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Resilience Ruler for Energy Efficiency: An Evaluation of Social Housing Refurbishment

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ABSTRACT

This study evaluated refurbishment focusing on energy efficiency to improve the resilience of the built environment of social housing from five and ten years ago. Both residential complexes studied were built by the Brazilian social housing program "Minha Casa Minha Vida" ("My House, My Life" in English) in the city of Uberlândia, Minas Gerais state, Brazil. Design science research (DSR) and post-occupancy evaluation (POE) were applied to the energy audit process for built environments. This work aimed to study energy efficiency, behavior, and resilience in the built environment; to introduce the concepts related to the development of indicators and a questionnaire on energy efficiency; and to develop the Resilience Ruler (RR) for energy efficiency and its application in two social housing complexes located in Uberlândia. This paper presents a methodology for energy efficiency resilience assessment (RR) and its result. The RR was developed to measure the resilience level in the built environment based on energy efficiency indicators. The main results indicated that the materialities in the refurbishment and house maintenance received the worst assessment. The roof and the walls materials aren't compatible with the local climate and the residents usually don't have maintenance habits.

1. INTRODUCTION

In 2022, a survey showed that around 96% of the houses in one of the residential complexes in the city of Uberlândia (Minas Gerais state, Brazil) underwent some refurbishment within ten years [1]. This research also reported that most residents in the neighborhoods Pequis (63.5%) and Shopping Park (69.23%) observed an increase in their electricity bills over the years. The level of dissatisfaction was high for both residential complexes: 75% for Pequis and 83.34% for Shopping Park. This study assessed the refurbishment of one-story houses in two residential complexes built by the Brazilian social housing program "Minha Casa, Minha Vida" ("My House, My Life" in English) (MCMV) located in the city of Uberlândia, Minas Gerais state, Brazil. The main purpose was to evaluate the refurbishment and interventions performed by the residents to understand their impacts and develop the indicators and methodologies to assess energy efficiency resilience in the built environment. This paper is also a way to achieve the goals Sustainable Cities and Communities and Good Health and Well-being, of the Sustainable Development. The contribution is made by analyzing the MCMV houses and assisting in more sustainable refurbishments.

This research sheds light on the theme of resilience in the environment built in SH in the Brazilian context through investigation "[RESILIENT HOUSE] Design strategies for promoting resilience in social housing from post-occupancy evaluation methods". The research, developed during the years 2020 to 2023 by the group [MORA] Housing Research at the Faculty of Architecture and Urbanism and Design at the Federal University of Uberlândia, was funded by the CNPq - National Council for Scientific and Technological Development (PQ-CNPQ Nº 311624/2021-9). The ongoing research project aims to identify and provide design strategies for refurbishment and interventions in horizontal single-family social housing, promoting their resilience. The information will be available to architects, contractors, and residents on multiple digital platforms (web and mobile applications). The design strategies were identified by post-occupancy evaluation (POE) applied to the case study. We also aimed to identify the main design attributes and resilience indicators of these refurbishments, including energy efficiency. Figure 1 presents a schematic view of the Resilient House matrix developed by the research group, in which each researcher investigated one attribute, such as environmental comfort, flexibility, etc., to define the indicators. This paper investigates energy efficiency.

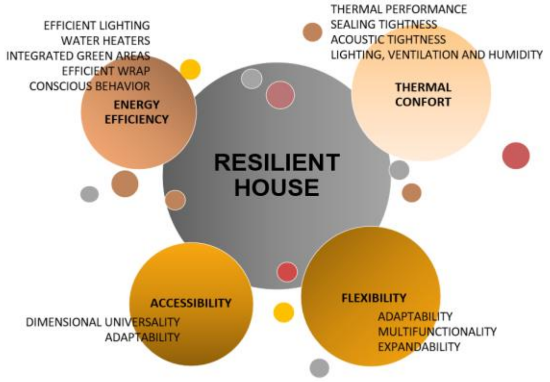

Figure 1. Resilient house assessment matrix (RHAM): Attributes and indicators

We present the results of the proposed methodology for the energy efficiency resilience assessment, named the Resilience Ruler (RR). The RR is a way to assess the resilience, inspired in a tool developed by World Resources Institute (WRI). In this work, the objective was to measure the resilience level in the built environment based on energy efficiency indicators and parameters. The parameters are references to numbers, used to describe the measurement scales for resilience. They are supported by scientific research that has already been consolidated and validated, technical standards, and the national context of Brazil. The indicators on the ruler identify important structural components or social practices that enable homes and their occupants to defend themselves against external forces and thereby increase their resilience [2]. This paper is divided into theoretical basis, methods, case study, results and discussion, and conclusions to validate and develop the RR.

2. THEORETICAL BASIS

Resilience has become a popular term in recent years due to the challenges caused by climate change and the COVID-19 pandemic. Resilience means "the ability to recover" and derives from the Latin word *resilio*. However, the definition of resilience has expanded to different fields in the academic area [3]. In Engineering, the concept of resilience is the ability of a material to return to its initial state after being submitted to extreme force and mechanical deformation [4]. The resilience was also defined as a system in which instabilities change the mode of operation and new stability arises [5]. That is, it is the ability of the system to handle new situations, absorb them, and transform itself. Therefore, the concept of resilience has become plural, being applied to several social contexts. In the academic area, these concepts of resilience can be found, but it is important to highlight that the last one guides this paper.

