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Cast-in-place concrete walls: thermal comfort evaluation of one-storey housing in São Paulo State

Vedações verticais em concreto moldadas in loco*: avaliação do conforto térmico de habitações térreas no Estado de São Paulo*



H. M. SACHT [a]
hmsacht@civil.uminho.pt

J. A. ROSSIGNOLO [b]
rossignolo@usp.br

C. BUENO [c]
cbueno@sc.usp.br

Abstract

This paper presents a proposal of thermal performance evaluation of a one-storey housing typology (TI24A) executed by CDHU - Companhia de Desenvolvimento Habitacional e Urbano do Estado de São Paulo, considering the use of cast-in-place monolithic panels of concrete, with different thicknesses panels (8, 10 and 12 cm) and density between 1600 and 2400 kg/m³. In this study, the specific purpose was discussing the influence of the characteristic of concrete walls on the housing thermal performance without slab. Was defined of first parameters of study (definition of the one-storey housing typology, survey about housing users behavior and cities choose) and executed computational simulation (winter and summer), for four São Paulo State cities (São Paulo, São Carlos, Santos e Presidente Prudente), with the software Arquitrop 3.0 in a one-storey housing. Was observed that in winter and summer the typologies analyzed, the panels thickness variation had more influence about results than different concrete densities. The minimum level of thermal performance (M) in winter has been granted for some cities, with exception of Santos. In summer one of São Paulo city's typology was attended the minimum level of thermal performance in agreement with standard "NBR 15575 Residential buildings up to five storied – Performance, Part 1: General requirements".

Keywords: Thermal performance; Low-cost one-storey housing; Cast-in-place monolithic panels of concrete.

Resumo

Neste artigo apresenta-se a avaliação do desempenho térmico de uma tipologia habitacional térrea (TI24A) executada pela CDHU - Companhia de Desenvolvimento Habitacional e Urbano do Estado de São Paulo, utilizando o sistema construtivo de painéis monolíticos de concreto moldados in loco, com painéis de diferentes espessuras (8, 10 e 12 cm) e massas específicas variando entre 1600 e 2400 kg/m³. Analisou-se especificamente a influência dos tipos de vedação no desempenho térmico de habitações sem laje. Foram determinados os critérios iniciais de estudo (definição da tipologia habitacional térrea, levantamento de dados comportamentais dos usuários e determinação das cidades) e executadas simulações computacionais (inverno e verão), para 4 cidades do Estado de São Paulo (São Paulo, São Carlos, Santos e Presidente Prudente), empregando o software Arquitrop 3.0. Observou-se que para inverno e verão, nas tipologias térreas analisadas, a variação de massa específica do concreto pouco influenciou nos resultados, já a variação das espessuras dos painéis representou maiores diferenças nas temperaturas internas. Para o inverno foi atendido o nível mínimo de desempenho térmico para grande parte das cidades, com exceção de Santos. Para o verão, somente para a cidade de São Paulo o nível mínimo de desempenho térmico foi atendido de acordo com a norma "NBR15575-1 Edifícios habitacionais de até 5 pavimentos – Desempenho, Parte 1: Requisitos Gerais".

Palavras-chave: Desempenho térmico; Habitação térrea de interesse social; Painéis de concreto moldados *in loco*.

[a] *Architect and Urbanist, MSc in Architecture, Urbanism and Technology by EESC/USP, Civil Engineering PhD Student at University of Minho, hmsacht@civil.uminho.pt, Building Physics and Construction Technologies Laboratory (LFTC), Campus de Azurém, 4800-058, Guimarães, Portugal.*

[b] *Associate Professor, Biossystems Engineering, University of São Paulo, School of Zootechny and Food Engineering FZEA-USP, rossignolo@usp.br, Av. Duque de Caxias Norte, 225 – ZEA/Campus da USP - 13635-900, Pirassununga-SP, Brazil.*

[c] *Architect and Urbanist, MSc in Architecture, Urbanism and Technology by EESC/USP, Architecture and Urbanism PhD Student at EESC/USP, cbueno@sc.usp.br, Department of Architecture and Urbanism, Sao Carlos Engineering School (EESC/USP), Av. Trabalhador São-carlense, 400, 13566-590, São Carlos - SP, Brazil.*

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1. Introduction

Building systems applied to the production of partitions in most Brazilian building constructions have a high wastage index of manpower, materials and components due to the use of non- rationalized techniques. Besides its function of dividing the environment into compartments, the building partition system should also protect it as well as the building installations, create housing conditions and meet the structural function or part of it, when these partitions are designed for that structural function, as in the case of structural masonry.

