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The Future of Responsive Facade for Multi-Storey Residential Buildings in Tropical Climates

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Abstract: The design study seeks to comprehend the principles and elements of a Responsive Facade and how they affect energy efficiency and user comfort for space cooling for multi-story residential buildings in tropical climates. The research is based on precedent studies, occupant behavior, and a critical analysis of challenges in existing building facades, having Brazil as case study. Identifies the different factors that interfere in the environmental conditions and building performance to build parameters that will optimize facade design proposals. As a result, a variety of facade features were put into place, with ceramic being the main material utilized to make perforated and opaque panels that function as shading and permeable envelope. Furthermore, the dynamic operation was investigated through automated elements that move in response to the sun or under occupant's control. In order to maximize performance in tropical conditions, a variety of intervention scenarios were examined.
Keywords: responsive facades, multi-storey residential building, building performance, user comfort, energy efficiency.

1. Introduction

The facade is one of the main features of a building that promotes internal comfort and building performance, and in tropical climates, this has become an essential feature to address due to the increasing peak temperatures. Unfortunately, they are frequently taken for granted, resulting in a series of residential tower buildings with homogeneous facades that are inadequately designed for the climate. A Responsive Facade is not static since its adaptability is mainly related to the climate, energy performance, thermal comfort aspects, Indoor Air Quality (IAQ), or visual and acoustic performances. They can also respond to occupants' needs by adapting accordingly. The envelope is one of the primary factors in improving internal comfort for the inhabitants. In addition to the thermal comfort improvements, it also reduces the energy consumption by lowering the demand for active systems to cope the weather. Therefore, the design study addresses the following research question; Which parameters are necessary for better user thermal comfort and building energy efficiency for space cooling for multi-storey residential buildings in tropical climates, and what best responsive facade accounts for them?

As a result, to comprehend the facade principles required to achieve comfort inside buildings, literature research, and precedent studies were first conducted. In a subsequent step, a questionnaire was developed to better understand occupant attitudes towards the use of passive and active systems. Also, the facade and energy performance of a existing building in a tropical climate of Brazil were studied. As a result, several scenarios were developed to evaluate the design and energy efficiency of proposed interventions.

2. Assessment Method

2.1 Questionnaire: Occupant's thermal preferences and behavior towards the use of active cooling systems in Brazil

The questionnaire was made and sent it online to one occupant of the family. The survey was answered for 26 families from 11 states of Brazil characterized for the high temperatures throughout the year. The survey questions were based on the paper from Ramos, Greici, et al. "Adaptive behavior and air conditioning use in Brazilian residential buildings." (2021) comprising a total of 16 questions. Based on the findings, a family profile could be developed to identify people's behavior patterns toward the use of air conditioning and fans in hot climate regions of Brazil; most families interviewed consisted of three people, and all of them were at home in the evening, but 65% of the time there is only one person at home in the morning and afternoon, indicating a 24-hour occupancy.

When it comes to the ideal temperature, the average range of answers ranges from 20ºC to 26ºC. However, the results also showed a preference for naturally ventilated space at home, with 76.9% preferring it over air-conditioned space (23.1%). It also demonstrates a tolerance for high temperatures and a preference for passive strategies over fans and air conditioning. When asked what the maximum temperature acceptable without the AC was, the responses ranged from 26ºC to 30ºC. Furthermore, 38.5% of families do not use the air conditioner on a weekly basis, and when they do, it is 84.6% of the time at night. In this case, this behavior is related to more than just human adaptive ability; it is also related to a general concern about energy consumption; 84,6% of responses stated avoiding the use of AC due to the cost. Keeping an AC on all day is expensive, making it unaffordable for middle-class families. In terms of air conditioning costs, the thermostat setting is critical for energy savings. When asked what AC setpoint they usually use, the responses range from 16ºC to 22ºC. According to the Brazilian Association of Refrigeration, Air-conditioning, Ventilation, and Heating (ABRAVA), the best air-conditioning setpoint for energy savings is 24ºC. According to their research, every degree decreased in the setpoint results in a 3.5% increase in energy consumption. In terms of fan use, 65% of interviewed families say they use it on a daily basis, and 50% have at least one fan at home, compared to 15% who say they have 1 and 26% between 2 to 3 AC units. They were also asked what the maximum temperature acceptable for using only fans before introducing air conditioning was; the answers ranged from 24ºC to 35ºC, indicating a high tolerance for heat before requiring the use of AC.

