Energy Policy 87 (2015) 524–541

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Characterisation of representative building typologies for social housing projects in Brazil and its energy performance

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HIGHLIGHTS

- Characterisation of representative typologies built for social housing in Brazil.
- More recurrent building physics characteristics considered.
- Energy efficiency and thermal performance of Brazilian social housing analysed.
- Regulation for Energy Efficiency Labelling of Residential Buildings in Brazil used for analysis.

ARTICLE INFO

Article history:
Received 26 March 2015
Received in revised form
28 August 2015
Accepted 31 August 2015

Keywords:
Social housing
Residential buildings
Housing typologies
Energy performance of buildings

ABSTRACT

In Brazil the housing deficit is around 5.5 million houses. To address this need, the government created a programme called "My house, My life". The main subsidies of the programme are for families earning up to three times the minimum wage. In order to formulate strategies for more energy efficiency buildings, it is necessary to understand the thermal and energy performance of what is being built. This article defines representative projects for typologies being built in the Brazilian social housing sector through the analysis of 108 projects considering two groups of income levels and investigates the thermal and energy performance of the representative projects in relation to the Regulation for Energy Efficiency Labelling of Residential Buildings in Brazil for two bioclimatic zones. Five representative building models were defined. Considering the most common features found on the sample, the study suggests the importance of addresing energy efficiency measures on the sector since current building techniques for social housing shows a tendency towards a low performance in relation to the thermal and energy performance criteria of the Energy Labelling especially for lower income projects. This provides a basis for future policy and allows for more in depth studies within the sector.

1. Introduction

In Brazil 46.4% of primary energy is generated from renewable sources, mainly hydropower (13%), wood (9.5%) and sugar cane (19.1%) (Brazil, 2014). However, the situation is changing. The installed capacity of thermal generation in Brazil has increased by 41.2% between 2006 and 2010 due to an escalation in energy demand (Brazil EPE, 2013). The residential sector in Brazil accounts for 24.2% of the 48.5% of the total electric power consumption, which is attributed to the building sector (Brazil, 2014).

Brazil's housing deficit is estimated at 5.5 million homes, being approximately 83.5% urban (Brazil, 2011). 89.6 % of the deficit is among the population with income up to three times the minimum wage (Brazil, 2011) and Southeast and Northeast regions account for the majority of housing needs (Brazil Mincidades, 2012a).

1.1. Social housing plan "My House, My Life"

In 2009 the National Housing Plan (PlanHab) introduced a long-term plan for 2023 for the housing sector. This plan included the "My House, My Life" Programme (Programa Minha Casa, Minha Vida – PMCMV) to address the housing deficit. The Programme on its second phase has subsidies based on fixed values by family income Band. The first family income Band was up to R$ 1600.00 per month[1]; 2nd Band up to R$ 3275.00; and 3rd Band between R$ 3275.01 and R$ 5000.00 (Brazil, 2013a). The

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[1] 1 US$ = around R$ 2.70 in December 2014 and the minimum national wage in 2014 was R$724.00.

http://dx.doi.org/10.1016/j.enpol.2015.08.041
0301-4215/

Programme intends to subsidise home ownership for families in Band 1st and facilitate access conditions to property for families with income up to R$ 5000.00 (Brazil, 2015).

In the Programme, social housing projects for lower income families (1st Band) are mainly implemented through Housing Companies and State Agents, which, in most cases, are responsible for the projects and sometimes subcontract private companies to implement and/or design the projects, operating the municipal government in cooperation with the State or the Federal government. On the other hand, housing for people with higher incomes (2nd and 3rd Bands) are developed largely by private companies or entrepreneurs (UNEP, 2010). There are 34 Housing Companies and Financing Agents in 18 Brazilian States (ABC, 2013).

Among the projects prioritisation criteria for the Programme, especially for the 1st Band is the "lower cost of the housing units" as set out in Annex I[2] of "Portaria No. 465" of October 3rd 2011 (Brazil Mincidades, 2011). The minimum specifications (regarding unit area, windows dimensions, among others) required for the projects and the maximum value and subsidies of the units in 1st Band are determined by the housing typology according to the Programme strand and financing adopted (FAR, FDS or Public Offer) (Brazil Mincidades, 2012a). In relation to sustainability, for this Band, the programme only demands items such as individual metering of water and gas, and the mandatory use of solar heating is implemented mainly in detached and two storey houses projects of 36 m^2 and 39 m^2 financed by the FAR, and of 38 m^2 financed by the FDS. There are some differences in requirements that are mandatory for the building projects according to the Programme strands attended that affect thermal and energy performance, but it is observed that there are not significant differences regarding floor area, number of rooms or layout of the requirement projects within the diverse Programme strands.

The limited budget available for the significant number of houses to be built often results in low build quality and thermal performance, and the absence of energy efficiency measures (Bodach and Hamhaber, 2010) in particular for projects aimed at lower income families (Almeida et al., 2013; Linck et al., 2013; Silva et al., 2013; Curcio et al., 2013). Especially in this sector, the current situation of housing policy in the country tends to prioritise capital costs, without much consideration on the long term benefits and thermal performance.

For projects of Bands 2 and 3, rules are for more general guidelines with issues like accessibility, compliance with environmental preservation standards, municipal ordinances regarding the quality of building and participation of companies holding the SiAC[3] (Brazil Mincidades, 2012b). Resources from FGTS are mainly used in these Bands. Recently, criteria were defined for application of environmental and social guidelines for housing on the Programme financed with this resource (CAIXA, 2015). Measures recommended related to energy efficiency and eligible to be financed are renewable energy systems like solar water heating and micro-generation for electricity and white roofs for multifamily buildings, among others. Also, incentive could be given for national environmental certification process.

1.2. Building typologies as a basis for policy

Projects in Brazil should respond to the different climatic needs. NBR 15220-3 (ABNT, 2005a) divided the country in eight bioclimatic zones. Zone 1, includes climates in the southern part of the country with more necessities for heating; zones 2 and 3, especially in the south and southeast have similar requirements for summer and winter; zones 4, 5 and 6 have necessities for summer and winter strategies, but the differences between them is less pronounced than on the previous zones. Zones 7 and 8 mainly located on the north and northern part of the country, need only strategies for summer (CAIXA, 2010).

To encourage energy efficiency in buildings, Inmetro with the support of Procel Edifica launched in 2010, the Regulation for Energy Efficiency Labelling of Residential Buildings (RTQ-R) in Brazil as a voluntary scheme, for now on called here Energy Labelling. The aim is the identification of the energy efficiency level of residential buildings and houses, with levels ranging from A (most efficient) to E (least efficient) focusing on naturally ventilated buildings.

Considering the impact and growth of the social housing, it is critical to address this sector in order to achieve Brazil's government energy reduction targets. A characterization of the projects that are being built today, with the formulation of typologies and analysis of their thermal and energy performance, would help in forming the basis for effective policy in the housing industry.

Building typologies can be used to assess the energy performance of buildings. The International Energy Agency (IEA) defines two fundamental modelling methods to analyse aspects of energy use from buildings: bottom up and top-down method. The top-down modelling tends to be used to investigate interrelations between the energy sector and economy (Kavgic et al., 2010). In the bottom-up model are two approaches, one based on statistical and, other based on the physics of buildings which include consideration of samples of representative buildings (Shorrock and Dunster, 1997). Carlo and Toccolini (2005) argue that a representative building should be determined considering similar features representing characteristics of the sample.

Studies of the existing building stock are numerous (Balaras et al., 2007; Dall'O' et al., 2012; Nik, Sasic Kalagasidis 2013; Theodoridou, et al., 2011) but usually do not address building typologies of recent buildings with much detail.

In Brazil, some research has resulted in representative models of the residential sector. Tavares (2006) proposed a methodology for measuring the energy life cycle of Brazilian residential buildings, including five models as representative of the sector based on a top-down approach. However, floor areas assumed for the lower income models do not match the average areas that are delivered today within the PMCMV.

Schaefer and Ghisi (2012) developed a representative model of existing social housing in Florianópolis, south of Brazil to be used in computer simulations based on data from 10 buildings. Later, Schaefer et al. (2012) collected data from 30 homes resulting in two typologies models considering family income up to R$ 1600.00 and between R$ 1600.00 and R$ 5000.00. Data were processed with statistical methods through mean values, standard deviation and confidence interval considering the most recurrent features of the sample. These projects are a sample of existing social housing in Florianópolis, however, not necessarily what is being built in PMCMV. In particular, the model for lower income shows only one room, outside the requirements of the Programme.

Thus, the purpose of this paper is to define representative models of new projects currently being built in Brazilian social housing sector and to evaluate the thermal and energy performance of these projects against the Energy Labelling considering two Brazilian bioclimatic zones. This provides a basis for future policy and allows for a more in depth study of the impacts and benefits of incorporating energy efficiency measures within the sector.

2. Methods

To develop and evaluate representative projects of social housing being built through the PMCMV based on real data with

[2] Provides guidelines in the National Program of Urban Housing (PNHU) for projects in PMCMV with FAR resources for Band 1st.

[3] Certificate of Assessment System of Services and Works Compliance.

focus on thermal and energy performance, the following stages were undertaken:

- Characterization of social housing based on 2010 Census information.
- Mapping and characterization of project typologies by income levels.
- Development of representative buildings models by income levels.
- Thermal and energy performance analysis of representative models against the Energy Labelling in Brazil considering two bioclimatic zones.

2.1. Characterization of social housing based on the 2010 Census information

The Census of 2010 (Brazil IBGE, 2010) was used as an initial information source for the typologies constructed differentiated by income level, based in urban permanent private housing. Data related to the most frequent typology was sought and its characteristics were identified.

2.2. Mapping and characterization of project typologies by income levels

The sample of projects was determined from the guidelines placed by PMCMV, focusing on the established income Bands and the way the projects are developed. A division by income level was defined, considering two levels: Level 1 – projects for family income up to three minimum wages, but focusing up to R$ 1600.00 (Band 1 – PMCMV) and Level 2 – projects for family income from R $1.600,01 to R$ 5000.00 (Band 2 and 3 – PMCMV). 2nd and 3rd bands were put together because many projects built for these levels attended both bands with difference in the subsidies given for the families. Different methodologies were adopted for each level.

For projects in Level 1, the compilation of information was made from three different sources constituting 2 samples:

a. Sample 1: identification of main typologies built on PMCMV using a list of the projects contracted for the 1st Band (CAIXA, 2014) released by CAIXA, Programme's financing agency.
b. Sample 2: architecture projects requested from Housing Companies/Public Agents, municipalities and construction companies active in this income level.

For Sample 1, a list of projects funded through PMCMV for Band 1st from the beginning of the programme until April 30, 2014 was used. The intention was to do visual identification of the main typologies being built in general basis, without considering projects in detail, since it was not possible to obtain all project's details. Only urban multiple unit projects funded between 2013 and 2014 were selected, as more recent projects could have some information available on Internet. For 2013, projects with 1000 units or more were selected, giving a total of 51 projects. For the year 2014, it was decided to select projects with 300 units as fewer developments had been completed by the data collection date of April 2014, and by including smaller developments similar data sample sizes could be selected for the two years. A total of 40 projects were selected for 2014 making a grand total of 91 projects for visual analysis in this sample.

Sample 2 constitutes a total of 29 projects from different regions, for which full construction details were obtained via email from the Housing Companies and Public Agents (16 projects) and builders and municipalities (13 projects) responsible for the projects. Of the 29 projects, 21 projects could be grouped into the three main typologies chosen for analysis.

The data collected in the projects were divided into: a) general data, including bioclimatic zone, typology, accessibility consideration, floor areas, heights, existence of cross ventilation, number of rooms, floors, typical units, project extension if applicable; b) hot water system; c) rooms' floor areas, exterior and interior walls, integration between rooms; d) envelope's data, materials of walls, roofs and floors, thermal capacity and transmittance, exterior walls colour; e) openings' data (windows and doors), quantity, area, material, ventilation and daylighting factor, type, form of operation, existence of shutters and type of glass. Ventilation and daylighting factors for windows were taken from Annex II from the Energy Labelling (Brazil, 2012a). Physical properties of the envelope components were specified through calculations using NBR 15220-2 (ABNT, 2005b), also using data from Annex V of the Energy Labelling (Brazil, 2013b) and NBR 15220-3 (ABNT, 2005a).

The sample of projects for level 2 in the country tends to be much larger than sample for level 1 and more difficult to select and obtain. At this level, projects are led by smaller construction companies, but when the Programme was released, bigger companies accounted for 13% of the projects approved in that year (Pereira, 2011). Since the end of 2013 a drop in participation was observed (Brodbeck, 2013), however, some major construction companies maintain their involvement with projects for the Programme and information can be obtained from their websites. The ITC-Ranking 2013 (ITC, 2013) was used to select and identify projects from construction companies that built for the Programme. Projects from nine companies were identified, of which six were in the top 10 ITC Ranking and the other 3 are known as companies that work in the sector. The ITC Ranking shows the 100 largest construction companies in the country. The 10 largest construction companies in 2013 accounted for around 44% of the total that were built in the country that year by the main 100 companies. The projects selected were located in the capitals or the largest cities of the Brazilian states considering projects being launched or under construction. A total of 79 projects made up the sample for this income level. In level 2, the projects that belong to typologies with greatest number were analysed in detail, and consequently 67 projects were included divided in 2 typologies. The analysis considered apartments with standard designs (i.e. no duplexes or accessible apartments).

