Container Modular System for Social Housing in Rio de Janeiro

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ABSTRACT: As any other country from the majority world, Brazil is struggling to balance the equation between population growth and provision of infrastructure and shelter. Rio de Janeiro is the location of this case study due to the evident combination of these facts. 22% of cariocas lives in more than 700 favelas scattered thought the whole city.

The need to improved residential dwellings in favelas is crucial. Most of houses are constructed based on limited expertise and experience offering risks to its users and surrounding community. Besides that, the environmental conditions of favelas in Rio de Janeiro is challenging because the sites are build up to its limit, crowed on all sides by mountains and/or urban centre. The natural development of favelas has produced overpopulated and dangerous conditions that do not account for the general safety and comfort of its inhabitants.

This study tries to reveal the potentials to achieve thermal comfort in regenerated dwellings in favelas combining the traditional brick construction with reclaimed containers, which is a modular system by its nature. Together the assembly offers numerous possibilities and higher standards for safety and comfort. In order to do so, this modular system study took into account climate sensitive design, low energy cooling technologies and economical restrains imposed by the context of this research, leading the challenge of proving that thermal comfort in favelas in Rio de Janeiro can be fulfilled using only a variety of passive strategies.

The potential of each passive design strategy was tested, including different materials for envelopes combined with natural ventilation and fans, solar chimney and earth duct system. The main parameter used for result analysis and variants comparison was the PMV (Predicted Mean Vote), indicating the comfortable levels based on human behavior.

The findings in this report facilitate the comprehension of the importance of passive design systems for building design and users comfort. It also highlights important points and offers guidelines for the proper combination of passive strategies for semi tropical climates, improving the performance of buildings and rethinking the typical approach of air conditioned spaces.

Keywords: containers, favela, hot and humid climate, comfort, passive design

INTRODUCTION

Over the last years, the population growth developed a close link between developing countries and the needed infrastructure for shelter, sanitary and healthy living conditions.

When poverty and urban growth are combined together the problems related to urban regeneration and infrastructure are even more evident. There is the urgent need to develop and create new solutions.

Most countries have recently re-examined their urban policies and have put legislation into place to emphasize the need for greater effort to improve the condition of urban areas. In 2007, Brazilian government started an urban investment program – Programa de Aceleração do Crescimento PAC - promoting the resumption of the planning and execution of social, urban, logistic and energy infrastructure, contributing to its rapid and sustainable development. The social program was thought of as a strategic plan for investments recovery in important sectors of the country.

Among other guidelines, PAC also addresses urban regeneration of favelas seeking renewal of local economy, social interaction and equity, an effective approach to deal with informal settlements in the inner city.

1. Modular System

Implementing a modular system inside a favela should allow the rearrangement of the local community according to their needs, improving their living conditions. At the same time consolidating the favela as a living organism that requires flexibility.

Besides that, the economical restrain should be overcome by the use of local man force and materials that can have their life cycle extended.

Within this case study, the traditional brick dwelling was combined with reclaimed containers, which is a modular system by its nature. Together the assembly offers numerous possibilities and higher standards for safety and comfort.

Choosing container units as main actor of this study was not a random decision. The unbalance flow between Brazil exportation and importation rate of goods also leads to an unbalance flow of standard containers through the Brazilian ports that are not being used.

2. Climate Analysis

The city of Rio de Janeiro offers a semi tropical climate. Located on the South Hemisphere, the warm and humid weather is present all year long. Outside temperatures varying between 16° to 38°C and mean yearly average as 24°C.

The total horizontal solar radiation is high as well, total 1843Kwh/m²/year since Rio de Janeiro has mainly clear sky conditions. To this extent, there is the need to overcome undesired heat at all times independently of activity, schedule or building design.

OBJECTIVE

The goal of this study is to provide comfort using container units in combination with traditional brick construction for social housing in Brazil, Rio de Janeiro.

The challenge is to prove that cooling in Rio de Janeiro – and other cities in tropical developing countries - can be fulfilled using a variety of passive strategies. Such as schedules, clothing and activities adaptations according to temperature variation during the day, climate sensitive and passive design and low energy cooling technologies, taking into account the cultural favela's conditions. The correct combination of such strategies will hopefully require neither sacrifice nor discomfort for its users.

METHODOLOGY

A workshop was carried out in order to shape a container assembly that would increase the living quality and comfort of its users.