2.2 Case Study

The case study was carried out in a tropical hot and dry city in Brazil. The Brazil choice was due to a high demand in the residential market, with tall buildings arising at a high velocity across the country now, but with no adequate treatment or strategies applied for the climate on its facades. The reasons are the densification of cities that led to the verticalization of buildings, the rise of land prices, and the cheapening of construction. The current goal is to build as many units as possible on a small plot of land, focusing on quantity rather than quality. Hence, critical factors to consider when designing a building, such as orientation and insolation, began to be overlooked.

As a result, the facades of Brazilian residential towers have become homogeneous repetitions on all four facade sides, devoid of any innovation or concern for internal comfort, resulting in buildings that look the same in a seamless wave of uncharacterized buildings.

- Case Study: Residential Tower Jardim Beira Rio, Cuiabá – Mt, Brazil.

The City of Cuiabá is known for its tropical climate characterized by being hot and dry for most of the year. The temperatures can get above 30ºC all year, which intensifies when the draught season happens, between June and September, when temperatures can get up to 35ºC. According to future weather file generated by Meteonorm software, the temperature can increase up to 37ºC if no action had been taken on total ghg emissions in the country. For this type of climate, there is a high demand for natural ventilation, evaporative cooling, mass cooling and night ventilation, and air-conditioning.

The building chosen is the Residencial Jardim Beira Rio. The assessed flat is in the 10º floor and has two facades exposed to the outside, the main one facing north-east, thus exposed to the morning mid-day sun. Due to the layout, the flat can provide cross ventilation between rooms. However, the facade does not have any shading element, and the walls and windows do not have any insulating material/feature to decrease the thermal conductivity. The constructive materials are (Ceramic block walls, and single glazing windows, door facing outside (aluminum frames and glass 4mm). The simulation was made in selected rooms on a typical day of the year with temperatures up to 35ºC (mean maximum average temperature of the year), and a clear sky.

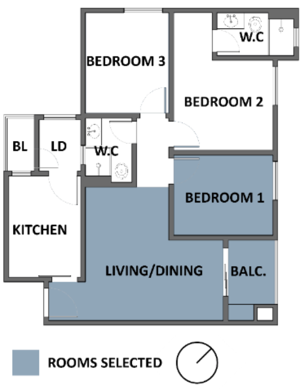

Figure 01: Key Plan – Residencial Beira Rio

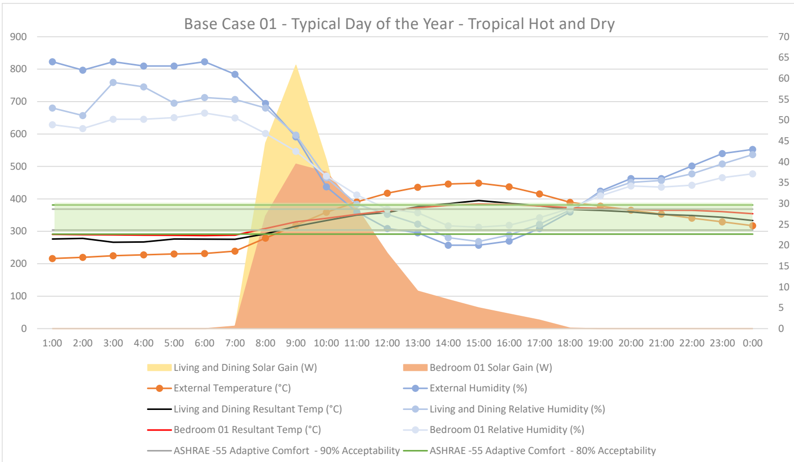

Figure 02: Thermal Simulation for the case study 01. Residencial Jardim Beira Rio. Chart derived from TAS software.

The thermal result graph depicts how a typical day behaves throughout the hours and how it affects the flat's internal conditions. Peak hours of the day are observed between 1 pm and 3 pm, with external temperatures reaching 35ºC and relative humidity falling to 20%. However, it can drop significantly at night. The hours with less overheating risk are the morning until 2 pm. and the end of the afternoon from 5 pm., when radiation levels are lower. During peak hours, however, the temperature rises above the comfort levels.

