Self-build amid rising temperatures: the case of Cantinho do Céu, São Paulo

Autoconstrução em contexto de elevação de temperatura: o caso do Cantinho do Céu, São Paulo

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Abstract
This article seeks to identify the main envelope elements that hinder the thermal performance of self-construction in a context of rising temperatures, an important effect of climate change. Based on a set of self-built houses located in Cantinho do Céu, an irregular settlement in the southern region of São Paulo, we used an evaluation method that combines the analysis of the building envelopes with field research, interviews, and thermographic photographs. The results indicate that the heating of the dwellings is predominantly related to the inappropriate use of materials and to the wrong disposition of construction elements. Technical advice is recommended as a tool that acts on the construction defects of precarious housing, contributing to a better adaptation of the most vulnerable population to climate effects.

Keywords: climate change; heating; self-construction; technical advice; Cantinho do Céu - São Paulo.

Resumo
Este artigo busca identificar os principais elementos da envoltória que prejudicam o desempenho térmico da autoconstrução em um contexto de tendência de elevação das temperaturas, importante efeito da mudança climática. Com base em um conjunto de moradias autoconstruídas, localizadas no Cantinho do Céu, loteamento irregular da zona sul de São Paulo, aplica-se um método de avaliação que combina a análise das envoltórias das habitações, com pesquisa de campo, entrevistas e fotografias termográficas. Os resultados indicam que o aquecimento das habitações se relaciona, predominantemente, com o uso inadequado de materiais e a disposição equivocada dos elementos construtivos. Recomenda-se a assessoria técnica como instrumento atuante sobre as deficiências construtivas das habitações precárias, contribuindo para a melhor adaptação da população mais vulnerável aos efeitos do clima.

Palavras-chave: *mudança climática; aquecimento; autoconstrução; assistência técnica; Cantinho do Céu-São Paulo.*

Introduction

Climate change encompasses a shift in the climate evidenced by atypical variations in mean temperatures and precipitation, and also variability in its properties or intensity, persisting for a long period spanning decades or more. Its origin may be natural, involve external components (variation in radiation and change in Earth´s orbit) or even be subject to anthropic influences, such as changes in the composition of the atmosphere or land use (Field et al., 2012, p. 5). This phenomenon hampers sustainable development of cities, in as far as these have been affected by ever more frequent natural disasters as a result of climactic extremes (Apollaro and Alvim, 2017).

One of the effects of climate change is fluctuations in temperature. In the last 150 years, the pace of warming is 50 times faster than before that point in time (Nobre, Reid and Veiga, 2012). Studies show that global warming is the result of increased organic carbon dioxide (CO_2), the consequence of human activity which increased the concentration of greenhouse gases (CO_2 and CH_4) in the troposphere, raising the atmosphere´s heat retention potential and the temperature of the planet (ibid.).

Fluctuations in temperature in cities cause so-called "Heat Islands", a climatic phenomenon characterized by a rise in temperature of one area relative to another. In this context, impermeabilized urbanized areas can reach temperatures of 27°C to 50°C greater than the air temperature during summer; whereas shaded or damp surfaces remain near air temperature. These surfaces which absorb and release large amounts of heat, have a major impact on the formation of Heat Islands (EPA, 2018). Thus, large built-up areas in cities become heat stores, absorbing large amounts of thermal energy during the day and releasing heat gradually at night, influencing the air temperature.

The exponential increase in the urban population,[1] accompanied by growing socio-spatial inequality, with settlement of environmentally fragile areas by poor-quality housing, show the effects of climate change. People living in urban slums are more exposed to warming, the elements, pollution and also higher health risks (United Nations, 2019).

Specialists note that the effects of climate change are worse on low-income populations, especially those living in poor housing conditions. In other words, climatic events have a direct relationship with the impoverishing of the world population, whether due to natural disasters or anthropogenic causes (Hallegatte et al., 2016). Hallegatte et al. (ibid.) showed that over 60% of the world population[2] is exposed to the constant risks from threats driven by climatic events. Khoday and Ali (2018) estimate that by 2030, around 100 million people will face extreme poverty, owing to the deleterious effects of climatic events. According to Nobre (2011), the risk of being a victim of a disaster caused by the climate increases commensurately with poorer social conditions and lower incomes. The more vulnerable a population is in a given place and the poorer the urban and housing infrastructure, the more susceptible the community is to climate-related disasters.

Quality of housing plays a primary role in the search for alternatives to mitigate the effects of climate on the population.

Precarious settlements, particularly slums and irregular housing, generally translate to substandard constructions which fail to comply with building regulations. This problem, compounded with a lack of basic urban infrastructure (water and sewer system networks), further exacerbate the difficulties in these populations brought on by climatic events. Invariably, these are types of housing that expose their dwellers to numerous health risks, including diseases promoted by poor wetproofing or ventilation, such as those affecting the respiratory tract and cardiovascular conditions, as well as the psychiatric disorders induced by overcrowding (WHO, 2018).

Despite the wide array of studies and public policies addressing climate change and its impact on the regions of Latin America and the Caribbean, few tackle the issue of poor housing and the effects of increased temperature. Generally, such studies focus on the issue in terms of energy efficiency (McTarnaghan et al., 2016). Research and public policies should explore the issues of maintenance and management of the existing housing stock, allocating sufficient resources to improve build-quality aspects and thereby reduce the risks posed by climate change (Un--Habitat, 2003).

The objective of the present study was to shed light on the factors contributing to poor quality dwellings, particularly self-build properties, a modality of housing construction prevalent in Brazil´s towns and cities, and a type of dwelling that is particularly susceptible to changes in climate, especially warming. This knowledge can be applied in devising solutions to mitigate the effects of climate in poor areas. This is relevant because, because besides risk of landslides, increase in temperature is one of the main elements of climate change impacting the quality of life of the population.

This article, part of a broader study[3] investigating low-income housing, seeks to identify the key elements of the building envelope (walls, openings and roof) which compromise the thermal performance of self-built houses in the context of rising temperatures (a significant phenomenon in climate change). Based on a group of self-build houses located in *Cantinho do Céu*, an irregular settlement in the southern region of São Paulo city, an evaluation method was applied combining analysis of the housing enclosures with field research, interviews and thermographic photography.

Although not an exhaustive solution to this complex issue, it was concluded that the role of architects is vital, through the provision of technical advice to low-income populations, and that housing improvements should center on adaption to the climate, promoting comfort, health and energy efficiency in self-built houses.

Climate change, self-build and role of technical assistance

Climate change and build aspects

The effects of climate change have distorted typical weather patterns of São Paulo city and much of the Greater São Paulo area, which has shown a tendency for hotter nights than historically reported (Oliveira and Alves, 2011). In the last few years, São Paulo has seen bouts of heavy rainfall, heatwaves and long dry periods. The effects are deleterious: floods, draughts, high temperatures and pollution.

Nobre (2011) emphasized a direct relationship between urban land use and the process of urbanization in São Paulo that influences (and has been influenced by) extreme weather, such as heavy rainfall and elevated temperatures. Readings made by the University of São Paulo (USP) and by the Center for Emergency Management (CGE) have shown that highly impermeabilized areas in the city, i.e. densely built-up and asphalted, contribute to the formation of brief violent storms and, in turn, are affected by flash flooding and inundations. Besides the issue of intense rains, these densely built areas absorb large amounts of heat during the day, releasing this gradually throughout the night, raising air temperature.