2.3. Development of representative buildings models by income levels

The representative projects were established based on average and mode of the most common features found in the samples. Average with standard deviation was used for parameters that include inaccuracies such as floor areas, and mode was applied in the case of envelope components, commercial elements like openings or data that tend to repeat. Data for floor area was normalised using Kolmogorov–Smirnov test for samples with up to 30 cases, and with QQ Square for sample with more than 30. For smaller samples the *t* student distribution was applied to square deviation to find the intervals required to adopt for the representative project with a maximum probable error with 95% confidence. This follows the method adopted by Schaefer et al. (2012). For bigger samples the interval was adopted as the standard deviation. For the detached house typology the representative project was adjusted when necessary to meet the Brazilian Accessibility Standard – NBR 9050 (ABNT, 2004), one of the current programme requirements in 1st Band. This enables to represent more accurately what is currently required in PMCMV.

2.4. Thermal and energy performance analysis of representative projects according to the Energy Labelling in Brazil considering two bioclimatic zones

Finally, the representative projects were analysed using the Brazilian Energy Labelling methodology (Brazil, 2012a). The analysis for both income levels was made in two bioclimatic zones that represent extremes of weather in the country and higher housing deficit: Bioclimatic zone 3 (BZ3) and bioclimatic zone 8 (BZ8).

The Energy Labelling can be evaluated through the prescriptive method, a more generic approach established on multiple linear regression equations that were developed based on simulations (Sorgato and Lamberts, 2011) and/or through thermal and energy simulation, for a more detailed analysis. Bearing in mind the aim of the study the prescriptive method was used.[4]

On the Energy Labelling methodology, the evaluation is done in stages with the identification of levels ranging from A to E, considering only main rooms.[5] First the living and bedrooms are evaluated in terms of degree hours for cooling considering a naturally ventilated building, and secondly the main rooms are evaluated in respect of heating requirements measured in kWh/m^2. The second evaluation applies to Brazilian bioclimatic zones one to six only. The air conditioning needs for bedrooms only is also estimated in kWh/m^2, but is for information only and does not count towards the final energy performance level. A further evaluation is done for the envelope as a whole, which combines summer and winter performance weighted according to the bioclimatic zone. A final evaluation combines the envelope performance and the hot water system performance.

For the evaluation of the envelope, the compliance with some pre-requisites in each of the main rooms, the characteristics of the envelope and possible extra credits are considered. The pre-requisites are regarding limits by bioclimatic zone for thermal transmittance, thermal capacity and solar absorptance of external walls and roof; limits for minimal percentage of ventilation in main rooms in relation to room area (8% for BZ3 and 10% for BZ8); cross ventilation and natural daylighting. The envelope characteristics considered are among others the room's floor area, thermal properties of roof and external walls and window ventilation factor. Extra credits can be obtained related to special features for ventilation, enhanced daylighting, rational use of water and others (Brazil, 2012a). All representative projects comply with two of those possible extra credits related to enhanced daylighting associated to the room's depth and also higher reflectance of the ceiling which accounts for 0.3 points, influencing sometimes only the unit's final evaluation.

The hot water system's evaluation considers as a pre-requisite the duct's insulation and assesses the system. Solar and gas water systems have the potential to gain A rating while electric water system can only achieve level D or E depending on the power. In this study an assumption is made that when an electric system is used the power is more than 4600 W, rating the system level E.[6]

The methodology used on the Energy Labelling is more detailed in Scalco et al. (2012).

According to this, the results levels were shown graphically using the parameters of the Energy Labelling considering all stages:

a. thermal performance of main rooms in summer for BZ3 and BZ8, and in winter for BZ3;
b. the envelope considering summer and, winter together (for BZ3);
c. the unit considering the envelope plus the hot water system; and
d. the bedrooms in case artificial cooling is used.

Only in income level 1 where the hot water system used was possible to identify, the rating of the unit includes the level obtained by the envelope with the hot water system.

The external colour of the walls is a parameter not usually defined on the projects (especially in Level 1). To address this, three thermal absorptances (α) were considered for the evaluation: 0.3, 0.5 and 0.7 considering one azimuth (0°). Also, in this sector it is common for the same project to be used in various orientations disregarding a bioclimatic approach. Thus, an evaluation was performed for 1st Level typologies in four orientations considering azimuths 0°, 90°, 180° and 270° with wall absorptance 0.6. This absorptance represents the limit for higher or lower transmittance accepted for the walls in the Energy Labelling and therefore was used for analysis of the behaviour in different orientations. For the buildings typologies, an apartment with optimal North and East facade orientation was chosen for analysis.

Table 1
Data on households and percentage of typologies in relation to total number of urban households for incomes up to 10 times the minimum wage (M.W) based on (Brazil IBGE, 2010).

Urban	0 to 3 M.W	More than 3 to 5 M.W	Between 5 and 10 M.W (%)
House (%)	49.2	16.3	11.6
House part of a gated community (%)	0.9	0.3	0.3
Apartment (%)	2.8	2.2	3.3
Number of bathrooms – average per income level	1	1–2	2–3

3. Results and discussion

Results are presented in relation to:

- Establishment of representative projects by income level
- Characterization of typologies for social housing, and
- Analysis of their performance in relation to the Energy Labelling

For urban permanent private households and considering all income groups, houses represent 85% of all dwellings in the country, while apartments represent 12.5% (Brazil IBGE, 2010). When analysed in relation to family income, the detached house represented the most common typology for families with income up to 3 minimum wages. Some characteristics from the Census data are presented in Table 1.

3.1. Results for income level 1

From sample 1, it was only possible to identify the typology of 47 projects out of the 91 that constitutes the initial sample. A total of 54.591 units were calculated covering all regions in the country.

[4] It is observed that in the prescriptive method, evaluations for BZ3 takes as reference for the weather the city of Florianópolis, south of Brazil and for BZ8, the weather file of Salvador in the Northeast. More detail analysis through energy and thermal simulations using other weather files from the same bioclimatic zones could lead to different results.

[5] Rooms for extended stay (i.e. bedrooms, living and kitchen if integrated with the living).

[6] According to the consumption table of INMETRO from January 2015 (INMETRO, 2015), 82% of the electric water system labelled had the power over 4600 W. An electric water system with a power less than 4600 W will be rated D on the Energy Labelling and therefore changes could be observed for the final evaluation combining the envelope and hot water system performance.

Table 2
Values on the sample and for the representative project of detached house.

	Values on the sample				Values to adopt			Adopted value
Areas (m²)	**Min.**	**Max.**	**Deviation**	**Average**	**Interval *t* student**	**Min. value to adopt**	**Max. value to adopt**	**Value[a] of representative project**
Net area	32.72	44.49	3.35	37.27	2.36	34.91	39.64	**39.75**
Area with walls	37.84	54.57	5.06	43.36	3.56	39.80	46.92	**44.99**
Living	7.05	13.98	2.88	10.18	2.03	8.15	12.21	**17.83**
Kitchen	3.36	8.62	1.76	6.13	1.24	4.89	7.36	
Bedroom 1	7.2	10.01	0.86	8.34	0.61	7.74	8.95	**8.07**
Bedroom 2	6.81	8.58	0.63	7.61	0.44	7.16	8.05	**7.54**
Bathroom	2.67	4.72	0.78	3.51	0.55	2.96	4.06	**4.09**
Circulation space between rooms	0	2.93	1.03	1.19	0.73	0.46	1.92	**2.21**
Windows bedrooms	0.90	1.68						**1.50**[b]
Windows living	0.90	4.03						**1.50**[b]
Windows kitchen	0.40	1.44						**1.20**[b]

[a] Some values were adjusted to meet the requirements for the accessibility Brazilian Standard NBR 9050.
[b] Adopted mode value.

The main typologies identified with most frequency of occurrence were single detached house (35%) and apartment building with an H shaped floor plan of 4 and 5 floors (29%). Terrace single storey and maisonette 2 floors linear were around 10%.

In sample 2, 29 projects were obtained. Out of them, 16 projects were acquired from eight housing companies covering the eight bioclimatic Brazilian zones. The most common typology was the detached house, followed by the single storey terrace. The other 13 projects were achieved by contacting construction companies and city halls, most were single storey terraces and apartment building with H shaped floor plans of four or five floors. Considering samples 1 and 2, the typologies adopted as representative models for this income level are detached house, terrace single storey and building in H format plan of four or five floors. This is coherent with the data obtained from the Census 2010.

Of the 29 projects in sample 2, just 21 projects corresponding to the three main typologies were analysed, being 11 projects detached houses, 6 projects were single storey terraces and 4 projects were 4 to 5 storey apartment building. The characteristics and thermal and energy analysis of these representative projects are presented below.

3.1.1. Detached house

The 11 projects of the sample covered regions North, Centre-West, South-East and South of the country. Most of them are used for the whole State and some on municipal basis. The project's year ranges from 2012 to 2014. Six of them addressed accessibility requirements and all had cross ventilation. Only four specified solar water heating system, the others electric shower and only four had external shutter for bedrooms with two of them being also for the living room. Most projects were financed by FAR, the remaining were either financed by Public Offer or did not specify the source. Most projects (7) offer the possibility of enlargement, one of the requirements of PMCMV in this type of housing. The most common is the enlargement of 1 bedroom and circulation by 9.0 m^2 and 1.18 m^2 respectively. Table 2 shows values from the sample and for the representative project adopted for this typology.

Externals walls of the sample were specified primarily as perforated brick and roofs mostly of red clay tiles.[7] The walls colours were not specified in most projects. The floor is in most cases floor tile on 2 to 3 cm mortar, 4 to 5 cm concrete subfloor and 3 to 5 cm of gravel bed.

The percentage of ventilation and daylighting per m^2 floor area of the main rooms had significant variations in the sample. The Energy Labelling considers the minimal percentage for windows ventilation of 8% of the room floor area for BZ3 and 10% for BZ8. In comparison, the Standard for minimal performance for the residential sector in Brazil, NBR 15575 (ABNT, 2013) requires a ventilation area equivalent to at least 7% of the floor area in BZ3 and 8% in BZ8.[8] While some projects achieved this percentage or more, others failed to achieve these requirements in some or all main rooms. For daylighting, the Energy Labelling set for window daylighting area a minimum of 12.5% of room floor area as prerequite for main rooms for both zones and some of the analysed projects failed to achieve these requirements (Fig. 1).

The representative project for the detached house with the most frequently occurring layout and its main characteristics, floor plan and 3D image is presented in Table 3.

For the energy evaluations considering BZ3 and azimuth 0° the results are very similar for all wall absorptances (Fig. 2) with a slight difference in the summer results in bedroom 1. Only bedroom 1 obtained level C with wall absorptance 0.3. For the other spaces and with absorptances 0.5 and 0.7 the classification for the individual rooms in summer performance is between levels D and E. The rating for the envelope and the envelope together with hot water is always level D. The best performance is for the winter, when the spaces achieve between levels B and C. Also, if artificial cooling is used in the bedrooms, the level is C in most cases. When adopting the absorptance of 0.6 for the wall (Fig. 4), the performance is very similar for most orientations with exception of changes observed in azimuth 270°, but nonetheless the final ranking for the envelope is D in all cases. A further exploratory analysis done for different orientations with lower absorptances showed azimuths 90°, 180° and 270° being level C on the envelope evaluation. Some pre-requisites of the Energy Labelling are not met, including minimum percentage for ventilation and daylighting in the living room. Another factor affecting the performance is lack of shading on the windows. And for the whole house, the hot water electric system is affecting the rating level.

The same evaluation for BZ8 (Figs. 3–5) shows a lower performance, with the envelope achieving level E in all orientations with absorptances 0.5, 0.6 and 0.7. If artificial cooling was used in the bedrooms, a level D would be obtained in all cases. The project

[7] In this study the absorptance of the red clay tile is being considered 0.6 based on Brazil (2012b) bearing in mind the water absorption property of this kind of tile (Cani et al., 2012).

[8] Considering North-East region.