Regarding the *Energy Performance*, the simulation methodology used to assess the energy consumption of the flat accounts for air-conditioning applied in a 24-hour occupancy to analyze how the apartment will behave in a worse scenario, when people are working from home. (Bedroom occupied all day and living room only during daytime). The air conditioner is on when the external temperature reaches **28ºC**, and the thermostat value used to assess the flat efficiency was **24ºC**, considered a good setpoint for for energy savings according to the Brazilian Association of Refrigeration, Air-conditioning, Ventilation, and Heating (ABRAVA), their research also shows every degree decreased in the setpoint results in a 3.5% increase in energy consumption. A lower value of **16ºC** was also calculated to demonstrate the usual people's behavior towards using the air conditioning system in Brazil. Which also impacts energy consumption. This scenario identified an increase of **180%** in the cooling loads.

Table 1. Cooling Loads – Residencial Beira Rio

SETPOINT	COOLING ENERGY DEMAND
24ºc	336.94 KWh/m^2
16ºC	944.10 KWh/m^2

3. Design Proposal

The Facade proposal is the result of an extensive simulation analysis to find the best shading device for each orientation. It is divided into three configurations, each of them includes a double-skin panel that is movable and perforated in front of an aperture and fixed and opaque when not. The proposed shadings' typology was based on Brazil sun-path to optimize shading efficiency according to the orientation and can be both automated or controlled by the occupant.

EAST ORIENTATION
Horizontal Shades + Double-Skin Façade

Figure 03: Design Facade Design: East Orientation

WEST ORIENTATION
Vertical Shades + Double-Skin Facade

Figure 04: Design Facade Design: West Orientation

NORTH & SOUTH ORIENTATION
Vertical Shades + Transitional Space

Figure 05: Design Facade Design: North & South Orientation

The Horizontal shading was used due to the high sun altitude from 51º to 77º on the east orientation. The dynamic operation folds up and becomes a horizontal shade in front of the bedroom windows. However, for the West facade the shade was not required on the balcony; simply having the proper balcony depth according to the sun altitude that can act as a shading device for the living room. However, vertical shades were required on the West facade due to the lower sun altitude from 1º to 4º. In this case, the shades in front of the bedroom windows fold horizontally, allowing for greater sun and daylight control. In contrast to the East, a proper balcony depth alone would not suffice; thus, vertical shades were also inserted in a different operating system; they can rotate on their axes and be completely moved to the sides, not obstructing the view. During the day, the north and south facades are the most exposed to the sun. A different approach was required in this case. To control the amount of sunlight inside the flat, a combination of horizontal and vertical shades would be preferable for these orientations. As a result, a transitionary space (either a corridor or a common balcony) was used to investigate the benefits of this larger space between the envelope and indoor.

3.1 Thermal Comfort Anlysis

Scenarios were created to simulate various levels of intervention to the facade for the thermal comfort analysis. For the simulations, the improved wall structure was used as a base case; from there, external facade features ranging from minor interventions that only used passive strategies to more complex interventions that included active systems. Also, the the simulation were performed using 2050 predicted future weather files. The best scenario for both climate was the combination of double-skin façade with flexible shadings. Comparing with the case studies, the optimized design dropped **4ºC** in the dry climate, and **2ºC** in the humid climate, which contributed to maintain the internal temperature in the comfort zone for most of the day.

