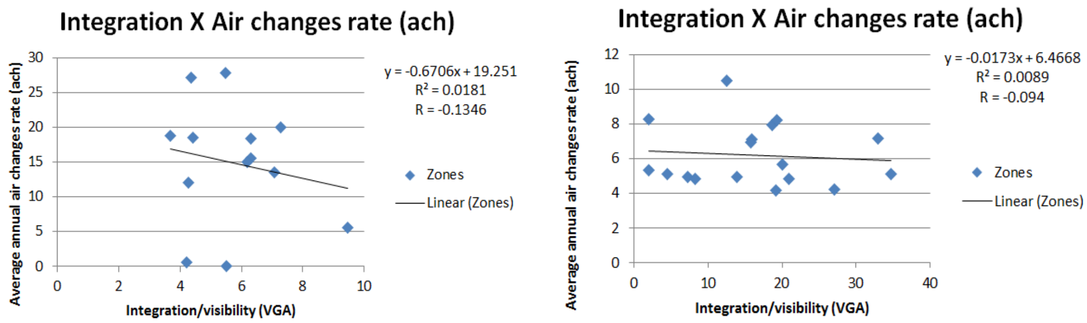


Figure 17: Integration (visibility) versus annual average air changes rate per hour (ach) for each zone, single floor houses and two floors houses respectively.

The correlation found between Connectivity values (visibility) and the annual air changes rate (ach) is, for single floor houses, -0.12, very weak. For two floors houses, the correlation found is 0.02, also very weak. For the correlation between Integration (permeability) values and annual air changes rate (ach) values it was found -0.18, a weak correlation, for single floor houses. For two floors houses we found the correlation of -0.22, also a weak value. We found even lower correlations between Integration (visibility) values and annual air changes rate (ach) values, -0.13 (single floor houses) and -0.09 (two floors houses). Perhaps, integration and connectivity do not correlate to air changes because this last one also depends on the building's solar orientation.

After analysing all the values extracted from the research we could assume that there is correlation only between Integration (permeability and visibility) and Connectivity values and Degree-hours>26ºC values, considering the two floors houses group for the reasons we have already mentioned before. Those were the highest correlation values found in the research, as moderate correlations. For the other relations we could assume that there are not correlations between those variables considering that the values found are low or very low.

The analyzed sample is still small for confidently generalizing conclusions about the mutual influences between the spatial distribution and thermal analysis in buildings, considering that only ten cases were analyzed. We are currently working in expanding the sample in order to give more representativeness and robustness to the findings.

References

Beck, Mateus and Benamy Turkienicz. 2009. "Visibility and Permeability. Complementary Syntactical Attributes of Wayfinding." *7th International Space Syntax Symposium* Ref 009: 1-7

Eletrobras/Procel. 2009. *Manual RTQ-R-T2(Versão em desenvolvimento)*. Florianópolis: Laboratório de Eficiência Energética em Edificações(LABEE/UFSC).

Hanson, Julienne. 1998. *Decoding Homes and Houses*. Cambridge: Cambridge University Press.

EnergyPlus. 2012. *Input Output Reference – The Encyclopedic Reference to EnergyPlus Input and Output*. University of Illinois and Ernest Orlando Lawrence Berkley National Laboratory.

Hillier, Bill, and Jullienne Hanson. 1984. *The social logic of space*. Cambridge: Cambridge University Press.

Holanda, Frederico de (Org.). 2011. *Arquitetura & Urbanidade*. Brasília: FRBH Edições.

Lu, Yi, John Peponis, and Craig Zimring. 2009. "Targeted Visibility Analysis in Buildings Correlating Targeted Visibility Analysis with Distribution of People and Their Interactions within an Intensive Care Unit." *7th International Space Syntax Symposium* Ref 068: 1-10.

Prefeitura Municipal de Natal. Secretaria Municipal do Meio Ambiente e Urbanismo. 2009. *Instrumentos do Ordenamento Urbano de Natal*. Natal: Departamento de Informação, Pesquisa e Estatística.

Sorgato, Marcio José. 2009. "Desempenho térmico de edificações residenciais unifamiliares ventiladas naturalmente." MSc diss., Universidade Federal de Santa Catarina (UFSC).

Turner; Alasdair. 2003. "Analysing the visual dynamics of spatial morphology." *Environment and Planning B*: *Planning and Design* 30: 657-676.

Turner, Alasdair et al. 2001. "From isovists to visibility graphs: a methodology for the analysis of architectural space." *Environment and Planning B*: *Planning and Design* 28: 103-121.

Versage, Rogério de Souza. 2009. "Ventilação natural e desempenho térmico de edifícios verticais multifamiliares em Campo Grande, MS." MSc diss., Universidade Federal de Santa Catarina (UFSC).