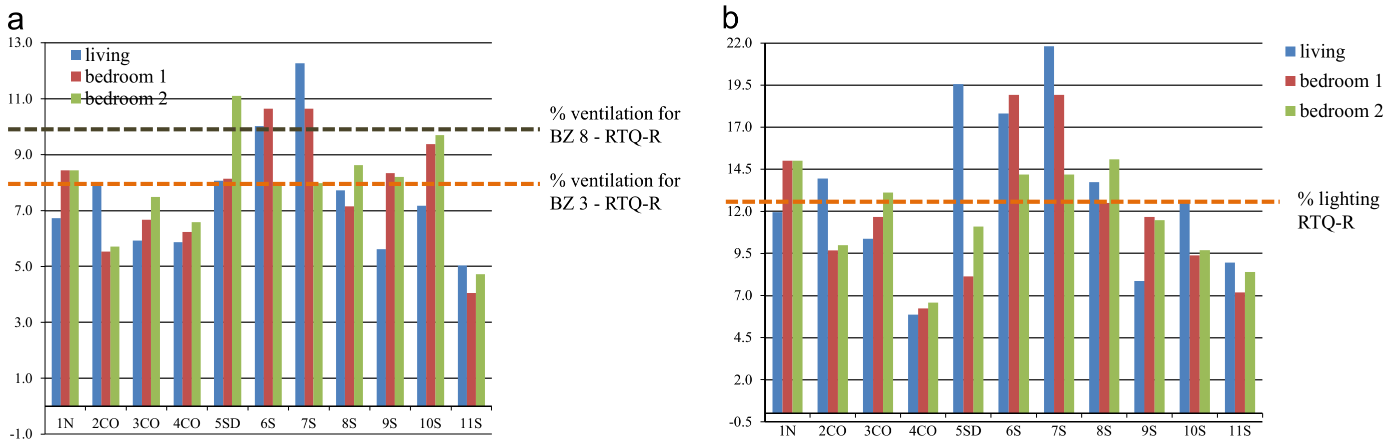
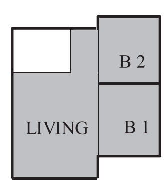


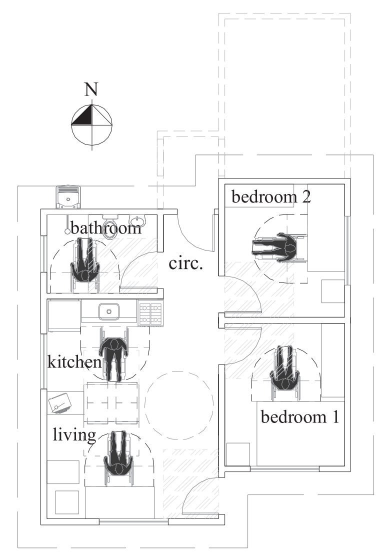
Fig. 1. % of ventilation (a) and daylighting (b) in relation with the floor area for the main rooms for the detached house sample. OBS: in figures regarding ventilation and daylighting percentages, projects are identified by region in the country (N=North, ND= Northeast; CO=Centre-west; SD=Southeast; S=South).

Table 3
Main features and floor plan of the representative project for the detached house, with future enlargement.

-Cross ventilation;
-Roof overhang: 50 cm;
-Floor to ceiling height: 2.50 m
-Electric heating for hot water, considering power of the equipment > 4600 W;
-Project extension with 1 bedroom and circulation;
-Not external living area;
-External service area;
-Floors: Ceramic tile 1cm + 2 cm mortar + 5cm concrete subfloor + 3 cm concrete ballast gravel;
-Walls: 13 cm (perforated clay brick 9x14x19 cm with internal and external plastering) with U=2.43 W/m² K and Thermal capacity=132 kJ/m² K;
-External doors: 2 of 0.80×2.10 m² in metal;
-Internal doors: 0.80×2.10 m² in wood;
-Roof: 2 pitches, red clay tile + attic with PVC ceiling. Slope of 23.6º. Wooden roof structure, U =1.75 W/m² K, Thermal Capacity=21.4 kJ/m² K; Absorptance=0.6;

-Windows: Living and bedrooms: 1.50 m^2 – 2 Slide sashes horizontal, sill=1.10 m (VF=0.45, LF= 0.8);
Kitchen: 1.20 m^2 – 2 Slide sashes horizontal (VF=0.45, LF=0.80);
Bathroom: 0.48 m^2 – framed glass louvres, sill=1.50 m, VF=0.90; LF= 0.65. No external shutters;
-Glass: 4 mm transparent;
-Frames in aluminium or steel;





OBS: Ventilation factor =V.F; Lighting Factor =LF.

always achieves level D when evaluating the fabric together with the hot water system. Some features affecting the performance of the envelope include lack of shading, the pre-requisites for ventilation are not met in the three main rooms and the daylighting pre-requisite is not met in the living room. Also, for BZ8, the pre-requisite of the roof considering transmittance and absorptance is not met.

In this typology the use of solar hot water system is mandatory for some cases, so even though in reality not all housing projects include it, the same evaluation was made with the use of the system, to identify the effect on the final evaluation. This was done for azimuth 0° with the three absorptances for the two bioclimatic zones. Results show that the performance of the house considering the envelope plus hot water system improves on BZ3 from D to level C with wall absorptances of 0.5 and 0.7, or even to level B with wall absorptance 0.3, showing the importance on the use of solar water heating.

This performance represents the representative project set out with frequency of occurrence characteristics from the sample. Differences on programme strands specifications or other characteristics of singular projects, in practice could affect the performance of the unit.

3.1.2. Single storey terrace

From the six projects of this sample, three were from construction companies in the North and South-East, located on bioclimatic zones 8 and 4 respectively and the other three came from Housing Companies on the South covering BZ 1, 2 and 3.The projects' year ranges from 2010 to 2014. All had cross ventilation, accessibility requirements were not addressed for most, and five projects had electric water heating system with only one solar.

Table 4 shows characteristics of the sample, limits for values to

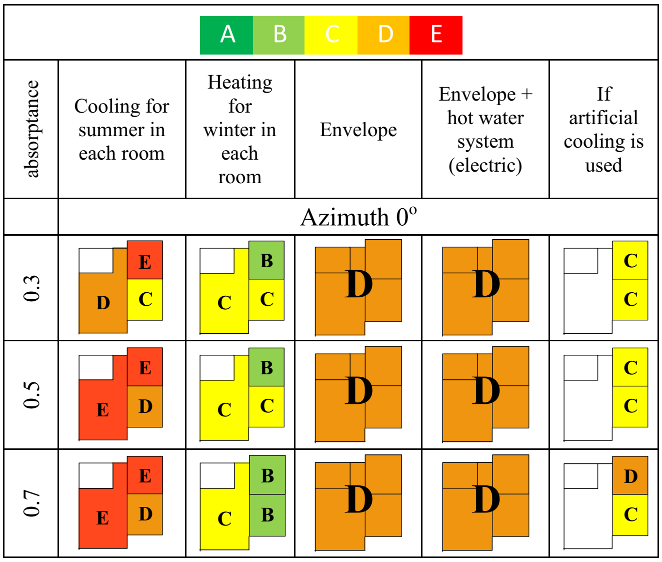


Fig. 2. Results for BZ3 with azimuth 0° and 3 (α) of the wall 0.3–0.5 and 0.7 for the detached house. The evaluation of the living includes the kitchen space since is connected.

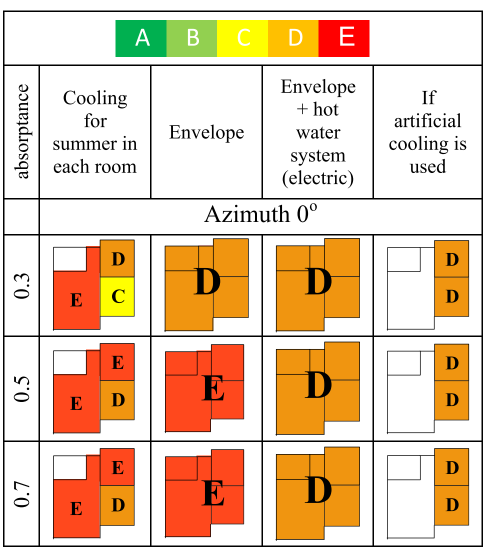


Fig. 3. Results for *BZ8* with azimuth 0° and 3 (α) of the wall 0.3–0.5 and 0.7 for the detached house.

be adopted and the adopted value for the representative project. Features found with at least 50% of occurrence were adopted for the project.

The predominant features include internal and external walls of 13 cm made of clay brick of 4 or 6 holes or concrete block, both with internal and external plaster. Another kind of wall included 10 cm concrete walls. Roofs had red clay tiles and attic with PVC or 8 cm concrete slab ceiling. There were more layouts than for the previous sample and the most frequently occurring layout was adopted. It can be observed that the percentage required for ventilation on the Energy Labelling is not met in some rooms and the 12.5% required for daylighting is met by half of the projects (Fig. 6).

The main characteristics adopted for the representative project, the floor plan and 3D image of the terrace single storey are shown in Table 5.

Results of the energy evaluation for BZ3 with azimuth 0° are shown in Fig. 7. The evaluation for each room in summer, with walls absorptance 0.3 and 0.5 achieves a level between C and D,

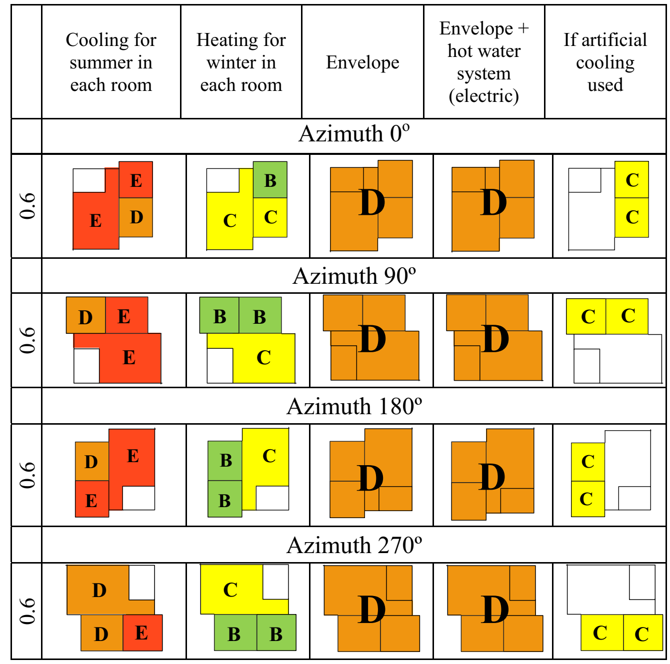


Fig. 4. Results for *BZ3* with 4 azimuths and the (α) of the wall of 0.6 for the detached house.

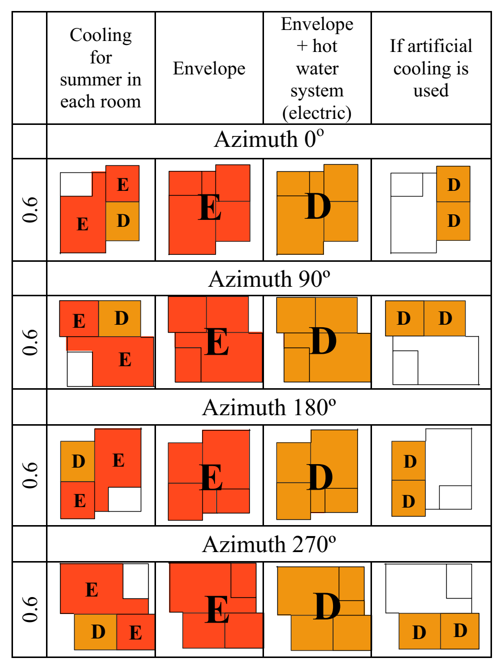


Fig. 5. Results for *BZ8* with 4 azimuths and the (α) of the wall of 0.6 for the detached house.

and with wall absorptance 0.7 between D and E. The evaluation in winter is always C for the living and B for the bedrooms. With cooling a C level rating is achieved regardless the absorptance. For the final evaluation of the envelope and also considering the hot water system a C or D rating is achieved depending on the absorptance. For the analysis of different orientations and considering external walls with absorptance 0.6 (Fig. 9) the level for summer cooling in every main room varies between C, D and E depending on the azimuth. The other results are for all orientations: levels B and C for winter, mainly C for the envelope and D for the final note with the water system. Also level C if artificial cooling were used in the bedrooms. For BZ8, the evaluation

Table 4
Values of the sample and values adopted for the representative project of terrace single storey.

	Values of the sample				Values to adopt			Adopted value
Areas (m^2)	Min.	Max.	Standard deviation	Average	Interval t student	Min. value to adopt	Max. value to adopt	Value of representative project (m^2)
Net area of unit	35.2	40.41	1.98	37.35	1.61	35.74	38.95	38.12
Area with walls	39.8	44.55	2.09	41.98	1.70	40.28	43.68	43.24
Living	6.75	14.14	2.91	10.70	2.37	8.33	13.06	10.90
Kitchen	3.97	6.75	0.99	5.17	0.81	4.36	5.97	5.87
Bedroom 1	7.68	9.00	0.50	8.59	0.40	8.18	8.99	8.58
Bedroom 2	6.96	9	0.92	7.88	0.75	7.12	8.63	7.80
Bathroom	2.04	3.88	0.76	3.11	0.62	2.50	3.73	3.00
Circulation between bedrooms[a]	0.9	2.16	0.57	1.49	0.47	1.02	1.96	1.96

[a] Only considering the projects that have circulation between bedrooms.