In this paper, the concept of resilience leads to a social context, linking with the low quality of MCMV' houses with a focus on sustainability and energy efficiency. The concept of energy efficiency corresponds to thermal, visual, and acoustic comfort (with low energy consumption) in buildings. Thus, any architecture presenting the same environmental features as another one but lower energy consumption is stated as efficient [6]. According to the 2022 Brazilian Energy Balance, the electricity consumption by the residential sector corresponds to 26.4% of the total electricity generation [7]. Energy consumption (in kWh) increased in the last 15 years due to electrical appliances and air conditioning. Energy efficiency in the residential sector positively impacts the energy sector and public economy, reducing the national subsidies for electricity generation. Some other advantages directly interfere with the resident's quality of life, which include cleaner air in indoor and outdoor environments, cooling systems for warm places, electricity bill reduction, and environmental impact mitigation [8].

Minimizing human vulnerabilities, such as housing and energy, enables individuals and families to achieve a standard of living beyond mere survival. In addition, a basic level of well-being also allows people to handle unforeseen circumstances [9]. In inclusive economic growth, resilience is a goal in the urban economy together with energy efficiency, renewable energy, productivity, environmental protection, and sustainable growth.

By mapping resilience and sustainability, observations should be considered [3]. Sustainability is easily understood as a global concept, while resilience is local and depends on specific issues, such as social housing. Sustainability is a goal, and resilience is part of the system. However, both concepts are related to decision-making facing some situations. Decisions identify what should be maintained, improved, or highlighted. Thus, POE tools are important to assess resilience in the built environment since they can measure a particular aspect, as on social housing and energy efficiency, whether this be conscious or unconscious for the users [10]. In this study, resilience is defined as the ability of the built environment to resist, adapt, and transform itself to handle the changes and impacts that rise over time [3].

3. METHODS

First, we applied Design Science Research [11] to the energy audit procedure for buildings adapted from ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers), summarized by Figure 2. In DSR, the project is researched and studied through the design of artifacts, developing solutions for existing systems. Two aspects were developed following these methodologies. The first aspect is a set of POE procedures that include data collection on energy consumption, a questionnaire on energy efficiency, a walkthrough, and the RR (a). The second aspect comprises the registration forms created from the RR results, highlighting the main efficiency problems in social housing (b). These items (a) and (b) are artifacts. This paper focuses on item (a).

POE is crucial in this study since it is a set of methodological procedures that verifies if the built environment meets the subjective and objective needs of the residents over time. Mapping human behavior, observing the standard activities of the residents, and collecting photographs of the built environment can provide good elements to analyze and improve the concepts [10].

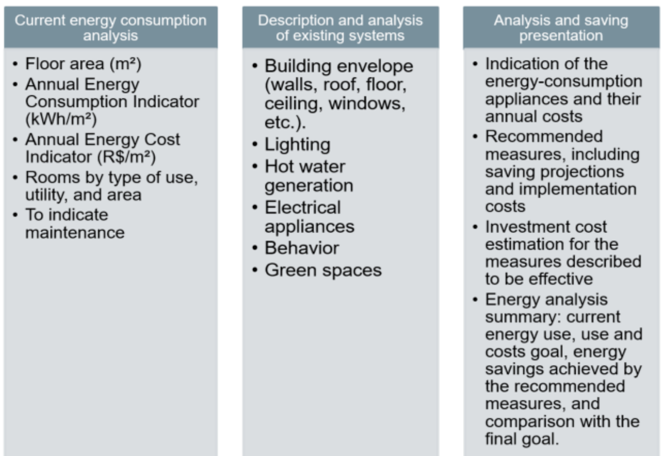

Figure 2. Set of mechanisms used for impact identification and energy efficiency resilience assessment

The first step for an energy audit is to analyze the current energy consumption. We analyzed the electricity bills of 18 houses, nine from each residential complex, for one year. The houses were selected after pass for three moments: different solar orientations of the main facade, houses with refurbishments with and without extensions and finally convenience, according with the resident availability. Energy consumption varied due to external factors, such as climatic variation, and internal factors, such as occupancy changes. From this analysis, energy consumption became clear.

In the second step, we analyzed architectural designs, electrical designs, and descriptive memoranda provided by the construction companies. In the third step, we applied a questionnaire together with a technical visit, in which we could check the electrical appliances, building envelope, lighting, and other systems that could interfere with energy consumption.

The energy efficiency resilience assessment is based on the [RESILIENT HOUSE] research mechanism, which was inspired by the Urban Community Resilience Assessment (UCRA), a tool developed by World Resources Institute (WRI). This RR was applied in collaboration with Rio de Janeiro and Porto Alegre municipal governments to evaluate urban community resilience to extreme weather events.

