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UNIVERSIDADE Ð COIMBRA

Bruna Del Priore Croce

O Impacto de Diferentes Metodologias de Cálculo para Avaliação do Desempenho Térmico de Edificações. Casos de Estudo: Brasil e Portugal.

Dissertação de Mestrado intitulada "O impacto de diferentes metodologias de cálculo para avaliação do desempenho térmico de edificações. Casos de estudo: Brasil e Portugal.", realizados no âmbito do Mestrado Integrado em Engenharia Civil, na área de Especialização em Eficiência Acústica e Energética para uma Construção Sustentável, sob a orientação do Professor Doutor Nuno Albino Vieira Simões e apresentada ao Departamento de Engenharia Civil da Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

Março de 2022

Faculdade de Ciências e Tecnologia
da Universidade de Coimbra

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DISSERTATION AKNOWLEDGEMENTS

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ABSTRACT

Simulation for assessing buildings energy efficiency and performance is an integral part of the design process. Simulations are prediction tools that are extremely useful for evaluating design strategies and assessing environmental and energy impacts of each design decision, improving building energy efficiency and overall building performance. Different calculation procedures are used worldwide for assessing building thermal performance. In Brazil, ABNT NBR 15.575: 2021 represents an important regulatory system for ensuring performance standards of building systems, and its current procedures considers two alternatives for achieving thermal performance: simplified and detailed method through computational dynamic simulation. In Portugal, EN ISO 13790: 2008 is the current reference standard for characterizing buildings thermal performance. Seasonal calculation procedure indicated by this standard is applied. However, change is expected towards dynamic method since the publication of EN ISO 52016-1:2017, document that supersedes EN ISO 13790: 2008 and determines the removal of seasonal method.

In this study, calculation methods based on seasonal and dynamic simulations recommended by Brazilian and European standards are compared. For such purpose, residential case studies in both countries were carried out by use of calculation sheets and software Energy Plus. Methods were analysed and results compared for evaluating the impact of different calculation methodologies on determining thermal performance of buildings.

Overall conclusions show that dynamic simulation method according to NBR 15.575: 2021 presents less acceptable results when applied in Portugal: construction solutions equally applied in both case studies impact differently on results considering climate varieties. Despite differences, mandatory labelling level based on NBR 15.575: 2021 was reached for all simulated scenarios for both countries. Seasonal method applied in São Paulo also showed satisfactory results for all simulated scenarios, particularly for predominantly north-oriented façades. Energy labelling according to Portuguese REH and Dispatch (extract) No. 15793-J: 2013 ranged to B- to B, when replacing glazing surfaces with more efficient thermal transmittance (U) and solar factor (*g-value*). When assessing Lisbon case study through seasonal method, results are particularly acceptable for south orientation, but only when applying ETICS on façades and replacing glazing thermal parameters. Energy classification in Portuguese case study ranges from E to C on north façades and from D to B on south façades.

Key words: Energy, Buildings Performance, Thermal Simulation, Seasonal Method, Dynamic Simulation.

SUMMARY

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GENERAL NOMENCLATURE

BZ – Bioclimatic zone;
U – Thermal transmittance ($W/m^2.K$);
α – Solar radiation absorptance;
g-value – Solar factor;
gtot – Global solar factor;
ρ – Mass density (kg/m^3);
λ – Thermal conductivity (W/m.K);
c – Specific heat (kJ/kg.K);
R-value – Thermal resistance ($m^2.K/W$).

DYNAMIC METHOD NOMENCLATURE

APP – rooms with long occupancy;
APT – rooms with transient occupancy;
UH – housing unit;
$PHFT_{,APP}$ – percentage of occupation hours of APPs within an operating temperature range (%);
$PHFT_{,UH}$ – percentage of occupation hours of the UHs within an operating temperature range (%);
NhFT – number of hours in which the APP is occupied and with operating temperatures within an operating temperature range;
NhOcup – number of hours in which the APP is occupied throughout the year, equivalent to 2 920 hours for living-rooms and 3 650 h for dormitories;
$Tomax_{,APP}$ – maximum annual operative temperature of APPs (ºC);
$Tomax_{,UH}$ – minimum annual operative temperature of APPs (ºC);
$Tomax_{,UH}$ – maximum annual operative temperature of UHs (ºC);
$Tomin_{,UH}$ – minimum annual operative temperature of UHs (ºC);
$\Delta tomax$ – tolerance value for the maximum annual operating temperature, in ºC;
$\Delta tomin$ – tolerance value for the minimum annual operating temperature, in ºC;
$Pt_{,APP}$ – percentage of transparent elements of APPs (%);
$CgTR_{APP}$ – thermal cooling load of APPs expressed in kilowatt-hours per year (kWh/year);
$CgTA_{APP}$ – thermal heating load of APPs expressed in kilowatt-hours per year (kWh/year);
$CgTR_{,UH}$ – thermal cooling load of UHs expressed in kilowatt-hours per year (kWh/year);
$CgTA_{,UH}$ – thermal heating load of UHs expressed in kilowatt-hours per year (kWh/year);
$CgTT_{,UH}$ – total thermal load of UHs expressed in kilowatt-hours per year (kWh/year).

SEASONAL METHOD NOMENCLATURE

γ – Dimensionless parameter related to the building thermal balance;
ηg – Utilization factor;
ηk – System k efficiency;
a – Dimensionless parameter which depends on the building thermal inertia;
Ap – Treated floor area (m^2);
$E_{ren,p}$ – energy produced by renewable sources p, (kWh / year);
$f_{a,k}$ – Fraction of domestic hot water energy needs supplied by the system k;
$f_{i,k}$ – Fraction of heating energy needs supplied by the system k;
$f_{v,k}$ –Fraction of cooling energy needs supplied by the system k;
GD – Heating degree-days ($°C$ · days);
$G_{sol,j}$ – Monthly average of incident solar energy on a surface with orientation j;
G_{sul} – Average of incident solar energy on a south vertical surface;
$H_{tr,i}$ – Heat transmission coefficient (W / °C);
M – Length of the heating season (month);
N_i - Maximum limit of the heating energy needs (kWh / m^2 · year);
N_{ic} – Annual heating needs (kWh / m^2 · year);
N_{TC} – Primary energy ($k$$Wh_{EP}$ / m^2 . year);
N_T – Maximum limit of primary energy ($k$$Wh_{EP}$ / m^2 . year);
Nv – Maximum limit of the cooling energy needs (kWh / m^2 .year);
N_{VC} – Annual cooling energy needs (kWh / m^2 · year);
Q_a – Domestic hot water energy needs (kWh / m^2 · year);
Q_g – Total solar and internal gains (kWh);
$Q_{gu,i}$ – useful heat gains which occur during the heating season (kWh);
$Q_{tr,}$ – transmission heat losses through the envelope (kWh);
$Q_{ve,}$ – heat losses by air renovation (kWh);
$Q_{sol,}$ – solar gains (kWh);
$H_{ve,}$ – global coefficient of heat transmission by ventilation (W / °C);
$Q_{int,}$ – internal gains (kWh);
$Q_{g,i}$ – reference value for the total gains during the heating season (kWh);
$Q_{g,v}$ – reference value for the total gains during the cooling season (kWh);
$F_{pu,j}$ – conversion factor for primary energy (kWh_{EP} / kWh);
δ – fraction corresponding to overheating risk;
Wvm – electrical energy used by the ventilation system (kWh / year).

1 INTRODUCTION

The increasing demand of energy consumption and harmful CO_2 emission related to building sector indicates an urgent need for developing strategies to reduce environmental impacts associated with all stages of construction, from design, to manufacture of products, site construction and operation, such as the enormous amount of energy being consumed to run lighting, cooling, and heating devices. Buildings and construction sector globally accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO_2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement, and glass [1].

According to the International Energy Agency [2], transportation, industry and building sectors account today for the highest energy consumption in global economy and are expected to consume more than one-third of the global energy consumption by 2040. In Brazil, the National Energy Balance [3] states that the building sector corresponds to 51% of the country's total consumption. Actions to improve present-day situation and avoid future expectations of increased consumption are being discussed in Europe’s main environmental policy instruments: Energy Performance of Buildings Directive (EPBD) 2018/844/EU and the Energy Efficiency Directive 2018/2002/EU [4] approved by the European Parliament and of the Council, which requires nearly zero-energy building (NZEB) targets to stimulate the energy transition of buildings sector.

The amount of energy being consumed can be significantly reduced through measures appliable for new and existing buildings, for instance, by ensuring efficient construction systems and passive guidelines during design stages or establishing operational strategies for monitoring energy and water consumption.

Regarding the importance of evaluating thermal comfort and energy demand of building systems and construction solutions for orienting building design strategies, simulations are extremely useful prediction tools for assessing impacts of each decision, aiming at improving building energy efficiency and overall performance. Simulation is currently performed by different means in Brazil and Portugal, according to specific standards. In Brazil, NBR 15.575: 2013 and its amendment published in 2021 [5] represents an important regulatory system for ensuring performance standards of building systems. Its current procedures consider two alternatives for achieving thermal performance: simplified and detailed method through computational dynamic simulation. In Portugal, ISO 13790: 2008 [6] is the current reference standard for characterizing buildings thermal performance. Seasonal calculation procedure indicated by this standard is applied. However, change is expected towards dynamic simulation since the publication of ISO 52016-1:2017 [7], document that supersedes ISO 13790: 2008 and determines the removal of seasonal method.

This research aims to evaluate the impact of methodologies applied in Portugal and Brazil for assessing building energy efficiency and overall performance. For this purpose, calculation methods based on seasonal and dynamic simulations recommended by Brazilian and European standards are analysed and discussed for residential case studies in both countries.

1.1 State of art

An investigation of similarities and differences between prescriptive and simulation methods for buildings thermal performance assessment established in Brazilian standards NBR 15.220-3: 2005 [8], NBR 15.575: 2021, Blue House Label [9] and RTQ-R: 2012 (Technical Quality Regulation for Energy Efficiency Levels of Residential Buildings) [10] is proposed by Oliveira *et al* [11]. Authors also investigate issues for improvement on the suitability and sustainability analysis of buildings located in different bioclimatic zones in Brazil. The study states that all current Brazilian regulations present prescriptive method for building performance evaluation that considers envelope thermal performance, use of natural ventilation, crossed ventilation and daylighting in rooms with long occupancy. These previsions are shown in Table (1).

Table 1 – Requirements for the prescriptive method according to Brazilian standards. (Source: Oliveira *et al* [11], adapted by the author)

Requirements	Standards	Limits required
Thermal performance of walls	RTQ-R and Blue House Label	TC ≥ 130 kJ / (m².K) (BZ1 to 7); U ≤ 2.5 (BZ1 and 2); U ≤ 3.7 for α ≤ 0.6 (BZ3 to 8); or U ≤ 2.5 for α > 0.6 (BZ3 to 8).
	NBR 15.575	TC ≥ 130 kJ / (m².K) (BZ1 to 7); U ≤ 2.7 (BZ1 and 2); U ≤ 3.7 for α ≤ 0.6 (BZ3 to 8); or U ≤ 2.5 for α > 0.6 (BZ3 to 8).
	NBR 15.220	TC does not apply. U ≤ 3.0; φ ≤ 4.3h; SF_o ≤ 5.0% (BZ1 and 2); U ≤ 3.6 φ ≤ 4.3h SF_o ≤ 4.0% (BZ3, 5 and 8); U ≤ 2.2 φ ≥ 6.5h SF_o ≤ 3.5% (BZ4, 6 and 7).
Thermal performance of roofs	RTQ-R, NBR 15.575 and Blue House Label	U ≤ 2.3 (α does not apply for BZ1 and 2) for α ≤ 0.6 (BZ3 to 6) and for α ≤ 0.4 (BZ7 and 8); and U ≤ 1.5 (α does not apply for BZ1 and 2) for α > 0.6 (BZ3 to 6) and for α > 0.4 (BZ7 and 8).
	NBR 15.220	U ≤ 2.0; φ ≤ 3.3h; SF_o ≤ 6.5% (BZ1 to 6); U ≤ 2.3; φ ≤ 3.3h; SF_o ≤ 6.5% (BZ8, in this case if the attic is ventilated it must be considered a correction factor for U); U ≤ 2.0 φ ≥ 6.5h SF_o ≤ 6.5% (BZ7).
Natural ventilation parameter	RTQ-R	A_v ≥ 8 % (BZ1 to 6) A_v ≥ 5 % (BZ7) A_v ≥ 10 % (BZ8). Proportion of crossed ventilation is calculated by ratio A1/A2, where A1 is the total area for openings corresponding to the façade with greater number of openings and A2 is the total area of openings corresponding to the other façades. Required: A1/A2 ≥ 0.25 (BZ 2 to 8).

	NBR 15.575 and Blue House Label	A ≥ 7 % (BZ1 to 7) A ≥ 8 %, for the Northeast and Southeast Region or A ≥ 12% floor area, for the North Region of Brazil (BZ8). Crossed ventilation is required by dynamic method according to NBR 15.575.
	NBR 15.220	15% < A < 25 % (BZ1 to 6) 10% < A < 15% (BZ7) A > 40% (BZ8). Crossed in the summer (BZ2, 3 and 5). Crossed ventilation selective in summer (BZ4, 6 and 7) and permanent crossed for BZ8 (Does not apply to BZ1).
Percentage of transparent elements and daylighting parameter	RTQ-R	A ≥ 12.5 % for all bioclimatic zones.
	NBR 15.575	Floor areas ≤ 20 m^2 : Pt = 20 %; Floor areas > 20 m^2 : At < 4,0 m^2 * For BZ 3 to 8, there are also provisions for determining Pt according to SF_o of glazings.
	Blue House Label	A ≥ 7% (BZ1 to 7) A ≥ 8% for the Northeast and Southeast Region or A ≥ 12% for the North Region of Brazil (BZ8).
	NBR 15.220	Does not apply.
Where: U – Thermal transmittance, in W/ (m².K); CT – Thermal capacity, in kJ / (m².K); α – Solar absorptance; φ – Thermal delay, in hours; SF_o – Solar factor; FT – Transmittance correction factor (dimensionless); A_v – Percentage of the window opening area compared to the floor area of the room (%); Pt – Percentage of transparent elements (%); At – Area of transparent elements (m^2).		

In a final practical phase, the applicability, standardization, accuracy, and consistency of requirements established on Brazilian regulation concerning residential buildings thermal performance was discussed. The authors state that Brazilian thermal performance standards present different limits from each other in prescriptive methods and distinct procedures for building simulation (i.e., dynamic calculation procedures are only required by NBR 15.575 and RTQ-R, while other regulations deal only with prescriptive methods). Adjustments are recommended in the study to equalize requirements presented in all standards. For that purpose, authors suggest that NBR 15.575, the only mandatory standard, could bring prescriptive limit values to be adopted as a minimum. Whereas other regulations could address additional strategies: NBR 15.220-3 in determining calculation procedures and Bioclimatic Zoning, RTQ-R proposing level classifications according to energy performance and Blue House Label addresses sustainable and social criteria. Concerning building simulation method according to NBR 15.575, authors indicate that this standard shows insufficient criteria to ensure adequate conditions for human thermal comfort.

Different calculations methods of energy use for space heating and cooling in accordance with European standard instructions is discussed by Almeida [12]. Calculation methods described in this paper are:

A) Seasonal quasi-steady state method;
B) Simple hourly method;
C) Dynamic simulation method.

A comparative analysis of the studied methods applied to a common building case was undertaken to calculate annual energy needs for heating and cooling, considering different Portuguese climates (Algarve, Grande Lisboa e Alto Trás-os-Montes) and different typical Portuguese constructions. Simplified methods (seasonal and hourly method) were built on MS Office 2013 and dynamic simulation was created using program EnergyPlus v.2.03. Regarding annual energy requirements calculations, the study concludes that all methods are effective as their results were similar. Nevertheless, the author points to limitations when hourly method is applied to analyze daily variations of indoor air temperature due to thermal inertia: larger thermal amplitudes waves are observed with 1 ºC difference error fluctuation on daily temperature peaks in relation to dynamic simulation on Energy Plus.

Energy benefit of opaque ventilated façades compared to cladding façades in multi-floor residential buildings in Brazil was investigated by Maciel and Carvalho [13]. The authors divided methods in four parts: ensuring primary investigation on the subject through a systematic mapping of literature (SML) and verifying the best software BIM (Building Information Modeling) and BES (Building Energy Simulation) in terms of interoperability for thermal simulation of the case study. The authors performed several simulations for nine different climate regions and validated the collected data with a statistic tool. The study showed through bibliographic revision that the most comprehensive BES software to use with BIM models were IES-VE (software for Virtual Environment modelling from company Integrated Environmental Solutions) and GBS (Green Building Studio). Both can be plugged into BIM authoring tools. GBS software was used in the research. Building design used as case study was developed by the authors based on Brazilian residential standards and considering commonly used construction systems in the country. After the models were ready, several configurations were made following instructions of regulations NBR 15220-3: 2005, ASHRAE 90.1: 2019 [14], ISO 17772: 2017 [15] and NBR 15.575, providing reliability to the process. Outputs contents were analysed by statistical treatment. Data treatment was carried out for all cities for both heating and cooling seasons. As main contribution, this paper shows in detail that computational simulation by use of BES software GBS and IES-VE inter-operate satisfactorily in terms of data being generated, enabling broad samples and possibilities of analyses.

Based on the literature review findings, no studies discuss the new amendments of NBR 15.575 for thermal performance assessment of residential buildings and its comparison with calculation methodologies currently applied in Europe.

1.1.1 International standards

Standard ISO 13790: 2008 provided three methods for assessing building's annual heating and cooling energy needs: seasonal, hourly, and dynamic. Seasonal calculation procedure indicated by this standard is currently applied in Portugal.