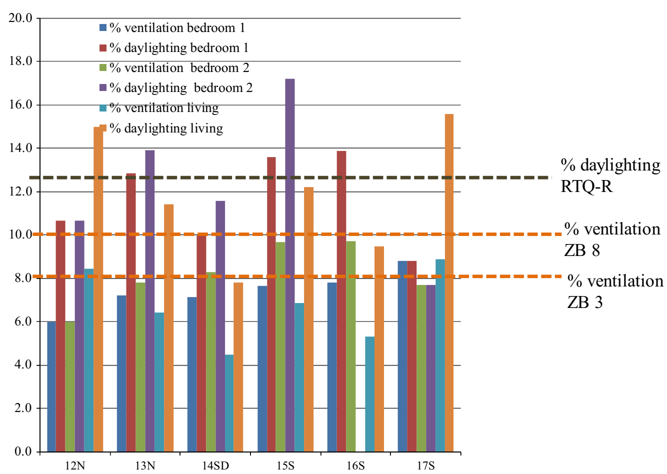


Fig. 6. Percentage of ventilation and daylighting regarding the floor area for the main rooms for the terrace single storey sample.

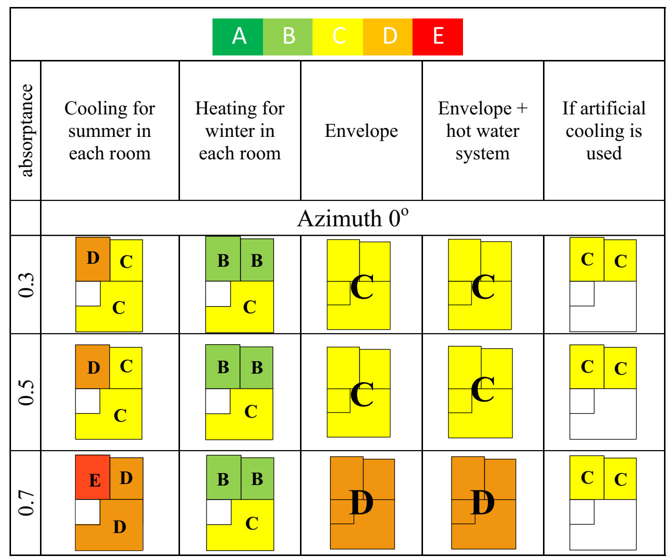
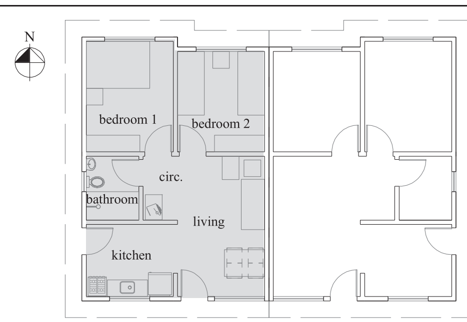
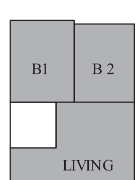


Fig. 7. Results for BZ3 with azimuth 0° and 3 (α) of the wall of 0.3–0.5 and 0.7 for the terrace single storey representative project.

Table 5
Main features and floor plan of the representative project for the terrace single storey.

-Cross ventilation; -Roof overhangs: 50 cm; -Ceiling height: 2.50 m; -Electric shower for hot water > 4600 W; -Service area: external; -Walls: 13 cm (clay brick 6 holes with internal and external plaster) U=2.43 W/m²K; Thermal capacity=132 kJ/m²K; -Roof: 2 pitches, red clay tile + attic with PVC ceiling, Structure wooden roof, U = 1.75 W/m²K, Thermal capacity = 21.4 kJ/m²K, Absorptance=0.6, slope 21.36° -Not external living area.	-Windows: Bedrooms and living:1.50 m^2, 2 slide sashes horizontal (VF = 0.45; LF= 0.80); Kitchen: 1.20 m^2 2 slide sashes horizontal (VF = 0.45; LF= 0.80); Bathroom: 0.36 m^2 framed glass louvres (VF=0.90 and LF=0.65); -No external shutters; -Glass: 4 mm transparent; -Frames in iron; -External doors: 2 metal 0.80×2.10 m^2 in the living and kitchen; -Internal doors: 0.80×2.10 m^2 in wood; -Project without enlargement;	  

OBS: In the floor plan the unit highlight is the one being assessed.

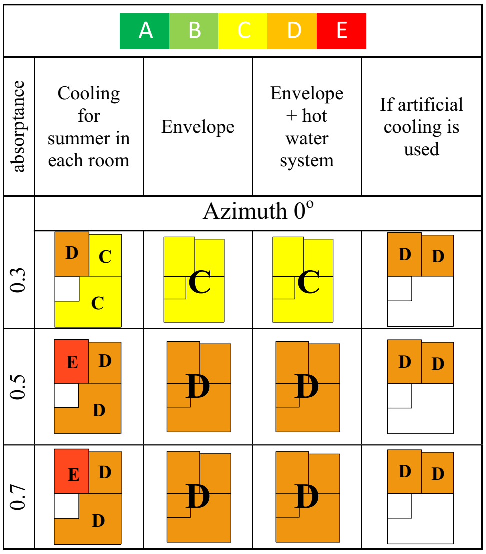


Fig. 8. Results for BZ8 with azimuth 0° and 3 (α) of the wall of 0.3–0.5 and 0.7 for the terrace single storey.

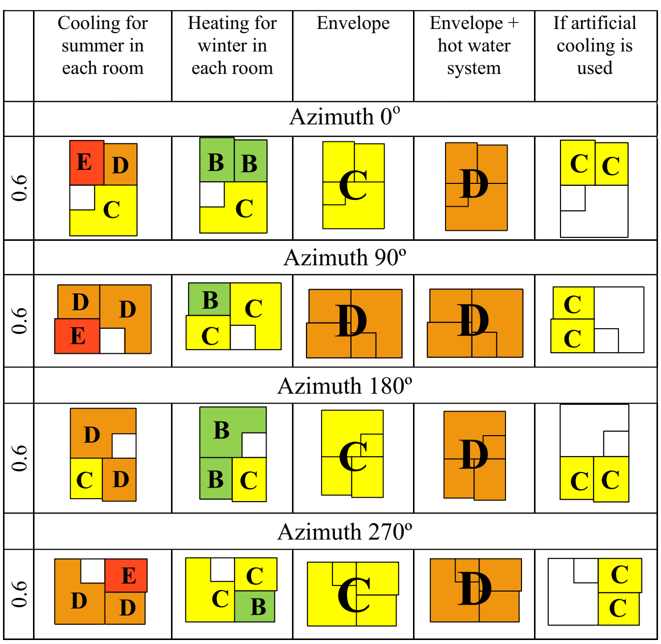


Fig. 9. Results for BZ3 with 4 azimuths and the (α) of the wall of 0.6 for the terrace single storey.

achieves lowest levels compared to BZ3 analysis, especially for the envelope. Only for wall absorptance 0.3 (Fig. 8) the level of the envelope and the envelope with hot water are C, while for absorptances 0.5, 06 and 0.7, the results are D for all azimuths (Fig. 10). For artificial cooling the level is D.

Factors affecting the performance of the envelope are lack of shading on windows and the pre-requisite of the roof regarding transmittance and absorptance not being met for BZ8. Daylighting pre-requisites are not met in both zones and ventilation pre-requisites are not achieved for the living and bedroom 1 in BZ3 and for all windows in BZ8.

The construction components and openings of the single storey terraced and the detached house are very similar, but the terrace typology tends to performs better than the detached house in both bioclimatic zones.

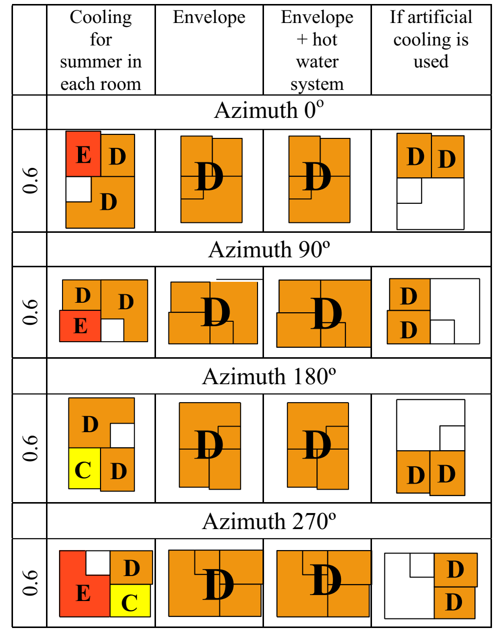


Fig. 10. Results for BZ8 with 4 azimuths and the (α) of the wall of 0.6 for the terrace single storey.

3.1.3. *Building in H format of 4 or 5 floors*

This sample was composed of four projects, with all presenting only one typical apartment, 4 apartments per floor and electric water heating system. Projects were located on regions Southeast, South (BZ3) and North (BZ8). Table 6 shows the values of the sample for the typical apartment unit and adopted values for the representative apartment project.

Almost half of the sample fails to achieve the pre-requisites for daylighting and ventilation in particular for the living room. The features adopted for this representative project with the typical apartment, floor plan and 3D image are shown in Table 7.

For the energy evaluation three positions of apartments were considered: ground floor, intermediate floor and top floor apartment, as this is mandatory on the Energy Labelling methodology. The analysis made for the typical apartment (A) considering azimuth 0° is discussed below.

For BZ3 (Fig. 11), the ground floor apartment has better performance for all absorptances compare to the upper floor apartments, obtaining for the envelope evaluation and envelope plus hot water system level C, being level D for the last evaluation with wall absorptance 0.7. The top floor apartment has the poorest performance as expected, being in all cases E for all main rooms considering cooling for summer, level D for the envelope, for the final evaluation considering the envelope and hot water system and also if the bedrooms used artificial cooling. In general all apartments are performing better in winter than for summer, obtaining level C.

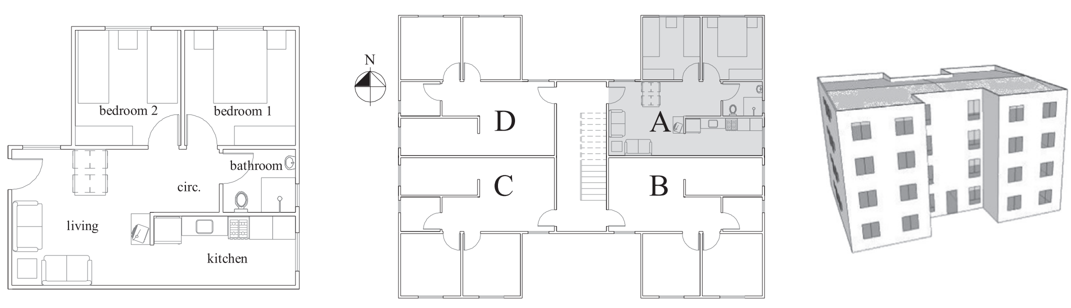
The performance for BZ8 (Fig. 12), is inferior than in BZ3 especially for the top floor apartment. The ground floor apartment is for most evaluations level C, except with higher wall absorptance and if artificial cooling is used, in which case it obtains level D. The intermediate apartment is mostly C level with low absorptance and mainly level D with wall absorptances 0.5 and 0.7. The top floor apartment is mostly level E for all evaluations with wall absorptances 0.5 and 0.7; being level D with wall absorptance 0.3.It achieves mostly level D if artificial cooling is used. Factors affecting the performance of this representative project are walls and roof that do not meet the Energy Labelling criteria for the bioclimatic zones in terms of absorptance, transmittance and thermal capacity. Furthermore, in both zones, the criteria for natural ventilation is not met by the three main rooms and the

Table 6
Values for the sample of the typical apartment unit for the representative project of the multifamily building with H shaped floorplan for income level 1

	Values on the sample				Values to adopt			Adopted value
Areas (m^2)	Min.	Max.	Standard deviation	Average	Interval *t* student	Min. value to adopt	Max. value to adopt	Value of representative project
Net area	38.24	45.07	3.14	42.61	3.16	39.45	45.76	43.07
Living	10.54	16.06	2.39	12.80	2.40	10.39	15.20	12.81
Kitchen	6.06	7.75	0.69	6.93	0.70	6.23	7.62	6.84
Bedroom 1	8.19	9.15	0.42	8.60	0.42	8.18	9.03	8.70
Bedroom 2	8.12	8.75	0.27	8.46	0.27	8.18	8.73	8.28
Bathroom	2.80	3.69	0.40	3.22	0.40	2.82	3.62	3.13
Circulation between bedrooms	0.98	3.23	1.09	1.24	1.09	1.51	3.70	2.97

Table 7
Main features and floorplan of the representative apartment (a); representative typical floor (b) and 3D image (c) for the apartment unit with H shaped floorplan – 1st level.