Chart 1 presents the 3 main events promoted by climate change that are recurrent in São Paulo together with the consequences of each for the local population and for the built envelope. It is important to note the influence of the thermal characteristics of the enclosure materials used and the size of openings on dweller comfort and energy consumption of the houses visited.

Chart 1 – Summary of effects of climate change in São Paulo state and on housing and occupants

Climate change	Consequences for population	Effects on housing
Intense heat	• Increased need for cooling • Reduction in quality of life of population due to ill-adapted housing • Greater impact on high-risk populations (elderly, infants and poor) • Deterioration in air quality	• Thermal characteristics of masonry • Windows (placement, sealing and sizing) • Thermal characteristics of roofing
Drought	• Water shortages affecting population and commercial activities • Reduced potential for electricity generation • Increased migratory flow	• Water-saving devices • Rainfall collection • Reuse of graywater • Use of biodigestor septic tank • Impermeable areas negatively impact water cycle, hampering maintenance of levels of water bodies • Rational water use in the home can help maintain reservoir levels • Not directly linked to construction, but vulnerabilities exacerbated by it can be a factor determining migrations
Intense precipitation	• Increase in frequency and intensity of precipitation, flood and inundations	• Watertightness of roofing • Sturdiness of roofing • Resistance of roofing materials against rain and wind

Source: produced by authors based on Oliveira and Alves (2011).

With regard to construction aspects, the WHO (World Health Organization) emphasizes the need for protecting the population against extreme weather events as a basic aspect for ensuring resilience (WHO, 2018). The adverse effects of the climate have clearly demonstrated the importance of housing as shelter for protection against weather events. Housing has taken center stage in the debate, since it allows humans to fulfill their basic physiological needs, such as sleep, feeding and protection against external hazards. The quality of housing is directly related with degree of exposure of dwellers to the weather. The poorer the housing, the lower the protection it can confer to its occupants.

In the scope of this article, there is a need to investigate the aspects of thermal comfort for energy performance of the building. This is especially relevant in self-build, the housing method focused in this study, given that warming is one of the most common problems. Thermal comfort is a relevant aspect for the satisfaction and health of dwellers; this factor also influences the energy required to mechanically condition the environment (Roaf, Crichton and Nicol, 2009). Knowledge on the thermal characteristics of the building materials and the speed of heat transmittance, absorbance, and also thermal resistance and placement of openings relative to the sun and prevailing winds, are all pivotal in reducing the adverse effects of climate. Information on the building elements, together with human ability for heat management, either via the body´s thermoregulatory mechanisms or through the use of air-conditioning units, can reveal whether the building is minimally comfortable or otherwise.[4]

In Brazilian cities, there is clearly a mismatch between climate and construction which impacts the quality of life of dwellers, particularly in relation to poor-quality housing.

Self-build and the role of technical assistance

Self-build housing features heavily in the scenario of Brazilian cities, irrespective of income level. According to a seminal survey conducted in 2015 by the Board of Architecture and Urbanism (CAU),[5] in collaboration with the Datafolha Institute, involving 2.419 individuals throughout Brazil, 54% of the economically active population had built or refurbished a residential or commercial property. Of this group, 85% had performed this work themselves, without engaging a qualified professional.

With no regard to building codes or any manner of design plans, self-build fulfils the housing needs of the low-income population (Sampaio, 1990), constituting the only architecture available to this large contingent of the Brazilian population (Maricato, 1979). In the absence of a design plan, this is a building approach drawing on the creativity of its owners, who fail to observe standards defined in performance requirements, building codes or laws controlling land use. This type of housing, more often than not, occurs in conjunction with irregular land occupation, breaching construction laws (Caldeira, 2017). According to Baltazar (2012), the violation is not in building per se, but in constructing without permits or approved design plans, flouting land use laws and building codes, precluding the issuance of a certificate of occupancy. In general, these are houses that involved much improvisation and DIY, but represent the dream of the dweller in search of an ever better home (Caldeira, 2017).

Self-build requires extensive use of materials, which tend to be acquired in stages, particularly owing to difficulties accessing credit. Financing is rarely granted by financial institutions due to an absence of deeds for the land plot and no proof of income of potential credit holders. Materials depots often assume the role of lender, loaning money with interest well above market rates (Caldeira, 2017; Maricato, 1979). Caldeira (2017) also highlights that all this takes place within a parallel market, specialized in catering to the needs of the low-income population, occupants of irregular or poor-quality settlements, and outside the formal system.

The effects of climate change, particularly increase in temperature, are most felt in the enclosure of self-build houses, i.e. in the external walls, windows, roofing and flooring. The increase in heat, together with poor use of building materials in most low-income buildings, typically impacts the thermal comfort of the residence, an important factor contributing to the health of the dweller (Roaf, Crichton, Nicol, 2009).

The unfavorable relationship between climate and construction, principally in terms of poor build quality, is indicative of the need for involvement of the authorities with policies aimed at improving housing. The National Plan on Climate Change cites the importance of improving the quality of housing as a means of mitigating the effects of climate change, increasing its adaptability.

But how to best improve the conditions of homes occupied by populations without financial resources and/or access to credit?

Technical assistance to improve housing, an instrument provided for by Federal law n. 11.888/2008 (Law on Technical Assistance), can help attenuate some of the problems. This approach involves making available technical assistance provided by professions in architecture and engineering fields to give specialized support to the sector of the population (urban or rural) with monthly incomes of up to 3 minimum wages. Under the Law, the Government, the States, the Federal District and cities should ensure entitlement to free public technical support for the design plan, construction of the building for needy populations, and for the maintenance and refurbishment of the poor-quality homes of this contingent of the population. Unfortunately, during the 12-year period since enactment of the law and the present day, it´s implementation remains limited.[6]

In the case of São Paulo, if this legislation were to be embraced in public housing policy, it could help in the production or adaptation of self-build housing with materials and techniques that minimize the impacts of heat, drought and precipitation, the most notable effects of climate change.

Without intending to address the full scope of this broad theme, the present study aimed to further the debate on poor-quality housing, particularly self-build, against the backdrop of climate change.

The study

Method

The method applied to assess the case study of the irregular settlement known as Cantinho Céu, located in the area of protected water sources of the Billings sub-basin in southern part of São Paulo city, comprised three parts:

a) *Field study*

The field study involved a photographic record and application of a questionnaire[7] at a group of 32 houses, whose criteria for selection shall be outlined in the ensuing text. The questionnaire applied included both quantitative and qualitative questions.

The quantitative questions were formulated to collect the following data: relationship of the owner with the building – tenant or owner – and time residing at abode; number of rooms, number of windows, existence of rooms without windows; occurrence of respiratory or cardiovascular diseases among the residents; existence of mold, damp and dust; expenditure on water and electricity; and whether heat was a problematic issue.

The qualitative variables were intended to collect information on the housekeeping routine regarding cleaning, whether the dwelling was liked by the residents; identification of positive and negative aspects of the dwelling and aspects which could be improved; complaints of the other dwellers; and, finally, whether health problems were seen to be connected with the state of the houses.

The visits to the dwellings, conducted during application of the questionnaires, allowed inspection of the state of the buildings, together with gathering of a photographic record. In 13 of the dwellings, with permission of the residents, measurements were taken of the spaces in order to enable a detailed analysis of the design elements of the building.

b) *Building envelope analysis*

As part of the assessment of impact of the heat, the building envelope elements of the houses were inspected, given these act as a protective barrier for occupants (walls, openings and roof), namely: enclosure materials making up the walls, together with their finish; type of roofing and existence of ceiling lining or otherwise; and, lastly, the placement and size of the openings in the houses.