The RR was developed to assess the resilience level in the built environment based on indicators and their parameters. This analysis evaluates the physical features of the houses, considering their capacity to meet the needs of the residents, presenting a behavioral scale. Thus, the RR could be developed based on the energy efficiency criteria for bioclimatic zones, which includes the social housing selected, and the definition of indicators and design strategies. The design strategies evaluate the designs' resilience related to energy efficiency and, based on the results, define the possible strategies that should be developed for the resident and architect.

The RR measures resilience by considering attributes and indicators, the physical features of the built environment (floor and lot area), and residents' behavior. It measures the adaptive/vulnerability capacity within each attribute. From this built environment assessment, we seek refurbishment design strategies for these vulnerabilities to improve resilience. In addition, this analysis also increases the importance of the methods used in the case study and relates them to the problems identified, which allows the relationship between the parameters and the qualitative and quantitative data.

Figure 3 shows the Resilience Ruler (RR), which is structured as follows: (i) indicators; (ii) sub-indicators and definitions; (iii) score varying from 1 (not resilient) to 5 (very resilient); (iv) parameters based on national and international references and researcher experience; and (v) data collection tools, which included walkthrough and questionnaire.

ATTRIBUTE							
INDICATOR	SUB INDICATOR + DEFINITION	1 Not Resilient	2 Low Resilient	3 Moderately Resilient	4 Resilient	5 Very Resilient	PARAMETER

Figure 3. Resilience Ruler (RR)

To measure the resilience level in building energy efficiency, we compiled parameters that could evaluate indicators in social housing. These criteria are based on the literature review, current regulations, some Brazilian certifications, such as Selo Casa Azul (Blue House Seal), and procedures for building energy efficiency labeling.

The Resilience Ruler for energy efficiency resilience assessment included five indicators: energy-efficient building envelope, water heating system, energy-efficient lighting, energy-efficient electrical appliances, and integration of green spaces. The indicators were chosen after a detailed literature review: the survey of ownership and use habits of electrical equipment in the residential Class 2019 of Brazil, brought the weight of the consumption of electrical equipment in energy consumption [7]; the ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) emphasizes the building envelope, lighting, hot water and electrical appliances as a scope of energy consumption. From a Brazilian residential perspective, the same items appear [6, 12-14]. Overall, the authors agree that how occupants control heating and ventilation systems is an important factor [14-16]. In addition, the integration of green spaces in the residential context has been studied internationally by some authors, influencing on the time spent outdoors and indoors [15, 17, 18]. Figure 4 summarizes the concepts developed by the group.

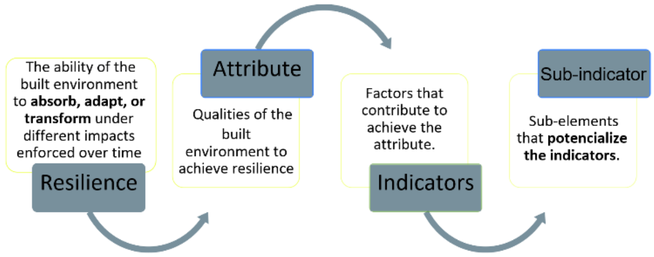

Figure 4. Concepts obtained from the studies performed by the research group

The energy-efficient building envelope sub-indicators were efficient materiality, efficient geometry, and maintainability. The water heating system sub-indicators were efficient heating systems and maintainability. The energy-efficient lighting sub-indicators were natural lighting and LED lighting. The energy-efficient electrical appliance sub-indicators were electrical appliances with the PROCEL (National Program for Energy Conservation) Seal and newer electrical appliances. The conscious behavior sub-indicators were daily habits and consciousness. Green spaces sub-indicators were integrated landscaping and green preservation. Each sub-indicator parameterization was based on normative ruling, methodologies for sustainability assessment, such as seals and certifications, and researcher experience. The parameterization was rated from 1 to 5, in which 4 (resilient) is the minimum level to maintain the quality of the housing units. The RR was applied using walkthrough and questionnaire tools. The scores were processed using a spreadsheet, with the rating for each house after applying the parameters. The general rating of the sub-indicators was the result of a simple general average. In the result section, statistical tests were performed to determine the significance between the two neighborhoods: G Test (likelihooh ratio test) for Table 1 and Mann-Whitney test for Table 2. The design strategies were derived from the 1 to 3 scores. The application of the RR made during the research aimed to provide initial guidance for calibration. The approach was carried out based on the presentation of the researcher, duly identified, with the use of safety equipment (mask, face shields and alcohol gel). Soon after the presentation, there was an invitation to participate in the questionnaire (reinforcing the confidentiality of the data), if a positive response was received, a disposable mask would be offered. The instruments were applied only after the respondent read, understood and accepted the Free and Informed Commitment Term.

4. CASE STUDY

4.1 Social housing

The social housing complexes are located in the city of Uberlândia, Minas Gerais state, Brazil. Uberlândia is located in the Triângulo Mineiro and Alto Paranaíba mesoregions and has about 700 thousand inhabitants. The city stands out as a wholesaler center due to its strategic location, connecting major cities such as São Paulo, Rio de Janeiro, and Brasília, as indicated in Figure 5.

