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Generation of a reference dataset with twenty low-income single-family houses in Fortaleza, Brazil and thermal discomfort assessment

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Abstract Although created with the purpose of reducing the Brazilian housing deficit, the "Minha Casa, Minha Vida" government program (PMCMV) presents a large part of its constructions with low built and indoor environment quality. Expecting the increase of the families' income in the following decade, it is important to improve the living conditions of those inhabitants, which may result from improving the thermal comfort, reduce the energy consumption or mitigate the energy needs. To determine which is the most cost-effective, which can be corrective passive design measures, the use of HVAC systems, or production of renewable energy for self-consumption, this work describes the creation of a dataset of twenty building models of current buildings to be used as reference set on which to test different scenarios.

The reference set has several indoor space arrangements of a single-family typology in Fortaleza, which follow the minimum requirements of level 2 of the PMCMV program. The dwellings were created using a floor plan generative design approach and the thermal comfort evaluated using dynamic simulation (EnergyPlus) according to the thermal performance for housing norm NBR 15575 and Technical Regulation of Quality for Residential Buildings (RTQ-R). The typical urban context was taken into consideration during the building generation process and evaluation (reflection and shadowing of solar radiation). The synthetic dataset presents diverse building solutions and all buildings ranked A according to the Brazilian building energy ranking system.

1. INTRODUCTION

In Brazil, housing deficit is characterized by precarious dwelling conditions, family cohabitation, excessive rent expenses, and excessive density of residents per dormitory. According to the *Fundação João Pinheiro*, based on *Instituto Brasileiro de Geografia e Estatística* information, in 2009 Brazil had a deficit of almost six million dwellings, particularly for families with 5 or less minimum wages of income [1]. Hence, the Brazilian government implemented a R$ 388 billion housing program to tackle the housing deficit. The program was called "Minha Casa, Minha Vida" (PMCMV) and it was available between 2009 and 2017, allowing more than three million families to benefit from financial support [2]. The program divides the funding of houses into four levels. The first level corresponds to families with income equal or lower than R$ 1,800 and the state subsidies up to 90 % of the value of the property, without interest. The level 1.5, created in 2018, will support families with an income between R$ 1,801 and R$ 2,600, and the subsidy reaches R$ 47,500, with interest rate of up to 5 % per year. The level 2 supports families with income varying between R$ 2,601 and R$ 4,000, whose subsidy can reach R$ 29,000.00, with an interest rate of a maximum of 8 %. Lastly, level 3 aims families with income ranging from R$ 4,001 to R$ 9,000, without any state subsidy but with a below-market interest rate of 9.16 % [3].

Until 2017, 4,503,231 contracts were signed, 1,740,711 in level 1, 2,200,082 in level 2, and 562,438 in level 3. Despite the number of signed contracts, the quality of the dwellings was questionable. In a report by the Ministry of Transparency in 2016 [4], which analyzed the quality of the residential units built between 2012 and 2014, 55,9 % had some sort of construction problems, such as cracks, fissures, leaks, and problems with coverage. Dantas and Barbirato [5] analyzed the thermal performance of the dwellings built in the city of Maceió, Alagoas, and concluded that the houses of PMCMV are not adjusted to the climate conditions. Moreno [6] simulated a PMCMV reference house and found that constructions based mainly on concrete in the building envelope presented the worst thermal performance in all climate regions in the study.

In 2013, a building energy standard (NBR 15575) was created as a guide to improve the thermal and energy efficiency of the houses. Hence, a minimum thermal performance of dwellings was established [7]. In addition, the Technical Regulation on Quality of Residential Industries (RTQ-R) specifies the requirements for the energy efficiency assessment of dwellings [8].

This work describes how a set of twenty low-income houses (level 2) were created to be used as reference buildings to determine cost-effective strategies to improve the quality of those dwellings (to study combined options of passive measures, implement energy production, and use of air conditioning systems).