The materials used for the enclosures (masonry, roofing and openings) were analyzed according to the guidelines of standard n. 15.220 – Thermal Performance of Buildings[8] for Zone 3[9] and Technical Regulations for Quality (RTQ-R) for Energy Efficiency Level of Residential Buildings (Eletrobras/Procel, 2015), as summarized in Chart 2. Tables show thermal transmittance, thermal lag and thermal resistance of the walls and roof derived from the *properties calculator* available on the platform Projeteee – *Projetando Edificações Energeticamente Eficientes* – Designing Energy Efficient Housing.[10] The openings were assessed in terms of dimensions and effective area for ventilation and natural lighting.

c) *Data Treatment*

The data collected from the two previous stages were assessed and allowed separation of the analysis categories for heat and subsequent identification of the weaknesses of the these houses in terms of high temperatures.

Chart 2 – Summary of parameters of standard n. 15.220 and RTQ-R

Bioclimatic Zone	Component	Solar absorptance (dimensionless)	Thermal transmittance W/(m^2K)	Thermal capacity KJ(m^2K)
ZB 3	Masonry	$\alpha \le 0{,}6$ $\alpha > 0{,}6$	$U \le 3{,}70$ $U \le 2{,}50$	≥ 130 ≥ 130
	Roof	$\alpha \le 0{,}6$ $\alpha > 0{,}6$	$U \le 2{,}30$ $U \le 1{,}50$	no requirement no requirement
	Openings			usable area (A)
		medium ventilation openings		A ≥ 8%
		allow the sun in winter		A ≥ 12%

Source: produced by authors based on NBR n. 15.220 and RTQ-R (Technical Regulation for Quality).

During field visits, the type and constitution of the masonry and roofing were assessed by applying the thermal parameters from standard n. 15.220, and according to number of openings. The data collected in the field, for both the form of the dwelling and thermal characteristics of the systems employed, were tabulated (thermal performance) and set against the aspects identified as resulting from the climate change in São Paulo, intense heat, droughts and heavy precipitation. Based on this relationship with the climate, elements of the analysis were separated to classify the dwellings according to the building issues which led to inadequacies for protection against heat. A matrix was then devised in which a pattern of recurrent deficiencies can be identified, according to standard n. 15.220, resulting in a diagnosis of the current situation. The solar graph and thermographic photographs were employed in the 3 worst houses to corroborate the conclusions drawn from the diagnosis of the issues.

During the visits, it was noted that the masonry was shielded from the heat owing to the proximity of the other houses, which shaded these wall surfaces, whereas the roof revealed inadequacies in thermal characteristics, whereas openings showed problems in relation to position.

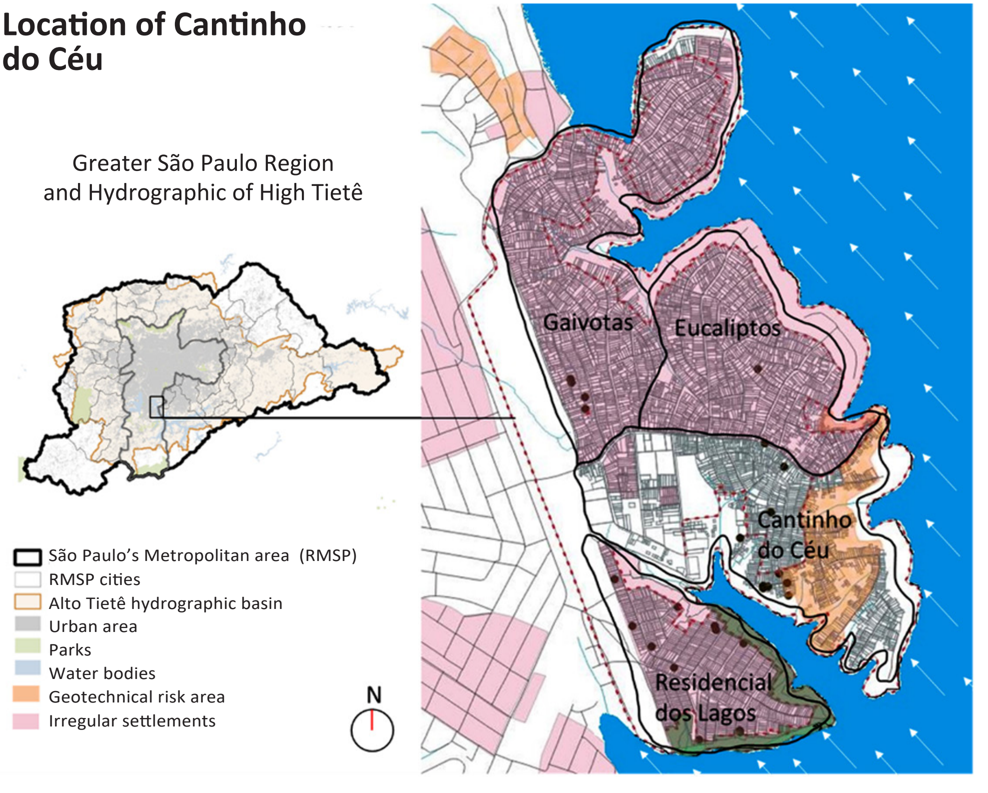
Lastly, the 32 houses were classified according to building elements which demonstrated the capacity of the enclosure to protect the interior against the heat: slabs without roofing; corrugated fiber-cement roofing; windows facing onto narrow corridors; spaces without openings to the outside; rooms without windows; and openings all on the same wall face. This involved assessment of the thermal aspects of the elements, as compared with the parameters of NBR n. 15.220, and the issues concerning placement of the openings. The 3 houses with worse results were photographed using a thermographic camera to determine the temperatures of the materials employed and confirm the impact of the deficiencies. The results revealed the main problems in the houses studied with respect to the use of materials and building systems that were unsuitable for the local climate, hampering passive conditioning, as well as restricting natural lighting of the self-built homes.

Case study and method application

Brazilian irregular settlements consist predominantly of self-build housing (with or without self-management), constructed without a design plan and limited financial resources and techniques. The present study centers on studying the self-built houses in a peninsula of the Billings reservoir, in the region called *Cantinho do Céu* comprising: *Cantinho do Céu, Residencial dos Lagos, Gaivotas* and *Eucaliptos* settlements.

This group of settlements was chosen for the case study owing to several factors. First, it constitutes a region situated within an area designated for the protection and recuperation of water sources and thus environmentally fragile, and is also an area with a high level

Figure 1 – Map showing location of the irregular settlements within study area



Legend: white arrows indicate prevailing wind direction based on data from the Windfinder site (https://pt.windfinder.com/#14/-23.7421/-46.6558). Access on: October 31, 2019.
Source: map produced by authors, adapted from França and Barda (2012), Miranda (2003) and Geosampa Map (São Paulo, 2019).

of social vulnerability; it has been the target of public urban and environmental policies; and has been studied by researchers for some years. Given that it is close to a reservoir, the region should not inherently be subject to a major impact of warming; however, irregular occupation has overlooked its natural attributes, leading to impermeabilization of a major part of the peninsula. Its houses, mostly self-built, replicate the building pattern seen in the poorer outlying areas of the city.

A total of 32 houses were investigated, a sufficient quantity to achieve statistical relevance:[11] 14 houses in the *R*esidencial dos Lagos; 11, in the Cantinho do Céu settlement; 5 in Gaivotas; and 2 in Eucaliptos settlements.