Figure 5. Social housing location in the city of Uberlândia, Brazil

The Sucesso Brasil residential complex is located in the Shopping Park neighborhood in the south of the city, and it was the first location chosen for implementing the MCMV program in Uberlândia. The MCMV is a federal housing program in Brazil, created in March 2009 by the government. The PMCMV subsidizes the purchase of a house or apartment for low-income families. The largest public housing program ever implemented in Brazil, MCMV has already delivered more than 6 million housing units. According to the City Hall of Uberlândia, 3632 horizontal semi-detached housing units were built in the Shopping Park neighborhood between 2010 and 2012, within the income level 1 (0 to 3 minimum wages). The residential complex comprises 141 housing units, with 33.4 m² of floor area. The housing units share one common wall in the bedrooms, which characterizes the semi-detached houses. The housing units' environment follows a standard and restricted layout, with two bedrooms, one bathroom, and a combined living room and kitchen, as shown in Figure 6a. The neighborhood Pequis comprises a total area of 1,998,424.37 m² and 3942 lots. The residential complex was approved under the MCMV program in 2014 to assist low-income families (income level 1). This approval occurred just after the expansion of the urban perimeter toward the western side of the city, which reinforces the location of the houses on the outskirts.

The housing units are freestanding houses, which is a factor to compare to the housing units in the Shopping Park neighborhood (semi-detached houses). These housing units comprise 200 m² of individual lots and a floor area of 33.4 m², with a living room, kitchen, two bedrooms, bathroom, outside laundry, and a solar water heating system for the bathroom, as shown in Figure 6b. This architectural standardization repeats the BNH (Banco Nacional de Habitação, National Housing Bank in English) model, homogenizing families and urban landscape's objective and subjective needs [19].

(a) (b)

Figure 6. Floor plan for the Shopping Park Residential neighborhood (a) and the Pequis neighborhood (b) housing units

4.2 Sample frame

The sample frame for the questionnaire application resulted in 52 representative samples from the 350 lots investigated in the two neighborhoods. We assumed a sampling error equal to 8%.

The sample size for finite population (*n*) is calculated as follows:

$$n=Z^2.\ p.\ q.\ Nd^2(N-1)+Z^2.p.\ q \qquad (1)$$

where, Z is the abscissa of the normal curve (1.96), $p.\ q$ is the variability of the data ¼=(0.25), N is the population size (350), d is the sampling error of 0.08 (8%), and $n=(1.96)^2.0.25\ .3500.08^2(350-1)+(1.96)^2.0.25$.

Fifty-two residents were selected, 26 from the Shopping Park neighborhood (Sucesso Brasil residential complex) and 26 from the Pequis neighborhood (plot 2-A4). At first, houses with different solar orientations were selected. In a second selection, houses that had extensions and others that did not have extensions were chosen. In a third moment, we selected random and convenience samples within those houses previously selected.

5. RESULTS AND DISCUSSION

5.1 Indicators

We aimed to identify the main elements of energy consumption in the housing units during their use and occupancy based on the literature review and the items listed in the energy audit procedure. Table 1 presents the indicators for energy efficiency resilience in the built environment.

To evaluate the energy-efficient building envelope, we considered the literature review, the Regulation for Energy Efficiency of Residential Buildings (RTQ-R), and the Immetro Normative Instruction for the Classification of Energy Efficiency in Residential Buildings (INI-R). These methodologies allow us to understand the building energy performance, helping to seek and guarantee more efficient buildings [20]. Climate context should be considered to choose the materiality together with the housing design [18].

Lighting plays an important role in reducing energy consumption. Natural and artificial lighting are linked to environmental comfort and space usage [18]. In Brazil, artificial lighting represents, on average, 15% of the electricity consumption [7]. The lighting design should consider the best use of natural light. Thus, the housing units can significantly save energy if the artificial light remains off [6].

Table 1. Energy efficiency indicators to increase resilience in social housing

Indicator	References
Energy-efficient building envelope	LAMBERTS, DUTRA, and PEREIRA, 2013; INI-R; WRI; Eletrobras, 2019; H. YOSHINO et al., 2017; BAKER, 2015; BODE, 2015; KHALID and SUNIKKA-BLANK, 2018 and 2020.
Energy-efficient lighting	INI-R; Eletrobras, 2019; SUNIKKA-BLANK, 2018 and 2020.
Water heating system	LAMBERTS, DUTRA, and PEREIRA, 2013; INI-R; WRI; Eletrobras, 2019.
Energy-efficient electrical appliances	LAMBERTS, DUTRA, and PEREIRA, 2013; INI-R; WRI; Eletrobras, 2019.
Conscious behavior	KHALID and SUNIKKA-BLANK, 2018 and 2020; Eletrobras, 2019; YOSHINO et al., 2017; BAKER, 2015.
Integration of green spaces	GOULART, 2007; BODE, 2015; MARTELLI et al., 2020; SOUZA et al., 2013; KHALID and SUNIKKA-BLANK, 2020.

