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 analyzed, 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.

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 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 examples selected.

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.

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

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

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

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

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 250,00m², placing them in medium-to-high class 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 2000 ahead.

Five houses were selected for the research. Four of the houses, House 01, 02, 04 and 05, were designed for the city of Natal/RN whereas House 03 was designed for the city of Parnamirim/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.

Figure 12 shows how each house is configured and how they were zoned for the simulations.

RESULTS

House 01

Following what was stated in the topic "Methods and Samples", permeability maps (VGA) and visibility maps (VGA) were created illustrating the visibility and accessibility analyses of the House 01.

We notice that in the case of the House 01 the terrace, the entrance and the living room show up as the most integrated spaces considering the permeability analysis (Figure 15).

According to the visibility analysis (Figure 14) the most connected spaces of the House 01 are still the living room, the terrace, and the entrance. However, the dining room becomes also more connected.

For the thermal performance analysis the House 01 was zoned in order to make it easier to simulate. The two interconnected zones were labeled as Intimate Zone (ZI), and Social Zone (ZS).

We can observe through Figure 1 that the Social Zone (ZS) is the one with the lowest number of degrees-hour over 26ºC, revealing itself as the most comfortable zone of the house considering the number of hours analyzed during the whole year. However, the zone which would demand the highest costs for refrigeration is the Intimate (ZI). It is interesting to notice that the difference between each zone's performance is not so big, considering the windows opened during the whole time.

House 02

The permeability analysis shows (Figure 15) that in this particular house the mean entrance is the most integrated space. However, an intimate space such as the hallway is relatively well integrated to the rest of the spaces.

The visibility analysis (Figure 14) also follows the same strategies used in the earlier case. But since the house has more than one floor, the connections between them are also considered.

The most connected spaces of this particular house are, as in the earlier case, the social ones. This situation is intensified in the dining room located in the inferior floor. It is also interesting to note that the hallway, supposedly an intimate space, is also relatively highly connected to the whole house system.

For the thermal performance analysis the House 02 was zoned into three interconnected zones such as Intimate Zone 01 (ZI01), Intimate Zone 02 (ZI02), and Social Zone (ZS).

It may be observed through Figure 1 that the Intimate Zone 01 (ZI01) is the one with the lowest number of degrees-hour over 26ºC, 3474 hours. However, the zone which would demand the highest costs for refrigeration is the Intimate Zone 02 (ZI02), with a total of 5845 hours over 26ºC. The Social Zone (ZS) presents 3714 of uncomfortable hours over 26ºC. Considering the windows opened.

House 03

It is observed through the permeability analysis illustrated by Figure 15 that in this particular house the dining room, the living room and part of the terrace are the most integrated and connected ones. The bathrooms and the bedrooms are the most segregated rooms in this case as expected.

It was observed through the visibility analysis (Figure 14) that the most connected spaces of this particular house are the dining room and part of the terrace. The kitchen and the downstairs hallway are also well connected.

For the thermal performance analysis the House 03 was zoned into five interconnected zones such as Intimate Zone 01 (ZI01), Intimate Zone 02 (ZS02), Social Zone (ZS), Hallway Zone 01 (ZC01), and Hallway Zone 02 (ZC02).

It is observed through Figure 1 that the Intimate Zone 01 (ZI01) is the one with the lowest number of degrees-hour over 26ºC, 3806 hours. However, the zone which would demand the highest costs for refrigeration is the Intimate Zone 02 (ZI02), with a total of 5735 hours over 26ºC. In this case, considering the windows opened.

House 04

It is observed through the permeability analysis illustrated by Figure 15 that in this house the social hallway and the back terrace are the most integrated ones. The kitchen also gets a little more integrated than the rest of the rooms.

It was observed through the visibility analysis (Figure 14) that the most connected spaces of this house are the dining room, the social hallway, the living rooms, the back terrace and the main entrance.

For the thermal performance analysis the House 04 was zoned into three interconnected zones such as Intimate Zone 01 (ZI01), Intimate Zone 02 (ZS02), and Social Zone (ZS).

It is observed through Figure 1 that the Social Zone (ZS) is the one with the lowest number of degrees-hour over 26ºC, 4127 hours. However, the zone which would demand the highest costs for refrigeration is the Intimate Zone 02 (ZI02), with a total of 5815 hours over 26ºC. In this case, considering the windows opened.