The study area encompasses 42 IBGE (Brazilian Institute of Geography and Statistics) census sectors; 71.4% of the area has a Paulista Vulnerability Index (IPVS)[12] rated as very high (IPVS 6), and 9.5% as high (IPVS 5); the population is approximately 36,610, and average monthly income is R$453.20 *per capita*, based on the sum of all census sectors included in the study area (São Paulo City Hall, 2019).

According to State law n.13.579/2009, which defines the Area of Protection and Recovery of Bacia Billings Water sources, the region lies within the Subarea of Governed Occupation, with the worse area designated an Area of Environment Recovery (ARA type 1).[13] Within the scope of the 2010 Municipal Housing Plan (PMH, 2010), this group of settlements was earmarked, by city authorities, as a priority intervention area, for involving a high-vulnerability situation, particularly given the presence of the sub-standard housing situated in an area with environmental protection status.

Throughout the 1990s, the region was the focus of partial improvements in infrastructure, commencing with connection of the houses to the national grid in 1992, followed by provision of access to mains water in 1995 (Matsunaga, 2015). In the 2008-2012 period, part of this group was included in an urbanization program, with subsequent improvements in the transport communication system and new roadways, water, sewer and drainage networks; the land section occupied by the *R*esidencial dos Lagos was made the pilot for implementation of the Parque Linear Cantinho do Céu, a project developed by the Boldarini Arquitetos Associados architects offices (Alvim, 2011; França and Barda, 2012).[14]

Although the urbanization project at the Residencial dos Lagos did not directly target the housing, it is clear that implementation of the environmental sanitation infrastructure (water, sewer and drainage systems), improved road networks and especially implementation of the system of public spaces within the Parque Linear Cantinho do Céu, promoted improvements in many houses. During the inspections performed as part of the field research, numerous works were observed on the land plots. Many of the houses visited in this part were undergoing further refurbishment and modifications, had been refurbished in the last few years, or were soon to be refurbished, according to reports by the dwellers interviewed.

The process of selecting which houses would be studied was assisted by community social workers[15] from the Cantinho do Céu and Residencial dos Lagos settlements, who proved pivotal in defining which abodes would be subject to application of the method.

Of the 42 census sectors making up the study area, houses with different income and vulnerability characteristics were investigated in 10 of these sectors. Information on income *per capita*, number of inhabitants, the IPVS level of the sectors visited, in addition to the list of houses assessed (identified by house number) is given in Chart 3. Of the 32 houses researched, 8 were located in sectors with IPVS 6, i.e. high vulnerability with presence of subnormal clusters; of this subset, 2 (house numbers 25 and 26) were located in a sector with mean *per capita* income of R$371.79, the sector with the second-lowest income within the settlement. By contrast, only one house (n.12) was situated in a sector with IPVS 3, corresponding to lower vulnerability and a monthly *per capita* income of R$583.50.

Results

Application of the method allowed several important outcomes to be measured.

With regard to the construction characteristics of the house investigated, the types of material were analyzed, along with the sizing and placement of frames, flaws identified and the thermal characteristics of the materials used, according to NBR standards n. 15.220.

The enclosing walling used for the houses mainly comprised 6-hole hollow ceramic bricks. Only one of the houses visited at Cantinho do Céu had cinder block walls without internal or external cladding and block surfaces exposed. External finish, when applied, consisted of a thin layer of mortar,

Chart 3 – Socioeconomic characteristics of study area and location of houses investigated

Sector	Monthly income (R$)	Population	Vulnerability	House number
	Per capita (2010)	Inhabitants (2010)	IPVS (2010)	
355030830000132	444,84	1.079	4	6
355030830000200	493,99	1.033	6	5,7,8,9,10
355030830000203	490,84	858	6	1
355030830000243	564,30	1.210	5	2,11,15
355030830000273	488,97	380	4	31
355030830000274	567,96	1.080	5	3,4,13,14,27,28,29,30,31,32
355030830000294	**371,79**	564	6	25, 26
355030830000385	461,17	622	4	16,17,18, 19,21, 22, 23, 24
355030830000386	466,47	1.115	6	20
355030830000420	**583,50**	768	3	12

Source: produced by authors based on data from the IBGE Census (2010), the Seade Foundation (2010) and on the Geosampa Social Indicators Map (PMSP, 2019).

painted or unpainted, and occasionally plastered and painted. Of the whole group of houses assessed, 5 had no finish on external walls. Most houses were finished internally using ready-mix render, plaster, pre-mix and paint. Only 2 houses had enclosures consisting of blocks exposed both outside and inside: house 6 (cinder block) and house 10 (ceramic block).

The roofing ranged from pre-cast concrete slabs (type H8), often without sealant, and fibre-cement roofing panels. In some cases, a combination of roofing shingles and slab and shingles and ceiling liner (PVC or wood) was used. The system most commonly used in the houses visited was flat slab (37.5%), followed by slab and shingle panel roof (34.38%) (Table 1).

Frames were predominantly of aluminum construction, purchased from building supplies outlets. The most common sizes used for the swivel-type window frames were 1.20m width by 1.0m height (36.36% of total assessed) or 1.0m x 0.60m (18.18%). Most commonly used sliding-type windows measured 1.20m width by 1.0m height (43.48%) or 1.5m x 1.0m (17.39%).

In order to allow cross ventilation, an important aspect in construction, there should ideally be two openings in juxtaposing or opposing walls. Three of the homes visited had openings only on one face, while 6 had only a small swivel opening in the adjacent or facing wall, hindering air flow.

Effective natural ventilation, which provides passive conditioning, relies on factors that hinge on the construction itself, such as size and placement of openings, as well as their implementation. This ventilation also depends on aspects inherent to the urban setting and prevailing wind direction, i.e. Southeasterly, in the case of Cantinho do Céu. Löw and Nader (2019) point out that natural ventilation interacts with buildings, and disorganized land occupation results in slower wind speeds, together with higher land temperatures, negatively impacting comfort.

During the inspections, it was clear that the placement of the houses or their openings were not oriented to the sun´s trajectory, given they enjoyed solar incidence during the summer and shading during the winter and houses were built to maximize use of the land plot. Of the group of houses,

Table 1 – Houses investigated and roof type

Roof type	Frequency	%
Slab	12	37.5
Slab + shingles	11	34.38
Slab + solid floor	1	3.13
Shingles	5	15.63
Shingles + ceiling liner	3	9.38
Total	32	100.00

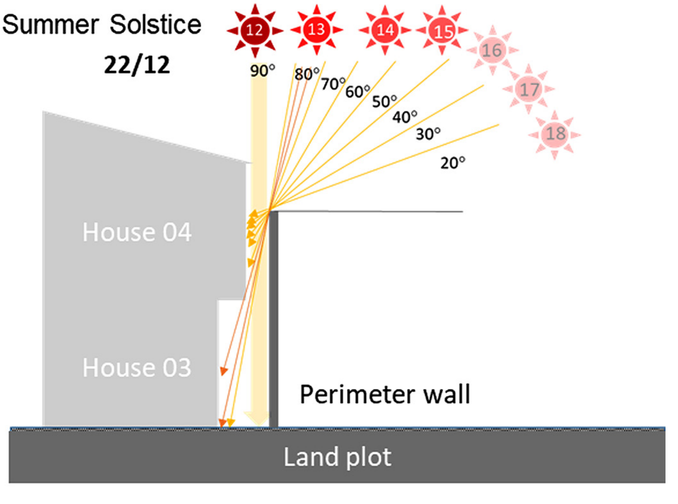
Source: produced by authors based on the field survey.