This research focuses on a rationalized building system of cast-in-place monolithic concrete panels shown in Figures 1 and 2. This system, which has been used in Brazil since the 80s, brings innovations in frames settlement, and partitions and building systems execution. The reinforced concrete partitions, i.e. those that have structural function, are shaped *in situ* by using double mold, and can incorporate part of the building systems and frames installations during the production process.

According to Lordsleem Junior [1], the cast-in-place massive monolithic panel can be defined as an element of the laminar format partition subsystem, obtained by molding the material into its place of final use. It is further characterized as being monolithic, i.e., it can distribute its efforts across the wall when requested.

The characteristics of the concrete, particularly the workability, applied to this building system, have a key role in the execution and performance of the partition panels. The traditional concrete is usually applied to multi-storey buildings and the cellular lightweight concrete is used for one-storey ones. To be used in this construction system, the concrete must provide adequate workability for casting (reduction in the truncated cone usually above 150 mm); compressive strength above 1.0 MPa between 8 and 12 hours to allow de-forms with no damage to panels, compressive strength in 28 days according to the structural design and environmental exposure, and durability in accordance with the fixed project lifespan.

1.1 Brief History of the Construction System

In 1966, the creation of the National Housing Bank – BNH, brought large housing programs in the 70's. Following the "industrialization" philosophy, the construction sector was boomed until the beginning of that decade, starting to show depletion signs at the end of that period. In the 80s, with the extinction of BNH and the housing policy redirection, there was a new position in the buildings market. In that period new technologies were imported and there was a growing interest of the builders and material producers in unconventional construction processes. The companies then embarked on a quest to rationalize the buildings production through the optimization of the construction activities, deadlines reduction, and costs minimization, without implying a productive base disruption which characterizes this subsector [2].

Among the building systems developed in that period stands the constructive system of cast-in-place monolithic panels. Among these constructive processes that were consolidated in the 80s, only the masonry and the Outinord system showed advancement potential. Outinord is an industrialized system which allows the construction through the use of tunnel-type metallic molds. It has a "half-tunnel" form composed of a vertical panel and a horizontal one supported by a structure. This basic element may receive other components to meet the structure´s particular needs. Facing the modernization required by the building construction subsector since the 80's, one of the alternatives has been the rationalization of vertical partitions by improving the cast-in-place monolithic panel constructive system.

1.2 Assessment of Social Housing Thermal Performance

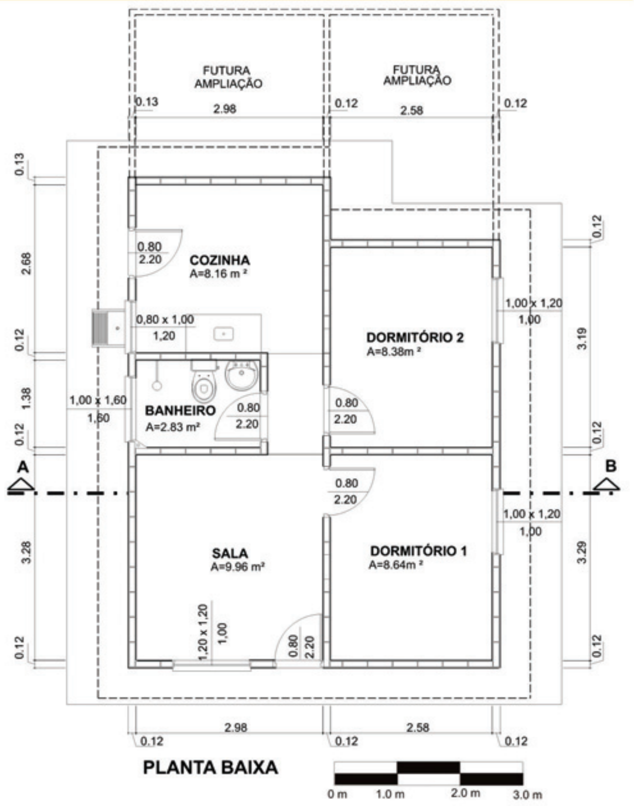
In most cases, the repetition of standard designs for housing intended for low-income population has unnecessary expenses on electricity and poor conditions of hygiene and comfort. This is due