House 05

It is observed through the permeability analysis illustrated by Figure 15 that in this particular house the living room, the dining room and the front terrace are the most integrated spaces.

It was observed through the visibility analysis (Figure 14) that the most connected are both the front and the back terraces, followed closely by the living room, dining room and kitchen.

For the thermal performance analysis, due to its design simplicity, the House 05 was zoned into only two interconnected zones such as Intimate Zone (ZI), and Social Zone (ZS).

It is observed through Figure 1 that the Intimate Zone (ZI) is the one with the lowest number of degrees-hour over 26ºC, 3562 hours. However, the zone which would demand the highest costs for refrigeration is the Social Zone (ZS), with a total of 3637 hours over 26ºC. It is clear that the difference between both zones' performance is not as significant, considering the case when the windows are opened.

CONCLUSION

It can be noticed that the House 05, the one with the Social Zone's highest values for integration and connectivity, is also the design which obtained 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 and connectivity for the social zone similar to the House 05, but with some other zones presenting lower values, Figure 1 and Figure 2.

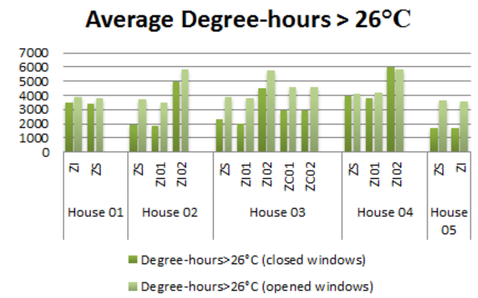

Figure 1- Average Degree-hours >26°C per zone for both closed and opened windows conditions.

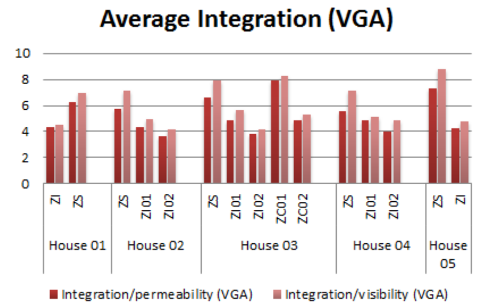

Figure 2 - Average Integration values per zone for both permeability and visibility analysis.

While the thermal performance simulations reveal the House 05 as the most comfortable one, and with the most compact design, it also presents one of 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 second highest value for the closing index as well as low average rate for air changes per hour.

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 3 and Figure 4).

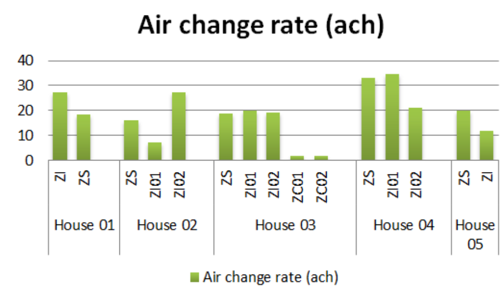

Figure 3 - Average Annual air change rate (ach) per zone.

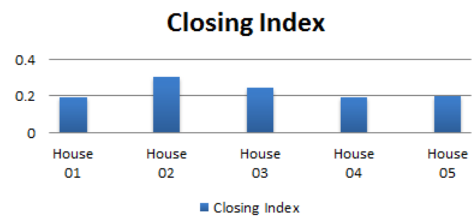

Figure 4 – Closing Index per house.

More compact systems have less outside surface area and less heat exchange with the outside. The same 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 5 and Figure 6 show this relation in more details.

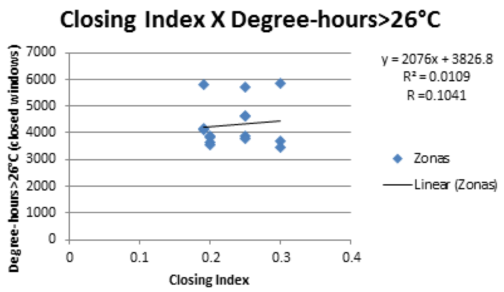

Figure 5 – Closing Index values versus Degree-hours >26°C for opened windows condition per zone.