23 (72%) had façades facing due southeast, south or southwest, which received the sun in the summertime but remained in the shade during winter, contrary to recommendations for best exploitation of passive conditioning of buildings. Ignoring sun position, the houses were instead built to fit the land plot, covering the largest area possible and not exploiting offsets of any kind, resulting in spaces deprived of natural light.

Figure 2 depicts a schematic showing the proximity of houses 3 and 4 (latter built above former) to the perimeter wall of the land plot. In this case, the passageway at ground level was 1.05 meters in width, while on the second floor this was approximately 0.60m. The diagram clearly shows that house 3 has limited access to sunlight during the summer solstice owing to the position of the wall, passageway and façade with openings. In the winter, with the sun lower in the sky (smaller angles of 5-15º), sunlight reached only the upper story, reducing the impact of warming.

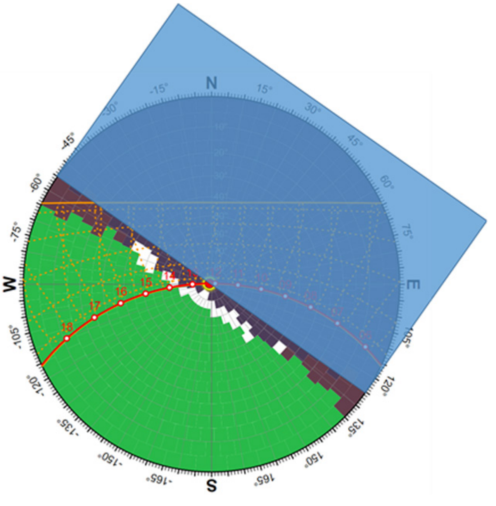
Figure 3 and 4 present solar graphs for houses 3 and 4, respectively. The green area represents the shading of the façade that incorporated 4 openings (living room, kitchen, bathroom and bedroom) of house 3, and the two openings (living room/ kitchen and bedroom) of house 4. The

Figure 2 – Schematic cross-section of houses 3 and 4, and angles for height of sun during summer solstice



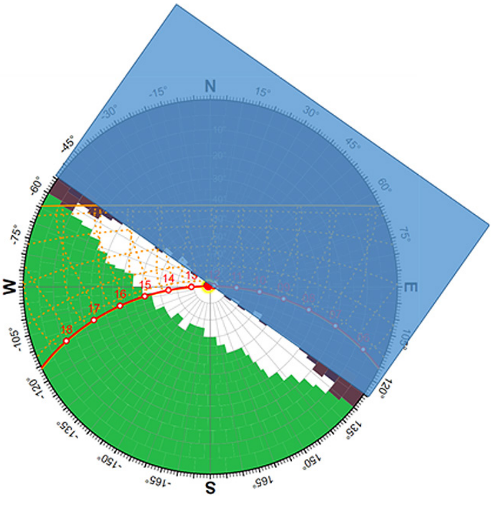
Legend: position of houses and plot perimeter wall restricts solar radiation incidence during summer solstice (22/12), date present in solar graph from LabEE, used as reference for calculating angles between 12:00 and 18:00 hours.
Source: produced by authors.

Figure 3 – Solar graph for southwest façade of house 3



Legend: blue rectangle represents the building volume, green and purple depict influence of wall and obstruction by building, respectively, on façade of ground floor.
Source: graph generated by Dynamic Overshadowing software, available at: http://andrewmarsh.com/software/shading-box-web/

Figure 4 – Solar graph for southwest façade of house 4



Legend: blue rectangle represents the building volume, green and purple depict influence of wall and obstruction by building, respectively, on façade of 2nd floor.
Source: graph generated by Dynamic Overshadowing software, available at: http://andrewmarsh.com/software/shading-box-web/

purple area represents the shading effect caused by the volume of the house. The white area represents the practically non-existent access of the sun to the ground floor and limited access of the top floor to the sun, which received up to 3 hours of sunlight in the summer and less than 1 hour in the winter.

It is evident that this proximity between the houses reduces the possibility of using the sun as a heating strategy in the winter; and, in the specific case of houses 3 and 4, allows overexposure to the sun in the summer, erroneous strategies for weather with rising temperatures.

In order to determine whether opening dimensions were compliant or otherwise with RTQ-R parameters, the floor areas of kitchen, bedroom and living room of the 13 houses were measured (Eletrobras/Procel, 2015). The footage of the room spaces and area of the openings for ventilation are compared in Table 2, while data for natural lighting are given in Table 3.

Chart 4 – Evaluation of openings for natural ventilation potential

NATURAL VENTILATION															
Houses	Kitchen					Living room					Bedroom				
	Floor area	Ventilation area	8%	Compliant?	Outer	Floor area	Ventilation area	8%	Compliant?	Outer	Floor area	Ventilation area	8%	Compliant?	Outer
house 2	17,30	0,84	1,38	no	yes	17,97	0,60	1,20	no	no	17,30	0,60	1,38	no	yes
house 3	10,05	0,76	0,80	no	yes	13,80	0,64	1,10	no	yes	13,75	0,93	1,10	no	no
house 4	18,41	0,46	1,47	no	yes	integrated kitchen and living room					14,26	0,48	1,14	no	yes
house 5	12,45	1,36	1,00	yes	no	12,59	0,71	1,01	no	no	11,56	0,39	0,92	no	yes
house 7	7,76	0,45	0,62	no	yes	12,32	0,71	0,99	no	yes	8,57	0,59	0,69	no	yes
house 8	13,38	0,81	1,07	no	yes	integrated kitchen and living room					13,48	0,46	1,08	no	yes
house 9	11,08	0,76	0,89	no	no	10,57	1,10	0,85	yes	yes	7,88	0,73	0,63	yes	no
house 11	9,99	0,61	0,80	no	no	12,22	1,11	0,98	yes	yes	12,15	0,51	0,97	no	no
house 13	15,49	0,50	1,20	no	yes	18,52	0,00	1,20	no	no	10,12	0,46	0,81	no	yes
house 14	12,13	0,95	1,20	no	yes	9,49	1,13	0,76	yes	no	14,53	1,11	1,16	no	no
house 17	11,87	0,48	0,95	no	yes	16,77	0,60	1,34	no	yes	6,41	0,48	0,51	no	yes
house 18	11,21	0,70	0,90	no	yes	10,66	0,49	0,85	no	yes	11,21	0,46	0,90	no	yes
house 22	10,27	0,00	0,82	no	yes	8,31	0,48	0,66	no	yes	14,20	0,42	1,14	no	yes
house 28	7,97	0,80	0,64	yes	no	absent					8,44	0,60	0,68	no	yes

Source: produced by authors, based on data from the field survey and on parameters from PBEEdifica Manual (Eletrobras/Procel, 2015, p. 8).

As shown in Chart 4, only 6 rooms in the 13 houses had adequate openings for natural ventilation. The houses which conformed to the parameters adopted were: numbers 5 and 28 in the kitchen; 9, 11 and 14 in the living rooms; and, lastly, house 9 also had one bedroom which satisfied the standards.

Natural lighting proved even more critical, in as far as the opening area should be equivalent to 12.5% of the room space, according to the standards of the Brazilian Labelling Program – PBE Edifica, by Procel (Eletrobras/Procel, 2015). The results in Chart 5 reveal that only houses 9 and 13 had adequate openings for the parameters of natural lighting in just one room each: both living rooms; while the other spaces were non-conformant.