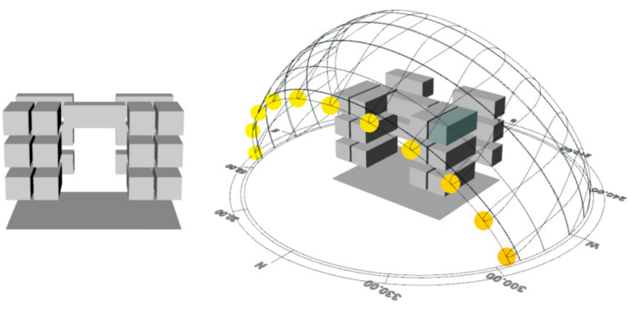

Figure 1: Container assembly of 18 container units and common ground floor; solar path and worst case scenario for analysis

The analysis was divided into 2 separate parts: container unit and common ground floor. For each of them the daylight condition, thermal performance and comfort levels were set as main parameters to be optimized reaching standard acceptable rates.

The technical supports to obtain the desired results were mainly TRNLizard and TRNSYS for dynamic thermal simulation and DIVA for daylight conditions. Excel was used to post process the results and visualization purposes.

ASSESSMENT

1. CONTAINER UNIT

The container unit being assessed represents the worst case scenario (North-West orientation) with 2.4m in width, 6.1m in depth and the height of 2.6m located in Rio de Janeiro, Brazil.

The analysis begins setting up a base case scenario for residential use: envelope composition of 4cm of polyurethane plus steel; 3 persons with 75W each as internal loads and 0.5 clothing factor; external shading device; night schedule; no equipment; openings on different facades to stimulate cross ventilation; and fans running from 0.1 to 1.2m/s to increase comfort sensation by high air speed velocity.

In order to upgrade the results of the base case scenario, the envelope of the container was selected as variant and four different compositions were assessed:

1. Base case
2. 20 cm of sand + insulation
3. 3cm insulation + 20cm silicatum magnesium + 3cm insulation
4. 20cm concrete + insulation

1.1 Operative Temperatures

According to ASHRAE standard 55, thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment.

The operative temperature – temperature sensed by people – throughout the year is shown for the four different envelope compositions.

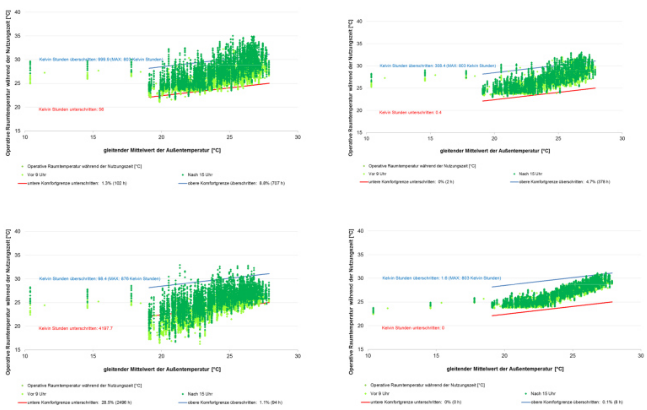

Figure 2: Adaptive charts for operative temperatures for the 4 different proposed container unit's envelopes

All material options, apart from base case, can take advantage of thermal mass effect, which means that the envelope can absorb, store and release heat. It moderates internal temperatures by averaging out day and night extremes *(figure 2)*

Both constructions performed well, with heavyweight performing slightly better than lightweight buildings.

1.2 Comfort_PMV

The model used for this analysis is the Adaptive PMV (Predicted Mean Vote) which is a thermal scale that runs from Cold -3 to Hot +3 based on environmental conditions such as solar gains, air and operative temperatures and relative humidity. It also assumes that, if changes occur in thermal environment to produce discomfort, people will adapt their behavior and act in a way to restore their comfort, such as changing clothing factor, reducing activity levels, opening a window or increasing air speed velocity (0.1 to 1.2 m/s).

The graphs reveal the quality and quantitate for PMV results throughout the year. Each single point represents one out of 8760 hours in the year. The acceptable PMV range for thermal comfort from ASHARE is between -0.5 and +0.5.

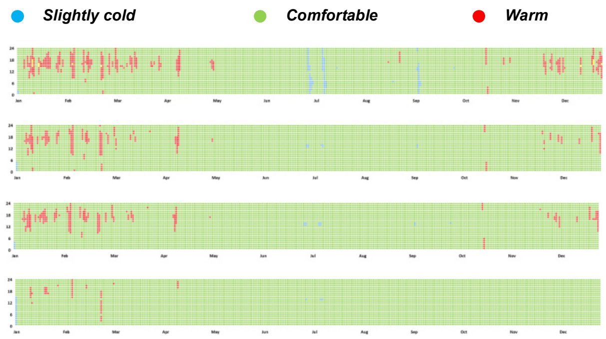

Figure 3: Hourly thermal comfort throughout the year in Rio de Janeiro for each choice of envelope

Regardless of the material, when air speed velocity is introduced in the equation, all four types of envelope proposed offer high level of comfort, >90%.