The characteristics of each Brazilian bioclimatic zone should be considered to define a more efficient water heating system. The Survey of Ownership and Habits of Use of Electrical Appliances in Residential Class, released in 2019, mapped the use of electrical showers in Brazil. Within the income level D-E in the southeast region, 69.11% of Brazilians use electrical energy for heating water, and for those using solar water heating systems (0.64%), only 50% perform periodic cleaning of the solar panels. Solar water heating system is unknown for 43.18%. Most residents would not change the heating system (60.14%) or would not use the solar heating system (47.14%). These data show that promoting alternative sources for heating water is necessary.

The energy consumption of electrical appliances in Brazil tends to increase. In addition, the electrical appliances inside the residences have been growing. For instance, a function earlier performed exclusively by a refrigerator is now also performed by a freezer or an electric water filter [3]. Promoting the use of electrical appliances that save energy can contribute to energy safety and lower environmental impacts.

The resident behavior sets the relationship between building occupancy and energy saving. Several studies have highlighted that building characteristics and resident behavior are important in energy consumption levels. Energy consumption significantly varies in buildings with the same characteristics, mainly due to space usage, domestic work, lifestyle, cognitive variation, and comfort perceptions [18].

The relationship between buildings and vegetation is crucial to mitigate microclimate since green spaces change the air moisture and temperature, filter the sunlight, and absorb the noise and air pollution. Afforestation and vegetation in urban areas, including in the lots, positively influence air moisture and temperature and provide a friendly microclimate, improving the resident's quality of life [21].

5.2 Questionnaire on energy efficiency

To identify the impacts and problems related to energy efficiency, the questionnaire addressed building envelope, lighting, water heating system, electrical charge, behavior, and green spaces. These items are the indicators, and they are detailed as follows.

The first part of the questionnaire aimed to identify the family configuration of the residents, the number of people, age, the value of the electricity bill, and if they considered the electricity bill expensive. For the building envelope, we analyzed whether there was some refurbishment and whether the original house characteristics were preserved or replaced. For lighting, we evaluated the use of artificial or natural lighting. Considering the water heating system indicator, we analyzed whether the solar system delivered was working or being used and whether there was an electric shower. The questions on electrical appliances observed the number of appliances, time and frequency of use, and whether they received the National Energy Conservation Label (ENCE). For the behavior indicator, we evaluated how long the residents stayed at home, the residents' professional occupation, and what may interfere with using electrical appliances, such as natural ventilation or natural lighting. The green space indicator assessed whether there was vegetation in the buildings, which mitigates the effect of heat.

We also considered more accessible language to the residents when developing the questionnaire. Before applying the questionnaire, a test was conducted in ten houses randomly selected to calibrate the questions. A walkthrough model was also developed, with items to be observed by the researcher to complete the understanding of the built environment.

We performed a descriptive analysis of the results to identify the scenario experienced by the residents and the impacts observed by them. We also observed the most repeated issues related to the energy efficiency indicators.

Most residents that answered the questionnaire earn between one and two minimum wages and pay between R$100.00 and R$200.00 in their electricity bills. Some families fit into the Social Tariff, in which only the minimum rate is charged while the resident is unemployed. The electricity bill is expensive for 80% of the residents in both neighborhoods. The results showed that the number of people living in the house did not affect the value of the electricity bill.

In the Shopping Park neighborhood, all residents answering the questionnaire had already done some refurbishment, in which 57% performed expansions, 23% replaced some frames, and 6% replaced the type of roof tile. In the Pequis neighborhood, 65% of the residents had already done some refurbishment, which corresponded to expansion (50%), frame replacement (23%), roof replacement (3%), and electrical panel replacement (3%). In the Shopping Park neighborhood, 73% had already performed some maintenance, 53% replaced the electrical wiring, 23% painted the house, 15% cleaned the solar heating system, and 3% cleaned the roof. In the Pequis neighborhood, 65% performed maintenance in the houses, corresponding to electrical wiring replacement (34%), house painting (7%), and cleaning the solar heating system (3%). These constant interventions show the low quality of the houses delivered to the families.

Table 2. Main results for the energy-efficient building envelope indicator

Indicator – Energy-Efficient Building Envelope				
		P (26)	**SP (26)**	**p-value**
Refurbishment of the housing unit	Yes	65.38% (17)	100% (26)	0.0001
	No	34.62% (9)	0% (0)	
What was done in the refurbishment	Expansion (Terrace or rooms)	42.31% (11)	50% (13)	0.0940
	Frame replacement	23.08% (6)	23.08% (6)	0.9999
	Roof replacement	3.85% (1)	7.69% (2)	0.5710
	Electrical panel replacement	3.85% (1)	0% (0)	0.2424
Maintenance	Electrical wiring replacement	30.77% (8)	42.31% (11)	0.5568
	Solar panel cleaning	3.85% (1)	11.54% (3)	0.3241
	Painting	7.69% (2)	19.23% (5)	0.2793
	Roof cleaning	0% (0)	3.85% (1)	0.2424