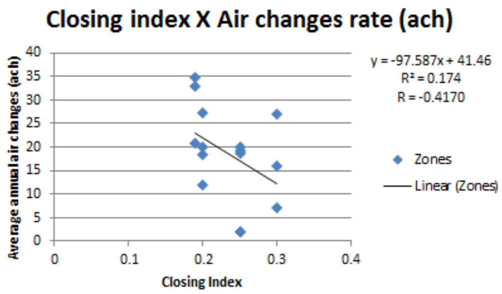

Figure 6 - Closing Index values versus annual average air change rate per hour (ach) for each zone.

The correlation found between the Closing Index values versus the annual average air change rate (ach) is -0,42, a moderate correlation. Other completely different values were found for the correlation between Closing Index values and Degrees-hour>26°C, those are 0.10 (opened windows), weak correlation, and 0,86 (closed windows), this last one as the strongest correlation found in the entire research. We could conclude that as more compact the design is, the better is its thermal performance, considering all the windows shut for all situations.

Considering the system depth of both houses with one floor (House 01 and House 05) compared to the others with two levels we notice that the deeper the system is, the higher is the number of degree-hours over 26°C it presents. Maybe the answer for better design methods, aiming to improve thermal performance, would be shallow systems, however with low closing index, and high visual connectivity as well as visual integration. Not forgetting of the design's compactness. The relation between visual connectivity, integration and thermal performance is better illustrated through Figure 7 and Figure 8.

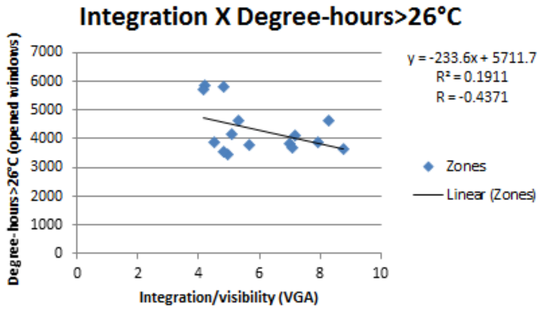

Figure 7- Integration (visibility) versus Degree-hours >26°C for opened windows condition per zone.

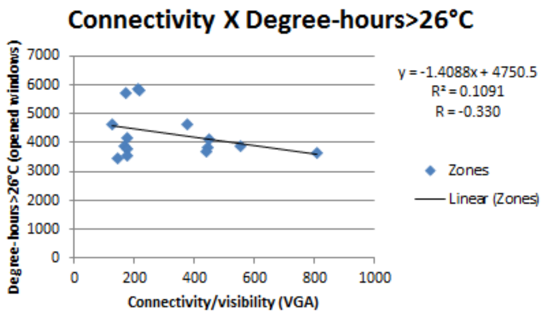

Figure 8 - Connectivity (visibility) versus Degree-hours >26°C for opened windows condition per zone.

The correlations found between Integration (visibility) values and Degrees-hour >26°C are -0,44 (opened windows) and -0,44 (closed windows), moderate correlations. For Connectivity (visibility) versus Degrees-hour >26°C it was found a correlation of -0,33 (closed windows) and -0,31 (opened windows), weak correlations, lower than integration's correlations.

It is important to notice that the thermal performance of the houses improved, especially for Houses 02, 03 and 05, when the external windows were considered shut during the whole simulation time, Figure 1. From this result we could conclude that keeping the windows shut, in these cases, is better than what is commonly done in Natal. However, both analyses (closed and opened windows) follow the same pattern of thermal performance distribution by zone.

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

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 9.

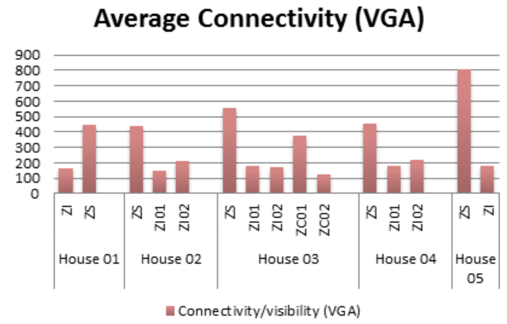

Figure 9 – Average Connectivity values per zone for visibility analysis.