-Cross ventilation;
-Ceiling height=2.50 m;
-Electric shower heating for hot water >4600 W;
-Integrated service area with the kitchen;
-Dining/living integrated;
-Floor: ceramic;
-Walls: concrete panel of 10 cm; U= 4.4 W/m²K; Thermal capacity =240 kJ/m²K;
-Roof: fibre cement tile, 4 hipped roof average slope 4.33° with metal roof structure and attic space with concrete slab of 10 cm; U=2.06 W/m²K, Thermal capacity =233 kJ/m²K, Absorptance=0.7
-Balcony= No;
-Windows: Bedrooms: 1.44 m^2, 2 horizontal slide sashes (VF=0.45; LF=0.8).
Living: 1.60 m^2 2 horizontal slide sashes with a fixed part underneath (VF=0.375; LF=0.8);
Kitchen: 1.20 m^2, 2 horizontal slide sashes (VF=0.45; LF=0.80);
Bathroom: 0.36 m^2, top hung tilting window, sill 1.50 m;
-External shutters: Not;
-Glass: 4 mm transparent;
-Window frames in iron or aluminium;
-Doors: 0.80×2.10 cm^2 of wood;
-Accessibility: no;



(a) (b) (c)

daylighting criteria for the living. Also, lack of shading for the windows has an impact and, the roof performance as expected, influences most the top floor apartments.

For the typical apartment an exploratory evaluation was also done on the same azimuth and position D (Table 7) to evaluate differences on performances. More differences were observed for BZ8, being with a slightly lowest performance than the apartment on position A.

Also, the sample had equal numbers of projects with and without external shutters on the bedrooms. Further study of this option was undertaken. It was observed in the two bioclimatic zones the improvement of the performance, especially for the intermediate and top floor apartments were the envelope evaluation was only level E for bioclimatic zone 8 with wall absorptance 07. For the other cases, the envelope evaluation was between level C and D, not being better because the pre-requisite of lighting percentage is not met, since the shutters that are usually used only let to enter the daylight through half of the window.

3.2. Results for income level 2

The distribution by region and typology of the projects analysed in this income level is shown in Table 8.

From the sample of 79 projects, the main typologies found were linear and apartment block with H shaped floor plan (considering together the H and H linear) and those were the typologies chosen as representative projects for this level. The results were analysed initially from the whole sample and later just for the two main typologies that summed together 67 projects.

For these projects it was more difficult to identify the materials of walls and roof, ceiling height, height of openings and hot water system based on the information available via institutional websites. Also, the floor areas of some projects were not clearly stated on the plans, so dimensions were scaled from drawings. Due to lack of specification detail, the hot water system is not considered on the energy evaluation, the walls and roof were assumed to be as the ones with most frequency of occurrence based on the projects that were possible to identify, the ceiling height is assuming to be 2.60 m. For the openings, external shutters were usually not used in

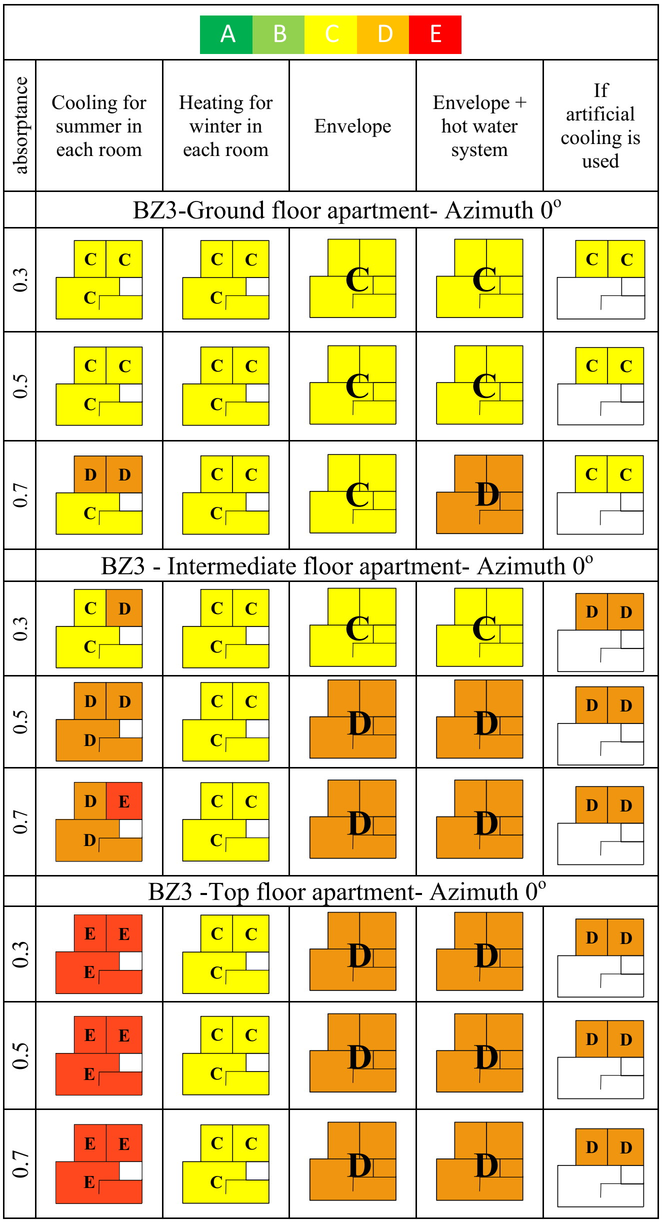


Fig. 11. Analysis of the Energy Labelling for typical apartment of multifamily building in H format for 1st Band – BZ3.

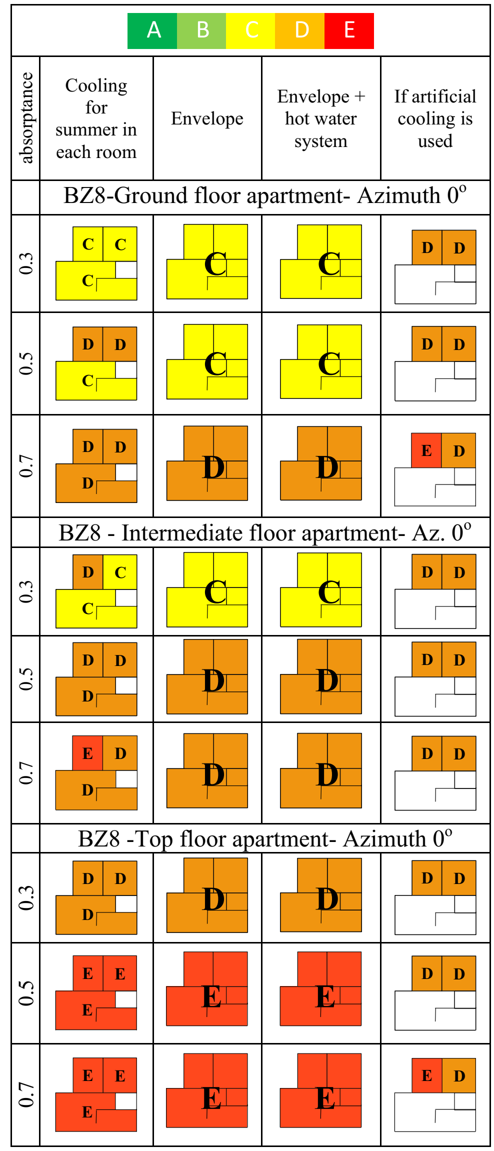


Fig. 12. Analysis of the Energy Labelling for typical apartment of multifamily building in H format for 1st Band – BZ8.

all regions and the dimensions were based on the drawn information with the height assessed visually from the facades proportion, shown on the institutional websites of the projects.

3.2.1. Results for linear typology

42 projects were identified of this typology. The main characteristics of this sample with more frequency of occurrence are complexes of 5 to 10 housing blocks; 5 floors, and mainly 6–8 apartments per floor. The sample showed three types of significantly different and more recurrent apartments, regarding the number of bedrooms, bathrooms and position on the floor plan (corner or middle) that differentiate cross ventilation access. The most common apartments found were in first place two bedrooms and one bathroom that could be on the corner of the building (apartment type 1) or in the middle (apartment type 2). Apartments with the characteristics of apartment 1 were identified in 42 projects and apartments with the characteristics of type 2 in 41 projects. The other type of apartment identified had two bedrooms and two bathrooms mostly located in the middle of the building (apartment type 3). This type of apartment was found in 24 projects of the sample.

Table 9 shows general data of the three main apartments' types.

When identified, the most recurring materials were ceramic floor tiles, walls in concrete block with total width around 14–15 cm self-structure, roof in fibre cement with concrete slab ceiling and light and medium externals colours. The main characteristics for the 3 apartment's types are described in Table 10 showing data from the sample and the values adopted for the representative apartments.

In relation to the percentage of ventilation for bedrooms (Fig. 13) comparing with the Energy Labelling pre-requisites, it can be seen that for bedroom 2, most projects achieve the 8% ventilation area in relation to floor area, while for bedroom 1 some of them do not achieve the requirements, especially in apartment types 2 and 3. For the daylighting percentage most of them achieve 12.5% or more in the two bedrooms.

The floor plan for the three main apartments, the whole floor typical plan and 3D image of this representative project for the linear typology can be seen in Fig. 14.

The energy evaluation of the apartments in BZ3 (Fig. 15), done in

Table 8
Sample for projects by region and typology for level 2 with floor plan of the typologies for identification.

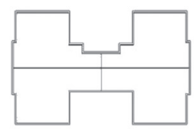
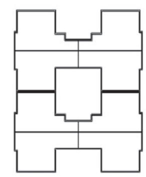
Number of Projects analysed - Total per region					Total
North	NorthEast	Center-West	SouthEast	South	
6	19	9	33	12	79
Number of Projects by tipology					Total
Linear (building)	Tower (building)	H format (building)	H format and linear (building)	Terrace single storey (houses)	
					
42	5	18	7	7	79

Table 9
General data for the three main types of apartments for the linear typology based on the sample of 42 projects.

Type of apartment		Mode	% of occurrence
Apartment 1	Position	Corner	**93**
	Cross ventilation	Yes	95
	No. of bedrooms	2	**95**
	No. of bathrooms	1	**95**
Apartment 2	Position	Middle	**93**
	Cross ventilation	Not	93
	No. of Bedrooms	2	**93**
	No. of bathrooms	1	**88**
Apartment 3	Position	Middle	**92**
	Cross ventilation	Not	92
	No. of bedrooms	2	**100**
	No. of bathrooms	2	**96**

only one azimuth, shows the ground floor of all apartments being level C for almost all evaluations, considering the three absorptances. For apartments 2 and 3 – intermediate floor – also level C is achieved in most of the cases and for apartment type 1 on the intermediate floor between level C and D. The top floor has always the lowest performance of all apartments, especially for cooling in summer obtaining always for the envelope evaluation level D. Also top floor apartments performed better in winter, than in summer.

The performance of the three apartments for BZ8 (Fig. 16) is slightly inferior compared with BZ3 especially with higher absorptances. The top floor apartment performs lower of all, being E for the envelope evaluation in apartment 1 with wall absorptances 0.5 and 07, and for apartment 3 with wall absorptances 0.7. The performance is due in part to a failure in achieving the pre-requisites for the Energy Labelling, such as not having cross ventilation for the apartments type 2 and 3, minimal ventilation

Table 10
Main characteristics for the three main apartment types in the linear typology sample and for the adopted representative project – income level 2.

		Average/mode of the sample			Standard deviation			Adopted on the project		
		Ap1	Ap2	Ap3	Ap1	Ap2	Ap3	Ap1	Ap2	Ap3
General	Average net area (m^2)	38.64	39.24	42.46	2.87	2.66	2.81	38.46	39.04	43.73
	Mode – balcony/(m^2)	0	0	0				0	0	0
Living	Area (m^2)	11.43	11.10	12.04	1.54	0.99	1.45	11.42	11.11	12.77
	Living/dining together – mode	Yes	Yes	Yes				Yes	Yes	Yes
Kitchen/	Integrated	Yes	Yes	Yes				Yes	Yes	Yes
Service area	Area (m^2)	6.45	6.49	6.35	0.51	0.56	0.47	6.58	6.58	6.57
Bedroom 1	Area (m^2)	7.95	9.02	9.48	0.64	0.98	0.78	7.94	9.52	9.90
	Window – mode (m^2)	1.44	1.44	1.44						
Bedroom 2	Area (m^2)	7.41	7.72	7.81	0.47	0.75	0.74	7.41	7.77	7.80
Circulation between bedrooms	Area (m^2)	1.19	1.78	1.78	0.22	0.26	0.30	1.28	1.86	1.82
Bathroom 1	Bwc area (m^2)	2.44	2.46	2.43	0.19	0.25	0.21	2.44	2.52	2.40
Bathroom 2	Area (m^2)			2.59			0.32			2.59
Entrance hall	Area (m^2)	1.57	Mode 0	Mode 0	0.25			1.53	0	0
Roof	Adopted: fibre cement tile with concrete slab ceiling (10 cm), U=2.06 W/(m^2 K); thermal capacity=233 kJ/m^2 K									
Walls	Adopted: concrete block with internal and external plaster; U=2.78 W/(m^2 K); thermal capacity=209 kJ/m^2 K									
Doors	(Mode – adopted) Access door of 1.68 m^2; bedrooms doors of 1.47 m^2; bathrooms doors of 1.26 m^2, all in wood									
Windows	Bedrooms, living and kitchen	(mode) 2 sashes slide horizontal VF=0.45 LF=0.80. Living: 1.80 m^2; bedrooms and kitchen: 1.44 m^2								
	Bathroom	(mode) hung tilting window VF=0.8 LF=0.8 Area:0.36 m^2								
	External shutters	(mode) not								

OBS: Some service area has no windows, just the opening, but this was not the most common to be found.
Thermal properties of walls and roof from Brazil (2013b).