The energy supply system is single-phase, and both neighborhoods presented electrical overload. The residents have already recorded fire and power failures due to short circuits induced by the electrical appliances. Some residents decided to replace the electrical panel with a two-phase system and replace all the electrical wires. Regarding lighting, 54% of the residents in Pequis considered natural light to be very good. In Shopping Park, 46% of the residents considered natural light to be good. Excess sunlight was more inconvenient for the residents of Pequis than for Shopping Park. Thus, when there is excess sunlight, artificial lighting is used for internal balance. Both residential complexes were delivered with a solar water heating system. However, most residents still use electrical showers. The solar water heating system presented some operational problems, such as heating problems and leakage. Due to lack of maintenance, we observed that the residents tend not to use the solar water heating system over time. In addition, few residents reported they received the user and maintenance manual.

Regarding electrical appliances, the fridge was the most common in the residences. Most of the fridges, 65% in Shopping Park and 77% in Pequis, were bought more than five years ago. Only 50% of the residents in Pequis stated that their fridge has the ENCE label, against 80% in Shopping Park. Regarding sidewalk trees, most residences in Shopping Park did not have them and had no interest in having them.

To analyze the behavior indicator, we compiled the main results that show the behavioral profile of the residents. In the social housing context, passive building strategies play an important role and are partially controlled by the resident. The housing units were delivered with window shutters in all bedrooms, but some were replaced in the refurbishment. In Shopping Park, 11.45% of the housing units no longer have window shutters, while 3.85% in Pequis ignore the use of window shutters. Most residents use window shutters for lighting control (darken the room) and natural ventilation (refresh the room). We also observed that most residents in both neighborhoods close the glass window at some point, 61.54% in Shopping Park and 80.77% in Pequis, either to stop the ventilation (> 34%) or for security measures (> 26%). Analyzing the green space, we considered the presence of vegetation inside the lots and on the sidewalk, as shown in Figure 7. Plants and tree cultivation can help filter the air and provides shade. We observed plants in the houses, and the residents understood their importance to the environmental quality of the house. Most houses had permeable spaces with grass, shrubs, trees, or potted plants (more than 79%).

Figure 7. Vegetation inside the lots

5.3 Resilience Ruler (RR)

The RR was initially applied for calibration. We selected ten housing units, five from each neighborhood, to participate in the initial survey, questionnaire, and walkthrough. The first applications of the RR showed that the parameters needed some adjustments. The RR should be applied according to the Brazilian bioclimatic zone where the housing units are located since each local has climatic characteristics affecting the building energy efficiency. The RR application was descriptive, considering the particularities of each neighborhood. A weight was assigned for each letter, being A=5, B=4, C=3, D=2, and E=1, as indicated in Figure 8.

Identification							
Identification of the housing unit (Write address): Date: ________________Time:______________Phone(s):________________							
RESILIENCE ASSESSMENT CHART							
Attribute: Energy Efficiency							
Bioclimatic Zone 4							
Subtitle: APP - Room (living room or not) and Bedroom UH - Housing Unit S/C - Living Room and Combined Kitchen DORM - Bedroom BHO - Bath AMP - Extended environment that is characterized as an APP (if any)							
Data collection method: Walkthrough or analysis of the architectural design; The number of environments must be adapted for each house;							
	Room	Resilience rating scale					References for parameter proposition
		Very	Resilient	Moderately	Low	Not	
		A	B	C	D	E	
A	**Evaluate the solar orientation of APPs**. If there is more than one type of orientation, consider their predominance, including the position of the openings (glass doors and windows). 1°) Majority of the APP and/or openings to the West; Answer: I 2°) Majority of the APP and/or openings to the Northwest; Answer: D 3rd) Majority of the APP and/or openings to the North; Answer: C 4th) Majority of APP and/or openings to the Northeast; Answer: B 5th) Majority of the APP and/or openings to the East; Answer: A						
	UH	A	B	C	D	E	Author, 2022; Based in NBR15220-3/2005, Projeteee, INI-R.
B	**Evaluate the absorptance of the tile.** If green roofing or unglazed clay tile, consider A. 1°) Dark colored tile; Answer: Yes 2°) Medium color tile; Answer: C 3°) Light colored tile; Answer: A						
	UH	A		C		E	Author, 2022; INI-R, Cartilha EDUS ZB4.

Figure 8. Resilience assessment framework

Table 3 presents the main results of applying the RR. In general, the two neighborhoods were moderately resilient. Even presenting different architectural and constructive characteristics, the RR was similar to almost all indicators. Energy-efficient building envelopes reported the worst RR in both neighborhoods. Efficient materiality and maintainability were not resilient and little resilient, respectively. Efficient geometry achieved a satisfactory result, being resilient in both neighborhoods.

For the water heating system, the two neighborhoods were little resilient. Since the housing units in the Shopping Park neighborhood were delivered earlier than in the Pequis neighborhood, we observed a higher tendency to use an electrical shower than the solar water heating system. Maintenance in both neighborhoods was very low and characterized as not resilient.