Figure 1 – Overview of the system formwork, Santa Maria da Serra-SP (10)

Figure 2 – Housing and walls constructed (10)

to the low quality of construction systems and the unmet needs of their users, especially regarding thermal comfort conditions [3]. Several surveys in terms of both computational simulations and local measurements have been carried out to evaluate the performance of these types of dwellings often located in cities without worrying about architecture adaptation to the local climate, thermal comfort and energy consumption rationalization. These surveys have confirmed that the analysis of thermal performance of building systems is a key issue in designing and assessing social housing units.
The assessment of the thermal performance of a prototype housing can prove that by making simple designs and choices of materials it is possible to develop an affordable housing with better thermal performance, without having to necessarily invest far more resources than those already spent on the existing buildings of similar use [4].
For this purpose, energy simulation software can be applied. This software normally works with three main groups of variables, combining a number of parameters that influence the thermal performance of the building: local climatic variables, design variables and use and occupation variables. The latter allow great refinement regarding the thermal exchanges between internal and external environment, which occur through the elements of opaque and translucent envelope [5].
Rauber et al [6] presented a comparative analysis of three different computer programs to verify the user's interface and compare the results of each program. The simulation performed in the ARQUITROP software, which was used in this study, showed good agreement among the results.

Figure 3 – Design CDHU – Housing Standard TI24A (3)



1.3 Justifications

Although the constructive system of cast-in-place monolithic panels provides greater productivity and less waste than the traditional partition systems (e.g. masonry), for the consolidation of its use some studies of the properties of concrete to be used, as the density and thickness of the partitions according to the location of the building are still needed. These characteristics are directly associated with thermal performance issues. According to NBR 15575-1 [7] the improvement in construction systems available to social housing, as well as the development of new systems are required to contribute to the housing production at low cost, meeting the users' demands.

1.4 Objectives

This paper presents the assessment of the thermal performance of a one-storey housing typology (TI24A) without slab, in the design phase, executed by the Company for Housing and Urban Development of São Paulo State (CDHU), considering the use of concrete panels with assorted density and thickness values.

2. Materials and Experimental Program

The assessment was based on the recommendations of Annex E (levels of thermal performance) of the "NBR 15575-1 Housing Buildings up to 5 floors - Performance, Part 1: General requirements" standard [7]. The description of such procedures is presented below.

2.1 Initial Criteria of Research

The definition of the initial criteria for the research included the data used in thermal performance computer simulations of dwellings, comprehending the definition of the one-storey housing typology to be analyzed based on the typology constructed by CDHU at the time of the research development, the survey of behavioral data from users, and finally the determination of the cities representing the four bioclimatic regions in the state of Sao Paulo, in accordance with NBR 15220 [8].