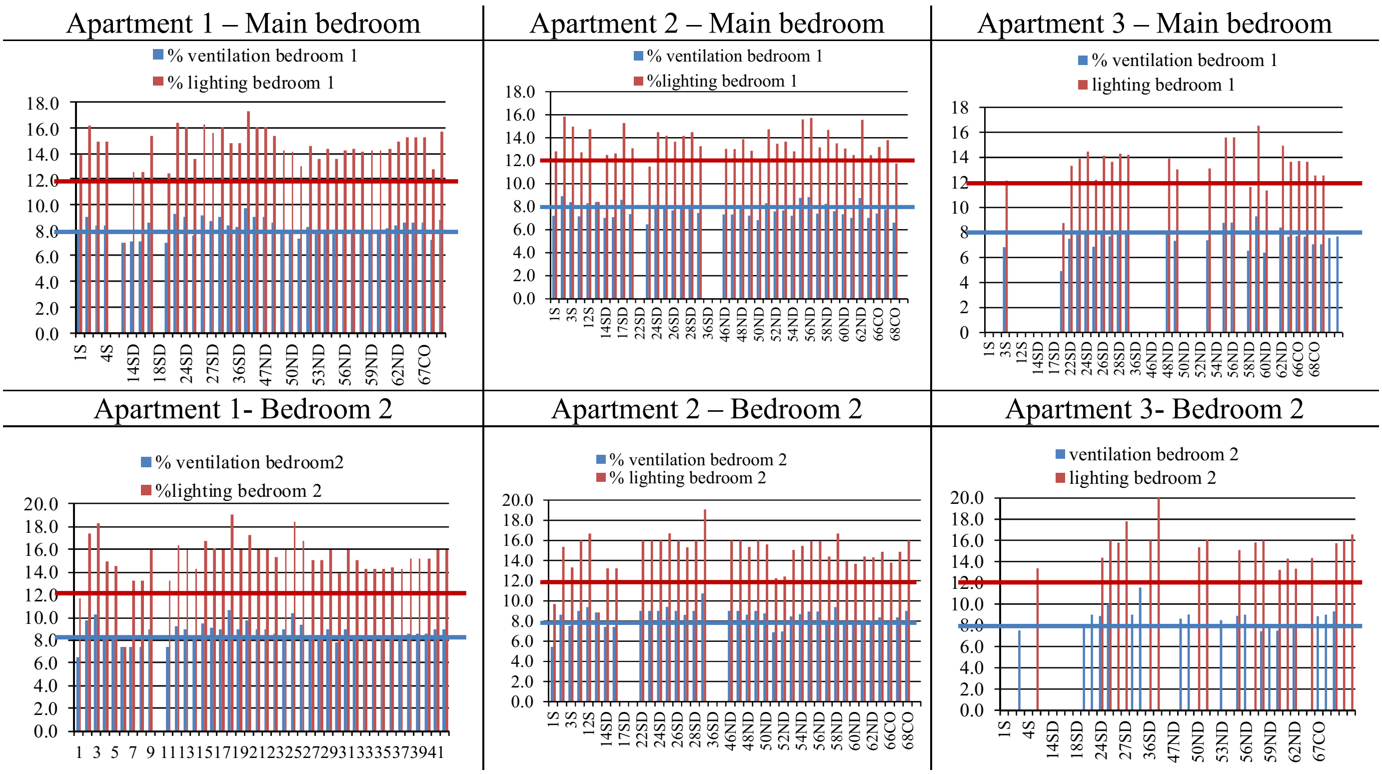


Fig. 13. Ventilations and daylighting percentages for the 2 bedrooms on the 3 apartment types on the linear typology sample – level 2.

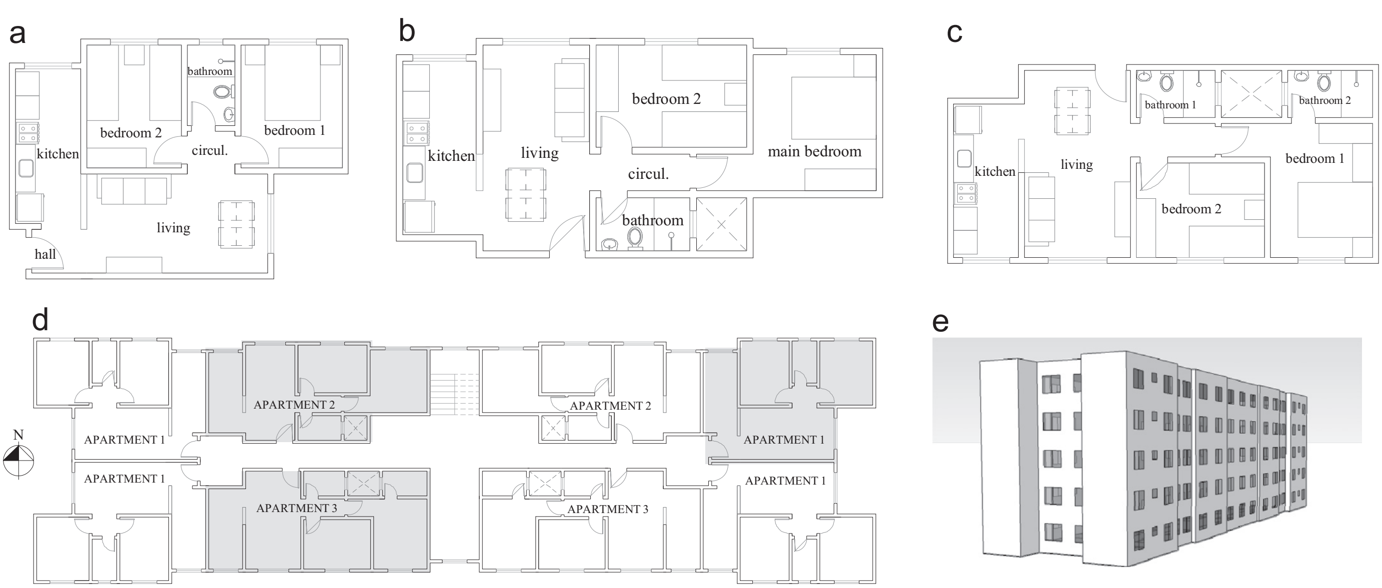


Fig. 14. Floor plan of the three type of apartments for the representative project of the linear typology (a,b,c) plan of the typical floor (d) and 3D image (e) higlighting the apartments being analysed.

requirement not being met in all rooms in BZ8 and in BZ3 mainly in the living room and occasionally in bedroom 1. Also, thermal transmittance limits are not being met considering higher absorptances for roof or walls.

3.2.2. Results for apartment building in H format plan for income level 2

The representative project of this typology is based on a sample of 25 projects. The number of housing blocks with most frequency of occurrence is up to 5, number of floors between 4 and 6, being mostly 4 floors (52%), apartments per floor are 4 (76%) and just one typical apartment per floor (64%). When identified, the most common materials use were fibre cement tile for the roof, especially in the south and southeast and in the north region some projects used ceramic tile. The typical apartment has 2 bedrooms and 1 bathroom. Table 11 shows the main features found for the typical apartment sample and the values adopted on the representative project for the building in H format, for Level 2.

Fig. 17 shows the typical apartment, the typical floor and a 3D image.

The energy analysis for BZ3 (Fig. 18) shows the ground floor apartment achieving level C for almost all evaluations. The intermediate and top floor apartments achieve in most cases D level for the performance of the envelope except for the intermediate floor

Fig. 15. Energy evaluation of the three apartments in BZ3 considering the (α) of the wall of 0.3–0.5 and 0.7 for the three apartment positions. Linear typology – level 2.

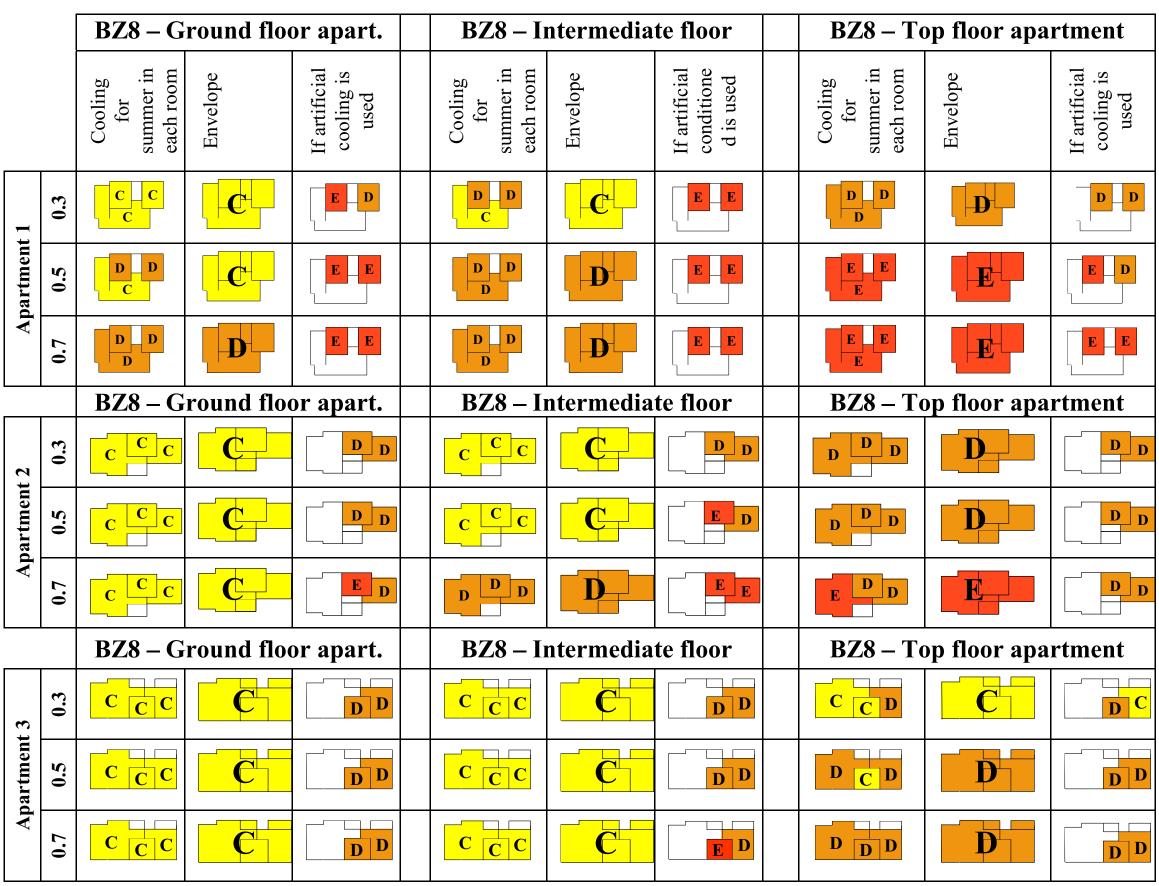


Fig. 16. Energy evaluation of three apartments in BZ8 considering the (α) of the wall of 0.3–0.5 and 0.7 in the three apartment positions for linear typology, level 2.

Table 11
Main characteristics of the typical apartment in the H format typology building for the income level 2.

		Average	Interval *t* student	Min. to adopt	Max. to adopt	Standard deviation	Mode/adopted on the project
General data	Position						Corner
	Total net area (m^2)	40.54	1.67	38.86	42.21	2.6	41.28
	Cross ventilation						Yes
	No. bedrooms						2
	No. bathroom						1
	Balcony/m^2						0
Living	Net area (m^2)	12.54	0.88	11.66	13.43	1.4	13.08
	Living/dining integrated						Yes
Kitchen/service area	Integrated						Yes
	American type						Not
	Net area (m^2)	6.51	0.42	6.08	6.93	0.65	6.58
Bedroom 1	Net area (m^2)	8.76	0.44	8.32	9.20	0.67	8.97
Bedroom 2	Net area (m^2)	8.05	0.56	7.49	8.60	0.85	8.48
Circulation between bedrooms	Net area (m^2)	1.30	0.14	1.15	1.44	0.22	1.21
Bathroom	Net area (m^2)	2.86	0.36	2.49	3.22	0.6	2.94
Entrance hall	Net area (m^2)						0
Roof		Adopted: fibre cement tile with concrete slab ceiling (10 cm), U=2.06 W/(m^2 K); thermal capacity=233 kJ/m^2 K					
Wall		Adopted: concrete block with internal and external plaster; U=2.78 W/(m^2 K); thermal capacity=209 kJ/m^2 K					
Doors		1.68 m^2 in wood					
Windows	Bedrooms, living and kitchen	(mode) 2 sashes slide horizontal VF=0.45 LF=0.80; living and bedrooms: 1.44 m^2; kitchen: 1.20 m^2					
	Bathroom	(mode) hung tilting window VF=0.8 LF=0.8; area:0.36 m^2					
	External shutters	(mode) not in 92%					

OBS: Thermal properties of walls and roof from Brazil (2013b).