Energy-efficient lighting reported the most divergent results between the two neighborhoods. The Pequis neighborhood was characterized as very resilient, while Shopping Park was moderately resilient. This difference is due to the number of expansions the Shopping Park housing complex underwent in ten years. In the expansions, some rooms may not receive natural light since the openings are blocked or removed.

Energy-efficiency electrical appliance results were similar and characterized both neighborhoods as moderately resilient. In Shopping Park, the residents showed better knowledge about ENCE labels and the importance of purchasing more energy-efficient appliances. Regarding conscious behavior, both neighborhoods were moderately resilient. However, residents in Shopping Park were more conscious than those in Pequis. The houses' energy bill in Shopping Park is more expensive than Pequis, leading the residents to save energy more often.

The results for integration of green spaces were different for both neighborhoods. Green preservation was little resilient in Pequis and moderately resilient in Shopping Park. Landscaping was moderately resilient in Pequis and very resilient in Shopping Park. The residents received the housing units without green space infrastructure. The residents built walls around the housing units to contain the dust from the permeable surface. Few residents have gardening habits or seek to preserve the trees in the lots. This standard behavior was more evident in Pequis than in Shopping Park.

Table 3. Main results for RR applied to energy efficiency

Indicator – Energy-Efficient Building Envelope					
Sub-Indicator – Efficient Materiality					
Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
POR positioning	1	1	0.9999	1.45	2.1
Type of roof	1	2.6	0.0200		
Aborstance of external walls	2.8	3.8	0.3160		
Thermal transmittance and thermal capacity of walls	1	1	0.9999		
		sub-indicator p-value		0.0904	
Indicator – Energy-Efficient Building Envelope					
Sub-Indicator – Efficient Geometry					
Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Transparent elements in the POR	5	5	0.9999	4.28	4.04
Ventilation in the POR	4	4	0.9999		
Natural ventilation and lighting of the bathrooms	4.4	4.2	0.9999		
Presence of window shutters in the PORs	3	3	0.9999		
Ceiling height	5	5	0.9999		
		sub-indicator p-value		0.5868	
Indicator – Energy-Efficient Building Envelope					
Sub-Indicator – Maintainability					
Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Exterior walls painting	1.8	1	0.1770	1.8	1.26
Painting of interior walls	2.6	1.8	0.4884		
Roof cleaning	1	1	0.9999		
		sub-indicator p-value		0.195	
Indicator – Energy-Efficient Building Envelope					
Average of P					**Average of SP**
2.51					2.46
Indicator p-value					0,9999
Indicator – Water heating system					
Sub-Indicator – Efficient water system					
Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Electric shower use	4.6	3.4	0.0573	4.12	3.4
Time of electric shower use	5	2.2	0.0232		
Presence of a solar water heating system	5	3.8	0.1797		
Electrical appliances with PROCEL Seal	5	4.2	0.4237		
		sub-indicator p-value		0.0151	
Indicator – Water Heating System					
Sub-Indicator – Maintainability					

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Solar panel cleaning	1	1.8	0.4237	1.4	1.8
User and maintenance manual	1.8	1.8	0.9999		
		sub-indicator p-value		0.5828	

Indicator – Water Heating System

Average of P	Average of SP
2.76	2.6
Indicator p-value	0.1162

Indicator – Energy-Efficient Lighting
Sub-Indicator – Natural Lighting

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Artificial lighting during the day	4.6	2.6	0.1515	4.6	2.6
		sub-indicator p-value		0.1515	

Indicator – Energy-Efficient Lighting
Sub-Indicator – LED Lighting

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
LED lighting in all rooms	4.6	4	0.6072	4.6	4
		sub-indicator p-value		0.6072	

Indicator – Energy-Efficient Lighting

Average P	Average SP
4.6	3.8
Indicator p-value	0.1185

Indicator – Energy-Efficient Electrical Appliances
Sub-Indicator – Electrical Appliances with PROCEL Seal

Definition	Average of P	Average of SP	p-value	Sub-indicator average P	Sub-indicator average SP
Electrical appliances with PROCEL Seal	3.2	4	0.3902	3.2	4
		sub-indicator p-value		0.3902	

Indicator – Energy-Efficient Electrical Appliances
Sub-Indicator – New Electrical Appliances

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Age of appliances since manufacturing	3.4	3.6	0.6312	3.4	3.6
	sub-indicator p-value			0.6312	

Indicator – Energy-Efficient Electrical Appliances

Average of P	Average of SP
3.2	3.8
Indicator p-value	0.6312

Indicator – Conscious Behavior
Sub-Indicator – Daily Habits

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Open windows for ventilation	5	4.6	0.4237	3.1	3.7
Activities outside the house	1.2	2.8	0.0565		
		sub-indicator p-value		0.4877	

Indicator – Conscious Behavior
Sub-Indicator – Consciousness

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Avoid the standby mode	1.4	3.4	0.0696	3.2	4.2
Avoid using an electrical transformer	5	5	0.9999		
		sub-indicator p-value		0.2618	