Seasonal method is described in Regulation on Energy Performance of Housing Buildings (REH) and Dispatch nº 15793-I: 2013 [16] approved by Decree-Law nº 118: 2013 [17], in accordance with European standard ISO 13790: 2008. The same methodology was recently republished in Decree-Law nº 101 D: 2020 [18]. Seasonal method analyzes the total balance of thermal gains and losses to keep buildings at a certain interior temperature reference both for heating and cooling seasons. However, change is expected towards dynamic simulation since the publication of ISO 52016-1: 2017, document that supersedes ISO 13790: 2008 and determines the removal of seasonal method.

Standard ISO 52016-1: 2017 is applicable to buildings at design stage, to new buildings after construction and to existing buildings in operational stage. This regulatory instrument specifies calculation methods that can be used for residential or non-residential buildings for assessing:

a) (sensible) energy need for heating and cooling, based on hourly or monthly calculations;
b) latent energy need for (de-) humidification, based on hourly or monthly calculations;
c) internal temperature, based on hourly calculations;
d) sensible heating and cooling load, based on hourly calculations;
e) moisture and latent heat load for (de-) humidification, based on hourly calculations;
f) design sensible heating or cooling load and design latent heat load using an hourly calculation interval;
g) conditions of air supply to provide necessary humidification and dehumidification.

ISO 52016-1: 2017 also contains specifications for assessing thermal zones in buildings or in fractions of a building. Calculations are performed per thermal zone.

There are two main calculation procedures described by ISO 52016-1: 2017: monthly calculation and hourly calculation. Hourly calculation method aims at evaluating the influence of hourly and daily variations in weather, operation (solar blinds, thermostats, needs, occupation, accumulation, etc.) and their dynamic interactions for heating and cooling. In this case, each construction element is modelled separately. Whereas monthly calculation procedure aims at evaluating thermal balance of buildings at a monthly timespan. Dynamic effects are considered by correction and adjustment factors which can be developed based on calculations using the hourly calculation method.

Monthly and hourly calculation procedures are based in the same assumptions and boundary conditions of energy need for heating and cooling. Besides, the same inputs are used, although averaged on monthly basis and corrected to approximate the impact of dynamic effects and interactions that are not covered by monthly procedure.

1.1.2 Brazilian standards

Social housing programs in Brazil are controlled by Banking institutions as *Caixa Econômica Federal*. Aiming at more sustainable construction processes, this institution created a certification named *Selo Casa Azul* (Blue House Label) in 2010 [9]. The document aims at recognizing and encouraging projects that can reduce environmental impacts by considering topics which are presented in Table (2) and concern: urban quality and well-being, design and users' comfort, energy efficiency, sustainable products, social practices, and innovation. Mandatory criteria are identified with "X" symbol and correspond to categories to which "basic" level must attend. "Basic" column describes minimum score for attending mandatory criteria. Other labels are classified in "Bronze", "Silver", "Gold" and "Diamond" and can be achieved for higher scores.

Table 2 – Categories, criteria, and classification according to *Selo Casa Azul*.
(Source: *Selo Casa Azul* [9])

CATEGORIES / CRITERIA	Score Range		Mandatory	Basic	Bronze	Silver	Gold	Diamond
				Number of points				
1. Urban Quality and Well-Being								
1.1 Surrounding Quality – Infrastructure	4	4	X	≥ 24	≥ 50	≥ 60	≥ 80	≥ 100
1.2 Surrounding Quality – Impacts	3	3	X					
1.3 Waste separation	2	3	X					
1.4 Surrounding Improvements	2	3						
1.5 Recuperation of Degraded Areas	3	3						
1.6 Buildings Rehabitilitation	3	4						
1.7 Landscaping	2	3						
1.8 Leisure, Social, Well-being and Sports Equipment	3	4						
1.9 Adaptation to lands and topography	3	3						
1.10 Sustainable solutions for mobility	2	4						
2. Design and users confort								
2.1 Sun and wind orientation	3	3	X	≥ 20	≥ 50	≥ 60	≥ 80	≥ 100
2.2 Thermal and natural lightning performance	4	4	X					
2.3 Energy saving devices	2	2	X					
2.4 Individual Measurements – Gas	1	3	X					
2.5 Relationship with Neighboring	2	3						
2.6 Ventilation / Natural Lightning of Bathrooms	3	3						
2.7 Solar heating system	4	4						
2.8 Renewable energy	3	5						
2.9 Efficient Lifts	2	2						

3. Energy efficiency								
3.1 Water saving devices	3	3	X	≥ 15	≥ 50	≥ 60	≥ 80	≥ 100
3.2 Individual Measurements – Water	3	3	X					
3.3 Permeable areas	4	4	X					
3.4 Gray water reuse	4	5						
3.5 Rain water reuse	4	4						
3.6 Rainwater retention / infiltration	3	3						
4. Sustainable products								
4.1 Waste management (RCD)	3	3	X	≥ 15	≥ 50	≥ 60	≥ 80	≥ 100
4.2 Reusable Molds and Props	1	3	X					
4.3 Certified timber	1	3	X					
4.4 Modular coordination	3	3						
4.5 Industrialized / Pre-fab. Components	3	3						
4.6 Paving with RCD	3	3						
4.7 Water management at works site	3	4						
5. Social practices								
5.1 Capacitation for Building Venture Management	2	2	X	≥ 15	≥ 50	≥ 60	≥ 80	≥ 100
5.2 Financial education and planning	2	2	X					
5.3 Mitigating community discomfort during construction	2	2						
5.4 Inclusion of local workers and suppliers	1	1						
5.5 Professional capacitation of workers	2	2						
5.6 Mitigation actions for social risks	3	3						
5.7 Workers environmental education	2	2						
5.8 Actions for jobs and income generation	2	2						
5.9 Actions for social integration of community	1	1						
5.10 Actions for post-occupation maintenance	3	3						
5.11 Security and health at work construction site	1	1						
6. Innovation								
6.1 Applying BIM for integrated management	3	3		≥ 10	≥ 50	≥ 60	≥ 80	≥ 100
6.2 Actions for reducing carbon emissions	5	5						
6.3 Efficient systems for building automation	3	3						
6.4 Connectivity	2	2						
6.5 Digital tools towards sustainable practices	3	3						
6.6 Possibility of adapting UHs to users' needs	3	3						
6.7 Others innovative proposals	3	10						
Bonus								
7.1 Bonus criteria	2	6		≥ 10	≥ 50	≥ 60	≥ 80	≥ 100

Another Brazilian standard towards buildings energy efficiency is RTQ-R. This document was created in 2010, modified in 2012 and is currently voluntary. It presents technical requirements and methods related to energy efficiency to evaluate and classify residential buildings. Classification criteria depends on buildings typology: housing units and multi-family buildings.

Building classification is based on the following topics: building envelope requirements – thermal transmittance (U), thermal capacity (CT) and solar absorptance (α) –, lighting and water heating systems. For each requirement, classification can range from level E (unsatisfactory efficiency) to A (excellent performance).

Regarding buildings construction systems and design strategies aiming at ensuring thermal performance, one of the main Brazilian regulatory instruments for such purpose is NBR 15.575: 2021. The document is a landmark in terms of housing regulation in Brazil and comprises quality standards by Brazilian Association for Technical Standards (*Associação Brasileira de Normas Técnicas, ABNT*). Unlike other Brazilian regulations, NBR 15.575 is mandatory and effectively came into force in 2013. The publication of NBR 15575 reinforces the need to comply with building quality and performance parameters by assigning responsibilities to those involved in the entire construction process (manufacturers, suppliers, designers, among others). NBR 15.575 was elaborated by Brazilian Civil Construction Committee (ABNT / CB-02) and by Building Performance Study Commission (CE-02: 136.01) and comprises six major areas subdivided into thirteen disciplines that refer to requirements used to measure buildings performance which is based on the safety, habitability, and sustainability guidelines.

Part 1 of NBR 15.575: 2021 recommends two methods for analyzing housing thermal performance: a simplified and a computational simulation method. NBR 15.575 refers to NBR 15.220, which was the first technical standard to include the topic of thermal performance in Brazil, published in 2005, and categorizes the national territory in eight different bioclimatic zones containing design recommendations for each zone.

Standard NBR 15.575 was recently revised (2021), and amendments were published to enhance thermal performance evaluation procedures. There were important updates in the following parts: part 1 - general requirements; part 4 - requirements for internal and external vertical seal systems; and part 5 - requirements for hedging systems. Current version must be applied for projects submitted for approval or licensing of competent environmental bodies from 180 days after the revised standard publication date (03/30/2021). Current evaluation of buildings thermal performance according to NBR 15.575: 2021 considers two alternatives for achieving thermal performance: simplified and detailed method through computational dynamic simulation. In case minimum performance is not achieved by simplified method, it is necessary to proceed to computational simulation.

A first analysis comparing simulation methods currently used in both countries shows differences on the outputs between Portuguese and Brazilian calculation methods: Portuguese method through seasonal calculation requires to assess energy need rates and Brazilian method through dynamic simulation requires to assess buildings performance by thermal comfort rates.

Ideally, both contents should be examined by methods described: the main content of the energy saving concept is to reduce energy consumption and improve energy efficiency, and this is related to the amount of energy required to keep thermal comfort, depending on climate conditions, room's type of use, envelope's characteristics, and solar radiation. Thus, contents complementary when assessing overall buildings thermal performance.

The importance of correlating thermal comfort and energy demand is discussed by [19], whose paper describes the influence of thermal parameters, namely conductivity, transmittance, and thermal mass, in estimating comfort and energy demand of a building with rammed earth walls. The study complies with ISO 9869, ASHRAE 55 and the Spanish Technical Code of Buildings, respectively for i) calculating transmittance values using the average method, ii) analysing comfort inside the room through adaptative model by considering the indoor operative temperature for naturally conditioned environments where no cooling or heating devices are in operation, and iii) meeting requirements of the Spanish Code in terms of energy savings by executing approximate calculations to analyse the behaviour of the building once it is in use. To achieve it, authors have used in-situ measurements for characterising thermal parameters of the construction solutions and monitored temperature and humidity in a room on the ground floor of the building, along with the outdoors dry-bulb temperature and relative humidity values to study the environmental conditions in the room and its surroundings during a whole year. In-situ results were used to analyse the correlation of four alternatives modelled in Design Builder using temperature as the variable of comparison, as it was the parameter that was measured for the whole period and that affects both comfort and energy demand of the room. Differences on all four simulated scenarios (S1 to S4) consisted of changing thermal parameters of conductivity and the consideration of thermal mass by the software: scenarios 1 and 2 consider thermal inertia and scenarios 3 and 4 do not consider it. When analysing comfort issues, the study showed that all four scenarios comply with ASHRAE standard limits for indoor comfort using the adaptative model in summer, and none of them in winter. Results show that the building model that uses in situ values and considers thermal mass (S1) is closer to reality when assessing thermal comfort. When focusing on energy demand, results are different among scenarios: S3 would require 30% more energy, S2 would require 73% more energy, and S4 would require 88% more total energy to reach comfort than S1. When analysing energy demand, the fact that there is little difference between considering thermal mass (S1 and S2) and not considering it (S3 and S4) leads to the idea that the calculation method used in the simulations did not take into account thermal inertia when evaluating energy demand. In conclusion, overall results show that using in situ measured parameters would lead to a better understanding of the behavior of traditional rammed earth buildings, and thus ease their compliance with energy saving standards. This way, authors encourage using the same methods in new buildings, for reducing carbon footprint due to materials used in construction and moving towards an ecological transition and sustainable development in buildings and construction sector.

In order to reduce energy consumption, realize the mapping of energy-saving concepts in buildings, and understand the energy consumption of different building materials and the influence of external factors on human thermal comfort, [20] conducted research on building thermal comfort based on energy-saving concepts. Firstly, the study introduces the concept and application mode of energy-saving concepts in buildings, thermal comfort and the SET index of standard effective temperature (based on the effective temperature and the new effective temperature, it is a comfort index that has been continuously verified and revised by several generations of researchers). In the experimental part, a model based on the concept of energy saving was designed to predict and analyze the energy consumption and thermal comfort effects of a building. In the analysis part, a comprehensive analysis of the effects of temperature, humidity, wind speed, and gender on thermal comfort, methods to improve thermal comfort, cumulative load changes with the heat transfer coefficient of windows, and the effects of windows of different materials on energy consumption was performed. By studying the thermal comfort of buildings based on energy-saving concepts, it was possible to obtain the effect of external factors on thermal comfort, thereby optimizing building materials and using building materials with lower heat transfer coefficients to reduce heating energy consumption. The authors conclude that external factors such as wind speed, temperature, and humidity have different degrees of influence on the thermal comfort of the human body. Among them, temperature has the greatest impact. The study also analyses the impact of windows of different materials on energy consumption: due to poor thermal insulation effect of inner windows in some buildings and weak shading performance, indoor solar radiation is higher in summer, which increases heat perception; while in winter, poor thermal insulation effects of the outer window results on a greater part of heat loss, meaning windows are very important to reduce heating load and air conditioning cooling load. This article's research on the thermal comfort of buildings based on energy-saving concepts has certain significance for the realization of energy-saving and emission reduction in buildings in China. At the same time, there are some shortcomings in this article: the study of materials used only selects the form for transformation research, which is not comprehensive enough. In addition, for energy conservation, the combination of the concept and the building is also not in place, and there is no certain optimization plan for energy saving. The authors hope that, with the in-depth study of building materials, this research can be further improved.

Building design must ensure that energy demands are as low as possible, while providing high demands on thermal comfort. This statement motivated research developed by [21], aiming at contributing to a better understanding of the effects of user-related energy demands on the total energy performance of a building, and the interaction of fully-automated and manual building systems, with regard to thermal comfort. For this purpose, post-occupancy investigations of energy demands and thermal comfort for a large-sized non-residential building were conducted for this study. The main findings are the following: i) user-related energy demands (URD) can have a significant influence on overall energy demand of a large-sized non-residential building, representing up to 41% of the total final energy demand; ii) primary energy demand of the investigated building was similar to the corresponding estimated target value and the decrease in primary energy demand achieved during the first three years of operation shows the significant impact of detailed building monitoring in general; iii) estimating heating demand is not highly accurate for large-sized office buildings, due to simplified assumptions required for the building simulations during the design stage; iv) a high level of thermal comfort was achieved using thermo-active ceilings. The desired comfort criteria were maintained for more than 97% of occupancy time throughout the year for the reference office spaces investigated; v) operating a building that relies on fully automated building systems in combination with manual systems controlled by the individual user can cause reduced thermal comfort due to unexpected user behavior; and vi) long-term building monitoring is recommended for any large-sized non-residential building that relies on a complex energy concept, in order to improve the interaction of building systems, and to operate the building at reasonable energy demands with correspondingly low CO2 emissions, and a high level of user comfort.

Having in mind issues related to thermal evaluation of buildings by computerized simulations, this thesis was motivated by the following questions:

- How applying Portuguese seasonal calculation method impacts on buildings energy demand in Brazil and what conclusions can be made when comparing results for both countries?
- How applying Brazilian dynamic calculation method impacts on buildings performance in Portugal and what conclusions can be made when comparing results for both countries?
- Considering the differences on the outputs between Portuguese and Brazilian calculation methods, namely energy need rates (seasonal) and indoor operative temperatures (dynamic), how can both output contents be related?
- Do construction solutions equally applied for both case studies have a similar impact on results considering climate differences between countries?

To obtain responses to these research questions a sequence of work tasks was performed, which are categorized in Sections 1.2 and 1.3.

1.2 Objectives

This master thesis focuses on comparing methods for calculating annual energy needs for heating and cooling in Portugal and Brazil by seasonal and dynamic calculation procedures according to European and Brazilian standards ISO 13790: 2008, ISO 52016-1: 2017 (document which supersedes ISO 13790) and NBR 15.575: 2021. The study objectives are as follow:

- Literature review of other published studies on the subject;
- Review of energy performance calculation methodologies used in Europe;
- Review of Brazilian energy performance calculation methodologies according to NBR 15.575 (before and after revision);

- Comparison of calculation procedures applied in Europe and critical analysis based on Portuguese regulatory requirements (which reflects the requirements of European directives);
- Discussion on regulatory requirements for construction products (construction systems, lining materials, glazing) for evaluating compliance with thermal performance requirements;
- Assessment of impacts of implementing the studied calculation methodologies. Seasonal and dynamic methods will be applied to a case study for Portuguese and Brazilian climates;
- Discussion on improvement measures for enhancing energy performance of both case studies analyzed;
- Reflection on improving methods for future studies.

1.3 Dissertation Structure

The masters work is structured in 6 chapters.

Chapter 1 contains the introduction, which consists of presenting background, state-of-art consisting of presenting conceptual and theoretical framework that supports the study, its significance, and objectives to be achieved. Literature review consisted of researching generally accepted methods, practices and interrelated theories based on international studies and standards on the subject.

In chapter 2, materials and methods are presented. This section includes the research design, procedures for data collection, application, and data analysis procedure. All input data which is necessary for running both seasonal and dynamic calculation procedures according to European and Brazilian standards is presented.

Chapter 3 characterizes the case study in detail, describing location, climate conditions, geometry, construction elements, thermal parameters, and other particularities of the case studies.

Chapter 4 presents and discusses results of energy requirements for heating and cooling, and results for thermal performance according to Portuguese and Brazilian calculation methods. Methods are analyzed and results compared for evaluating impacts of the different calculation methodologies used on determining thermal performance of buildings.

Chapters 5 and 6 presents final conclusions of the study and reflections for future studies.