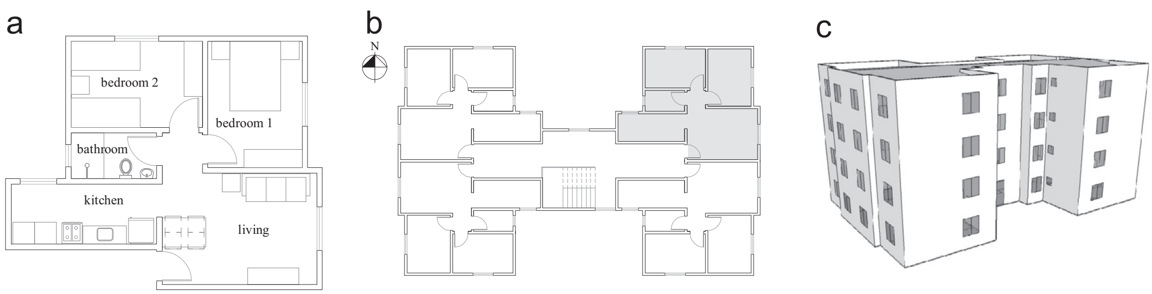


Fig. 17. Floor plan of the typical apartment (a), typical floor (b) and 3D (c) for the building in H format representative project for level 2, highlighting the apartment being analysed.

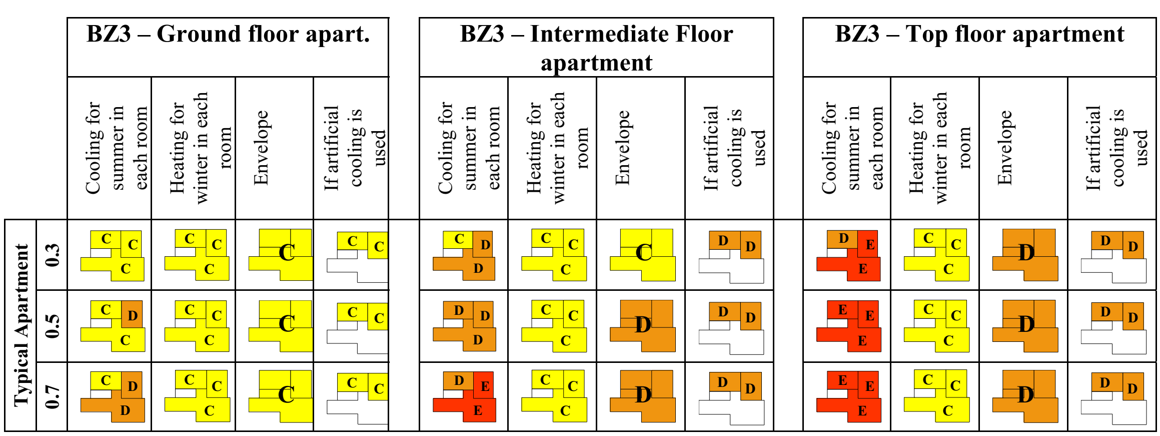


Fig. 18. Energy evaluation of representative apartment in multifamily building in H format for level 2 in BZ3 considering the (α) of the wall of 0.3–0.5 and 0.7 in the three apartment positions.

with wall absorptance 0.3 obtaining C level. Looking at individual performance of each main room for summer, the top floor apartment gets an inferior rating, being in most cases level E for all rooms.

For BZ8 (Fig. 19), the envelope ranges in most cases between D and E levels, with the exception of C level for the ground apartment considering wall absorptance 0.3. The top floor apartment's envelope is always level E regardless wall absorptance. Some parameters influencing the performance are lack of shading, roof and walls that with higher absorptances (0.7) do not meet the

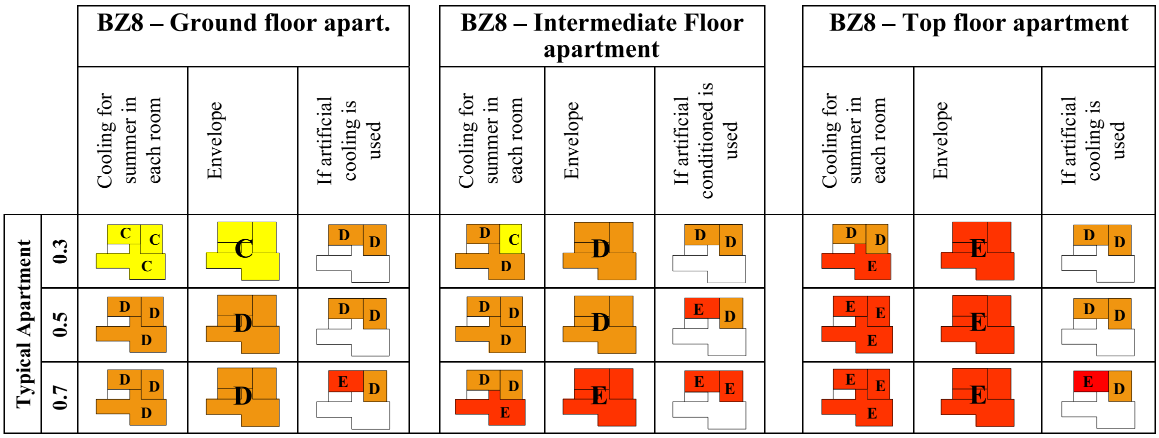


Fig. 19. Energy evaluation of representative apartment in multifamily building in H format for level 2 in BZ8 considering the (α) of the wall of 0.3–0.5 and 0.7 in the three apartment positions.

Table 12
Comparison of compliance of the representative projects against minimal requirements for NBR 15575- Minimal performance Standard

Income level	Representative project	Wall		Roof		Windows ventilation requirement					
		[BZ3 and BZ8 if $\alpha \leq 0.6$ then $U \leq 3.7$ and if $\alpha > 0.6$ then $U \leq 2.5$] [Thermal capacity ≥ 130 for BZ3 and no requirements for BZ8]		[BZ3 if $\alpha \leq 0.6$ then $U \leq 2.3$ and if $\alpha > 0.6$ then $U \leq 1.5$] [BZ8 if $\alpha \leq 0.4$ then $U \leq 2.3$ and if $\alpha > 0.4$ then $U \leq 1.5$]		[For BZ3 $A \geq 7\%$] [For BZ8 (Northeast) $A \geq 8\%$]					
		BZ3	BZ8	BZ3	BZ8	BZ3			BZ8		
						Liv.	Bed.1	Bed.2	Liv.	Bed.1	Bed.2
Level 1	Detached house	☑	☑	☑	☒	☒	☑	☑	☒	☑	☑
	Terraced	☑	☑	☑	☒	☒	☑	☑	☒	☒	☑
	Building H shape	☒	☒	☒	☒	☒	☑	☑	☒	☒	☒
Level 2	Linear building – Ap. 1	☑[a]	☑[a]	☒	☒	☑	☑	☑	☑	☑	☑
	Linear building – Ap. 2	☑[a]	☑[a]	☒	☒	☑	☑	☑	☑	☒	☑
	Linear building – Ap. 3	☑[a]	☑[a]	☒	☒	☑	☑	☑	☒	☒	☑
	Building H shape	☑[a]	☑[a]	☒	☒	☒	☑	☑	☒	☒	☒

☑=Attend the criteria. ☒=Not attend the criteria. This study is considering for BZ8 the Northeast region.

[a] Attend the criteria for $\alpha \leq 0.6$.

criteria of thermal transmittance and absorptance for the pre-requisites. Moreover, in both zones, all main rooms do not meet ventilation percentages and daylighting percentage is not meet only by the living rooms.

For comparison of compliance, the representative projects were compared (Table 12) with the minimal requirements of the Standard NBR 15575 (ABNT, 2013) regarding wall, roof thermal properties, and ventilation requirements for the 2 bioclimatic zones. The criteria of compliance for each bioclimatic zone are specified on the table. Results show highest compliance in more criteria with the minimal performance of NBR 15575, especially regarding ventilation requirements when compared to the pre-requisites from the Energy Labelling, as addressed in Sections 3.1 and 3.2. Criteria not attend are especially for the roof requirements in BZ8 for the houses typologies and in both zones for the buildings typologies. Also, for the walls in the income level 1 building. Windows' ventilation requirements for the living are not meet in typologies for level 1 in both zones and for some typologies occasionally in one bedroom for BZ8.

4. Conclusion and policy implications

Knowing the *status quo* of social housing sector being built is very important, since public policies can be based on that knowledge. This information could be used for policy makers to decide what to address on the national housing programme criteria and what need more research in order to achieve a better performance of the housing sector.

New buildings should encourage energy efficiency, since minimising energy consumption can have impact over the life cycle in terms of environmental, economic and social benefits. For the country, environmental and economic benefits include a more rational use of resources. Social benefits can include financial savings and better comfort levels, and consequently better health and well-being, for the building occupants.

This study defines representative projects being built in the social housing sector in Brazil nowadays and assesses its energy performance in relation to the Brazilian Energy Labelling considering the prescriptive method. It identifies representative projects considering two groups of income levels, for which main features that affect energy performance were raised. It has to be emphasised that these results do not represent the evaluation of any individual project of the sample, but instead represent the evaluation of representative projects considering the main features found in the collected samples and, differences could be observed using more detail analysis through simulation with specific weather files.

The initial database collected comprises 108 projects with typologies in both income levels. Out of them, 88 were used to set the representative projects. For level 1 (1st Band of PMCMV) from 21 projects with characteristics in detail, three typologies were identified to be representative: detached house, single storey terrace and apartment block in H floor plan format with four or five floors. For the income level 2 (2nd and 3rd Bands of PMCMV) from 67 projects, two typologies were identified as representative: linear multi-family building of five floors and building in H format of 4 floors.

For the representative projects, the roof performance in terms of absorptance and thermal transmittance in level 2 and in level 1 for BZ8, the window's ventilation area in BZ8 and often for the living in BZ3, usually do not meet the pre-requisites of the Energy Labelling. Also, although there is mandatory use of solar water heating for some projects at level 1, electric shower is still used as hot water system in some projects, which negatively affect the energy rating.

In level 1, the detached house is still the most common typology being built and the representative project shows a lower performance comparing to other typologies, particularly for summer evaluation.

Typologies for Level 2, although with a better performance on average than the projects for Level 1, are nonetheless rated medium and low in relation to the Energy Labelling depending on the apartment type and specially position. Ground floor and intermediate floor apartments in BZ3, obtained level C in most cases for the envelope. The top floor apartment performs inferior than all other apartments, usually achieving level D. As this is often due to lack of insulation at roof level, it also presents realistic potential for building with better performance.

At both level for BZ8 a lower performance compared to BZ3 is observed, especially with the use of higher solar absorptances for the walls.

Since the evaluation for summer in the Energy Labelling considers natural ventilated buildings, the results indicates that current building techniques for social housing show a tendency to fail to provide comfort for users specially in the lower income sector, which could lead to the need for greater use of air conditioning, consequently increasing energy demand throughout the country.

The study shows the need to improve thermal and energy performance of buildings in social housing sector, as the most common features found in projects currently being built, show a tendency towards a low performance by the Brazilian Energy Labelling, especially for lower income projects (Level 1).