Some of the houses had bedrooms whose windows and doors only opened onto internal areas, with no access to the outside, such as onto stairwells, service areas and internal passageways; in two cases, glass blocks replaced windows. These strategies were used to incorporate as many rooms as possible into the given space available, where this hampered access to sunlight and natural ventilation.

Chart 5 – Evaluation of openings for natural light potential

NATURAL LIGHTING															
Houses	Kitchen					Living room					Bedroom				
	Floor area	Light area	12,5%	Compliant?	Outer	Floor area	Light area	12,5%	Compliant?	Outer	Floor area	Light area	12,5%	Compliant?	Outer
house 2	17,30	0,78	1,88	no	yes	17,97	1,05	1,88	no	no	17,30	0,68	1,88	no	yes
house 3	10,05	0,73	1,26	no	yes	13,80	1,13	1,73	no	yes	13,75	1,64	1,72	no	no
house 4	18,41	0,81	2,30	no	yes	integrated kitchen and living room					14,26	0,54	1,78	no	yes
house 5	12,45	1,26	1,56	no	no	12,59	1,22	1,57	no	no	11,56	0,36	1,44	no	yes
house 7	7,76	0,42	0,97	no	yes	12,32	1,03	1,54	no	yes	8,57	0,66	1,07	no	yes
house 8	13,38	0,76	1,67	no	yes	integrated kitchen and living room					13,48	0,52	1,69	no	yes
house 9	11,08	0,71	1,39	no	no	10,57	1,79	1,32	yes	yes	7,88	0,82	0,98	no	no
house 11	9,99	0,57	1,25	no	no	12,22	1,11	1,53	no	yes	12,15	1,06	1,52	no	no
house 13	15,49	0,88	1,94	no	yes	18,52	2,17	2,32	yes	no	10,12	0,52	1,26	no	yes
house 14	12,13	0,95	1,52	no	yes	9,49	1,13	1,19	no	no	14,53	1,25	1,82	no	no
house 17	11,87	0,84	1,48	no	yes	16,77	1,05	2,10	no	yes	6,41	0,54	0,80	no	yes
house 18	11,21	0,65	1,40	no	yes	10,66	0,56	1,33	no	yes	11,21	0,51	1,40	no	yes
house 22	10,27	0,00	1,28	no	yes	8,31	0,54	1,04	no	yes	14,20	0,39	1,78	no	yes
house 28	7,97	0,75	1,00	no	no	absent					8,44	0,68	1,06	no	yes

Source: produced by authors, based on data from the field survey and on parameters from PBEEdifica Manual (Eletrobras/Procel, 2015).

Extensions and refurbishments were commonplace in the houses to cater to the needs of its residents. In general, extensions of one or more rooms took place horizontally, taking up the whole land plot, or vertically expansion, using flat floor slabs with inadequate weight-bearing capacity. The majority of the extensions in the residences visited were executed to provide more room for sons/daughters who had married, and sometimes as a source of extra income (rent). The new roofing was generally fiber-cement shingles, chosen for fast installation and low cost.

In order to better understand the thermal characteristics of the materials used in building the homes visited, the information collected in the field survey were compared with the parameters of the standard NBR n. 15.575 with thermal performance in buildings, defined by thermal comfort guidance,[16] specified in the Brazilian Bioclimatic Zoning (ABNT-NBR n. 15.220, 2005).

It is important to note that the Brazilian Bioclimatic Zoning defines construction guidelines for a single-family dwelling for low social classes and specifies the size and shading of openings, types of enclosures (walls and roofing), stipulating reference thermal transmittance and thermal lag values, besides strategies for passive conditioning based on the standard ABNT-NBR n. 15.220 (ibid.). This zoning splits the country into 8 zones according to weather records from 1931 to 1990, creating the Givono Bioclimate Chart for Brazil.[17]

São Paulo city lies in Bioclimate Zone 3, in which recommended mean openings are 15-25%, with shading in the summer and solar incidence in the winter. Masonry recommended by Standard n. 15.220 is light and reflective, with thermal transmittance ≤ 3.6 $W/m^2.K$, and light insulated roofing with transmittance ≤ 2.0 $W/m^2.K$. Among strategies for passive thermal conditioning, this same standard recommends, for summer, cross ventilation and, for winter, solar warming of the enclosures of the building and heavy internal partition walls and roofing, promoting thermal inertia.

Chart 6 presents data on the thermal performance of the systems used for roofing in the houses visited and the reference parameters of the NBR for transmittance (U), thermal lag (φ) and thermal capacity (Ct) (gray columns), in accordance with that specified for Bioclimate Zoning 3 (ibid.) of São Paulo.

Comparison against the thermal data of the systems employed and the parameters stated in Standard no. 15.220, revealed that all of the systems employed in the homes visited were inadequate for the minimal need of thermal comfort, i.e. they allow higher than desired heat penetration due to transmittance exceeding the parameters of the NBR in all

Chart 6 – Construction elements for roofing and respective thermal properties: absorbance (α), resistance (R), thermal transmittance (U), thermal lag (φ) and thermal capacity

Roofing materials	α	R (m²K/W)	U (W/m²k)	U NBR	φ (hours)	φ NBR	Ct	Ct NBR
Fiber-cement shingles	0,50*	0,22	4,6	U≤ 2,30	0,1	≤ 3,3	12,8	I
Pre-cast slab with hollow ceramic tiles + premix mortar underside	0,65**	0,35	2,8	U≤ 1,5	5,4	≤ 3,3	204,8	I
Fiber-cement shingles + slab + premix mortar underside	0,50*	0,38	2,6	U≤ 2,30	4,1	≤ 3,3	247,5	I
Fiber-cement shingles + ceiling lining	0,50*	0,36	2,8	U≤ 2,30	0,4	≤ 3,3	15,4	I

Legend: (I) in Ct NBR column means irrelevant. Red figures indicate non-conformance and green figures indicate conformance.
Source: Produced by authors based on parameters of NBR 15.220; α data derived from: * Coelho, Gomes and Dornelles (2017); ** Standard ABNT 02:135.07-002 (1998).

cases, in addition to higher thermal lag in those constructions which incorporate slabs. The reduction in thermal range in São Paulo city, as cited earlier, reduces the efficacy of thermal inertia, contributing to overheating of internal spaces.

The walling materials used for the enclosures exhibit different properties that satisfy the parameters determined by the bioclimate zone where they are situated. Chart 7 presents the data on the thermal performance of the systems used for the wall enclosures of the houses. For example, masonry without any manner of external finish is rated at one tenth below the figure stipulated by standard n. 15.220 (ibid.). Although most walls exhibited adequate thermal properties, the fact they were adjoined or in close proximity to each other, with corridors ranging in width from 0.60m to 1.30m, promoted shading of the wall surfaces, as exemplified by houses 3 and 4. This helps reduce heat, but creates a dampness problem owing to the total absence of solar radiation.

Figures 5 to 10 illustrate some of the recurrent issues identified in the group of 32 houses visited. Figures 5 and 6 reveal narrow corridors with restricted sunlight due to the small width or because they are partially covered, factors which impact both ventilation and access to sunlight, leading to dark stuffy internal spaces. Figure 7 shows a swivel-type window measuring 0.8m x 0.8m, serving as the sole source of natural light and ventilation in the bedroom, which had a floor area of 14.20m². In a bedroom of this size, a swivel-type window with a total area of 2.73m² would be needed, a sliding frame with louvre window (3 panel) measuring 3.94 m², plus a sliding glass pane window measuring 2.37m², much larger than the1.60m² installed.