2. MATERIALS AND METHODS

To assess the impact of recently published NBR 15.575: 2021 on assessing thermal performance of residential buildings, this research aims at investigating a case study both through seasonal calculation procedure based on a excel tool and dynamic simulation procedure through software Energy Plus. Simulations will be carried out both for Portuguese and Brazilian climates. Criteria for choosing cities in both countries was based on populational density: São Paulo and Lisbon were chosen for being cities with greater populational density. Two models were therefore implemented for both climates:

- Model 1 – Portuguese seasonal calculation method based on excel tool.
- Model 2 - Dynamic calculation method by use of software Energy Plus based on Brazilian standard NBR 15.575: 2021.

Simulation procedures were carried out as summarized in the following sections.

2.1 Model 1: Portuguese seasonal calculation method

Portuguese Decree-Law nº 118 based on ISO 13790: 2008 approves the Energy Certification System for Buildings (SCE), the Energy Performance Regulation for Residential Buildings (REH) and the Energy Performance Regulation of Commerce and Services Buildings (RECS). Decree-Law nº 118 transposes Directive 2010/31/EU of the European Parliament and Council, from May 19 2010, being therefore responsible for regulating calculation of energy demand and performance of buildings into national legal order. Both REH, Directive nº15793-I and Directive nº 349-B: 2013 describe seasonal calculation method, which determine annual energy demand for heating (Nic) and cooling (Nvc) of buildings. These parameters must meet specific energy reference limits – Ni and Nv, for heating and cooling, respectively.

2.1.1 Conditions for energy calculation according to REH

Annual energy demand for heating (N*ic*) and cooling (N*vc*) needs are calculated according to the following sections.

2.1.1.1 Heating demand (Nic)

Heating demand (N*ic*) is calculated by Equation (1):

$$N_{ic} = \frac{Q_{tr,i} + Q_{ve,i} + Q_{gu,i}}{Ap} \quad [kWh / (m^2 \cdot year)] \qquad (1)$$

Where:
$Q_{tr,i}$ is the transmission heat losses through the envelope (kWh);
$Q_{ve,i}$ is the heat losses by air renovation (kWh);
$Q_{gu,i}$ is the useful heat gains which occur during the heating season (kWh);
A_p is the treated floor area (m^2).
Heat losses by envelope transmission and air renovation are calculated according to Equations (2 – 3):

$$Q_{tr,i} = 0{,}024 \cdot GD \cdot H_{tr,i} \quad [kWh] \qquad (2)$$

$$Q_{ve,i} = 0{,}024 \cdot GD \cdot H_{ve,i} \quad [kWh] \qquad (3)$$

Where:
GD is the heating degree-days ($°C$ · days);
$H_{tr,i}$ is the heat transmission coefficient (W / °C);
$H_{ve,i}$ is the global coefficient of heat transmission by ventilation (W / °C).
Finally, the useful heat gains ($Q_{gu,i}$) are calculated by Equation (4):

$$Q_{gu,i} = Q_{int} + Q_{sol} \cdot \eta g \quad [kWh] \qquad (4)$$

Where:
Q_{int} corresponds to the internal gains (kWh);
Q_{sol} corresponds to the solar gains (kWh);
ηg is the utilization factor.

2.1.1.2 Cooling demand (Nvc)

Cooling demand (Nvc) is calculated by Equation (5):

$$N_{vc} = \frac{(1 - \eta v) \cdot Q_{g,v}}{Ap} \quad [kWh / (m^2 \cdot year)] \qquad (5)$$

Where:
ηv is the gains utilization factor for the cooling season;
$Q_{g,v}$ is the reference value for the total gains during the cooling season (kWh);

A_p is the treated floor area (m^2).

Gains utilization factor for cooling season depends on heat losses by transmissions and by air exchange, and also heat gains. The utilization factor for cooling season is calculated according to Equations (6 – 8):

$$\eta v = \frac{1 - \gamma_v^{a}}{1 - \gamma_v^{a+1}} \qquad \text{if } \gamma_v \neq 1 \text{ and } \gamma_v > 0 \qquad (6)$$

$$\eta v = \frac{a}{a+1} \qquad \text{if } \gamma_v = 1 \qquad (7)$$

$$\eta v = \frac{1}{\gamma_v} \qquad \text{if } \gamma_v < 0 \qquad (8)$$

Where:
γ and a are both dimensionless parameters related to buildings thermal balance and to buildings thermal inertia, respectively.

Total gains $Q_{g,v}$ is calculated according to Equation (9):

$$Q_{g,v} = Q_{int,v} + Q_{sol,v} \qquad [\text{kWh}] \qquad (9)$$

Where:
$Q_{int,v}$ corresponds to the internal gains;
$Q_{sol,v}$ corresponds to solar gains.

2.1.1.3 Primary energy (Ntc)

The total useful energy demand considers energy demand for heating and cooling, AQS, mechanical ventilation, deducted the contribution of renewable energy sources, as presented in Equation (10):

$$N_{tc} = \sum_j \left(\sum_k \frac{f_{i,k} \,.\, N_{ic}}{\eta_k} \right) \cdot F_{pu,j} + \sum_j \left(\sum_k \frac{f_{v,k} \,.\, \delta \,.\, N_{vc}}{\eta_k} \right) \cdot F_{pu,j} +$$

$$\sum_j \left(\sum_k \frac{f_{a,k} \cdot Q_a / A_p}{\eta_k} \right) \cdot F_{pu,j} + \sum_j \frac{W_{vm,j}}{A_p} \cdot F_{pu,j} + \sum_p \frac{E_{ren,p}}{A_p} \cdot F_{pu,p}$$

$[kWh_{EP} / (m^2 \cdot year)]$ (10)

Where:
N_{ic} is the heating energy need (kWh / m^2 · year);
$f_{i,k}$ is the fraction of heating energy needs supplied by the system k;
ηk – is the efficiency of system k, which take the value 1,00 if it is a renewable energy system;
$F_{pu,j}$ is the conversion factor for primary energy (kWh_{EP} / kWh);
N_{vc} is the cooling energy needs (kWh / m^2 · year);
$f_{v,k}$ is the fraction of cooling energy needs, supplied by the system k;
δ is the fraction corresponding to overheating risk;
$f_{a,k}$ is the fraction of domestic hot water energy needs supplied by the system k;
Q_a is the domestic hot water energy needs (kWh / m^2 · year);
A_p is the treated floor area (m^2);
W_{vm} is the electrical energy used by the ventilation system (kWh / year);
$E_{ren,p}$ is the energy produced by renewable sources p, (kWh / year).

2.1.2 Energy performance labelling system

In Portugal, labelling procedure can be applied for classifying building energy performance. Energy class is calculated in accordance with provisions of Dispatch (extract) No. 15793 - J, as shown in Equation (11):

$$\eta v = \frac{N_{TC}}{N_T} \quad \text{if } \gamma_v < 0 \qquad (11)$$

Where:
N_{TC} is the value of nominal needs corresponding to primary energy and N_T corresponds to the regulatory threshold value for nominal primary energy needs, both calculated according to REH.

Energy classification scale of buildings or autonomous fractions is composed by 8 classes, each one corresponding to a range of R_{TC} values, as shown in Table (3).

Table 3 – Energy class range according to Portuguese labelling system.
(Source: Dispatch, extract, No. 15793-J: 2013).

Energy Class	R_{tC} value
A +	$R_{tC} \leq 0{,}25$
A	$0{,}26 \leq R_{tC} \leq 0{,}50$
B	$0{,}51 \leq R_{tC} \leq 0{,}75$
B -	$0{,}76 \leq R_{tC} \leq 1{,}00$
C	$1{,}01 \leq R_{tC} \leq 1{,}50$
D	$1{,}51 \leq R_{tC} \leq 2{,}00$
E	$2{,}01 \leq R_{tC} \leq 2{,}50$
F	$R_{tC} \geq 2{,}51$

2.1.3 Input data

Itecons developed a spreadsheet implementing seasonal method. It requires information input respective to buildings location and geometry, material characteristics and thermal parameters, calculation of thermal bridges and windows, type of ventilation, heat recovery system and heating and cooling equipment. These parameters are presented in section 3.

2.2 Model 2: Brazilian dynamic calculation method

Computational simulation by NBR 15.575: 2021 requires buildings modelling for two scenarios: real and reference models. Thus, this procedure must be carried out by simulating two models:

a) real model, which preserves the geometric characteristics of evaluated housing units, thermal properties and compositions of transparent elements, walls and roof;

b) reference model, which represents the evaluated building with reference (ideal) characteristics. This model must contain buildings real volumetry but altering the percentage of transparent elements and ventilation openings, as well as thermal properties of buildings construction systems.

Dynamic simulation procedure according to NBR 15.575: 2021 evaluates thermal conditions of all building APPs (rooms with long occupancy) such as dormitories and living-rooms. Analysis is carried out by evaluating building envelopes (real model) with respect to the same envelope with reference (ideal) characteristics (reference model).

NBR 15.575: 2021 determines different levels (minimum, intermediate and superior) for evaluating thermal performance of buildings. Since this document is not prescriptive, at least minimum performance levels must be satisfied. When evaluating buildings thermal performance to meet minimum level, real and reference models are simulated considering the use of natural ventilation in APPs. Whereas for evaluating intermediate and upper levels simulation must be carried out without use of natural ventilation and include analysis of cooling and heating thermal loads.

2.2.1 Minimum performance level through use of natural ventilation.

This analysis is carried out by calculating the percentage of occupation hours for each indoor space within an operating temperature range ($PHFT_{APP}$). Operating temperature is the average between air temperature and radiant average temperature and ranges according to local climate, according to three intervals as shown in Table (4).

Table 4 – Operative temperature ranges for determining $PHFT_{APP}$.
(Source: NBR 15.575: 2021)

External temperature ranges	Operative range to be considered
1	18,0 ºC < TO_{APP}[a] < 26,0 ºC
2	TO_{APP} < 28,0 ºC
3	TO_{APP} < 30,0 ºC
[a] TO_{APP} is the APP operative temperature in accordance with thresholds established in this Table.	

For each APP, $PHFT_{APP}$ must be obtained by the Equation (12):

$$PHFT_{APP} = \frac{Nh_{FT} \cdot 100}{Nh_{Ocup}} \quad (12)$$

Where:
$PHFT_{APP}$ is the percentage of occupation hours of APPs within the operating temperature range (%);
NhFT is the number of hours in which the APP is occupied and with operating temperatures within the operating temperature range established by NBR 15.575: 2021 throughout the year;
Nh_{Ocup} is the number of hours in which the APP is occupied throughout the year, equivalent to 2 920 hours for living-rooms and 3 650 h for dormitories.

The percentage of occupation hours of housing units (*Unidade Habitacional*, UH) within the operative temperature range determined by Table (4) must be calculated by Equation (13):

$$PHFT_{UH} = \frac{\sum_{i=1}^{n} PHFT_{APP,\,i}}{n} \tag{13}$$

Where:
$PHFT_{UH}$ is the percentage of occupation hours of the housing unit within the operating temperature range (%);
$PHFT_{APP,i}$ is the percentage of occupation hours of APPs *i* within the operating temperature range (%);
n is the number of APP of the housing unit.

Furthermore, maximum annual operative temperature (ºC) of the real model's housing units ($Tomáx_{UH}$) must be calculated considering its APPs occupation hours. For buildings located in bioclimatic zones 1, 2, 3 or 4, minimum annual operating temperature ($Tomín_{UH}$) must also be calculated. $Tomáx_{UH}$ and $Tomín_{UH}$ are obtained from values of $Tomáx_{APP}$ and $Tomín_{APP}$ calculated for each APP.

2.2.2 Intermediate and upper performance levels without use of natural ventilation.

This analysis is carried out by calculating the number of hours in an annual timespan for cooling and heating thermal loads ($CgTR_{APP}$ and $CgTA_{APP}$). Heating load is only required for buildings located in climates with an annual average of dry bulb external temperature lower than 25°C. From values of $CgTR_{APP}$ and $CgTA_{APP}$ for APP, total values of thermal loads of the entire housing unit ($CgTT_{UH}$) must be determined. $CgTT_{UH}$ evaluates total thermal load of each simulated housing unit without use of natural ventilation. It is the result of individual assessment of thermal loads for cooling and heating of each UH ($CgTR_{APP}$ and $CgTA_{APP}$). Procedure for determining $CgTR_{UH}$, $CgTA_{UH}$ and $CgTT_{UH}$ are described in Equations (14 - 17).

Simulation output data must be hourly presented, with thermal loads for cooling and heating of each APP. The annual sum for thermal loads regarding cooling and heating values ($CgTR_{APP}$ and $CgTA_{APP}$) must be calculated for the following conditions:

a) when the APP is occupied;
b) when operating temperature of APPs is within limits of operating temperatures established by NBR 15.575, according to Table (5).

Table 5 – Values of operative temperatures for calculating $CgTR_{APP}$ and $CgTA_{APP}$.

(Source: NBR 15.575: 2021)

External Temperatures Ranges	Range of operative temperature for calculating CgTRAPP	Range of operative temperature for calculating CgTAAPP
1	TOAPP[a] $\geq$ 26,0 ºC	TOAPP $\leq$ 18,0ºC
2	TOAPP $\geq$ 28,0 ºC	Not applicable
3	TOAPP $\geq$ 30,0 ºC	Not applicable
[a] TOAPP is the operative temperature of APP for calculating $CgTR_{APP}$ and $CgTA_{APP}$.		

Thermal cooling load ($CgTR_{UH}$) of housing units must be calculated for real and reference models according to Equation (14):

$$CgTR_{UH} = \sum_{i=1}^{n} CgTR_{APP,I} \qquad (14)$$

Where:
$CgTR_{UH}$ is the housing units thermal cooling load expressed in kilowatt-hours/year (kWh/year);
$CgTR_{APP,i}$ is the APPi thermal cooling load expressed in kilowatt-hours/year (kWh/year);
n is the number of APP at the housing units.
Heating load ($CgTA_{UH}$) of housing units for both real and reference models must be calculated by Equation (15):

$$CgTA_{UH} = \sum_{i=1}^{n} CgTA_{APP,I} \qquad (15)$$

Where:
$CgTA_{UH}$ is the housing units thermal heating load expressed in kilowatt-hours per year (kWh/year);
$CgTA_{APP,i}$ is the APPi thermal heating load expressed in kilowatt-hours per year (kWh/year);
n is the number of APP at the housing units.

Total thermal load ($CgTT_{UH}$) of housing units must be obtained according to Equation (16), for buildings located in regions where the annual mean of dry bulb external temperature (TBS_m) is lower than 25ºC. For climates with TBS_m within the range of 25ºC and 27ºC or above 27ºC, calculation is provided by Equation (17).

$$CgTT_{UH} = CgTR_{UH} + CgTA_{UH} \qquad (16)$$

$$CgTT_{UH} = CgTR_{UH} \qquad (17)$$

Where:
$CgTT_{UH}$ is the total thermal load of the housing unit expressed in kilowatt-hours per year (kWh/year).

NBR 15575: 2021 also states other provisions for evaluating the increase of $PHFT_{UH}$ value and the reduction of total thermal loads ($CgTT_{UH}$) of real model in relation to reference model. For attending upper level, requirements differ in achieving higher reductions of total thermal load ($CgTT_{UH}$).

2.2.3 Energy performance labelling system

Brazilian labelling procedure for classifying building energy performance according to NBR 15.575 is carried out by analyzing attendance of specific criteria with respect to regulatory threshold values. The following criteria is assessed:

- $PHFT_{UH}$ – percentage of occupation hours of the housing unit within the operating temperature range [%];
- $Tomax_{UH}$ – maximum annual operative temperature of the housing unit (ºC);
- $Tomin_{UH}$ – minimum annual operative temperature of the housing unit (ºC);
- $CgTT_{UH}$ – total thermal load of the housing unit (kWh/year).

Compliance with $PHFT_{UH}$, $Tomax_{UH}$, $Tomin_{UH}$ and $CgTT_{UH}$ values to standard requirements are shown in Table (6) and Equations (18 – 19).

Table 6 – Criteria for evaluating thermal performance of façades with respect to $PHFT_{UH}$.

(Source: NBR 15.575: 2021)

Performance level	Criteria
Minimum (M)	$PHFT_{UH}$,real > 0,9.$PHFT_{UH}$,ref
Intermediate (I)	$\Delta PHFT^{a} \geq \Delta PHFTmin^{b}$
Superior (S)	ΔPHFT ≥ ΔPHFTmín
[a] ΔPHFT is an increase value of $PHFT_{UH}$,real with respect to $PHFT_{UH}$,ref. [b] ΔPHFTmin is a minimum increase value of $PHFT_{UH}$,real with respect to $PHFT_{UH}$,ref.	

$$Tomax_{UH,real} \leq Tomax_{UH,ref} + \Delta tomax \quad (18)$$

Where:
$Tomax_{UH,real}$ is the maximum annual operative temperature of the real model's housing unit (ºC);
$Tomax_{UH,ref}$ is the maximum annual operative temperature of the reference model's housing unit (ºC);
Δtomax is the tolerance value for the maximum annual operating temperature (ºC).

For single units located on roof floors, ΔTomax must be equal to 2°C. For units located on ground or type floors, ΔTomax must be equal to 1 ºC. For bioclimatic zones 1, 2, 3 or 4, the minimum annual operating temperature $Tomin_{UH}$, a tolerance value (ΔTomin) equal to 1 ºC must be adopted for all evaluated UHs. Minimum annual operating temperature criterion is described by Equation (19).

$$Tomin_{UH,real} > Tomin_{UH,ref} - \Delta tomin \quad (19)$$

Where:
$Tomin_{UH,real}$ is the minimum annual operative temperature of the real model's housing unit (ºC);
$Tomin_{UH,ref}$ is the minimum annual operative temperature of the reference model's housing unit (ºC);
Δtomin is the tolerance value for the minimum annual operating temperature (ºC).

Compliance with $CgTT_{UH}$ for intermediate and upper levels is analyzed as follows in Table (7):

Table 7 – Criteria for evaluating thermal performance of façades with respect to $CgTT_{UH}$.