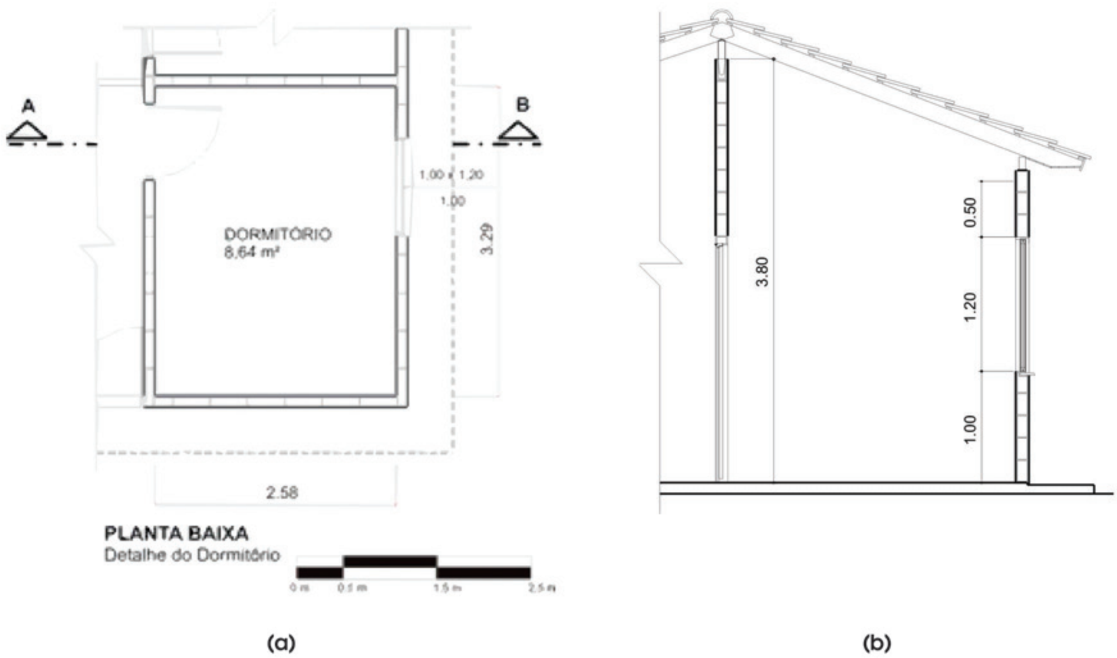
2.2 Determination of the One-storey Housing Typology

In consultation with CDHU [9] [10] [11] it was found that the most built one-story housing typology was TI24A, therefore it was chosen for this research (Figures 3 and 4).

2.3 Characteristics of Concrete Panels

The simulations used concrete panels with densities of 1600, 1800, 2000, 2200 and 2400 kg / m³ covering typologies from lightweight concrete (within lightweight aggregate) to traditional concrete and thicknesses of 8, 10 and 12 cm.

Figure 4 – Bedroom details of CDHU Design – Housing Standard TI24A (a) and a section of TI24A-CDHU typology with tile roof without slab (b) (3)



For the concrete production, the following materials, whose data subsequently entered the simulation software, were used: Portland cement within blast furnace slag (CPII E32) manufactured by CIMIN SA (Holdercim group), with 2.96 g/cm³ density and Blaine specific area of 4023 cm²/g; Metakaolin mineral additive, with 2.65 g/ cm³ density, surface area of approximately 327,000 cm²/g and SiO_2 content of 51.6% of natural quartz sand, basaltic gravel 01 and two types of expanded clay, Cinexpan 0500 (D_{max} = 5.0 mm) and Cinexpan 1506 (D_{max} = 12.5 mm) (Table 8) and Glenium 51 superplasticizer (polycarboxylate) with density between 1.067 and 1.107 g/cm³ and solids content between 28.5 and 31.5%. Table 1 presents the characteristics of the aggregates used in these concretes.

2.4 Survey of Users' Behavior Data

For the execution of computer simulations it was necessary to adopt some exact variables related to the occupancy and ventilation conditions, required by ARQUITROP 3.0 software, to obtain more accurate information about the behavior of social housing residents, making the results closer to reality. These data were obtained through interviews with 70 households, 43 of them in the Valdomiro Lobbe Neto Neighborhood and 27 in the Romeo Santini one, both in the city of São Carlos-SP. Even conducting this survey only for the city of San Carlos, it would allow for greater precision in the simulations if the variables related to occupancy and ventilation were only estimated.

Table 1 – Characteristics of Aggregates

Aggregate	D_{max} (mm) NBR7211	Density (g/cm³) NBR9776	Unitary Density (g/cm³) NBR7251	Water Absorption (% mass)	
				30 min.	24 hs
Sand	2,4	2,63	1,49	-	-
Basaltic Gravel 01	19,0	2,87	1,32	-	-
Expanded clay 0500 (CINEXPAN 0500)	5,0	1,51	0,86	1,8	6,0
Expanded clay 1506 (CINEXPAN 1506)	12,5	1,11	0,59	2,7	7,0

Table 2 – Cities adopted for the simulation of housing thermal performance

Cities	Climatic Zone
São Paulo – SP	3
São Carlos – SP	4
Santos – SP	5
Presidente Prudente – SP	6

2.5 Determination of the Cities for Computer Simulations

This paper presents the simulations data for one-storey dwellings of four cities (São Paulo, São Carlos, Santos and Presidente Prudente) in São Paulo State (Table 2). Their choice is justified by the intention of evaluating four different bioclimatic regions in the same state.