Chart 7 – Construction elements for walling and respective thermal properties: absorbance (a), resistance (R), thermal transmittance (U), thermal lag (φ) and thermal capacity

Walling materials	α	U (W/m²k)	U NBR	R (m²K/W)	φ (hours)	φ NBR	Ct	Ct NBR
Finished masonry, blocks and gray premix mortar finish	0.30**	2.4	U≤ 3.7	0.41	3.5	≤ 4.3	140.3	≥ 130
Finished masonry, blocks and white premix mortar finish	0.158**	2.4	U≤ 3.7	0.41	3.5	≤ 4.3	140.3	≥ 130
Masonry with internal but no external finish (on blocks)	0.65**	2.6	U≤ 2.5	0.36	4.2	≤ 4.3	90.3	≥ 130

Legend: red figures indicate non-conformance and green figures indicate conformance.
Source: produced by authors based on parameters of NBR n. 15.220; α data derived from: ** Standard ABNT 02:135.07-002 (1998).

Figure 5 – House 7,
uncovered side corridor

Source: private archive.

Figure 6 – House 9,
partially-covered narrow side corridor

Source: private archive.

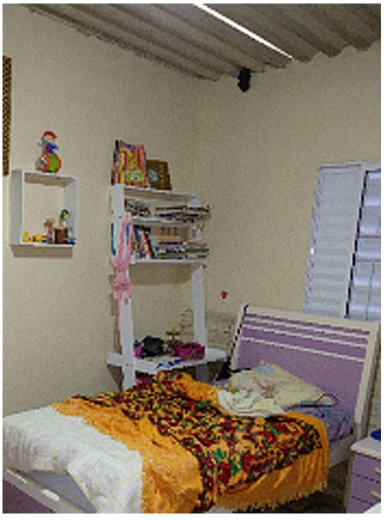
Figure 7 – House 22,
undersized window for bedroom

Source: private archive.

Figure 8 – House 22,
lack of space led to side corridor being
turned into kitchen and service utility area

Source: private archive.

Figure 9 – House 18,
visible light gap between fiber-cement sheeting after house extension



Source: private archive.

Figure 10 – House 18,
mold on walls and ceiling remain even after addition of second floor

Source: private archive.

It is important to highlight that natural ventilation on the urban microclimate scale depends basically on the topography, obstacles (natural or otherwise), and on the rugosity and permeability of the buildings to thermodynamic shifts, such as evaporation, evapotranspiration, heat transfer and emission of pollutants. Sousa (2014) shows that, when the spacing between buildings is low and their heights are very similar, as was the case in the settlement studied, an increase in the ventilation gradient occurs, compromising the quality of air due to low air refresh rate.

In Figure 8, the external offset was roofed and incorporated into the area of the house, rendering the space dark and unventilated. In Figure 9, the corrugated roofing sheets cover the second floor, raised to cater for the growing family, but the lower than recommended rake of the sheets, together with poorly installed material (visible gap between sheets), caused leaks. In Figure 10, the mold remained even after addition of the second floor.

Based on previous analyses, Chart 8 summarizes the building elements that impact the thermal performance of the houses, stipulating guidelines for assessing constructions. For this purpose, enclosure elements are divided according to the effects of extreme temperatures. The influence of heat was broken down into elements of the roofing and placement of openings. Because the masonry employed was generally compliant with the standards with regard to heat properties, together with the shading resulting from proximity of the buildings, the vertical enclosures were not assessed in the present study.

Chart 8 – Summary of the building elements impacting thermal performance and airtightness of the houses surveyed

Climate	Construction	Description
Extreme temperatures	Slab without roofing shingles	As seen in the review of the materials and their thermal characteristics, concrete slabs without roofing shingles fail to meet **performance** specifications in standard (NBR no. 15.220), and may result in overheating of the interior and greater use of electricity (air-conditioning).
	Fiber-cement roofing shingles	Fiber-cement roofing shingles fail to meet **performance** specifications in standard (NBR no. 15.220), and may result in overheating and greater use of electricity (air-conditioning).
	Windows opening onto narrow corridors	The close proximity of the houses and perimeter walls hamper air flow, restricting **refreshing of internal air**. This proximity also limits **natural lighting**, remedied by use of electric lighting.
	Space without opening to the outside	Space with opening to other internal spaces was common, such as bedroom with window opening onto living room. This type of strategy restricts **refreshing of air** and exploitation of natural ventilation and natural lighting.
	Rooms without openings	The absence of openings in a space prevents **natural ventilation and lighting**, leading to higher electricity costs for artificial lighting and conditioning of the space.
	Openings on same wall	Natural ventilation is facilitated by the positioning of openings in facing or adjacent walls. When a residence has windows all set in the same wall there is no **cross ventilation**.

Source: produced by authors.

The Table 2 presents the assessment matrix, showing that the building elements of the houses surveyed are more susceptible to the effects of heat. The results show that the main issue with the houses involves aspects related to the openings. Poorly positioned windows, facing into narrow side corridors, were found in 21 of the 32 properties surveyed. The second-most-common occurrence, openings facing into internal spaces, was identified in 16 houses. The placement of openings, together with undersizing, results in problems of environmental comfort, with lack of natural illumination and ventilation.

Issues associated with ineffective roofs are a secondary factor in the matrix. In each of the roof-related items, lack of waterproofing, poorly installed fiber-cement sheets, slabs without shingles, and fiber-cement shingles as the only roofing, featured in four of the houses, respectively. In any event, the unsuitable thermal characteristics of all the systems used as roofing is a factor exacerbating the discomfort caused by overheating, an issue not addressed in the matrix, but highlighted in Charts 6 and 7.

Aspects in which heat affects the building are more recurrent, related to either the openings or the roofing. The ineffectiveness of the outside walls in retaining heat of the houses led to complaints by 53% interviewees of the discomfort during

Table 2 – Assessment of the 32 houses based on parameters stipulated in Chart 2

House	HEAT WAVES					
	Slab without roofing shingles	Fiber-cement roofing shingles	Windows opening onto narrow corridors	Spaces without opening to the outside	Rooms without openings	Openings on same wall
1	1					
2				1		
3			1	1		
4		1	1	1		
5			1	1		
6	1			1		
7			1	1		
8		1	1			1
9			1			
10					1	
11				1	1	
12						
13			1			
14			1	1	1	
15						
16			1	1		1
17						
18		1	1			
19			1	1		
20		1	1			
21						
22	1			1	1	
23			1	1		
24			1			1
25			1	1	1	
26					1	
27			1			
28			1	1		
29			1	1	1	
30			1	1	1	
31	1		1			
32			1			
Total	4	4	21	16	8	3

Legend: a value of 1 was attributed to elements of matrix found in houses; empty cells indicate inexistence of these elements. The "Total" row indicates number of houses in which each of the indicators occurred.
Source: produced by authors based on field survey.

the application of the questionnaire, even though the visits took place mainly in the autumn and winter, where this had a negative impact on electricity use.

On the 3rd of Abril 2019, for example, thermographic image of house 4 were produced (Figure 11). The outside temperature of the air between 12:50am and 1.45pm, was approximately 28ºC and moisture level 43%, whereas the temperature of the surface of the shingles reached around 68ºC (Figure 14), in parts of the roof, while temperature of the internal wall reached 37.8ºC. The thermal lag of the fiber-cement shingles was 0.2 hours, i.e. the material began to irradiate heat into the house within12 minutes.

Corroborating the analysis, during field visits, the use of electric lighting during the day was observed, and therefore electricity use of the18 houses that furnished electricity bills was checked. Average energy used by these houses was 222 kWh per month. Despite paying subsidized rates for low-income of around R$0.45[18] per kWh (before tax), monthly average expenses with electricity exceeded R$100.00.