(Source: NBR 15.575: 2021)

Performance level	Criteria
Minimum (M)	Not applicable.
Intermediate (I)	$RedCgTT^{a} \geq RedCgTT_{mín}^{b}$
Superior (S)	$RedCgTT \geq RedCgTT_{mín}$

[a] RedCgTT is the reduction of total thermal load with respect to reference ($CgTT_{UH}$,ref).
[b] RedCgTTmín is a minimum reduction of $CgTT_{UH}$,real with respect to reference ($CgTT_{UH}$,ref).

2.2.4 Input data

Computer simulation program must be able to estimate operative temperature variations, thermal cooling and heating loads and use of natural ventilation 8 760 h throughout the year, considering hourly variations of occupancy, lighting, and equipment systems. It must also attend to the following:

a) comply with ASHRAE 140: 2017 [22], under Class I test procedure;
b) simulate thermal inertia effects;
c) simulate heat exchanges between building and ground;
d) calculate latent and sensitive thermal loads;
e) simulate shading from elements outside the thermal zones, such as brises, balconies and surroundings;
f) simulate effects of cross ventilation in an environment, or between two or more environments.

2.2.4.1 Occupation and internal loads

Building modeling through NBR 15.575 procedure must consider the occurrence of internal loads respective to users' occupation in all simulated APPs and the use of artificial lighting and equipment systems. Occupation and internal loads must be performed equally for both real and reference models throughout the year, including weekends, according to Table (8).

Table 8 – Daily occupancy patterns for APPs.

(Source: NBR 15.575: 2021)

Hour	Occupation			Hour	Occupation		
	Dormitory %	Living room %	Mixt use %		Dormitory %	Living room %	Mixt use %
00:00 – 00:59	100	0	100	12:00 – 12:59	0	0	0
01:00 – 01:59	100	0	100	13:00 – 13:59	0	0	0
02:00 – 02:59	100	0	100	14:00 – 14:59	0	50	50
03:00 – 03:59	100	0	100	15:00 – 15:59	0	50	50
04:00 – 04:59	100	0	100	16:00 – 16:59	0	50	50
05:00 – 05:59	100	0	100	17:00 – 17:59	0	50	50
06:00 – 06:59	100	0	100	18:00 – 18:59	0	100	100
07:00 – 07:59	100	0	100	19:00 – 19:59	0	100	100
08:00 – 08:59	0	0	0	20:00 – 20:59	0	100	100
09:00 – 09:59	0	0	0	21:00 – 21:59	0	100	100
10:00 – 10:59	0	0	0	22:00 – 22:59	100	0	100
11:00 – 11:59	0	0	0	23:00 – 23:59	100	0	100

NOTE 1 The amount of 2 occupants (100% occupancy) must be considered per dormitory excluding maid's quarters.
NOTE 2 Total amount of occupants (100%) for living-rooms is determined in accordance with the number of dormitories. For each dormitory, 2 occupants must be considered in the living-room, with a maximum limit of 4 occupants. In case of a greater number of occupants, the limit of four occupants must be considered for living-rooms.
NOTE 3 For mixed use conditions, occupancy value = 100% corresponds to 2 occupants in the evaluated space.

Tables (9 – 11) contain data regarding occupants' metabolic rates and radiant ratio, use patterns for lighting system and values of radiant / visible ratio that must be considered in dynamic simulation.

Table 9 – Occupants metabolic rate and radiant ratio.

(Source: NBR 15.575: 2021)

Indoor Space	Use period	Activity	Heat produced per body surface area W/m^2	Heat produced by one person with 1,80 m^2 of body surface area W	Radiant ratio
Dormitory	00:00 – 07:59 22:00 – 23:59	Sleeping or resting	45	81	0,30
Living-room	14:00 – 21:59	Seated or watching TV	60	108	0,30
Mixed use	00:00 – 07:59 22:00 – 23:59	Sleeping or resting	45	81	0,30
	14:00 – 21:59	Seated or watching TV	60	108	0,30

Table 10 – Use pattern for lightning system.

(Source: NBR 15.575: 2021)

Hour	Occupation			Hour	Occupation		
	Dormitory %	Living room %	Mixt use %		Dormitory %	Living room %	Mixt use %
00:00 – 00:59	0	0	0	12:00 – 12:59	0	0	0
01:00 – 01:59	0	0	0	13:00 – 13:59	0	0	0
02:00 – 02:59	0	0	0	14:00 – 14:59	0	50	50
03:00 – 03:59	0	0	0	15:00 – 15:59	0	50	50
04:00 – 04:59	0	0	0	16:00 – 16:59	0	100	100
05:00 – 05:59	0	0	0	17:00 – 17:59	0	100	100
06:00 – 06:59	100	0	100	18:00 – 18:59	0	100	100
07:00 – 07:59	100	0	100	19:00 – 19:59	0	100	100
08:00 – 08:59	0	0	0	20:00 – 20:59	0	100	100
09:00 – 09:59	0	0	0	21:00 – 21:59	0	100	100
10:00 – 10:59	0	0	0	22:00 – 22:59	100	0	100
11:00 – 11:59	0	0	0	23:00 – 23:59	100	0	100

Table 11 – Installed power density (DPI), radiant / visible ratio for lighting system.

(Source: NBR 15.575: 2021)

Indoor Space	DPI (W/m^2)	Radiant Ratio	Visible Ratio

Dormitory	5,00	0,32	0,23
Living-room	5,00	0,32	0,23
Mixed use	5,00	0,32	0,23

Internal equipment loads must only be considered for living - rooms and indoor spaces with mixed use depending on use timespan. Density values of internal loads and radiant fraction are presented in Table (12). Equipment usage pattern should be considered for all days of the year including weekends.

Table 12 – Equipments use hours, radiant ratio and power.

(Source: NBR 15.575: 2021)

Indoor Space	Use hours	Power (W)	Radiant Ratio
Living-room	14:00 – 21:59	120	0,30
Mixed use	14:00 – 21:59	120	0,30

2.2.4.2 Building envelope transparent elements and openings

Openings should be allowed according to two temperature criteria:
a) only when APPs are occupied;
b) when APPs internal dry bulb temperature is equal to or greater than 19°C; and
c) when indoor dry bulb temperature is higher than outdoor dry bulb temperature.

All APPs windows must consider infiltration by cracks when closed. NBR 15.575 requires attendance to three parameters:

- Coefficient of air flow by ridges when opening element is closed kg/(s.m): mass flow air rate for pressure difference of 1 Pascal (Pa), corresponding to air flow caused by infiltration through cracks of doors or windows;
- Airflow exponent per cracks when opening element is closed (dimensionless): exponent value to which pressure difference between openings rises, when they are closed;
- Discharge coefficient (Cd) of opening (dimensionless): ratio of real and ideal air flow which is transmitted through an opening. Discharge coefficient is related to air flow resistances of door and window openings when they are opened.

Such parameters must be considered at dynamic simulation and are detailed in Table (13).

Table 13 – Parameters for natural ventilation of doors and windows from APPs and APTs.

(Source: NBR 15.575: 2021)

Parameters	Doors	Windows
Coefficient of air flow by ridges when opening element is closed kg/(s.m)	0,00 24	0,000 63
Airflow exponent per cracks when opening element is closed (dimensionless)	0,59	0,63
Discharge coefficient (Cd) of opening (dimensionless)	0,60	0,60

Windows of transitory permanence environments (APT) – except bathrooms –, are considered closed and infiltrated by cracks throughout the year, according to Table (13). For bathrooms, windows should be always considered open with a percentage of opening for ventilation as determined by buildings design.

Internal doors between APPs and APTs must be considered open, with exception of bathroom doors, which must always be considered closed. External balcony doors, which consist of transparent elements, must follow the same operation as windows.

Window areas of reference model façades must be adjusted to 17% of each APP floor area. After resizing transparent elements in the reference model, 45 % ventilation opening should be considered for each element. Solar factor (*g-value*), thermal transmittance (U) of transparent elements and window frame characteristics must attend to values described on Tables (14 - 15).

Table 14 – Characteristics of transparent elements for reference model.

(Source: NBR 15.575: 2021)

Element	Solar factor (*g-value*)	Thermal transmittance, U ($W/m^2.K$)
Transparent elements	0,87	5,70

Table 15 – Characteristics of window frames for reference model.

(Source: NBR 15.575: 2021)

Element	Solar radiation absorptance	Long-wave emissivity	Thermal transmittance, U ($W/m^2.K$)	Frame width (mm)
Frame profiles	0,58	0,90	56,00	50,00

Percentage of transparent elements, openings for ventilation, and glazings thermal parameters of rooms with transient occupancy (APTs) must be modeled similarly for both real and reference models, according to design provisions.

3. CASE STUDY

Definition of the simulated building details was based on selecting a representative case study of residential buildings in Brazil and Portugal, considering commonly used construction systems in both countries.

Both seasonal and dynamic simulation procedures were carried out by modeling housing units of a building located at the 15th type floor (48 meters from ground level), as indicated in Figures (1 – 2). Layout plan for both housing units (1 and 2) is the same. However, solar orientation of units is the opposite, enabling evaluation of both north and south facades. Table (16) shows dimensional characteristics and window to external wall ratio (%) of modelled rooms identified as “a” to “n” in Figures (1 – 2).

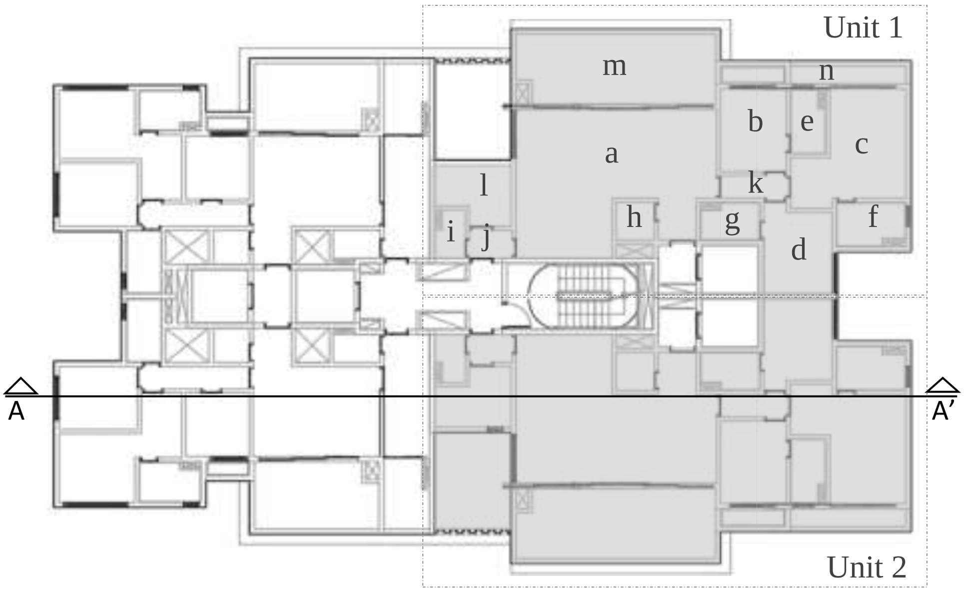


Figure 1 – Floor type (15th floor): simulated housing units (1 and 2).

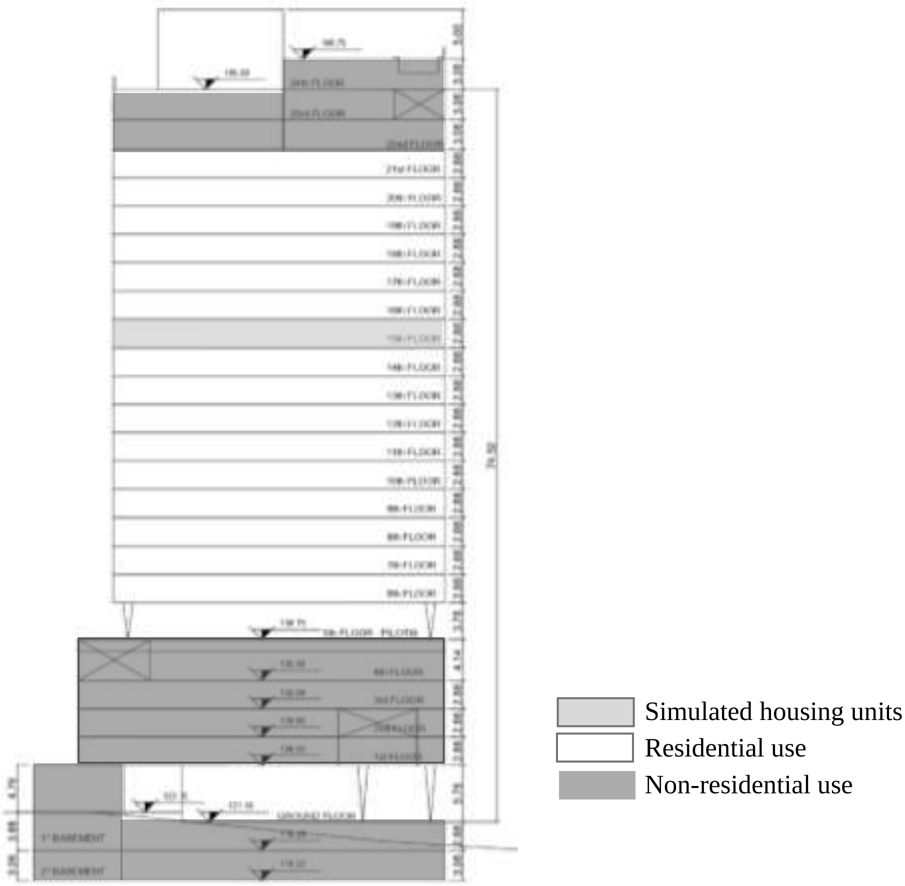


Figure 2 – Section AA'.

3.1 Construction systems and thermal parameters

3.1.1 Initial solution (IS)

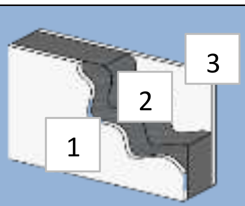
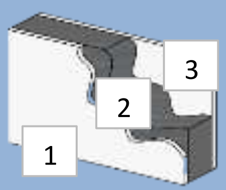
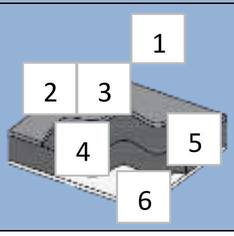
Initial solution (IS) adopted for both calculation methods (seasonal and dynamic) was based on conditions for building construction systems presented in Table (16), which shows dimensional characteristics and window to external wall ratio (%) of simulated housing units. Table (17) details used construction systems and its corresponding thermal parameters. Values are based on NBR 15.220-2. Thermal parameters adopted for the reference model were based on Tables (18 – 19) in accordance with NBR 15.575.

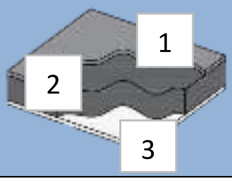
Openings and transparent elements were configured according to Tables 13, 14 and 15 for seasonal method and for dynamic method, as presented in section *2.2.4.2*, with U value = 5,70 W / m^2.K and *g-value* = 0,87.

Table 16 – Rooms dimensional characteristics of housing units 1 and 2.

Room	Area (m^2)	Height (m)	Window-Wall ratio %	Volume (m^3)
Living/Kitchen (a)	41,40	2,73	94,0	113,02
Suite 1 (b)	8,45	2,73	41,8	23,07
Suite 2 (c)	16,00	2,73	20,5	43,68
Suite 3 (d)	9,00	2,73	56,8	24,57
Bathroom 1 (e)	3,15	2,73	-	8,60
Bathroom 2 (f)	4,32	2,73	-	11,79
Bathroom 3 (g)	3,10	2,73	-	8,46
WC (h)	2,25	2,73	-	6,14
WC (i)	2,00	2,73	-	5,46
Hall (j)	1,87	2,73	-	5,11
Hall (k)	2,34	2,73	-	6,39
Service area (l)	6,12	2,73	-	16,71
Terrace (m)	20,97	2,73	-	-
Terrace (n)	4,96	2,73	-	-

Table 17 – Construction systems, and its corresponding thermal parameters.

			Material	*t*	*ρ*	*λ*	*c*
EXTERNAL WALLS		1	Cement mortar	4,0	1800	1,15	1,00
		2	Concrete block	19,0	2400	1,75	1,00
		3	Gypsum mortar	1,0	1200	0,70	0,84
INTERNAL PARTITIONS		Separating rooms within each housing unit:					
			Material	***t***	***ρ***	***λ***	***c***
		1	Gypsum mortar	1,0	1200	0,70	0,84
		2	Ceramic block	19,0	1600	1,00	0,92
		3	Gypsum mortar	1,0	1200	0,70	0,84
		Separating housing units:					
		1	Gypsum mortar	1,0	1200	0,70	0,84
		2	Ceramic block	14,0	1600	1,00	0,92
		3	Gypsum mortar	1,0	1200	0,70	0,84
BUILDINGS ROOF			**Material**	***t***	***ρ***	***λ***	***c***
		1	Concrete flooring	5,0	1600	1,00	0,92
		2	Membrane (asphalt)	2,5	2300	1,15	0,92
		3	Thermal insulation	2,5	25	0,04	1,42
		4	Concrete slab	12,0	2300	1,75	1,00

		5	Air gap	15,0	-		
		6	Gypsum board	1,25	800	0,35	0,84
FLOOR PAVING		**Material**		***t***	***ρ***	***λ***	***C***
		1	Concrete flooring	3,0	1600	1,00	0,92
		2	Concrete slab	12,0	2300	1,75	1,00
		3	Gypsum mortar	1,0	1200	0,70	0,84

Where:
t is the thickness (cm);
ρ is the mass density (kg/m^3);
λ is the thermal conductivity (W/m.K);
c is the specific heat (kJ/kg.K).