When combining lightweight steel, 4cm polyurethane and natural ventilation, the percentage for thermal comfort is 93%. This choice compromises the potential for thermal mass, but on the other hand, suits the character of a social housing project. Besides, the technologies related to the base case scenario are already available on the market and it compromises relatively less internal floor area compared to 20cm concrete wall.

1.3 Daylight

For passive design buildings, many decisions rely on the tradeoff between daylight and solar heat gains. To this end, shading devices are often implemented and openings are optimized to reach a balance equation.

Since the container unit operates mainly on night schedules, daylight was not an issue during the analysis.

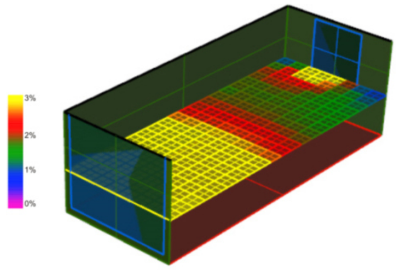

Figure 4: Daylight Factor for container unit

2. COMMON GROUND FLOOR

Second part of this research consists on the analysis of the common ground floor of the container assembly. During design process this area was assigned to provide the dwellers higher quality space for socializing and interaction reassuring the community culture inside favelas.

For the sake of trustworthy simulations, some assumptions were made for internal and environment gains: 15 people with 0.5 clothing factor using the space mainly during day; big openings and windows allowing cross ventilation and characterizing the space as semi outdoor environment; 80% shading device; no equipment; and finally, the mix use of heavy material on the ground floor with light construction on upper floors. In favor of higher comfort levels, fans were taken into account to improve comfort.

The central idea of this stage of the analysis is to study previous defined affordable and passive solutions for the common ground space. Due to the hot and humid climate, the choice of each approach was based on the interest to investigate the potential of those particular passive strategies in Rio de Janeiro. They are listed:

1. Full natural ventilation + fans
2. Solar chimney + fans
3. Earth duct + solar chimney + fans

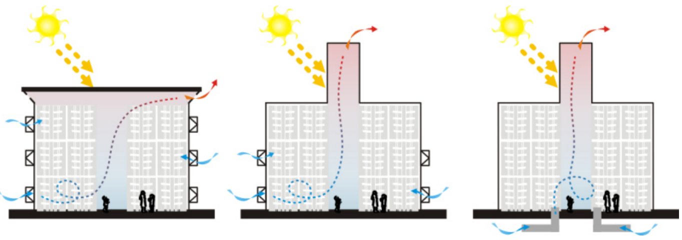

Figure 5: Three different passive strategies were tested: Natural ventilation through a detached roof; solar chimney; and solar chimney combined with earth duct air supply

2.1 Operative Temperatures

According to the project methodology, the three different variant were evaluated under dynamic thermal simulation in order to allow the comparison between then.

The air temperature inside the socializing area was calculated but it was not the main driver for decision making since the effect of fans is not considered, as it is a variant related to the human perception and unquantified.

2.2 Comfort_PMV

In order to reach a realistic and adequate scenario, high air speed velocity was added into the modelling. The Adaptive PMV graphs allow maximum insight and help with decision-making.

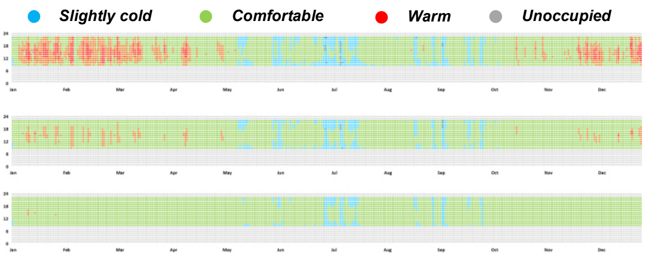

Figure 6: Hourly thermal comfort throughout the year in Rio de Janeiro for each passive strategy for common ground space

First case, fully natural ventilated building, offers 67% of comfortable hours during the year. Depending on ambient conditions, natural ventilation may lead to indoor thermal comfort without mechanical cooling. However, in cases like favelas where the wind effect is not well captured, stack ventilation may be a viable alternative as it is shown on the next option.