Lastly, it was clear the self-build houses analyzed had a variety of problems which are exacerbated by increasing heat, one of the main effect of climate change. Qualified technical advice can help minimize the adverse effects of increasing temperatures. Using basic materials and systems, readily available and installed, such as ceramic block masonry, pre-cast slabs and aluminum windows, self-build housing constructed with technical guidance can enable these materials to be applied and placed correctly and also combined so as to confer greater comfort to dwellers and provide better living conditions.

Figure 11 – Set of thermographic photos of house 4

Legend: the roof reached 68°C, the outside façade had a maximum temperature of 39.9°C, while the corresponding internal wall reached 37.8°C.
Source: private archive.

Conclusions

Changes in the climate are the reality faced by human settlements. Tackling this issue is key to the future success of society. Equipping the population, particularly the needy, with tools to remedy problems brought on by the climate is pivotal to improve their quality of life. The quality of housing, prepared as effective shelter against the elements, is of the utmost importance and a necessary mechanism for ensuring sustainable development.

The present study sought to identify elements of the enclosures of the self-built houses which are involved in the rising temperatures from two standpoints: issues related to design, i.e. position of openings, implementation of offsets; and thermal performance of the elements comprising the roofing and walls. Roofing, walls and openings are elements which mediate the relationship between the outside and inside, serving as reactive or passive protection against the climate.

With regard to openings, the placement and sizing of openings proved recurrent problems in the houses analyzed, compounded by poor positioning of houses relative to the sun and suboptimal land use, contributing to some of the issues found. The systems used, in the roofing of the houses assessed, were not compliant with prevailing standards, and the heat transmitted impacted internal temperature and electricity use, repercussing on the health, productivity and income of dwellers.

Gaining insights into the relationship between the climate and poor quality construction can help elucidate the extent to which the use of unsuitable materials or lack of technical input during home construction and/or improvement can reduce the quality of life of residents. The lack of technical assistance for designing the houses and carrying out the buildings, together with lack of financial resources of dwellers, lead to inadequate building solutions, exacerbated by local weather characteristics further compromising their livability. The inappropriate use of materials or lack of a good design for the house which places openings and walls to maximize the natural sunlight and ventilation, i.e., absence of a building plan, promotes uncomfortable internal spaces.

Residents often try to mitigate shortcomings in the enclosure through the use of mechanical devices (fans and air-conditioners) which are energy hungry and do not always protect against the heat, yet negatively impact the household budget, further increasing socioeconomic vulnerability. These are actions taken to counter effects as opposed to address the causes.

The techniques and materials available to residents of self-build houses often fail to meet the minimum requirement of thermal comfort or energy efficiency, and this impairs the dweller´s ability to adapt the current climate. The issue is not so much attributed to the materials per se, but on how these are deployed, exposing the lack of technical advice for the population undertaking self-build projects.

Recommended solutions include devising specific public policies that help provide the low-income population with technical advice to enhance the quality of self-built housing in the context of climate change. The Technical Service for Socially-disadvantaged populations, involving architects and engineers, is an important legal instrument available to Brazilian cities since 2008, aimed at providing guidance on self-build. When adopted, this can help reduce the effects of heat resulting from climate change, both in situations such as that presented in this case study, and more complex situations of extreme vulnerability. In this context, specific public policies for putting into practice the precepts of this instrument are needed, including raising awareness of the professionals involved to effectively contribute to the low-income population.

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Notes

(1) According to the World Urbanization Prospects report (United Nations, 2018), in 2018 the urban population was 55.3% worldwide, 80.7% in Latin America and the Caribbean, and 87% in Brazil.

(2) The urban population, in the mid-1990s, exceeded 7.7 billion people (United Nations, 2019).

(3) The study "Green retrofit as a means of mitigating the effects of climate change in poor settlements in São Paulo watersources" was conducted between 2017 and 2019, with support from the Fapesp, under the Post-graduate Program in Architecture and Urbanism of the Mackenzie Presbyterian University, supervised by Professor Angélica Benatti Alvim.

(4) Standard NBR n. 15.575 defines minimum thermal performance values, but does not mean the home is comfortable for all, but only ensures the user is exposed to equal or better conditions than those of the external environment, while also preventing further flaws in the buildings (Brito et al., 2017).

(5) Study available at: http://www.caubr.gov.br/pesquisa2015/. Access on: October 30, 2015.

(6) The CAU intends to allocate at least 2% of total revenues collected from the board for strategic actions of Technical Assistance in Social Housing (Athis). Available at: http://www.caubr.gov.br/56a-plenaria-cau-destinara-recursos-para-projetos-e-obras-de-assistencia-tecnica/. Access on: November 13, 2018.

(7) The survey was put before the Ethics Committee of the Mackenzie Presbyterian University, and approved on 15 May 2018, under permit n. 2.656.035. Interviews were conducted between 2018 and 2019.

(8) The NBR n. 15.220 defines recommendations on thermal performance of single-family social dwellings and establishes Brazilian Bioclimate Zones. Information available at: http://projeteee.mma.gov.br/glossario/nbr-15220/. Access on: May 21, 2020.

(9) São Paulo city lies in Zone 3 of the Brazilian Bioclimate Zoning, contained in standard NBR n. 15.220.

(10) The Projeteee site is the first national platform bringing together solutions for an efficient building design, providing continuation to the work carried out by Procel/Eletrobrás and the Federal University of Santa Catarina. This is an open access tool developed by the Laboratory of Energy Efficiency in Buildings LabEEE/UFSC, which allows manipulation of the sun path chart and wind rose with data for selected cities. Available at: http://projeteee.mma.gov.br/componentes-construtivos/. Access on: October 14, 2019.

(11) The Central Limit Theorem states that a succession of X variables, independent and identically distributed, converge to a normal distribution when size X is sufficiently large. i.e. for sample distributions, the number X of elements should be ≥ 30 (Alves, 2016, p. 12).

(12) The IPVS (Paulista Social Vulnerability Index) is an important instrument for surveying areas with high density of vulnerable populations that should be a priority target of public policies. The IPVS considers income, family composition, health status and access to medical services, and also access and quality of the education system, employability with adequate remuneration, and legal entitlement with respect to housing (Seade, 2010, p. 8).

(13) Occupation totally or partially devoid of environmental sanitation infrastructure, for which Government Authorities should promote urban and environment recovery programs. For further details, see Alvim (2011) and França & Barda (2012).

(14) The Parque project was resumed in 2018 with works in the section corresponding to the Cantinho do Céu settlement, the region with the highest vulnerability.

(15) Josiane Ribeiro, head of Cantinho do Céu, and Adolfo "Ferrugem", of the NGO Meninos da Billings, were pivotal in conducting the field research. They acted as the bridge interfacing between the researchers and the community, helping break down the barrier of distrust of the population.

(16) Thermal comfort depends on mechanisms of dissipating heat from the human body and on 4 environmental conditions: air temperature, relative humidity, mean radiant temperature and air motion (ventilation) (Lechner, 2009).

(17) It is noteworthy that, due to the imprecision stemming from poor weather data, proposals are afoot to review this division (Amorim e Carlo, 2017).

(18) Data from the Enel site, available at: https://www.eneldistribuicaosp.com.br/para-sua-casa/tarifa-de-energia-eletrica. Access on: July 29, 2019. PIS and Cofins Tax rates vary while ICMS is around 12%, where only a partial estimate of final value of electricity bill can be provided.

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