From the results some recommendations can be drawn in terms of energy policy implications:

- Investments in national housing programmes should have a long-term performance perspective, acknowledging operational energy use today and its likelihood to increase in future. For this, parameters for projects prioritisation particularly for the lower income sector should be addressed in a different way and not be based on minimal costs but in performance considering the building's life cycle.
- Results tend to suggest that current minimal standards are insufficient to achieve a good thermal performance. Income level 1 is the one presenting an inferior performance and the level with the highest housing deficit. This suggests that funding can be insufficient and that more ambitious compelling standards are needed as goals for social housing or more ambitious minimal criteria in the standard already accepted as compulsory.
- The Brazilian Energy Labelling could be used to set compulsory minimal levels of performance for buildings financed in the sector.
- Projects need to be adapted for each bioclimatic zone. The mapping of the projects highlighted the use of similar designs in different bioclimatic zones and the analysis identified that the representative projects usually have an inferior performance in BZ8. This shows the importance of considering building features in relation to the context to optimise performance.
- The lower performance is often observed for summer, being better in winter, which suggests a problem, due to the importance for summer comfort in most of the country.
- The study only analysed representative typologies for social housing and not individual projects, but it is clear that for these typical projects there is an urgent need to introduce energy efficiency measures, that could also lead to changes in typologies, and provide incentives to implement them.
- There are some features that need to be prioritised. Measures identified to improve the thermal and energy performance of the projects could be divided into two groups. The first refers to measures that can be accomplished without much effort and the second that implies greater changes to the projects. The first group includes adequate windows that fulfil natural ventilation needs and daylighting pre-requisites of the Energy Labelling, colour absorptance of walls and in some cases for roofs. The second group, includes changes in project design that allow cross ventilation in the units, reduced thermal transmittances of roofs, reduced transmittances for walls for higher solar absorptances, windows shading (external shutters) or the implementation of solar water heating, among others. The later can also include energy generation on the house through the integration of photovoltaic panels, which could be encouraged from the energy sector. Further study will be required to quantify and categorize potential improvements.

Representative projects of the social housing sector would allow for future analysis to inform public policy, although quantifying the impact of energy efficiency measures in the sector through building simulation, will be addressed in further research.

Finally, policies for the Brazilian social housing programme should also consider that measures to be incorporated in these projects should address impacts from a more holistic point of view, including energy, environmental and socio-economic impacts. This implies the need for further studies in this sector, to develop design guidelines or mandatory design regulations for projects that are being built by the national programme.

Acknowledgements

The authors would like to thank the financial support of the "National Council of Technological and Scientific Development" from Brazil through a “CNPq scholarship” for the first author.

References

ABC, 2013. Associação Brasileira de Cohabs e Agentes Públicos de Habitação. Institutional website. ⟨http://www.abc.habitacao.org.br⟩ (accessed 15.09.13.).
ABNT, 2004. NBR 9050. Norma Brasileira. Acessibilidade a edificações, mobiliário, espaços e equipamentos urbanos.
ABNT, 2005a. Desempenho térmico de edificações Parte 3 : Zoneamento bioclimático brasileiro e diretrizes construtivas para habitações unifamiliares de interesse social.
ABNT, 2005b. Desempenho térmico de edificações Parte 2 : Métodos de cálculo da transmitância térmica , da capacidade térmica , do atraso térmico e do fator solar de elementos e componentes de edificações.
ABNT, 2013. NBR 15575. Edificios habitacionais – Desempenho.
Almeida, L.S.S., Silva, A.S., Schneider, K., Ghisi, E., 2013. Avaliação da envoltória de habitações de interesse social de Florianópolis de acordo com o método prescritivo do RTQ-R. In XII ENCAC – Encontro Nacional de Conforto no Ambiente Construído/VIII ELACAC -Encontro Latinoamericano de Conforto no Ambiente

Construído (p. Conforto e Projeto. v. 1. pp. 1246–1255). Brasília.
Balaras, C.A., Gaglia, A.G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Lalas, D.P., 2007. European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. Build. Environ. 42 (3), 1298–1314.
Bodach, S., Hamhaber, J., 2010. Energy efficiency in social housing: opportunities and barriers from a case study in Brazil. Energy Policy 38 (12), 7898–7910.
Brazil, 2011. Déficit habitacional no Brasil 2008. Available: ⟨http://www.cidades.gov.br/images/stories/ArquivosSNH/ArquivosPDF/DHB_2008_Final_2011.pdf⟩ (accessed 05.06.14.).
Brazil, 2012a. Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Residenciais. Available: ⟨http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001788.pdf⟩ (accessed 01.09.14.).
Brazil, 2012b. Manual para aplicação do RTQ-R. Com base na Portaria No 18/2012. Available: ⟨http://www.pbeedifica.com.br/sites/default/files/projetos/etiquetagem/residencial/downloads/Manual_de_aplica%C3%A7%C3%A3o_do_%20RTQ-R-v01.pdf⟩ (accessed 10.01.15.).
Brazil, 2013a. Programa Minha Casa , Minha Vida. Available: ⟨http://www.cidades.gov.br/index.php/minha-casa-minha-vida⟩ (accessed 15.08.14.).
Brazil, 2013b. Anexo da Portaria INMETRO No. 50/2013. Anexo Geral V – Catâlogo de propriedades térmicas de paredes, coberturas e vidros. Available: ⟨http://www.pbeedifica.com.br/sites/default/files/projetos/etiquetagem/anexos_rac/AnexoV.pdf⟩ (accessed 04.06.15.).
Brazil, 2014. Balanço Energético Nacional 2014: Ano base 2013. Available: ⟨https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2014.pdf⟩ (accessed 04.06.15.).
Brazil, 2015. Saiba como funciona e como participar do Programa Minha Casa, Minha Vida. Available: ⟨http://www2.planalto.gov.br/excluir-historico-nao-sera-migrado/saiba-como-funciona-e-como-participar-do-programa-minha-casa-minha-vida⟩ (accessed 05.01.15.).
Brazil EPE, 2013. Anuário Estatístico de Energia Elétrica 2013. Available: ⟨http://www.epe.gov.br/AnuarioEstatisticodeEnergiaEletrica/20130909_1.pdf⟩ (acessed 20.05.14.).
Brazil Mincidades., 2011. Portaria N. 465 de 3 de outubro de 2011.
Brazil Mincidades, 2012a. Programa Minha Casa Minha Vida. Available: ⟨http://www.sedhab.df.gov.br/mapas_sicad/conferencias/programa_minha_casa_minha_vida.pdf⟩ (accessed 05.07.14.).
Brazil Mincidades, 2012b. Instrução normativa N. 33 de 23 de outubro de 2012. Regulamenta o Programa de Apoio à Produção de Habitações. Available: ⟨http://www.cidades.gov.br/images/stories/ArquivosSNH/ArquivosPDF/Instru%C3%A7C3%B5esNormativas/IN_MCidades_2012_033_Apoio_a_Producao_Compilada.pdf⟩ (accessed 10.07.14.).
Brazil IBGE, 2010. Resultados do Universo do Censo Demográfico 2010. Available: ⟨ftp://ftp.ibge.gov.br/Censos/Censo_Demografico_2010/Resultados_do_Universo/tabelas_pdf/tab6.pdf⟩ (accessed 16.07.14.).
Brodbeck, P., 2013. Gazeta Do Povo. Available: ⟨http://www.gazetadopovo.com.br/economia/conteudo.phtml?id=1426349&tit=Gigantes-do-setor-saem-de-finho⟩ (accessed 22.05.14.).
CAIXA, 2010. Selo Casa Azul. Boas práticas para habitação mais sustentável. (Coordenadores, V. Jhon, & R. T. A. Prado, Eds.). São Paulo: Página & Letras.
CAIXA, 2014. Projetos aprovados no PMCMV Faixa 1. Available: ⟨http://downloads.caixa.gov.br/_arquivos/habita/mcmv/Empreendimentos_MCMV_faixa1.pdf⟩ (accessed 05.05.14.).
CAIXA, 2015. Circular No. 681 de 10 de Junho de 2015. Available: ⟨http://pesquisa.in.gov.br/imprensa/servlet/INPDFViewer?jornal=1&pagina=13&data=11/06/2015&captchafield=firistAccess⟩ (accessed 18.06.15.).
Cani, B.F., Marinoski, D.L., Lamberts, R., 2012. Aplicação da termografia infravermelha para verificação da temperatura em telhas cerâmicas com diferentes teores de umidade e condições de limpeza da superfície. In XIV ENTAC – Encontro Nacional de Tecnologia do Ambiente Construído. Juiz de Fora.
Carlo, J.C., Toccolini, G., 2005. AET No. 02/04 Elaboração de regulamentação e classificação de edificações eficientes. Levantamento de dados visando a definição de protótipos de edificações brasileiras. (Relatório Técnico-200505). Universidade Federal De Santa Catarina, Florianópolis.
Curcio, D.da R., Da Silva, A.C.S., 2013. Desempenho térmico de habitações de interesse social, em edifícios multifamiliares , produzidas pelo programa de arrendamento residencial – PAR, na cidade de Pelotas / RS. In XII ENCAC - Encontro Nacional de Conforto no Ambiente Construído / VIII ELACAC -Encontro Latinoamericano de Conforto no Ambiente Construído. Brasília.
Dall'O', G., Galante, A., Torri, M., 2012. A methodology for the energy performance classification of residential building stock on an urban scale. Energy Build. 48, 211–219.
INMETRO, 2015. Instituto Nacional de Metrologia, Qualidade e Tecnologia. Programa Brasileiro de Etiquetagem. Tabela de consumo de energia elétrica chuveiros. Edição 01/2015. Available: ⟨http://www.inmetro.gov.br/consumidor/pbe/chuveiro.pdf⟩ (accessed 10.08.15.).
ITC, 2013. Ranking ITC 2013. Institutional website. Available: ⟨http://www.rankingitc.com.br⟩ (accessed 15.01.14.).
Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Djurovic-Petrovic, M., 2010. A review of bottom-up building stock models for energy consumption in the residential sector. Build. Environ. 45 (7), 1683–1697.
Linck, G.I., de Albernard, R.S., Grigoletti, G.de C., 2013. Avaliação do conforto térmico de habitações de interesse social da cidade de Santa Maria, RS, a partir da opinião dos usuários. In XII ENCAC – Encontro Nacional de Conforto no Ambiente Construído/VIII ELACAC – Encontro Latinoamericano de Conforto no Ambiente Construido. Brasilia.
Nik, V.M., Sasic Kalagasidis, A., 2013. Impact study of the climate change on the energy performance of the building stock in Stockholm considering four climate uncertainties. Build. Environ. 60, 291–304.
Pereira, V., 2011. Especial – Construtoras menores lideram "Minha Casa, Minha Vida." O Estado de Sao Paulo. Available: ⟨http://economia.estadao.com.br/noticias/economia-geral-economia,especial-construtoras-menores-lideram-minha-casa-minha-vida,50929,0.htm⟩ (accessed 10.06.14.).
Scalco, Veridiana Atanasio, Fossati, M., Versage, R., Sorgato, M.J., Lamberts, R., Morishita, C., 2012. Innovations in the Brazilian regulations for energy efficiency of residential buildings. Archit. Sci. Rev. 55, 71–81.
Schaefer, A., Almeida, L.S.S., Ghisi, E., Freitas, M.N., Duarte, E., 2012. Determinação de modelos de habitação de interesse social da Grande Florianópolis para uso em simulação computacional. In UFS (Ed.), IV Workshop – Rede de Pesquisa: Uso racional de água e eficiência energética em habitações de interesse social. (p. v. 1. pp. 259–280). Aracaju.
Schaefer, A., Ghisi, E., 2012. Desenvolvimento de um protótipo de habitação de interesse social para simulação computacional. In III Workshop – Rede de Pesquisa: Uso racional de água e eficiência energética em habitações de interesse social, (p. v. 1. pp. 156–165). Curitiba.
Shorrock, L., Dunster, J., 1997. The physically-based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock. Energy Policy 25 (12), 1027–1037.
Silva, R.B., de Paula, J.M.B., Barbirato, G.M., 2013. Programas de habitação social e qualidade de projeto : avaliação de arranjo construtivo e de condições térmicas internas de habitação no contexto climático de Maceió – AL. In XII ENCAC - Encontro Nacional de Conforto no Ambiente Construído / VIII ELACAC -Encontro Latinoamericano de Conforto no Ambiente Construído. Brasília.
Sorgato, M.J., Lamberts, R., 2011. Relatório Técnico da base de simulações para o RTQ-R. Relatório Técnico: RT_LABEEE-2011/02. Florianópolis. Available: ⟨http://www.labeee.ufsc.br/sites/default/files/projetos/etiquetagem/SORGATO_2011_Relatorio Tecnico da Base de Simulacoes para o RTQ-R.pdfSORGATO_2011_Relatorio Tecnico da Base de Simulacoes para o RTQ-R.pdf⟩ (accessed 03.06.15.).
Tavares, S.F., 2006. Metodologia de análise de ciclo de vida energético de edificações residenciais brasileiras. Universidade Federal de Santa Catarina – UFSC. Thesis. Available: ⟨http://www.labeee.ufsc.br/sites/default/files/publicacoes/teses/TESE_Sergio_Fernando_Tavares.pdf⟩.
Theodoridou, I., Papadopoulos, A.M., Hegger, M., 2011. A typological classification of the Greek residential building stock. Energy Build. 43 (10), 2779–2787.
UNEP, 2010. Sustainable Social Housing Initiative – SUSHI. Relatório 1: Mapeamento dos principais interessados e dos processos que afetam a seleção de soluções (tecnologias e materiais) para projetos de habitação social – São Paulo, Brasil. Available: ⟨http://www.cbcs.org.br/sushi/images/relatorios/Final_Brazil_reports_160511/1_Mapeamento_090511.pdf⟩ (accessed 20.02.14.).