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 higher the connectivity values are, the higher is the air changes rate. Similarly, the higher the integration values are, the lower the air changes rate is, as presented in the Figure 10 and Figure 11.

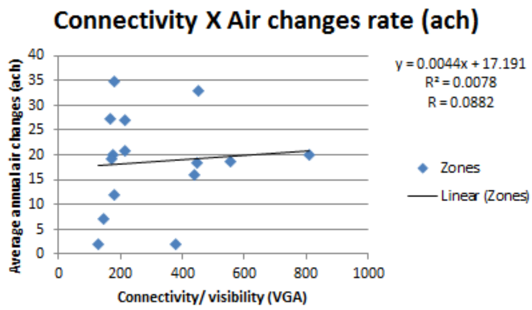

Figure 10 – Connectivity (visibility) versus annual average air changes rate per hour (ach) for each zone.

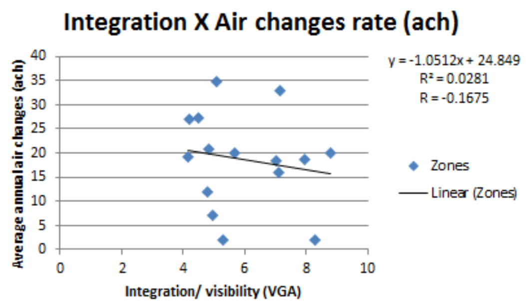

Figure 11 - Integration (visibility) versus annual average air changes rate per hour (ach) for each zone.

The correlation found between Connectivity values (visibility) and the annual air changes rate (ach) is 0,088, very weak. For the correlation between Integration (visibility) values and annual air changes rate (ach) it was found -0,17, also a weak correlation. However, considering the values for Integration (permeability), the correlation is a little stronger, -0,27, but still weak.

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 five cases were analyzed. We are currently working in expanding the sample in order to give more representativeness and robustness to the findings.

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Figure 12 – All houses' floor plans with its respective orientations and zones.