2.6 Assessment of the Thermal Performance of Buildings by Computer Simulations

The simulations were performed using the ISO 15575-1 guidelines and recommendations as parameters. Under the latter standard, the thermal performance assessment of buildings in the design phase must be made on critical project days for summer (December 22) and winter (June 22), using climatic data of the city, which, in this case, had already been included in the software database. The orientation of the housing units exposure was set according to ISO 15575-1 recommendations, which state in summer the bedroom window is in the west façade and the other opened wall is in the north façade, and in the winter the window is in the south façade and the other exposed wall is in the east façade.
ARQUITROP software, version 3.0, developed by Roriz and Basso [12], was used for the computer simulations. It is an integrated system of routines and databases to support project activities in architecture and engineering, aiming at thermal comfort and energy efficiency in buildings. Although this software has some limitations, it attended the simulated building typologies as it simplified the input data. It is possible to observe that in the early versions (projects) of the NBR 15575 standard, which were used in the simulation phase of this research, it was not necessary to use Energy Plus software as it was in the final version of the standard, published in May, 2008. In this research we adopted the bedroom as a standard environment for analysis, due to the larger permanence of the users in this environment (according to the users' behavioral data survey) and also aiming at the simplification of the analysis process.
The input data required by ARQUITROP 3.0 software are ceiling height, number of exposed façades, ventilation area, period of ventilation, solar orientation, glazing area, solar shading, room dimensions, façade painting colors, occupation, heat source equipment, materials, location, and air changes.

2.7 Levels of Performance

The performance levels were adopted in accordance with tables 2 and 3 of Appendix E of NBR 15575-1 standard and evaluated for each location. For both winter and summer conditions, the performance levels must be understood (Tables 3 and 4) as follows:
Performance Level M (Minimum) - It is the minimum performance level that must be met for acceptance (internal thermal conditions cannot be worse than the external ones).
Performance Level I (Intermediate) – It meets performance levels beyond the minimum requirements and its attendance is optional.
Performance Level S (Superior) – It exceeds the intermediate performance level and its attendance is also optional.
Performance levels I (Intermediate) and S (Superior) that exceed M (minimum) are determined in the standard considering the possibility of improving the quality of the building. In the analysis of the computer simulation results the criteria presented above were considered for both winter and summer.

3. Results and Discussion

3.1 Survey of Users' Behavior Data

From the data obtained in the interviews it was determined that the average number of occupants per environment was two, the start time of occupation was 9:00pm and its duration was 9 hours. Regarding ventilation, the window opening hours were from 9:00am

Table 3 – Criteria for thermal performance evaluation for winter (2)

Performance Level	Criteria	
	Bioclimatic Zones 1 to 5[1]	Bioclimatic Zones 6, 7 and 8
M	$T_{i,\,min} \geq (T_{e,\,min} + 3°C)$	For these zones it is not necessary to evaluate this criterion.
I	$T_{i,\,min} \geq (T_{e,\,min} + 5°C)$	
S	$T_{i,\,min} \geq (T_{e,\,min} + 7°C)$	

$T_{i,\,min}$ – minimum value for indoor daily temperature in °C;
$T_{e,\,min}$ – minimum value for outdoor daily temperature in °C;
NOTE: Bioclimatic Zones according to ABNT NBR 15220-3.

Table 4 – Criteria for thermal performance evaluation for summer (2)

Performance Level	Criteria	
	Bioclimatic Zones 1 to 7[1]	Bioclimatic Zone 8
M	$T_{i,max} \leq T_{e,max}$	$T_{i,max} \leq T_{e,max}$
I	$T_{i,max} \leq (T_{e,max} - 2°C)$	$T_{i,max} \leq (T_{e,max} - 1°C)$
S	$T_{i,max} \leq (T_{e,max} - 4°C)$	$T_{i,max} \leq (T_{e,max} - 2°C)$ e $T_{i,min} \leq (T_{e,min} + 1°C)$

$T_{i,\,max}$ – maximum value for indoor daily temperature in °C;
$T_{e,\,max}$ – maximum value for outdoor daily temperature in °C;
NOTE: Bioclimatic Zones according to ABNT NBR 15220-3.

to 10:30pm, i.e., the windows were open for approximately 13.5 hours. These data on the occupancy condition and ventilation of the dwellings were extremely important for better accuracy in the computer simulations.