2. METHODOLOGY

The reference buildings are created using the EPSAP algorithm [9–11], which consists of a hybrid evolution strategy that generates alternative building designs by finding the indoor space arrangements. After the buildings are generated, the thermal discomfort is evaluated [12,13]. The generation requirements correspond to a single-storey family house having six spaces – one living room, two bedrooms, one kitchen, and one corridor –, which is the minimum required by the PMCMV program. The houses have a preference of 60 m^2 gross area and are located in the city of Fortaleza, Brazil (region 8 – characterized by warm and tropical climate). The relation between these spaces follows the standard typological layout. The building entrance faces the street and belongs to the living room. The occupancy, lighting and equipment patterns correspond to the ones defined in the RTQ-R [8], with metabolic rates of 81 W/person in the bedrooms, 129 W/person in the kitchen, 108 W/person in the living room and 171 W/person in the bathroom; the lighting level is 6 W/m^2 in the kitchen, living room and bathrooms, and 5 W/m^2 in the bedrooms (during occupancy); and 1.5 W/m^2 and 2.0 W/m^2 are considered for the living room and kitchen electric equipment rates, respectively (constantly). Window shadings devices (exterior shutters) are considered to be active from 8:00 to 18:00, during all year, with a 0.80 reflectance coefficient, thermal conductivity of 0.90 W/m·K and a thickness of 1 mm [14,15]. The soil temperature was determined using the *Slab* program linked to EnergyPlus, considering the average indoor and outdoor air temperatures [7,8,14]. The natural ventilation model was defined using the AirFlowNetwork object of EnergyPlus, considering an indoor temperature of 20 °C as the setpoint above which windows and doors are allowed to open, if the indoor temperature surpasses the outdoor temperature, a discharge coefficient of 0.6, a mass flow coefficient when opening is closed of 0.001 kg/s·m and a mass flow exponent of 0.6, according to RTQ-R [8]. The evaluation is according to the thermal and energy codes NBR 15575 [7] and RTQ-R [8]. The dataset with the twenty EnergyPlus IDF files of the generated houses is publicly available in an open access repository [16].

3. RESULTS AND DISCUSSION

Figure 1 depicts two examples of the twenty generated solutions. The size and orientation of spaces, windows and roof present varied design solutions, having in common the Living Room entrance door facing the sidewalk located at south of the lot. The roof orientation is limited to the north-south and east-west, allowing, through its eaves, the shading of the respective facades. Thus, the geometric diversity varies between a longitudinal shape, in the direction of the largest dimension of the lot.

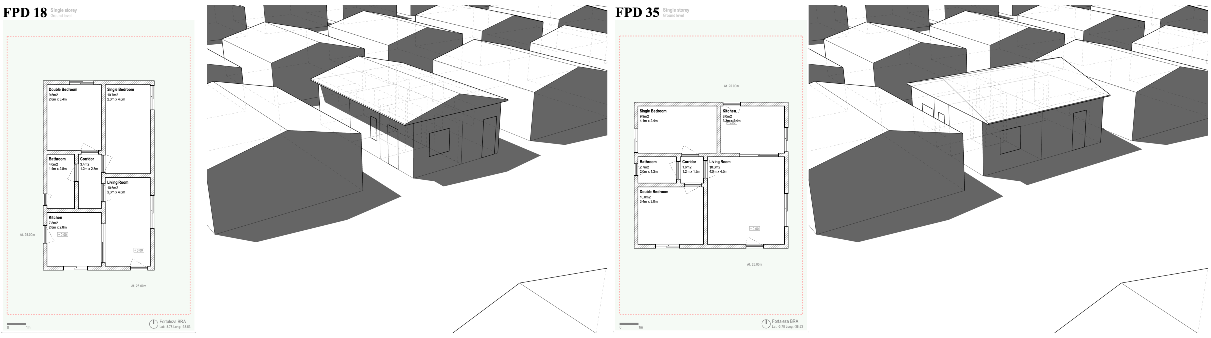

Figure 1: Floor plans and 3D views of two of the generated buildings in the reference dataset.