Table 18 – Thermal parameters for walls and flooring system adopted for reference model. (Source: NBR 15.575: 2021)

Element	**λ**	***c***	**Absorptance to solar radiation**	**Long-wave emissivity**	***ρ***
External walls	1,75	1000	0,58	0,90	2200
Internal walls	1,75	1000	Adopt real model value	Adopt real model value	2200
Floor	1,75	1000	Adopt real model value	Adopt real model value	2200

Table 19 – Thermal parameters for roof ceiling system adopted for reference model. (Source: NBR 15.575: 2021)

Element	**λ**	***c***	**Absorptance to solar radiation**	**Long-wave emissivity**	***ρ***
Roof tile Width = 6 mm	0,65	0,65	0,65	0,90	1700
Concrete slab Width = 100 mm	1,75	1000	Adopt real model value	Adopt real model value	2200

- *Heating and Cooling Devices, Ventilation and Sanitary Hot Waters*

Heating devices, cooling devices and sanitary hot waters (*Águas Quentes Sanitárias* – AQS) were considered on seasonal method. Values for nominal efficiency (η_i) of heating and cooling artificial devices were $\eta_i = 1$ and $\eta_i = 3$, respectively. Values for nominal efficiency (η_i) of electric water heater used was $\eta_i = 0,95$.

Analysis of heating and cooling loads for NBR 15.575 is only adopted for assessing non-mandatory intermediate and upper performance levels. It is only required for buildings located in climates with an annual average of dry bulb external temperature lower than 25°C and carried out by calculating the number of hours in an annual timespan for heating and cooling thermal loads without use of natural ventilation. This research aimed at evaluating mandatory mininum level of thermal performance and thus heating and cooling loads were not evaluated.

Regarding natural ventilation, calculation used on seasonal method complies with EN 15242: 2007 [23], which describes method for calculating ventilation air flow rates for buildings to be used for applications such as energy calculations, heat and cooling load calculation, summer comfort and indoor air quality evaluation. Ventilation parameters also comply with SCE (Manual of Buildings Energy Certification System).

Parameters used for natural ventilation on dynamic method were based on NBR 15.575 requirements as described in Section 2.2.4.2.

3.1.2 Improvement measures

Improvement measures aim at promoting higher efficiency on buildings energy balance. Measures implemented are discussed in the following sections.

- *Measure 1 (M1)*

Layer of ETICS (External Thermal Insulation Composite System) 60 mm white polystyrene board (EPS) applied to external wall with thermal conductivity $\lambda = 0,042$ W/m.K and R-value = 1.4 m^2 K/W.

- *Measure 2 (M2)*

Layer of XPS (extruded polystyrene) 60 mm applied to flooring system with thermal conductivity $\lambda = 0,034$ W/m.K and R-value = 1.76 m^2 K/W.

- *Measure 3 (M3)*

Replacement of glazing surfaces for more efficient global solar factors ($g_{tot} = 0,05$) with protection devices and U value equal to 2,80 W/m^2.K.

- *Measure 4 (M4)*

All 3 strategies combined.

3.2 Climate conditions

In cold or moderate climates, buildings should be oriented to benefit from heat gains during winter and to be as protected as possible from cold winds. In Portugal, the main divisions and buildings façades must be preferably south oriented, and north orientation should be avoided.

In hot climates, such as the southeast region of Brazil, buildings orientation must protect them from sun exposure and provide natural ventilation. South orientation is the least exposed to radiation throughout the year and should be avoided during winter season. Contrarily, west orientation is exposed to radiation during evening hours (sunset) and should be avoided during summer. North orientation receives radiation throughout the day as solar inclination in south hemisphere is directed towards north particularly during winter season. East orientation corresponds to morning hours of radiation (sunrise). NBR 15.575 previous edition (2013) required that simulations should be carried out for the most critical solar orientations: north and west for summer season and south and east orientations should be avoided during winter. 2021 edition requires that all UHs must be evaluated through dynamic simulation.

The following sections present specific characteristics concerning Lisbon and São Paulo climates.

A) City of Lisbon, Portugal

Lisbon is the most populous Portuguese city with a population 509.565 according to Contemporary Portuguese Database [24]. Climate conditions were based on data of Portuguese Institute for Sea and Atmosphere (IPMA - *Instituto Português do Mar e Atmosfera*).

Directive nº15793-F: 2013 divides Portugal into three climate areas for winter (I1, I2 e I3) and three climate areas for summer (V1, V2 e V3), as shown in Figure (3). Winter climate zones are defined by the number of degree days (GD) at the base of 18 °C, corresponding to heating season, and summer climate zones are defined by the average outdoor temperature corresponding to cooling season (Text, v). Criteria for choosing buildings climate area is shown in Tables (20 – 21).

Table 20 – Criteria for determining winter climate zones.

(Source: Dispatch, extract No. 15793-F: 2013)

Criteria	GD ≤ 1300	1300 < GD ≤ 1800	GD> 1800
Zone	I1	I2	I3

Table 21 – Criteria for determining summer climate zones.

(Source: Dispatch, extract No. 15793-F: 2013)

Criteria	$\theta_{ext,v} \leq 20°C$	$20°C < \theta_{ext,v} \leq 22°C$	$\theta_{ext,v} > 22°C$
Zone	V1	V2	V3

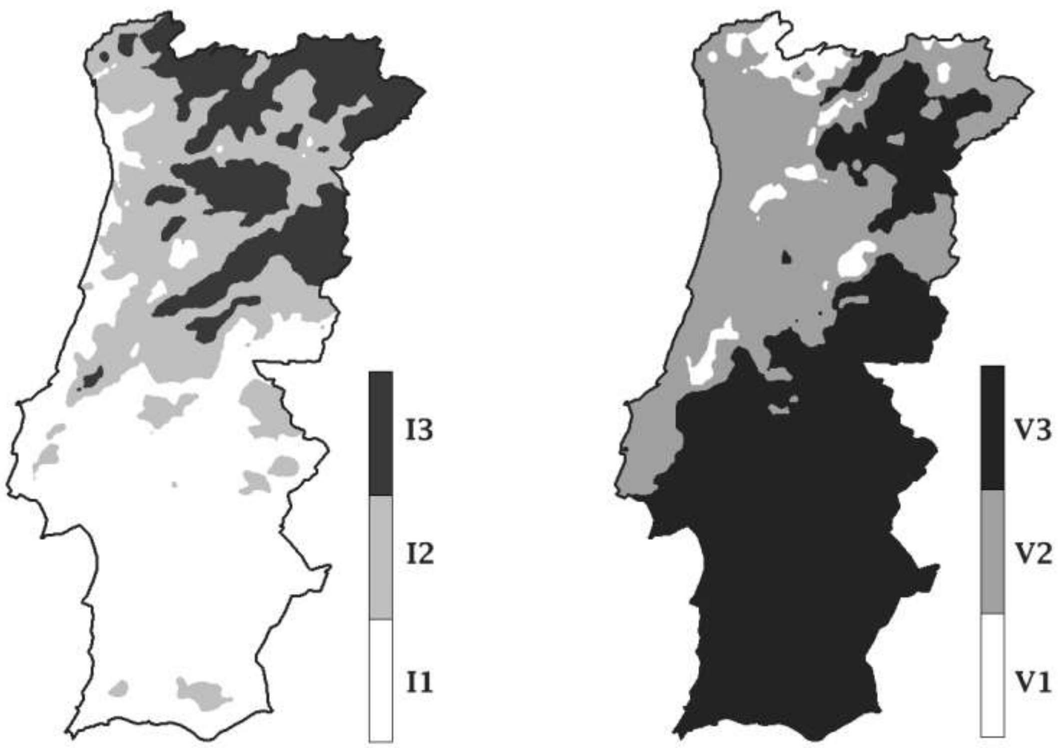


Figure 3 - Climate zones in Portugal.

Left: Winter climate zones. Right: Summer climate zones
(Source: Dispatch, extract No. 15793-F: 2013)

Directive nº15793-F: 2013 prescribes climate parameters for winter and summer seasons as shown in Tables (22 – 23).

Table 22 – Reference values and altitude-adjusted parameters for Lisbon winter season.

(Source: Dispatch, extract No. 15793-F : 2013)

	z REF m	M		GD		θext,i		Gsul
		REF month	*a* month /km	REF ºC	*a* ºC/km	REF ºC	*a* ºC/km	kWh/m² per month
Grande Lisboa	109	5,3	3	1071	1700	10,8	-4	150

Table 23 – Reference values and altitude-adjusted parameters for Lisbon summer season.

(Source: Dispatch, extract No. 15793-F : 2013)

	z REF m	θext,v		Isol kWh/m² accumulated from june to september					
		REF ºC	*a* ºC/km	0º	90º N	90º NE	90º SE	90º SW	90º NW
Grande Lisboa	109	21,7	-10	840	225	365	495	495	365

B) City of São Paulo, Brazil

Brazilian bioclimatic zoning comprises eight different zones according to 15.220-3:2005, as shown in Figure (4). This standard contains a list of 330 cities whose climates were classified in bioclimatic zones. For non-classified cities, recommendation is to adopt climate characteristics of a classified city with similar conditions.

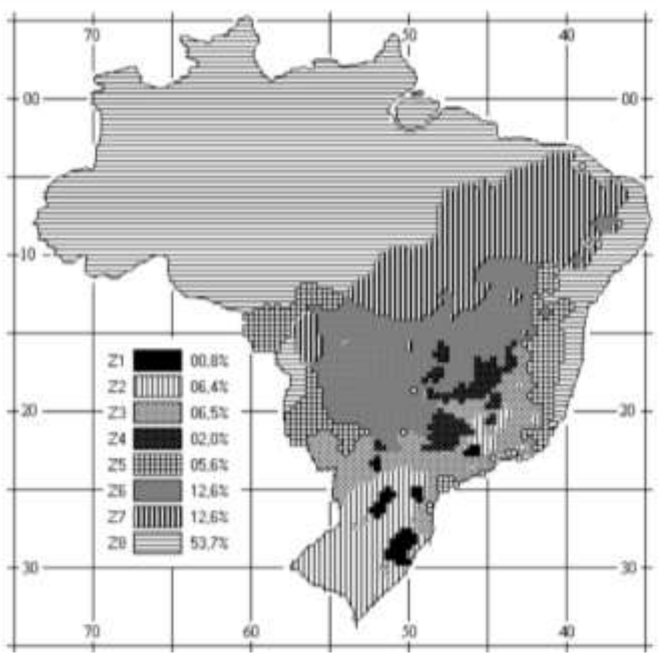


Figure 4 – Brazilian Bioclimatic Zones.

(Source: NBR 15.220-3: 2005)

São Paulo is the most populous Brazilian city with a population of 12.325.232 according to Brazilian Institute of Geography and Statistics (IBGE - *Instituto Brasileiro de Geografia e Estatística*) [25]. The city is classified by NBR 15.220-3 as Bioclimatic Zone 3, with characteristics as shown in Table (24).

Table 24 – Climate data of São Paulo.

(Source: NBR 15.220-3: 2005)

City	State	Bioclimatic Zone (BZ)	Latitude	Longitude	Elevation
São Paulo	SP	3	23º 50' S	46º 62'	792

Climate conditions used for São Paulo was based on data of National Institute of Meteorology (INMET – *Instituto Nacional de Meteorologia*). NBR 15.575 recommends the use of a climate files from INMET standard base. Climate file must provide monthly values of average soil temperature, in degrees Celsius (°C), for all months of the year, in addition to the following hourly values representing the 8 760 h of a typical meteorological year:

a) dry bulb temperature, expressed in degrees Celsius (°C);

b) dew point temperature, expressed in degrees Celsius (°C);

c) relative humidity, expressed as a percentage (%);

d) atmospheric pressure, expressed in Pascal (Pa);

e) long-wave horizontal radiation intensity, expressed in watt-hours per square meter (Wh/m^2);

f) global horizontal radiation, expressed in watt-hours per square meter (Wh/m^2);

g) direct normal radiation, expressed in watt-hours per square meter (Wh/m^2);

h) diffuse horizontal radiation, expressed in watt-hours per square meter (Wh/m^2);

i) wind direction, expressed in degrees (°), considering the clockwise direction from North direction;

j) wind speed, expressed in meters per second (m/s).

For seasonal method carried out through *Itecons* calculation spreadsheet, climate input for São Paulo was validated for conditions shown in Tables (25 – 26), based on information from INMET climate file.

Table 25 – Reference values and altitude-adjusted parameters for São Paulo winter season.

(Source: NBR 15.220-3: 2005)

	z REF m	M [month]	GD (ºC)	θext,i (ºC)	Gnorth [kWh/m² per month]
São Paulo	792	5	293	16.6	85

Table 26 – Reference values and altitude-adjusted parameters for São Paulo summer season.

(Source: NBR 15.220-3: 2005)

	z REF m	θext,v REF ºC	Isol kWh/m² accumulated from june to september				
			0º	90º NE	90º SE	90º SW	90º NW
São Paulo	792	21	859	373	506	506	373

4. RESULTS AND DISCUSSION

4.1 Model 1: Energy balance according to Portuguese seasonal method

Sections 4.1.1 and 4.1.2 present results for Portuguese seasonal method applied to São Paulo and Lisbon, respectively. Methods considered both predominantly north and south oriented façades for cooling and heating seasons.

4.1.1 Results for São Paulo

Energy balance for heating and cooling seasons is presented in Table (27) and Figure (5). Gain utilization factor (1 - η_V) both for São Paulo and Lisbon was considered equal to 0,54 for cooling season. It was obtained considering the thermal inertia and assuming similar conditions to lead with solar and internal gains.

Table 27 – Energy balance for heating and cooling seasons for São Paulo.

Solutions	**Housing Unit 1 - 15th floor - North oriented**					
	Heating Season					
	N_{ic} (kWh /m^2.year)	$Q_{tr,i}$ (kWh)	$H_{tr,i}$ (W/ºC)	$Q_{ve,i}$ (kWh)	$H_{ve,i}$ (W/ºC)	$Q_{gu,i}$ (kWh)
IS	3,07	2.483	353	1.034	147	3.131
M1	1,04	1.407	200	1.034	147	2.311
M2	3,07	2.483	353	1.034	147	3.131
M3	1,80	1.893	269	1.034	147	2.701
M1+M2+M3	0,43	817	116	1.034	147	1.797
Solutions	**Housing Unit 1 - 15th floor - North oriented**					
	Cooling Season					
	N_{vc} (kWh /m^2.year)	$Q_{g,v}$ (kWh)	$Q_{sol,v}$ (kWh)	$Q_{tr,v}$ (kWh)	$Q_{ve,v}$ (kWh)	$H_{ve,v}$ (kWh)
IS	38,88	9.159	6.572	7.255	3.022	147
M1	47,18	8.111	5.523	4.112	3.022	147
M2	38,88	9.159	6.572	7.255	3.022	147
M3	17,05	5.922	3.335	5.530	3.022	147
M1+M2+M3	21,01	4.874	2.287	2.387	3.022	147
Solutions	**Housing Unit 2 - 15th floor - South oriented**					
	Heating Season					

	N_{ic} (kWh /m^2.year)	$Q_{tr,i}$ (kWh)	$H_{tr,i}$ (W/ºC)	$Q_{ve,i}$ (kWh)	$H_{ve,i}$ (W/ºC)	$Q_{gu,i}$ (kWh)
IS	7,20	2.483	353	1.034	147	2.610
M1	2,86	1.407	200	1.034	147	2.082
M2	7,20	2.483	353	1.034	147	2.610
M3	4,60	1.893	269	1.034	147	2.348
M1+M2+M3	1,31	817	116	1.034	147	1.686
Solutions	**Housing Unit 2 - 15th floor - South oriented**					
	Cooling Season					
	N_{vc} (kWh /m^2.year)	$Q_{g,v}$ (kWh)	$Q_{sol,v}$ (kWh)	$Q_{tr,v}$ (kWh)	$Q_{ve,v}$ (kWh)	$H_{ve,v}$ (kWh)
IS	38,88	9.159	6.572	7.255	3.022	147
M1	47,18	8.110	5.523	4.112	3.022	147
M2	38,88	9.159	6.572	7.255	3.022	147
M3	27,96	7.180	4.593	5.530	3.022	147
M1+M2+M3	35,55	6.132	3.545	2.387	3.022	147

- *Results for heating season on predominantly north-oriented façades:*

Regarding heating and cooling seasons, an overall analysis shows that the best strategy for reducing annual energy demand would be through ventilation. This can be explained by values of transmission heat losses through the envelope, $Q_{tr,i}$ (kWh) and heat losses by air renovation, $Q_{ve,i}$ (kWh): $Q_{tr,i}$ (2.483 kWh) is approximately twice the value of $Q_{ve,i}$ (1.034 kWh).

Results for heating season show 66% reduction on energy consumption when applying ETICS to external walls (M1), with a decrease on annual energy demand for heating (Nic) values from 3,07 kWh / m^2. year to 1,04 kWh/m^2.year. Similarly, changing glazings U value and *g-value* (M3) impacts on Nic values, enabling energy savings in 41% compared to initial conditions. Improvement measure M3 shows that heat gains and losses through windows have a great influence on energy needs.

As expected, no impact on energy consumption is seen when applying layer of XPS (extruded polystyrene) 60 mm to flooring systems (M2). The analyzed flooring pavement makes no contact with exterior environment or ground level. Heat exchange in this case was considered zero (adiabatic). This strategy was analyzed on seasonal method for investigating the impacts of using insulation on flooring systems in dynamic simulation as presented in Section 4.3.

Overall solution considering combined improvement measures shows energy needs approximating to zero (from 3,07 kWh / m^2. year to 0,43 kWh / m^2. year), representing approximately 86% reduction in relation to initial conditions.

When looking at Nic reference values – Nic (ref) = 5 kWh / m^2. year –, all construction solutions comply with standardized threshold.