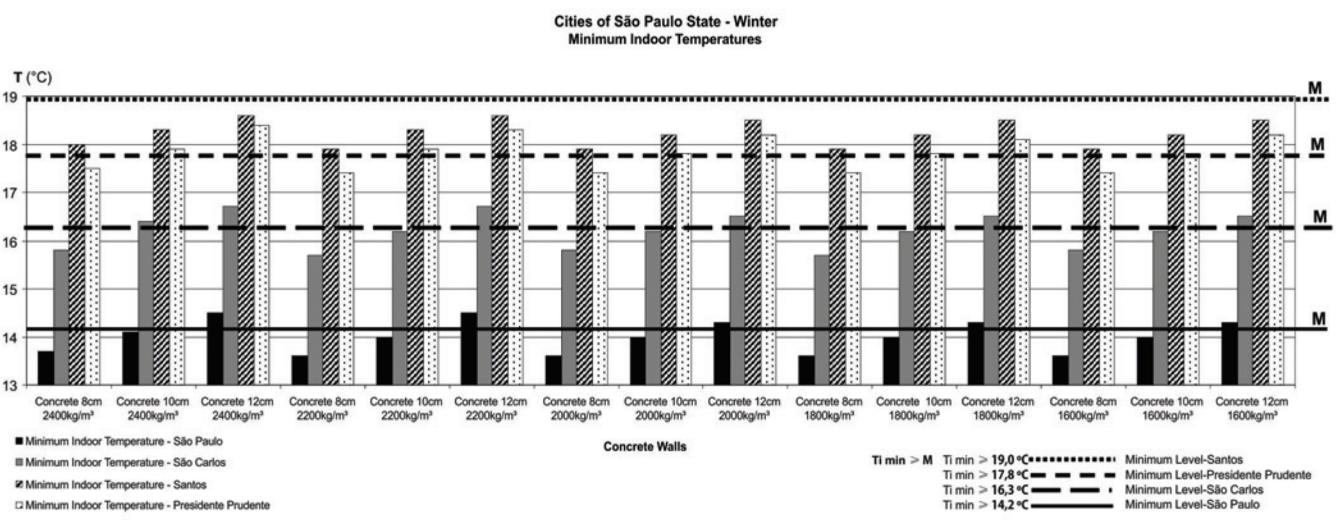
3.2 Results of Computer Simulation for Winter

From the results of computer simulations the tables of hourly variation of minimum temperatures inside and outside of the building (winter and summer) were obtained. The simulation results are shown in a diagram form in Figure 5.
Table 5 presents the temperatures according to performance levels per city and the season to support winter analysis.
Analyzing the results in Figure 5, it was possible to observe that, for winter, at least the minimum level of performance (M) (T indoor minimum ≥ T outdoor minimum + 3ºC) was reached in some locations. In São Paulo, the typologies with 12 cm thick panels met the minimum level of performance, independently of their density. In Sao Carlos all typologies which used 12 cm thick panels met the minimum level of performance, and the typology with 2400 kg/m³ density and 10 cm thick panels also met the minimum level of performance. In the city of Santos, no level of performance was reached for winter. In Presidente Prudente, although the check for winter was unnecessary, the minimum level of performance was reached for all typologies of panels analyzed.

3.3 Results of Computer Simulation for Summer

Figure 6 presents the results of computer simulations for summer. Table 6 presents the indoor temperatures for the analysis of the computer simulation results for summer.
According to the diagram in Figure 6, it was possible to observe

Figure 5 – Results of Thermal Simulations for Winter



that, for summer, even the minimum performance level was not reached for the studied localities, except for São Paulo, where the typology with 12 cm thick panels and density of 2400 kg/m³ was the only one to meet the minimum level of performance (M) (T indoor maximum ≥ T outdoor maximum).