Second graph prove right the statement above. There is a significant increase on comfort hours (87%) due to the stack ventilation driven by the super-heated solar chimney that has been attached to the roof of the assembly forcing the air movement and exhausting it.

Next in order, the combination between earth duct and solar chimney was tested offering 93% of comfortable hours. The biggest challenge related to the applicability of an earth duct in hot climates is the warm soil temperatures through the year.

It is known that the efficiency of this system mainly depends on the capacity of the soil to supply or extract heat from the air passing through. And this heat exchange capacity is based on the temperature difference between the two elements – air and soil. During summer in Rio de Janeiro, the soil temperature reaches its highest level as well as the air temperature, meaning that the amplitude between both of them is smaller, so its capability to absorb heat decreases - and thus its efficiency - during the critical time of the year.

To accurately define an earth duct for a dynamic simulation the climate of the chosen location is crucial not only because of the quantity data, but also due to the profile of air and ground temperatures swing between summer and winter (e.g. for tropical climate the amplitude of ground temperature during the year is smaller than in northern climates).

2.3 Daylight

Following the optimization approach of the common space, the daylight condition was tested several times in order to achieve the common standards for this type of usage – 100 lux evenly distributed on a surface 0.8m height from the ground.

Openings and windows were tested to meet a balance between natural light, solar loads and thermal comfort.

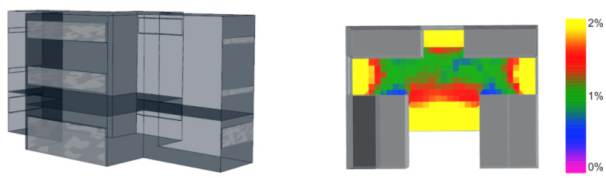

Figure 7: optimized openings according to solar and daylight conditions for common ground floor

CONCLUSION AND FUTURE POTENTIAL

This study tries to reveal the potential to achieve thermal comfort inside favelas in Rio de Janeiro. In order to do so, containers were used to integrate a modular system combined with traditional brick construction.

First, the container unit was used to study the effect of thermal mass using different types of envelopes compositions. Due to space constrains, the best suitable option was the one that compromised less internal floor area – light structure with insulation. However, according to the studies, the potential for thermal mass in tropical climates was proved to be effective.

Afterwards, the efficiency of passive design solutions for hot and humid climates was tested.

Since natural ventilation can be impaired by the high density of buildings inside favelas, during summer the users might experience thermal distress. So, the performance of solar chimney was tested and presents 87% of comfortable hours - which in this research means PMV between -0.5 and +0.5. This system induces air movement as a result of the stack effect, and comfortable hours are extended with the help of fans.

Furthermore, the effect of the solar chimney was enhanced when combined with an earth duct to supply fresh air. However, some relevant considerations were evaluated during the process regarding the use of this system in hot and humid climates.

First, there is an increase in efficiency when the system is buried at a deeper depth, due to even more constant temperatures. According to soil temperatures profile, in Rio de Janeiro, 2m is already sufficient to provide steady temperatures. Secondly, whenever outside air temperature is higher than inside the earth duct is set off and the building runs in natural ventilation mode along fans to upturn comfortable sensation.

Perhaps, the most important outcome of the research is the optional character of AC units for Rio de Janeiro. A relatively high number of comfortable hours can be achieved if the right approach leads the process from the beginning. From choice of materials, schedules, loads, orientation of the building, until size of openings and passive and active systems.

It is also important to clarify the influence of different functions for different spaces when it comes to passive design. In this particular study, containers and semi outdoor spaces should not have the same parameters and variants for analysis. Distinctive functions leads to distinctive schedules and loads, which would be crucial for thermal mass effectiveness for example.

This report introduces relevant concepts of passive design systems for building design in hot and humid climate and the importance of the integration among them to achieve higher levels of comfort for its users.

Additionally to the performance of the building, this research questions the typical approach for air conditioned spaces and its relevance when it comes to adaptive comfort.

The next steps for this proposal could include the detailed study and feasibility of earth duct system in Rio de Janeiro. Balance between advantages, challenges and its meaningful cooling potential.

A distinct coming step is the cost analysis of upcycling reclaimed containers.

Furthermore, modular units can generate an unlimited variety of design options, leading to other assembly possibilities which could also be studied. Additionally, combining multiple assemblies together could be a possibility for future evaluation of the benefits of a small container community.

And finally, the construction of an adequate container solution for favelas, benefiting from the discoveries and outcomes of this research and from future studies to determine following guidelines.

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