- *Results for cooling season on predominantly north-oriented façades:*

Results for cooling season show 21% increase on energy consumption when applying ETICS to external walls (M1), with annual energy demand for cooling (Nvc) values ranging from 38,88 kWh / m^2. year to 47,18 kWh/m^2.year. This can be explained because heat losses, which are positive when calculating Nvc values, is avoided by enhancing thermal performance of external walls.

Changing glazings thermal parameters (M3), however, leads to 56 % reduction on Nvc value, ranging from 38,88 kWh / m^2. year to 17,05 kWh / m^2. year. Combining all construction solutions (M1 + M2 + M3) is less efficient than strategy M3 due to contributions of ETICS on increasing Nvc value. Even so, total reduction on consumption is 45 % in relation to initial conditions.

When looking at Nvc reference values, for Nv (ref) = 11,29 kWh / m^2. year, all strategies exceed standardized threshold.

Overall conclusion by analyzing energy needs results for both cooling and heating seasons indicate that using ETICS on façades for north-oriented façades appears to be dispensable according to values of Nvc encountered. Best solution, which attends both seasons satisfactorily, is using efficient glazings and ventilation.

- *Results for heating season on predominantly south-oriented façades:*

As expected, impacts caused by building orientation show an overall decrease on useful heat gains ($Q_{gu,i}$) values for south rather than north orientation during heating season, as radiation exposure on south is lower than on north oriented façades. Figure 5 (a) compares values of $Q_{tr,i}$, $Q_{ve,i}$ and $Q_{gu,i}$ for São Paulo during heating season for both north and south orientations, showing that differences on results only occur for useful heat gains ($Q_{gu,i}$) values.

Results also indicate an increase on energy needs for south orientation in relation to north, seen by Nic values and explained by reduced heat gains through façades and therefore greater energy needs for heating. Total consumption reduction is 82% when applying all improvement measures in relation to initial solution (IS). The amount is 4% slower when compared to all improvements applied for north-oriented building, indicating that measures have a slight reduced impact on south rather than north façades.

Differently from north orientation, when looking at Nic reference values – Nic (ref) = 5 kWh / m^2. year – only improvement measures M1, M3 and combined solutions comply with standardized threshold. Figure 5 (a) shows Nic results for all improvement measures, considering both north and south oriented façades and compares Nic and Ni reference values.

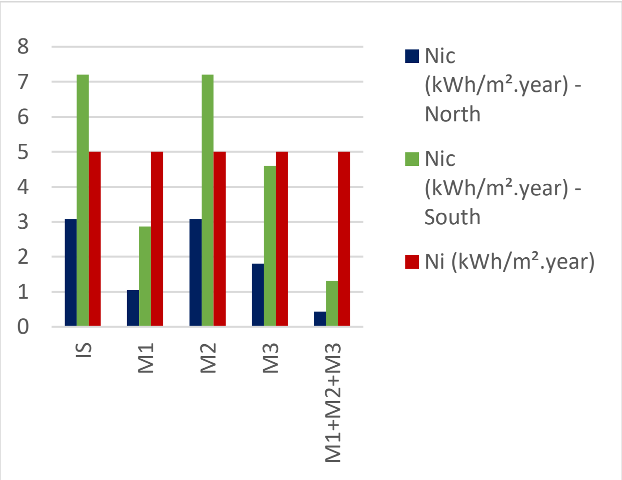
- *Results for cooling season on predominantly south-oriented façades:*

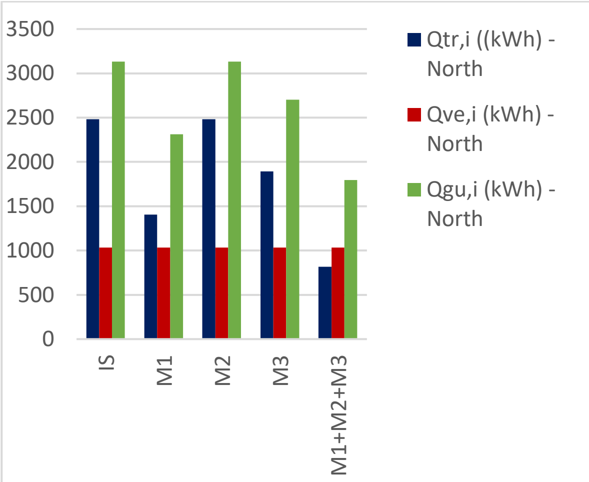
Nvc values behave identically for initial construction solutions and ETICS both for north and south orientations. However, changing glazing thermal parameters (M3) impacts differently between orientations: whilst energy needs decrease 56 % on north oriented building, for south orientation reduction is only 28 %. Conclusions to this may be driven with respect to total gains ($Q_{g,v}$) and solar gains ($Q_{sol,v}$) values which are higher for south rather than north orientation.

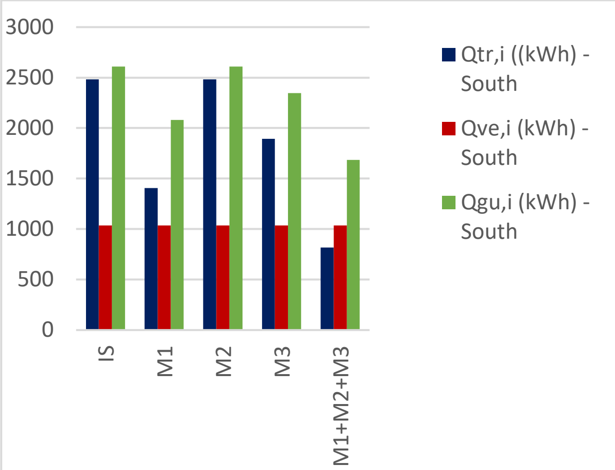
When looking at Nvc reference values – Nv (ref) = 11,29 kWh / m^2. year – Nv (ref) is exceeded for all adopted construction solutions. Figure 5 (b) shows Nvc results for all improvement measures, considering both north and south oriented façades and compares Nvc and Nv reference values.

Similar to heating season, results for Figure 5 (b) compares values of $Q_{g,v}$, $Q_{tr,v}$ and $Q_{ve,v}$ for São Paulo during heating season for both north and south orientations, showing that differences on results only occur for M2, M3 and M1+M2+M3 for values of total gains ($Q_{g,v}$).

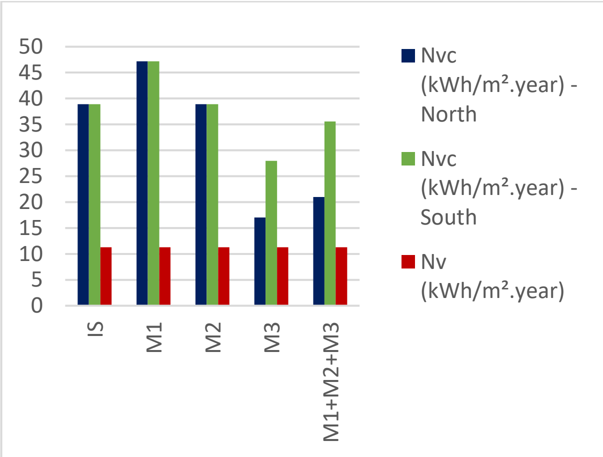
a) São Paulo: heating season

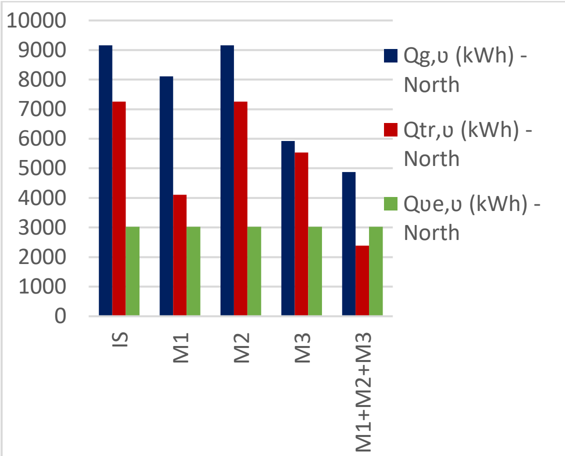






b) São Paulo: cooling season





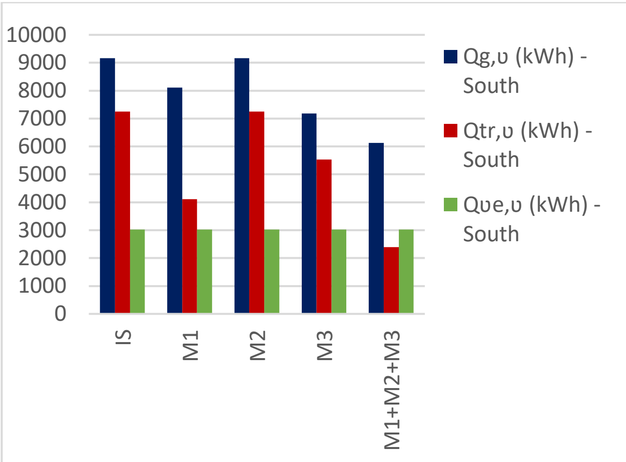


Figure 5 – Comparing results of heating and cooling energy balance for São Paulo.

a) São Paulo: heating season b) São Paulo: cooling season

4.1.2 Results for Lisbon

Energy balance for heating and cooling seasons is presented in Table (28) and Figure (6).

Table 28 – Energy balance for heating and cooling seasons for Lisbon.

Solutions	Housing Unit 1 - 15th floor - North oriented					
	Heating Season					
	N_{ic} (kWh /m^2.year)	$Q_{tr,i}$ (kWh)	$H_{tr,i}$ (W/ºC)	$Q_{ve,i}$ (kWh)	$H_{ve,i}$ (W/ºC)	$Q_{gu,i}$ (kWh)
IS	50,37	8.226	354	3.492	150	5.375
M1	26,06	4.680	201	3.492	150	4.891
M2	50,37	8.226	354	3.492	150	5.375
M3	36,64	6.280	271	3.492	150	5.159
M1+M2+M3	14,66	2.734	118	3.492	150	4.381
Solutions	Housing Unit 1 - 15th floor - North oriented					
	Cooling Season					
	N_{vc} (kWh /m^2.year)	$Q_{g,v}$ (kWh)	$Q_{sol,v}$ (kWh)	$Q_{tr,v}$ (kWh)	$Q_{ve,v}$ (kWh)	$H_{ve,v}$ (kWh)
IS	34,25	7.923	6.448	2.785	1.182	150
M1	33,96	6.883	5.408	1.584	1.182	150
M2	34,25	7.923	6.448	2.785	1.182	150
M3	22,57	5.766	4.292	2.126	1.182	150
M1+M2+M3	22,00	4.727	3.252	926	1.182	150
Solutions	Housing Unit 2 - 15th floor - South oriented					
	Heating Season					
	N_{ic} (kWh /m^2.year)	$Q_{tr,i}$ (kWh)	$H_{tr,i}$ (W/ºC)	$Q_{ve,i}$ (kWh)	$H_{ve,i}$ (W/ºC)	$Q_{gu,i}$ (kWh)
IS	29,25	8.226	354	3.492	150	8.035
M1	12,40	4.680	201	3.492	150	6.610
M2	29,25	8.226	354	3.492	150	8.035
M3	19,29	6.280	271	3.492	150	7.343
M1+M2+M3	5,98	2.734	118	3.492	150	5.473
Solutions	Housing Unit 2 - 15th floor - South oriented					
	Cooling Season					
	N_{vc} (kWh /m^2.year)	$Q_{g,v}$ (kWh)	$Q_{sol,v}$ (kWh)	$Q_{tr,v}$ (kWh)	$Q_{ve,v}$ (kWh)	$H_{ve,v}$ (kWh)
IS	46,72	9.607	8.132	2.785	1.182	150
M1	46,09	8.467	6.992	1.584	1.182	150
M2	46,72	9.607	8.132	2.785	1.182	150
M3	18,67	5.197	3.722	2.126	1.182	150
M1+M2+M3	17,09	4.057	2.582	926	1.182	150

- *Results for heating season on predominantly north-oriented façades:*

Results for heating season show 48% reduction on energy consumption when applying ETICS to external walls (M1), with a decrease on annual energy demand for heating (Nic) values from 50,37 kWh / m^2. year to 26,06 kWh/m^2.year. Changing U value and *g-value* of glazings (M3) enables energy savings in 27% compared to initial conditions. Compared to São Paulo (66 % for M1 and 41% for M3), reductions for both measures have less effect on energy savings.

Similar to São Paulo, applying XPS to flooring system (M2) continues to have no impact on consumption reduction. Overall solution (M1 + M2 + M3) represents 70% reduction in relation to initial conditions and Nic reference values – Nic (ref) = 13,61 kWh / m^2. year – is exceeded for all adopted construction solutions.

- *Results for cooling season on predominantly north-oriented façades:*

Results for cooling season show energy needs with measure M1 remains almost the same as initial solution, with slight reduction below 1 kWh / m^2. year (34,25 to 33,96 kWh/m^2.year).

Changing glazings thermal parameters (M3) decreases in 34% annual energy demand for cooling (Nvc), from 34,25 to 22,57 kWh / m^2. year. Total energy saving considering combined measures is 35 % in relation to initial conditions and Nvc reference values – Nvc (ref) = 14,40 kWh / m^2. year –, is exceeded for all adopted construction solutions.

- *Results for heating season on predominantly south-oriented façades:*

In Lisbon, south orientation is more exposed to solar radiation, as seen in increased values of useful heat gains ($Q_{gu,i}$). This behavior can be seen in Figure 6 (a).

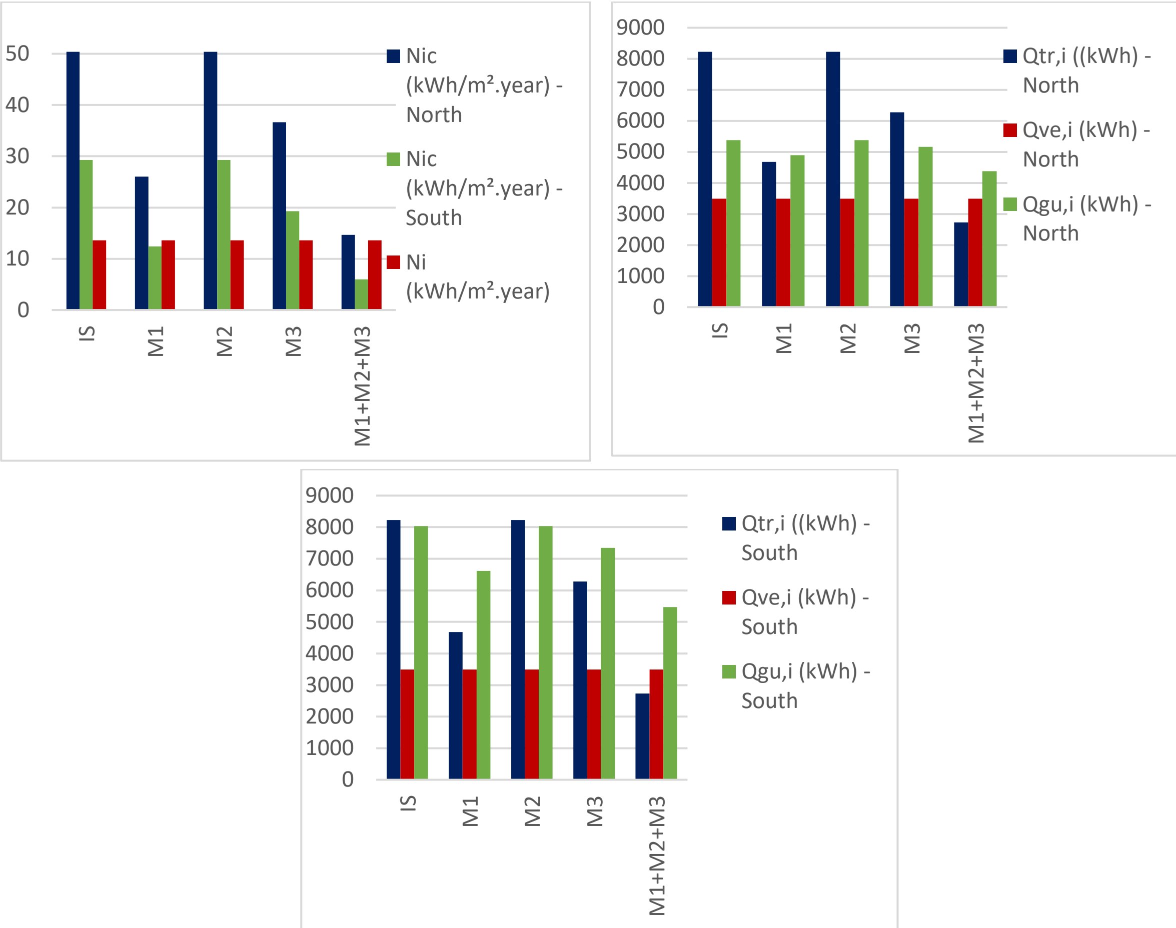
When looking at Nic values south-oriented façades summarize 80 % of total energy saving when adopting all improvement measures (10% less when compared to north orientation). As expected, results show a reduction on energy demand for heating on south orientation as the building is benefiting from heat gains during winter. Nic reference value – Nic (ref) = 13,61 kWh / m^2. year –, is only attended when applying ETICS on façades (M1) and for combined solutions. Figure 6 (a) shows Nic results for all improvement measures, considering both north and south oriented façades and compares Nic and Ni reference values.