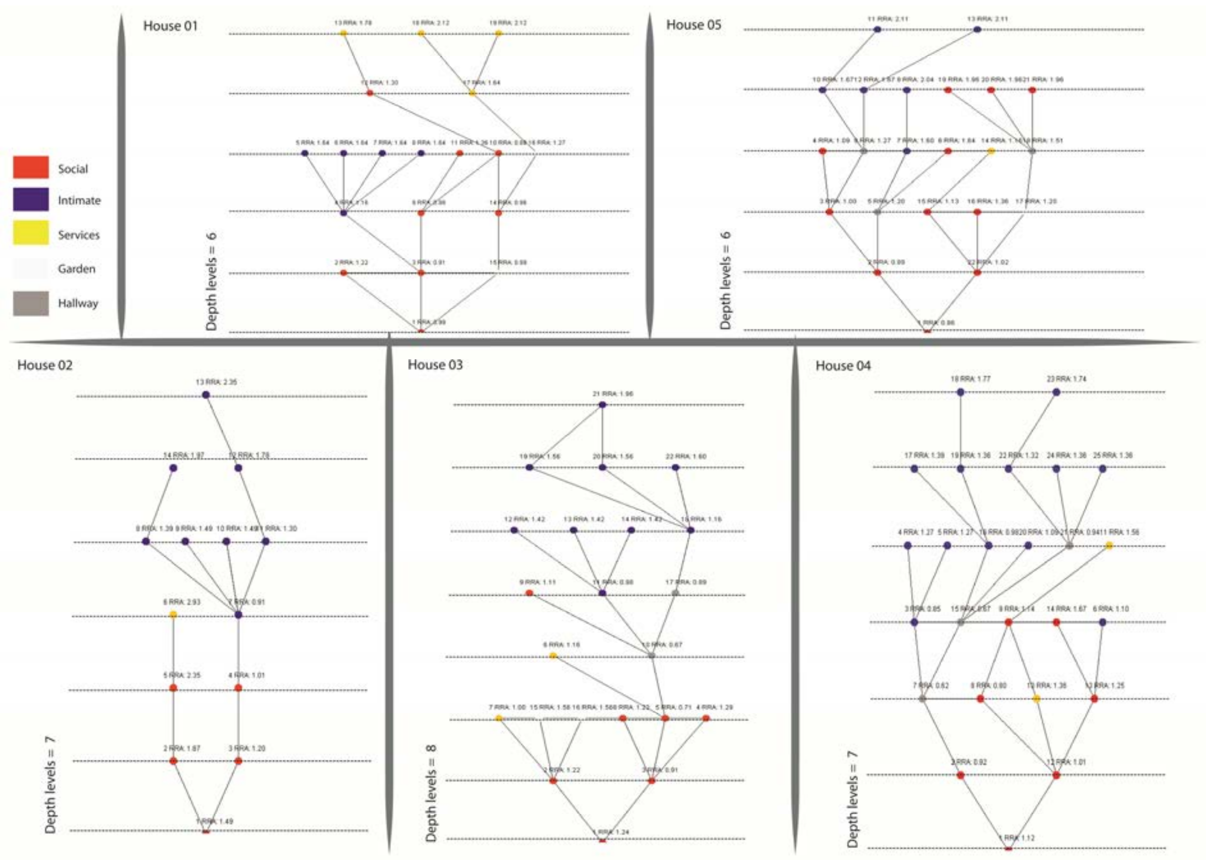

Figure 13 – Justified graphs of each house system.

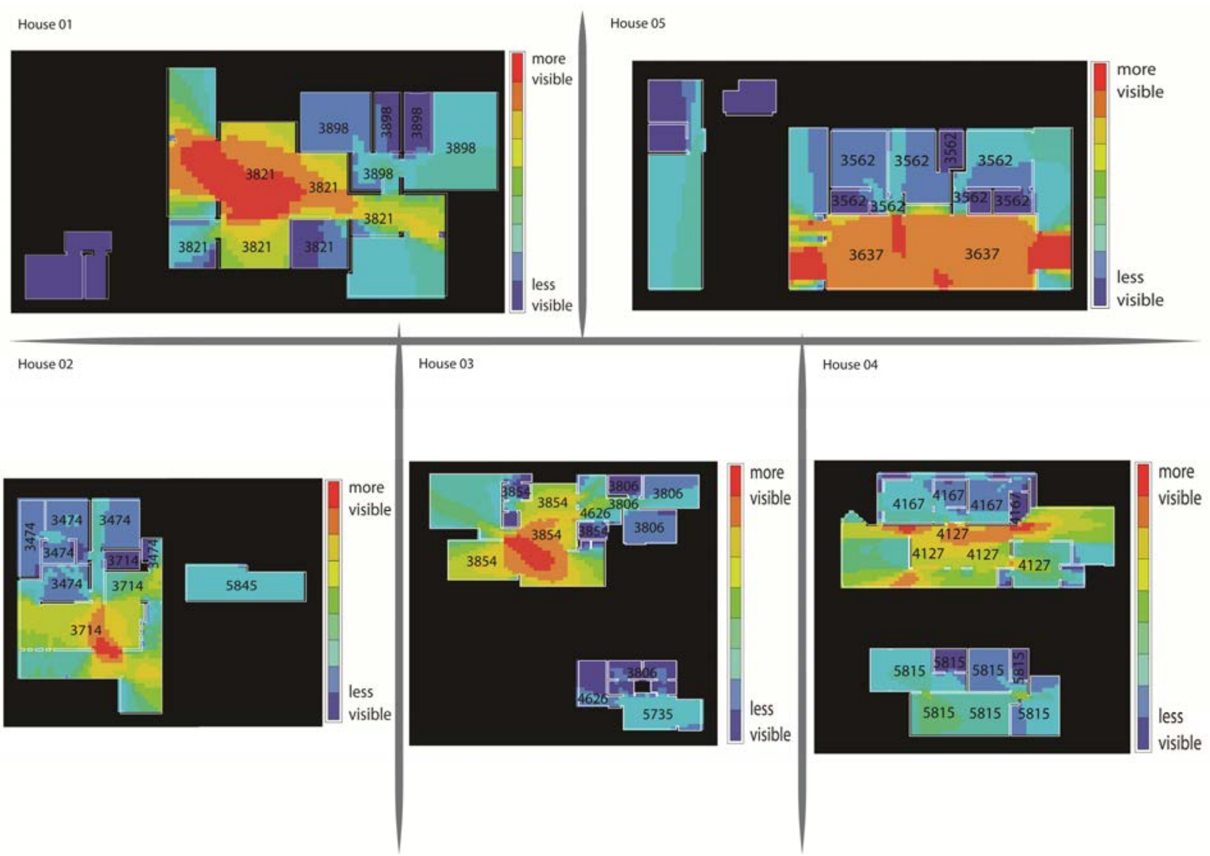

Figure 14 – Connectivity VGA Maps for each house considering the visibility analysis with its respective degree-hours >26°C values per zone, considering the opened windows situation.