Indicator – Conscious Behavior

Average of P	Average of SP
3.15	3.95
Indicator p-value	0.1924

Indicator – Integration of Green Spaces
Sub-Indicator – Landscaping

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Permeable space inside the lots	3.2	4.2	0.4083	3.2	4.2
		sub-indicator p-value		0.4083	

Indicator – Conscious Behavior
Sub-Indicator – Green Preservation

Definition	Average of P	Average of SP	p-value	Sub-indicator average of P	Sub-indicator average of SP
Sidewalk tree	3.4	2.6	0.5067	2.8	3
Gardening habits	2.2	3.4	0.4189		

sub-indicator p-value	0.8403
Indicator – Conscious Behavior	
Average of P	**Average of SP**
3	4
Indicator p-value	0.4918
Final Result for the RR Applied to Energy Efficiency	
P (Pequis Residential)	**SP (Shopping Park)**
3.10	3.02
p-value	0.7032

The p-value near or less than 0.05 shows the differences between the two neighborhoods that are statistically significant. In this way, we can highlight: the type of roof; electric shower use; time of electric shower use; activities outside the house; avoid the standby mode. For future applications in Brazilian bioclimatic zones, the RR parameters should be adjusted according to the relevant characteristics of the region. The RR application highlighted the main problems in energy efficiency resilience in the built environment. From this analysis, we can propose design strategies for refurbishments and interventions that are more energy efficient. Such as helping choose the best painting color for the external walls or calculating the windows' protection from the direct sunlight that can improve the energy consumption.

6. CONCLUSIONS

This study evaluated refurbishments and interventions focusing on energy efficiency applied to the built environment to improve the resilience of housing units built between five and ten years ago. The scenario of housing units differed from that found five years ago, when houses were delivered to residents. A different scenario was found in houses from ten years ago. The residents in both neighborhoods seek to be resilient and remain there, adapting to the built environment according to the information they have, which can be precarious and without proper direction. Thus, this research aimed to meet the residents' needs and provide assertive information based on the current situation. The term resilience without this understanding is still uncomfortable for other researchers who still apply the original definition for materials. This fact can be seen as a fragility but also as an opportunity to be disseminated to other contexts.

We found some difficulties in the development and application of the instruments. The questionnaire and walkthrough application schedule had to be postponed twice due to the high number of COVID-19 cases in the area. The research period was extended due to the availability of the researchers, who, for safety measures, decided to work in pairs when applying the individual instruments. Another fragility is that only the residents can provide information on electricity bills. There is not a unified data system provided by the energy company or the city hall containing these data. Individual collection of these data is unfavorable for the quantitative character and hinders the global analysis of energy consumption.

During the interviews, we observed that some residents are still unfamiliar with the ENCE label, and, therefore, they do not consider it when purchasing a new electrical appliance. The ENCE label can become more accessible by expanding mandatory uses. Currently, not all appliance manufacturers are required to report efficiency. When at home, most residents stay indoors. Few residents use the outdoor spaces. In some cases, this is due to the lack of quality outdoor spaces. The housing units are delivered without terraces or gardens, which could allow better indoor and outdoor environment integration. Brazil is a country with a vast territorial extension, with significant climatic diversity. The climate is mapped, divided into 8 bioclimatic zones. In future applications to other Brazilian bioclimatic zones, the RR should be adjusted to the relevant characteristics of the area, according in NBR 15.220 - Part 3: Brazilian bioclimatic zoning and construction guidelines for single-family housing of social interest.

This study allowed us to verify that the definition of energy efficiency indicators is important to guide the development of assessment instruments. This work advanced the study of integrated green areas in the context of energy efficiency. Other studies in this field usually are restricted only to other indicators, at most relating to behavior. In addition, they are elements that will be part of the new Resilient House matrix, reinforcing the importance of these items in energy efficiency resilience in the current social housing. Identifying the impact was the first step, knowing well the scenario is essential for taking action. The POE procedures, including the questionnaire on energy efficiency, helped to consolidate the methodology, which proved to be very powerful for identifying impacts. The main impacts were the value of the electricity bill, the poor quality of the electrical wires, and the problems with the solar water heating system. That information were essentials to the RR's construction. In both neighborhoods, the RR was moderately resilient. This may indicate the fragility of social housing before the impacts and the importance of strategies to improve this resilience. The architect and resident should give more attention to the results reported as not resilient and little resilient. These results were building envelope materiality and maintainability, water heating, and green preservation. This study highlighted that diversity and combined methods are important to better identify the impacts and problems of building energy efficiency as a dimension of sustainability.

The results presented can provide a path to achieving the SDGs targets in the Sustainable Cities and Communities and in the Good Health and Well-being, proactively leveraging design practice and education in support of resilient communities. The results can also help the architects and policy makers understand where the problems come from (low, little and moderately resilient). Once identifying the problem, the strategies can be implemented in the Technical Assistance for Social Housing (ATHIS), one of public policies in Brazil.

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NOMENCLATURE

SH	social housing
MCMV	Minha Casa Minha Vida program
HU	housing unit
EE	energy efficiency
POR (APP in Portuguese)	prolonged occupancy rooms (Ambiente de Permanência Prolongada in Portuguese)