- *Results for cooling season on predominantly south-oriented façades:*

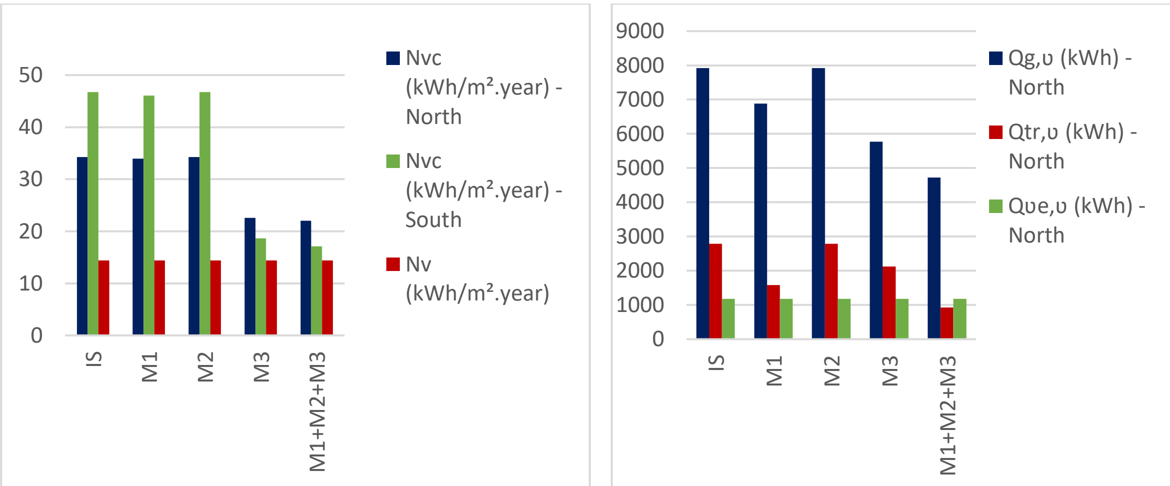
Nvc values show an increase on energy needs for cooling for initial solution and improvement measures M1 and M2 in south compared to north orientation. However, changing glazing U-value and *g-value* has a greater impact on reducing energy needs for south orientation. Overall solution (M1+M2+M3) results on Nvc value = 17,09 kWh / m^2. year (reduction is 5 kWh / m^2. year higher in relation to north-oriented façades). Nvc reference value – Nvc (ref) = 14,40 kWh

/ m². year –, for south-oriented building is exceeded for all adopted construction solutions. Figure 6 (b) shows Nvc results for all improvement measures, considering both north and south oriented façades and compares Nvc and Nv reference values.

a) Lisbon: heating season



b) Lisbon: cooling season



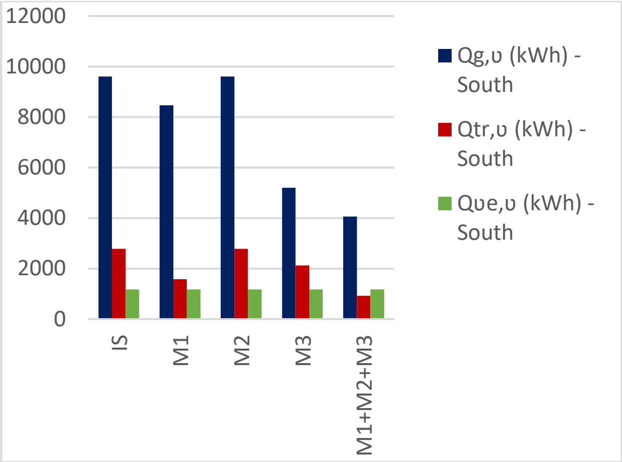


Figure 6 – Comparing results of heating and cooling energy balance for Lisbon.

a) São Paulo: heating season b) São Paulo: cooling season

4.1.3 Comparing results for São Paulo and Lisbon according to seasonal method

As expected, when comparing the same simulated scenarios both in São Paulo and Portugal, annual energy demand for heating in Lisbon is greater than in São Paulo case. This is explained by differences on climate characteristics such as greater exposure to radiation in São Paulo and reduced number of degree-days when compared to Lisbon. Results indicate that most construction solutions calculated for Brazilian climate are not satisfactory for Portugal's climate in terms of energy needs. This is more evidently seen during winter season, which in Portugal is more severe. Construction solutions appliable to Brazilian climate are not well suited to Portuguese climate: construction systems should avoid heat losses during winter. Results also indicate being unnecessary the use of insulation on external walls for São Paulo as Nic values for São Paulo are far way lower than Lisbon.

Lisbon case study show that with all improvement measures applied, predominantly south-oriented façades is preferable. São Paulo case indicates that north-oriented façades are preferable during winter in terms of energy savings, which was expected as south orientation is less exposed to radiation throughout the year. Contrarily, seasonal method points out to north orientation being preferable for cooling season: glazings impact differently on both orientations, being more effective for north orientation (due to greater exposure to radiation throughout the year).

Energy saving rates show that improvement strategies applied during heating season impacts less significantly in Lisbon. However, despite slight value differences, curves behave similarly for all improvement measures, as seen in Figure (7a).

Cooling season in São Paulo indicates an increase of 21% on energy consumption with solution M1 (from 38,88 kWh / m^2. year to 47,18 kWh/m^2.year) for south-oriented façades, as seen in Figure (7b). This is explained by effects of insulation on external walls on avoiding heat losses. Best results are seen for south-oriented façades in Lisbon when combining all improvement measures, as seen in Figure (7b).

a) Heating season *b) Cooling season*

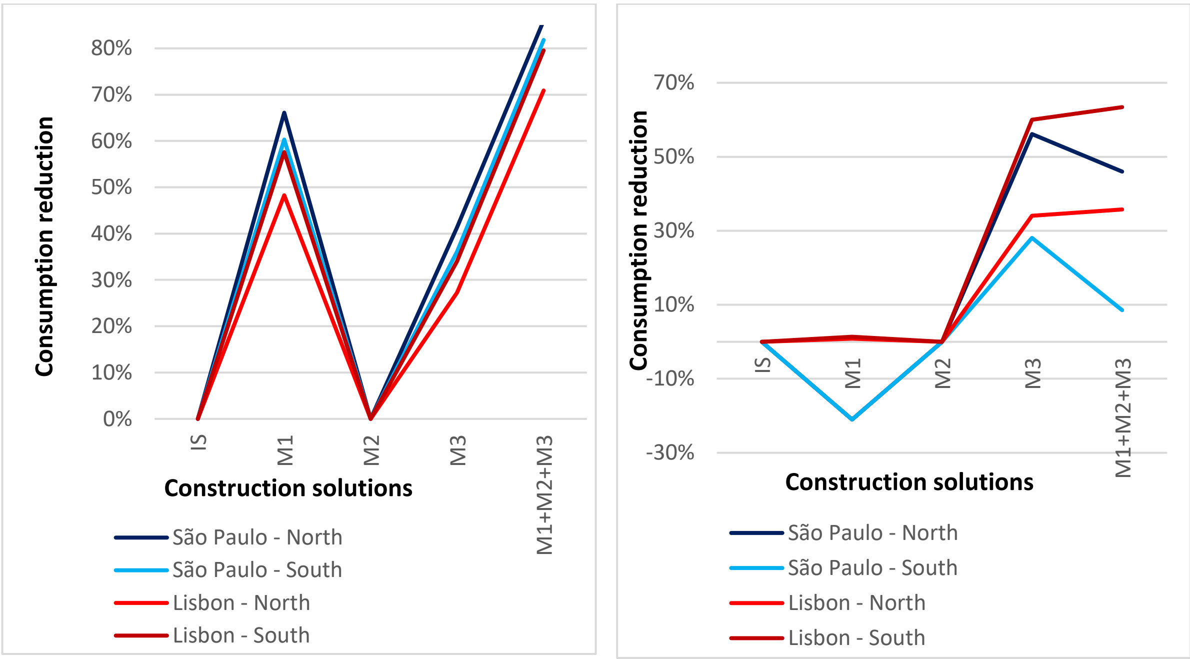


Figure 7 – Curve's behavior for both cities when analyzing all strategies.

a) *Heating season b) Cooling season*

Regarding nominal primary energy requirements (N_{TC}, kWh_{EP} / m^2.year) for all improvements discussed, results are compared in Figure (8). It can be noticed that most construction solutions in São Paulo are within N_T standardized reference value. However, Lisbon presents the opposite: N_T values exceed thresholds for almost all improvement measures, with only exception to combined solutions (M1 + M2 + M3) for north orientation.

a) São Paulo: Ntc values *b) Lisbon: Ntc values*

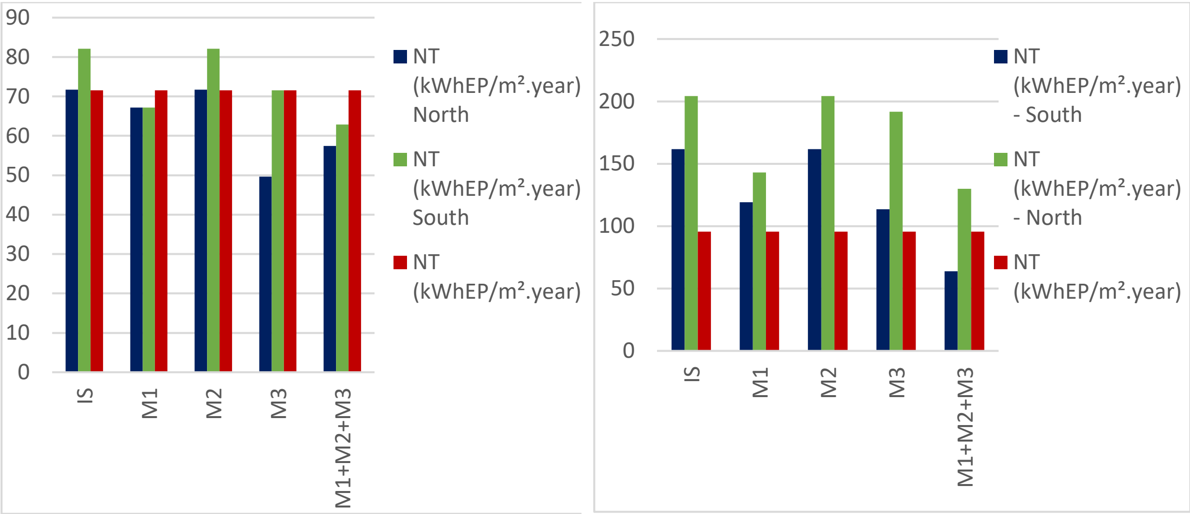


Figure 8 – Comparing results of N_{TC} values for São Paulo and Lisbon.

4.1.4 Energy class labelling according to Portuguese standard

Energy class labelling according to Portuguese method is assessed by N_{TC}, which is the value of nominal needs corresponding to primary energy and N_T corresponding to the regulatory threshold value for nominal primary energy needs, both calculated according to REH and in accordance with provisions of Dispatch (extract) No. 15793-J : 2013 [16], as shown in Equation (11). Results for São Paulo and Lisbon are presented in Table (29).

Table 29 – Energy classification for all scenarios discussed for São Paulo and Lisbon.

Solutions	São Paulo				Lisbon			
	North		South		North		South	
	N_{TC} / N_T	Energy Class	N_{TC} / N_T	Energy Class	N_{TC} / N_T	Energy Class	N_{TC} / N_T	Energy Class
IS	1,00	B -	1,15	C	2,13	E	1,69	D
M1	0,94	B -	0,94	B -	1,50	C	1,24	C
M2	1,00	B -	1,15	C	2,13	E	1,69	D
M3	0,69	B	1,00	B -	2,00	D	1,19	C
M1+M2+M3	0,80	B -	0,88	B -	1,36	C	0,67	B

Labelling shows satisfactory results for most of the strategies in São Paulo, particularly for north façades, ranging from B- (IS, M1, M2 and M1+M2+M3) to B class (M3), which is ideally required for new buildings. Results show the unnecessary use of insulation on external walls for São Paulo (M1) and analysis shows that the best strategy for reducing annual energy demand in São Paulo case would be through changing glazing thermal parameters and ventilation.

Whereas in Portugal energy labels are less satisfactory particularly for north façades, ranging from E (IS and M2) to C (M1 and M1+M2+M3), which is an acceptable label for renovations. South orientation presents a better result for overall solution only (class B).

It can be noticed that construction solutions equally applied for both case studies impact differently on results considering climate differences between countries. While for Brazilian climate all construction solutions are acceptable in terms of energy labelling, in Portugal this is seen only when implementing improvements: ETICS on façades and efficient glazings.

4.2 Building thermal performance according to Brazilian dynamic calculation method

4.2.1 Results for São Paulo

Brazilian thermal evaluation procedure through dynamic simulation was carried out for São Paulo case study by analyzing specific criteria with respect to regulatory threshold values. Results for the percentage of occupation hours of housing units within an operating temperature range, $PHFT_{,UH}$ (%), maximum and minimum annual operative temperature of housing units, $Tomax_{,UH}$ (ºC) and $Tomin_{,UH}$ (ºC), respectively, are shown in Table (30).

Table 30 – Results for building thermal performance for São Paulo.

Building solution	Housing Unit 1 - 15th floor					
	North oriented					
	$PHFT_{,UH}$ (%)		$Tomax_{,UH}$ (ºC)		$Tomin_{,UH}$ (ºC)	
	Ref	Real	Ref	Real	Ref	Real
IS	81,22	89,44	28,30	26,70	13,31	15,42
M1	81,22	97,44	28,30	25,47	13,31	16,72
M2	81,22	91,40	28,30	26,41	13,31	15,51
M3	81,22	97,50	28,30	25,64	13,31	16,83
M1+M2+M3	81,22	97,73	28,30	24,73	13,31	17,07

When analyzing $Tomax_{,UH}$ (ºC) and $Tomin_{,UH}$ (ºC) values according to Equations (18 – 19) for $\Delta tomax$ and $\Delta tomin = 1$ºC, results are considered within NBR 15.575: 2021 thresholds if $Tomax_{,UH,real} \leq 29,3$ ºC and $Tomin_{,UH,real} > 12,31$ ºC.

In a first analysis, results for $Tomax,_{UH,real}$ and $Tomin,_{UH,real}$ show that values for all solutions are attending the maximum and minimum temperature thresholds.

As expected, initial solution show higher $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) values compared to improvement solutions, which indicates a less satisfactory result in terms of building thermal performance. The same behavior is seen when applying insulation on flooring systems (solution M2). Contrarily, combining all strategies (M1 + M2 + M3) has a major positive impact on indoor temperatures during operating hours, with $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) distancing from threshold values, and thus within a more satisfactory temperature range in terms of human comfort.

When comparing solutions implemented on façades (M1 and M3), both ETICS and glazing with efficient thermal parameters impact similarly on indoor operative temperatures throughout the year. $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) values for M1 and M3 decrease and increase at least 1ºC in relation to IS, respectively. Percentage of occupation hours of the simulated housing unit within operating temperature range of 18 to 26 ºC, corresponding to $PHFT_{UH}$ values, increase at least 8% with both M1 and M3 solutions with respect to IS.

According to Table (6), minimum performance is achieved if $PHFT,_{UH}$,real > 0,9. $PHFT,_{UH}$,ref as determined by NBR 15.575: 2021. For results of $PHFT,_{UH,ref}$ shown in Table (29), minimum criteria is achieved if $PHFT,_{UH}$,real is at least equal to 73 %. All strategies comply satisfactorily with the standardized minimum criteria.

Similarly to results for $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC), $PHFT_{UH,real}$ values are more acceptable for isolated measures M1 and M3 and combined improvements (M1 + M2 + M3). This indicates that when applying ETICS and more efficient glazings on façades and XPS on flooring systems, almost in 100% of times indoor temperatures during operating hours of the year are within 18,0 ºC and 26,0 ºC. Moreover, $PHFT_{UH,real}$ value is almost identical for IS and applying XPS on flooring system (M2), showing the worst results among all solutions is M2.

Figure (9) show results for $PHFT,_{UH}$, $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for São Paulo.