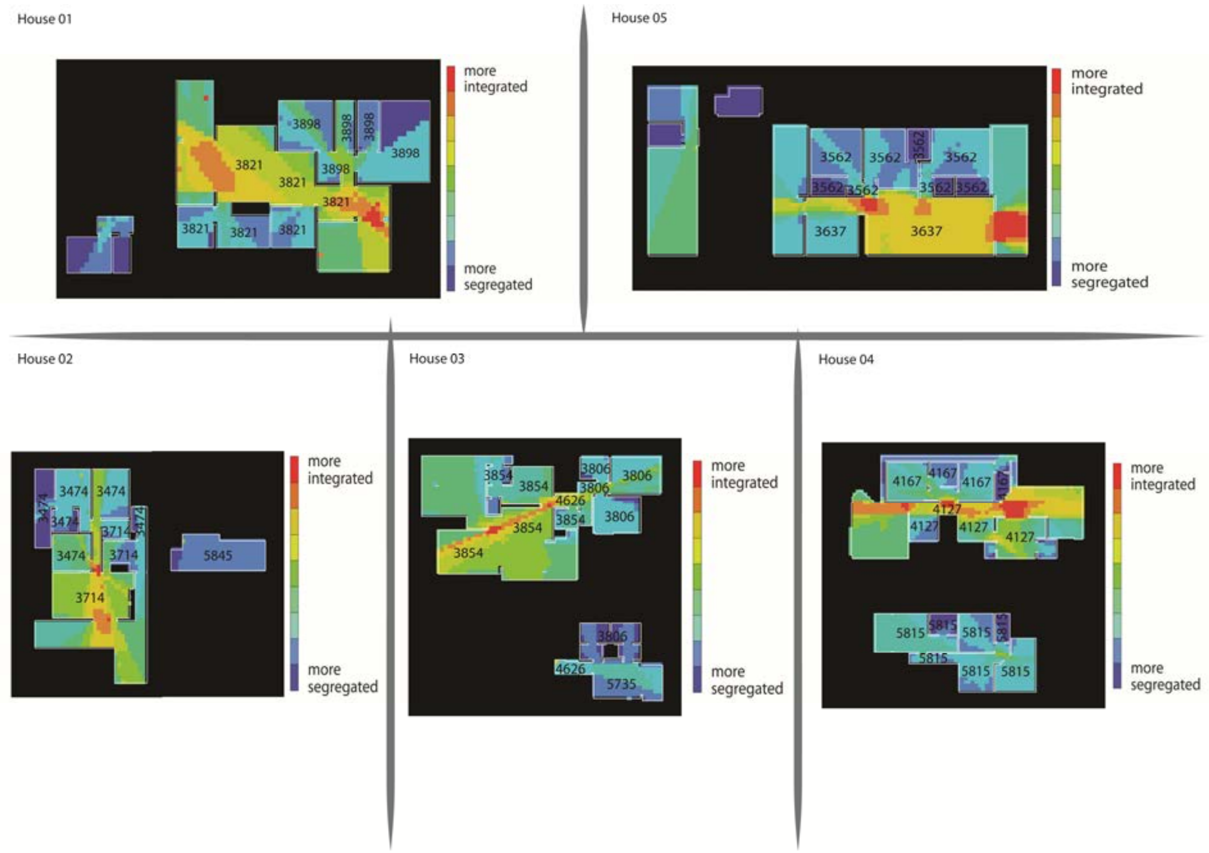

Figure 15 - Integration VGA Maps for each house considering the permeability analysis with its respective degree-hours >26°C values per zone, considering the opened windows situation.