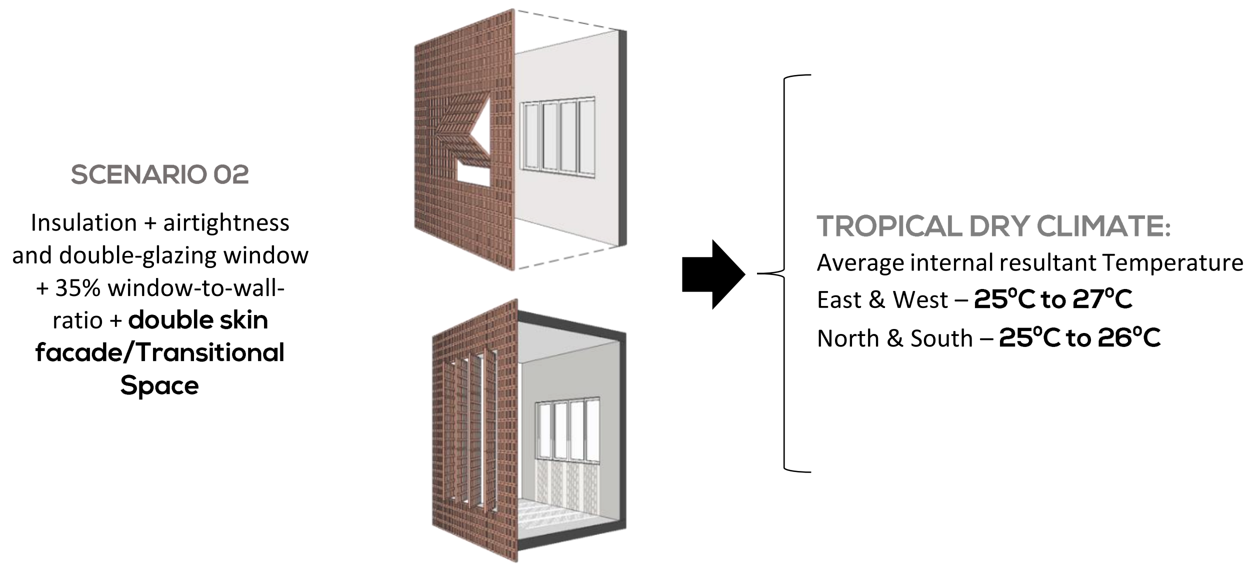

Figure 06: Facade intervention scenario 02.

3.2 Energy Performance

As a result of the questionnaire results obtained from families in hot climate regions of Brazil, a realistic pattern for the use of air conditioning was created. Even when the occupants are present during the day, the air conditioner is mostly used at night even if the temperature normally stays below 28ºC. Regarding the maximum temperature people can tolerate before introducing the air-cooling system, it can reach 30ºC, which can be increased to 35ºC if the fan is installed prior to the AC.

Based on those findings, scenarios of various ways of using air conditioning were developed in order to identify the impact of energy consumption and find ways to reduce it by implementing a more efficient pattern for AC operation. Scenario 01 used 24 hours of occupancy to analyze the worst-case scenario, and the thermostat was set to 24 degrees Celsius only when the temperature reached 30 degrees Celsius. The second scenario keeps the same occupancy and thermostat settings. Cooling is introduced, however, only when the temperature reaches 35ºC, assuming that a fan was previously used as a cooling strategy.

Finally, the third scenario assumes that AC is only used at night when the temperature exceeds 28ºC, which is a common user pattern identified in the questionnaire.

Table 02: scenario 01 - hot and dry climate

FACADE ORIENTATION	**COOLING ENERGY DEMAND**
DESIGN PROPOSAL - EAST	122.14 KWh/m²/yr
DESIGN PROPOSAL - WEST	97.66 KWh/m²/yr
DESIGN PROPOSAL - NORTH	83.83 KWh/m²/yr
DESIGN PROPOSAL - SOUTH	101.60 KWh/m²/yr

Table 03: scenario 02 - hot and dry climate

FACADE ORIENTATION	**COOLING ENERGY DEMAND**
DESIGN PROPOSAL - EAST	29.72 KWh/m²/yr
DESIGN PROPOSAL - WEST	23.96 KWh/m²/yr
DESIGN PROPOSAL - NORTH	25.16 KWh/m²/yr
DESIGN PROPOSAL - SOUTH	25.17 KWh/m²/yr

Table 04: scenario 03 - hot and dry climate

FACADE ORIENTATION	**COOLING ENERGY DEMAND**
DESIGN PROPOSAL - EAST	21.47 KWh/m²/yr
DESIGN PROPOSAL - WEST	21.20 KWh/m²/yr
DESIGN PROPOSAL - NORTH	21.28 KWh/m²/yr
DESIGN PROPOSAL - SOUTH	21.31 KWh/m²/yr

The results clearly show the impact of introducing the AC only when reaches a higher external temperature. From scenario 01 to 02, the cooling loads are reduced about 75%. The third scenario, the values for the dry climate are very similar to the values for the second scenario, demonstrating that both occupancy scenarios could work well in those conditions.

4. Conclusion

In hot climates, a facade that can respond to the environment has become critical for comfortable living. On the other hand, human behavior is an important consideration for building efficiency. As a result, the findings demonstrated the importance of occupant control over air-conditioning use combined with an adequate building envelope to improve energy savings and user thermal comfort Furthermore, reducing cooling loads reduces the operational carbon emissions associated with energy consumption.

5. References

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