3.4 General Analysis of Results

During this research it was not possible to follow the development of the NBR 15575 standard. From the results of computer simulations, it was observed that the requirements of the thermal per-

Table 5 – Indoor temperature for winter analyses

Performance Level per City – Winter			
Cities	M	I	S
São Paulo	$T_{i\,min} \geq 14{,}2$ °C	$T_{i\,min} \geq 16{,}2$ °C	$T_{i\,min} \geq 18{,}2$ °C
São Carlos	$T_{i\,min} \geq 16{,}3$ °C	$T_{i\,min} \geq 18{,}3$ °C	$T_{i\,min} \geq 20{,}3$ °C
Santos	$T_{i\,min} \geq 19{,}0$ °C	$T_{i\,min} \geq 21{,}0$ °C	$T_{i\,min} \geq 23{,}0$ °C
Presidente Prudente	$T_{i\,min} \geq 17{,}8$ °C	$T_{i\,min} \geq 19{,}8$ °C	$T_{i\,min} \geq 21{,}8$ °C

* $T_{i\,min}$ is the minimum value for indoor daily temperature in winter in °C.

Figure 6 – Results of Thermal Simulations for Summer

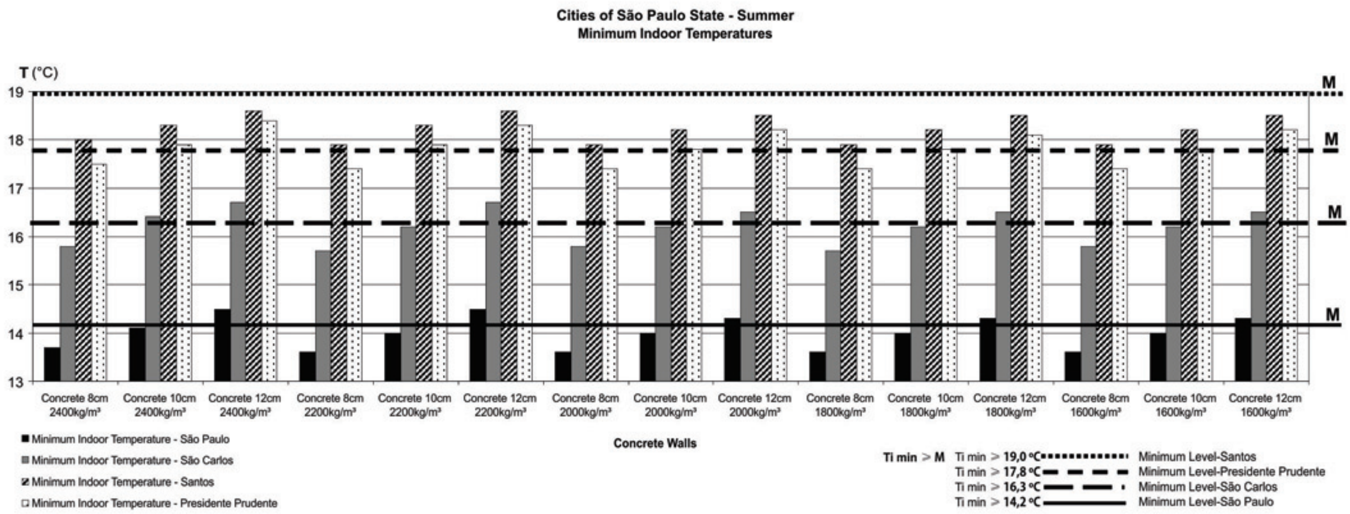


Table 6 – Indoor temperature for summer analyses

Performance Level per City – Summer			
Cities	M	I	S
São Paulo	$T_{i\,max} \leq 25{,}9$ °C	$T_{i\,max} \leq 23{,}9$ °C	$T_{i\,max} \leq 21{,}9$ °C
São Carlos	$T_{i\,max} \leq 26{,}9$ °C	$T_{i\,max} \leq 24{,}9$ °C	$T_{i\,max} \leq 22{,}9$ °C
Santos	$T_{i\,max} \leq 27{,}5$ °C	$T_{i\,max} \leq 25{,}5$ °C	$T_{i\,max} \leq 23{,}5$ °C
Presidente Prudente	$T_{i\,max} \leq 30{,}2$ °C	$T_{i\,max} \leq 28{,}2$ °C	$T_{i\,max} \leq 26{,}2$ °C