Table 1 lists the area, thermal comfort in cooling degree-hours (CDH), and energy ranking for each generated building and spaces with longer living presence. Despite ranking A in all spaces and in all overall buildings, the living indoor environment conditions are far from ideal, as the setpoint of 26 °C operative temperature for cooling, which defines the CDH and thus the rating according to the RTQ-R, is a high value for thermal comfort limit. When evaluating the thermal performance of the spaces with the longest living period (the living room and the bedrooms), the results observed in the Single Bedroom range from a minimum of 2631.6 CDH (FPD 258) to a maximum of 5502.3 CDH (FPD 299), showing that this space has, on average, 1 °C above the setpoint temperature of 26 °C, ranging from 30 % to 63 % of the hours in a year; the Double Bedroom presented solutions that ranged from 2244.2 CDH (FPD 441), the lowest result among all the environments of prolonged presence, to 5198.1 CDH (FPD 305), corresponding to 26 % to 59 % of the year. In turn, the Living Room presented a variation from 3578.2 CDH (FPD 289) to 7023.5 CDH (FPD 206), resulting in a thermal discomfort from 41 % to 81 % of the hours in a year. Although results show thermal averages above that recommended by the Brazilian standard NBR 15575, the analysis based on the RTQ-R shows that all the houses generated remain at level A, that is, the highest, according to the conformity requirements for energy efficiency of buildings.

Table 1: The area, cooling degree-hours, and thermal comfort ranking for each long-period living spaces and overall building.

	Living Room			**Single Bedroom**			**Double Bedroom**			**Building**	
Design	**Area** (m²)	**CDH**	**Rating**	**Area** (m²)	**CDH**	**Rating**	**Area** (m²)	**CDH**	**Rating**	**Area*** (m²)	**Rating**
FPD 15	12.5	4684.0	A	11.0	3673.5	A	13.8	3547.0	A	37.3	A
FPD 18	10.6	6328.6	A	10.7	5370.5	A	9.5	4559.5	A	30.8	A
FPD 35	18.0	4104.0	A	9.9	3786.9	A	10.0	3986.9	A	37.9	A
FPD 104	12.0	5216.2	A	11.6	3659.7	A	8.6	4674.0	A	32.2	A
FPD 158	13.0	6242.7	A	9.5	3559.4	A	9.9	4925.5	A	32.4	A
FPD 206	9.6	**7023.5**	A	8.8	4973.5	A	12.8	4202.9	A	31.2	A
FPD 258	13.8	5218.7	A	8.7	**2631.6**	A	10.2	4272.4	A	32.7	A
FPD 289	11.6	**3578.2**	A	10.5	3460.1	A	12.1	3813.7	A	34.2	A
FPD 299	14.5	4642.6	A	7.5	**5502.3**	A	11.2	4280.0	A	33.2	A
FPD 305	10.8	6904.0	A	8.5	3900.8	A	8.5	**5198.1**	A	27.8	A
FPD 308	10.2	5380.2	A	10.5	4102.2	A	13.5	3510.2	A	34.2	A
FPD 417	12.7	4922.0	A	11.0	3939.6	A	9.3	3464.9	A	33.0	A
FPD 441	13.6	4869.7	A	11.1	4332.9	A	7.9	**2244.2**	A	32.6	A
FPD 462	10.3	5165.6	A	11.8	4242.8	A	10.4	3994.7	A	32.5	A
FPD 577	8.4	6454.5	A	10.7	4264.6	A	8.4	2502.1	A	27.5	A
FPD 595	9.3	6135.4	A	11.5	4068.9	A	10.5	4165.9	A	31.3	A
FPD 636	9.5	6013.7	A	8.8	4458.8	A	11.6	3711.8	A	29.9	A
FPD 666	13.3	4376.0	A	12.4	3928.4	A	10.3	4653.2	A	36.0	A
FPD 696	13.3	4822.6	A	11.6	4503.3	A	11.4	3833.8	A	36.3	A
FPD 711	12.8	5193.2	A	9.5	4892.2	A	9.4	2607.2	A	31.7	A

* Area of the living room and the bedrooms.

4. CONCLUSION

The produced synthetic dataset presented diverse indoor building arrangements, shapes, and orientations, thus covering a wide range of design solutions found in several PMCMV built houses. Relatively to the thermal performance, despite every house ranks the highest of the rating levels, the occupants are a long period of the year under thermal discomfort, meaning that the indoor environment quality of the houses must be improved. This set will allow to test different cost-effective measures to improve the living conditions of their inhabitants, and possibly present solutions to mitigate the energy poverty that such population is under. Future work incorporates the definition of those measures and test them in each generated building.

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