* $T_{i\,max}$ is the maximum value for indoor daily temperature in summer in °C.

formance (M, I and S) of the final version used in this research (May 2007) were more rigorous than those of the original version used (October 2002). There were changes in the performance parameters, specifically the requirements for the minimum (winter) and maximum (summer) indoor temperature values, making these parameters more rigorous, especially in relation to winter temperatures. Therefore, it can be generally observed in the results that only the minimum level of performance was met by the analyzed typologies.
The influence of the panel thickness on the simulation results can be explained by the thermal conductivity (W/m²), a phenomenon of heat thermal transfer caused by a temperature difference between two regions in the same environment, or between two environments in contact [13]. Such a heat exchange occurring through the material (concrete) and combined with the superficial heat exchange (interior and exterior) results in the heat transfer coefficient U (W/m²ºC), which quantifies the ability of the material to be traversed by a heat flow induced by a temperature difference between two environments.
The fact that the concrete thickness of 12 cm stands out in terms of thermal performance can be explained by the intensity of the heat flow by conduction (W/m²), which is inversely proportional to the thickness of the wall. Thus, the greater the thickness of the wall, the lower the intensity of heat flow and, consequently, the smaller the heat exchange by conduction between the internal and external environments. In addition, the heat transfer coefficient U (W/m²ºC), which comprises heat exchanges on the inner surface through the material and on the outer surface is also inversely proportional to the thickness, and the lower this value, the larger the insulating ability of the wall.
The observed cases of "noncompliance" regarding the thermal performance requirements in accordance with NBR 15575-1, especially for summer, can be explained by an increase in the indoor temperature due to the absence of slab in the roofing system. This factor exerts a strong influence on the thermal comfort conditions. In other cases examined, the use of slab caused a fall in the dwellings indoor temperature in summer, as the ceramic tile combined with a horizontal partition creates an attic and the accumulated air between the tiles and the slab acts as a thermal insulator. According to Sacht [14] [15], the results for simulations of the same typology considering the use of a flat slab showed an indoor temperature reduction of around 1-2 ºC in summer.
It was possible to observe that for winter, in three out of the four cities examined, the parameter for the proper indoor temperature was below the values normally found in the literature. In accordance with the standard, the following typologies are appropriate: typologies with temperatures above 14.2°C in Sao Paulo; typologies with temperatures above 16.3°C in San Carlos; typologies with temperatures above 17.8°C in Presidente Prudente. However, according to studies by Givoni [16], these values should be above 18°C.
It is important to note that the fact that a certain typology does not meet the performance levels established by the norm can be circumvented by the use of additional features, mainly passive solutions to climate adaptation where possible. Although this research is about social housing, and complex solutions may imply additional expenses, regarding different performances according to the season, climate adaptation is recommended for the most rigorous season of the locality.

4. Conclusions

In the simulations performed in this study it was possible to observe that, for winter and summer, in the one-storey typologies analyzed, the use of different densities for the concrete exerted only a little influence on the results. On the other hand, the variation in the thickness of panels represented major differences in the indoor temperatures for all these typologies, as the increase in the wall thickness implies a lower intensity of the heat flow and, consequently, a decrease in the heat transfer by conduction between the internal and external environments.
For winter at least the minimum level of performance (M) (T indoor minimum ≥ T outdoor minimum + 3ºC) was reached for most localities, except for the city of Santos. The highlights were the typologies using concrete partitions with higher densities and thicknesses, with a little higher temperature.
The thermal performance conditions for summer, in most cases, did not meet the ISO 15575-1 minimum requirements. For the city of São Paulo, only the typology with panels of 12cm thickness and density of 2400 kg m³ met the minimum performance level (M) (T indoor maximum ≥ T outdoor maximum), showing that, for this season, almost none of the types of panels used in one-storey dwellings without slab are appropriate regarding thermal performance.
Based on these results, it is important to note that the reproduction of housing typologies without a major concern about the regional specificities should be avoided. The elaboration of social housing designs suitable to the local climate and characteristics represents an improvement of human settlements and life quality in the Brazilian cities as well as benefits to the residents.

5. Acknowledgements

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