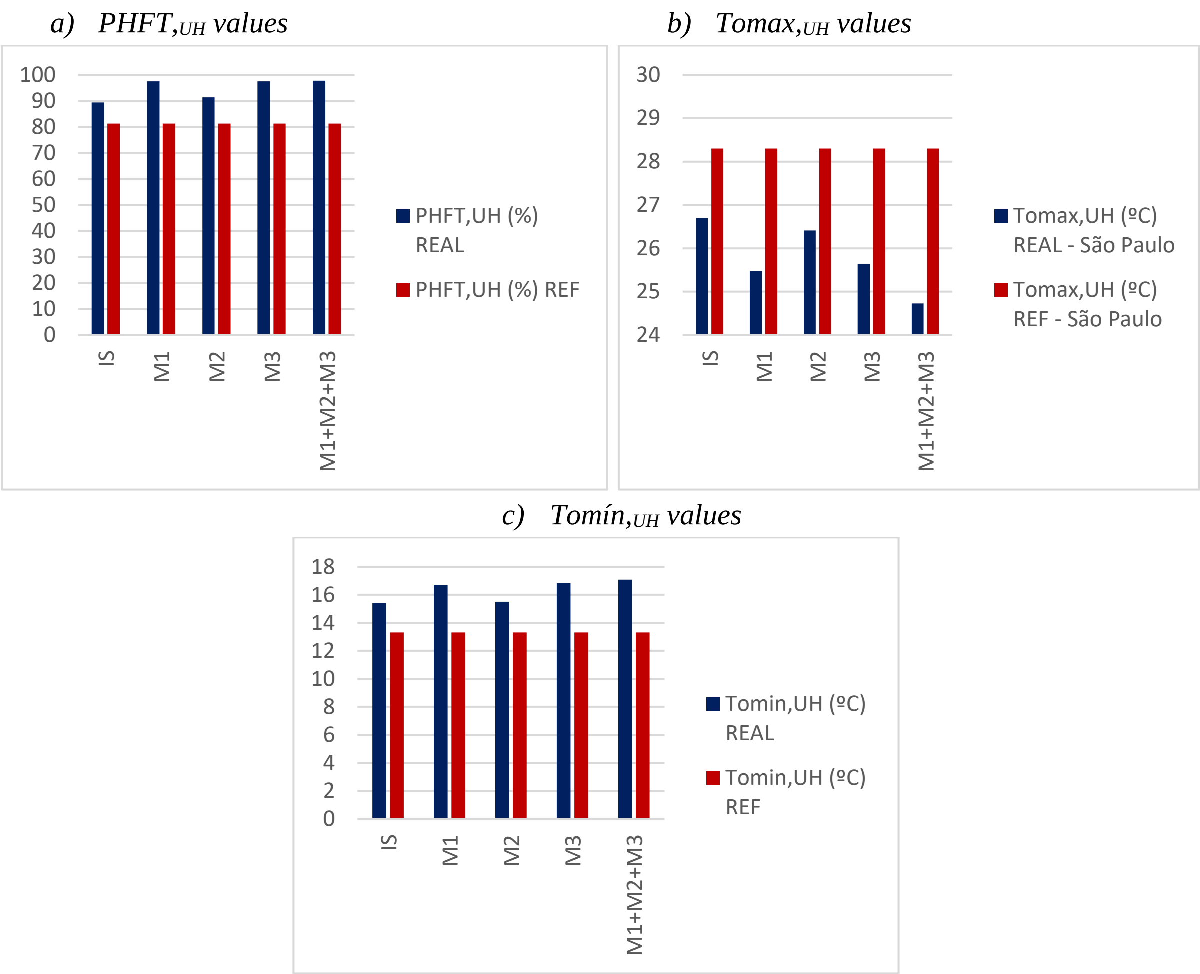


Figure 9 – $PHFT_{,UH}$, $Tomax_{,UH}$ (ºC) and $Tomin_{,UH}$ (ºC) for São Paulo.

a) $PHFT_{,UH}$ values b) $Tomax_{,UH}$ values c) $Tomin_{,UH}$ values

4.2.2 Results for Lisbon

Results for $PHFT_{,UH}$, $Tomax_{,UH}$ (ºC) and $Tomin_{,UH}$ (ºC) for Lisbon case study are presented in Table (31).

Table 31 – Results for building thermal performance for the city of Lisbon.

Housing Unit 2 - 15th floor						
Solution	Results					
	$PHFT_{,UH}$ (%)		$Tomax_{,UH}$ (ºC)		$Tomin_{,UH}$ (ºC)	
	Ref	Real	Ref	Real	Ref	Real
IS	53,25	60,14	28,80	28,00	9,14	11,38
M1	53,25	61,80	28,80	27,17	9,14	13,52

M2	53,25	60,35	28,80	27,77	9,14	11,67
M3	53,25	61,17	28,80	26,78	9,14	13,00
M1+M2+M3	53,25	63,86	28,80	25,37	9,14	13,34

When analyzing $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) values according to Equations (18 – 19) for Δtomax and Δtomin = 1ºC, results are considered within NBR 15.575: 2021 thresholds if $Tomax,_{UH,real} \leq 29{,}8$ ºC and $Tomin,_{UH,real} > 8{,}14$ ºC. A first analysis towards standardized criteria can be made concerning Δtomax and Δtomin constant values. When applied to Lisbon climate Equations (18 – 19) show more permissible results for minimum and maximum indoor operative temperatures throughout the year when compared to Brazilian climate: a reference minimum temperature value of 9.14ºC and thus, $Tomin,_{UH,real} > 8{,}14$ ºC fall short to what is expected in terms of comfortable indoor temperature.

Similarly to São Paulo, all $Tomax_{UH}$,real and $Tomin_{UH}$,real values attend to maximum and minimum temperature thresholds. Same behavior for $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for both IS and M2 is seen with values approaching the reference values. This indicates that for both São Paulo and Lisbon initial construction parameters and applying XPS on flooring systems are less efficient in terms of enhancing building thermal performance.

When comparing both solutions applied to facades (M1 and M3), it can be noticed that both ETICS and glazing behave similarly. $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) values are more acceptable for combined strategy (M1 + M2 + M3), indicating that when applying ETICS and more efficient glazings on façades, indoor temperatures throughout the year move away from threshold values, staying within a more satisfactory range. Overall results for $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) values indicate that indoor temperatures during the year are mostly influenced by solutions applied to building external opaque and transparent surfaces.

When looking at Lisbon $PHFT_{UH}$ values, minimum criteria is achieved if $PHFT_{UH}$,real is at least 90% of $PHFT_{UH}$,ref, which equals to 47,92 %. All values are at least 10% above this threshold, meaning that solutions applied comply with PHFT requirements according to NBR15.575: 2021.

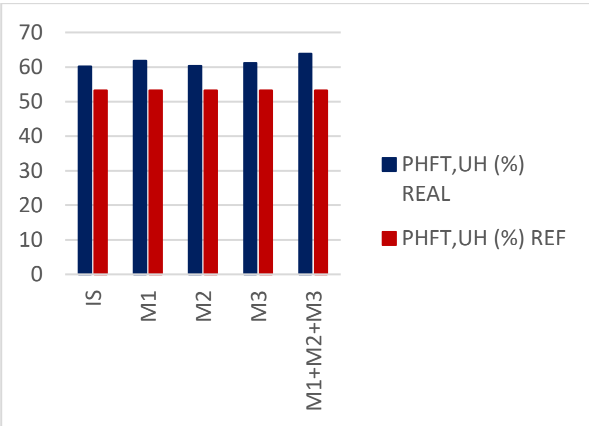
$PHFT,_{UH}$ ref value indicates that in 53,25 % of times for operating hours within the 8760 hours of an entire year indoor operative temperatures fall within 18,0 ºC and 26,0 ºC. As expected, this percentage is much lower in comparison with São Paulo case study (81,22 %). This is explained by particularities between climates of both countries: Portugal is subjected to a severe winter season with lower external temperatures throughout the year.

$PHFT_{UH}$, real values are more acceptable for combined strategy (M1 + M2 + M3): when applying ETICS and more efficient glazing on façades, the number of hours in which indoor temperatures during operating hours of the year are within 18,0 ºC and 26,0 ºC is 63,86 %.

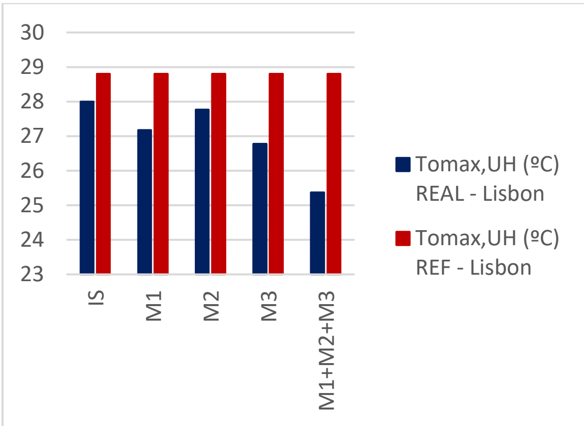
When comparing São Paulo and Lisbon case studies according to NBR 15.575: 2021 dynamic simulation procedure, results show that usual construction systems in Brazil are not well suited for Portuguese climate. This can be evidenced especially by PHFT values, which falls within the acceptable range of indoor operative temperatures (18,0 ºC and 26,0 ºC) in approximately 60 % of times comparing to 90 % to almost 100% of times for Brazilian climate.

Figure (10) show results for $PHFT,_{UH}$, $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for São Paulo.

a) $PHFT,_{UH}$ values



b) $Tomax,_{UH}$ values



c) $Tomin,_{UH}$ values

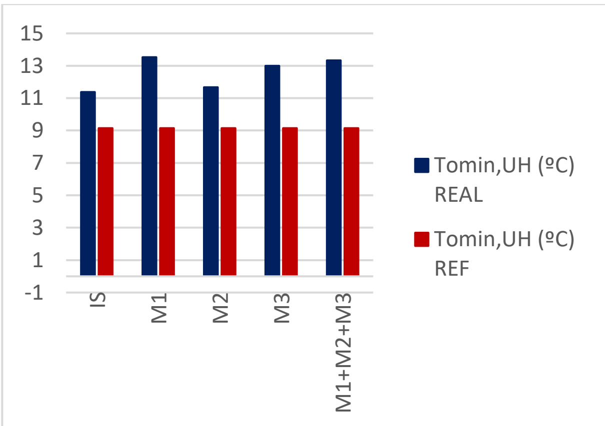


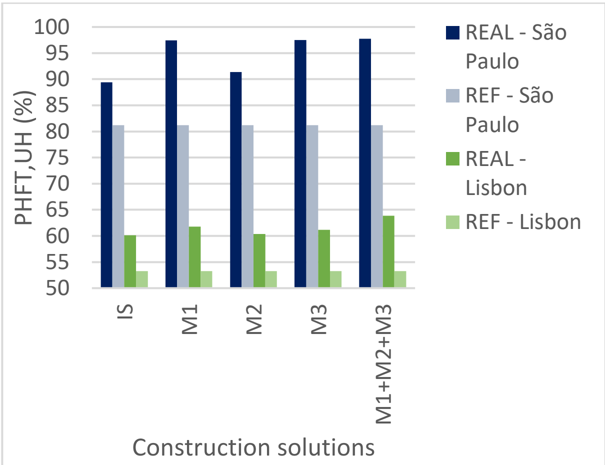
Figure 10 – $PHFT,_{UH}$, $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for Lisbon.

a) $PHFT,_{UH}$ values b) $Tomax,_{UH}$ values c) $Tomin,_{UH}$ values

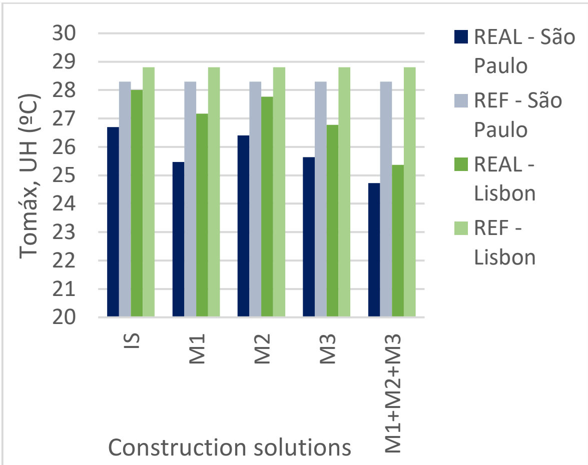
4.2.3 Comparing results for São Paulo and Lisbon according to dynamic method

Figure (11) presents compared results for $PHFT,_{UH}$, $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for São Paulo and Lisbon. When analyzing $Tomax,_{UH}$ and $Tomin,_{UH}$ results indicate a similar behavior between IS and improvement solutions for both cities, as described in detail on Sections 4.2.1 and 4.2.2, despite discrepancies on values.

a) $PHFT,_{UH}$ values



b) $Tomax,_{UH}$ values



c) $Tomin,_{UH}$ values

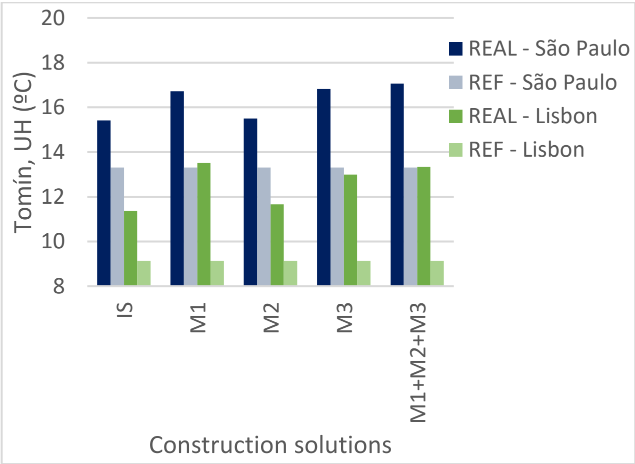


Figure 11 – Comparing $PHFT,_{UH}$, $Tomax,_{UH}$ (ºC) and $Tomin,_{UH}$ (ºC) for São Paulo and Lisbon.

a) $PHFT,_{UH}$ values b) $Tomax,_{UH}$ values c) $Tomin,_{UH}$ values

4.2.4 Energy class labelling according to Brazilian standard

Energy class is calculated in accordance with provisions of ABNT NBR 15.575 [5], as shown in Equations (13, 18 – 19). Results for São Paulo and Lisbon are presented in Table (32). Minimum level was reached for all scenarios.

Table 32 – Energy classification for all improvements discussed for São Paulo and Lisbon.

Solution	São Paulo			Lisbon		
	$PHFT_{,UH}$ (%)	$Tomax_{,UH}$ (ºC)	$Tomin_{,UH}$ (ºC)	$PHFT_{,UH}$ (%)	$Tomax_{,UH}$ (ºC)	$Tomin_{,UH}$ (ºC)
IS	Minimum level			Minimum level		
M1	Minimum level			Minimum level		
M2	Minimum level			Minimum level		
M3	Minimum level			Minimum level		
M1+M2+M3	Minimum level			Minimum level		

5. CONCLUSIONS

This dissertation aimed to compare calculation methods based on dynamic and seasonal simulations recommended by Brazilian and European standards ABNT NBR 15.575: 2021 and EN ISO 13790: 2008, respectively. The research consisted of evaluating impacts of applying Portuguese seasonal calculation method in a Brazilian case study, located in São Paulo and, analogously, implementing Brazilian dynamic simulation method in a Portuguese case study, located in Lisbon. For such purpose, simulation of residential case studies in both countries was carried out by use of calculation sheets provided by Itecons (seasonal method) and software Energy Plus (dynamic method), as recommended by NBR 15.575.

Definition of housing units to be simulated was based on selecting a representative case study of residential building with relevance for Brazil and Portugal, having in mind commonly used construction systems for both countries. The simulation models required data input respective to buildings location and geometry, material characteristics and thermal parameters, calculation of thermal bridges and windows, type of ventilation, heat recovery system and heating and cooling equipment. Moreover, for Brazilian dynamic simulation, detailed information is required with respect to occupation and internal loads, occupants' metabolic rate and radiant ratio, parameters for artificial lightning systems and building envelope transparent elements and openings.

An initial solution was simulated and then compared to improvement measures which aimed at promoting higher efficiency on buildings energy balance and performance. Initial solution consists on a concrete building, and transparent elements with thermal transmittance U=5,70 W/(m^2 .K) and solar factor, *g-value* = 0,87. Measures implemented consisted of applying a layer of ETICS (External Thermal Insulation Composite System) 60 mm white polystyrene board (EPS) applied to external walls, applying a layer of XPS (extruded polystyrene) 60 mm to flooring system, replacing glazing surfaces for more efficient global solar factors (*gtot* = 0,05) with protection devices and U=2,80 W/(m^2 .K), and combining solutions for all three strategies.

- *Conclusions on how output contents from Portuguese and Brazilian seasonal and dynamic methods can be related.*

Having in mind differences on outputs between Portuguese and Brazilian calculation methods, namely energy need rates (seasonal) and indoor operative temperatures (dynamic), output contents were related mainly by comparing results of N_{TC}/N_T and $PHFT_{UH}$ values, respectively.

Ideally, both methods should address correlation analysis to examine thermal comfort through indoor operative temperature and energy demand. Energy demand can be described as the amount of energy required to keep thermal comfort, depending on climate conditions, room's type of use, envelope's characteristics, and solar radiation. Thus, both contents are indispensable and complementary when assessing overall buildings thermal performance.

- *Conclusions on how applying Brazilian dynamic method impacts on Portuguese case study.*

Brazilian dynamic simulation method is carried out by comparing a real model and a reference model of the housing unit. The real model preserves the exact characteristics of the evaluated housing unit, such as geometric characteristics, thermal properties and compositions of transparent elements, walls, and roof. Whereas reference model preserves building volumetry, but construction systems, thermal properties and compositions of transparent elements, walls and roof and window to wall ratio are based on standardized parameters. Reference model adopts construction solutions which are commonly used in Brazil and would ideally meet buildings minimum thermal performance criteria for Brazilian climate. However, this reference model appears to be incompatible with Portuguese climate. This can be explained by values of $PHFT_{UH}$ (%), which is the percentage of occupation hours of the UHs within an operating temperature range, and values of $Tomax_{UH}$ (ºC) and $Tomin_{UH}$ (ºC), corresponding to maximum and minimum annual operative temperature of the housing unit, respectively.

Firstly, when observing $PHFT_{UH}$ results for Lisbon, real values approximate to 60%, representing the percentage of hours in which the simulated housing unit falls within the operating temperature range of 18 to 26 ºC. Having in mind that 18 to 26 ºC is considered the acceptable range by NBR 15.575: 2021 in terms of human comfort, Portuguese case study shows a much lower $PHFT_{UH}$ value when compared to Brazilian case study (ranging from 89 to almost 100%). Although minimum criterium is attended for Portuguese case study for all simulated strategies (IS, M1, M2, M3 and combined M1+M2+M3), this occurs because according to Brazilian standard, minimum criteria is achieved if $PHFT_{UH,real}$ is at least 90% of $PHFT_{UH,ref}$, which equals to 47,92 %. All $PHFT_{UH,real}$ values are at least 10% above this threshold.

Same behavior can be seen for $Tomax_{UH}$ (ºC) and $Tomin_{UH}$ (ºC) results: reference values are 28,80 ºC and 9,14 ºC, respectively. This means that results are considered within NBR 15.575: 2021 thresholds if $Tomax_{UH,real} \leq 29{,}8$ ºC and $Tomin_{UH,real} > 8{,}14$ ºC, according to Equations (18 – 19) shown in Section 2.2.3. Combined solutions (M1 + M2 + M3) show less satisfactory results for $Tomax_{UH}$ and $Tomin_{UH}$ for Lisbon, with values corresponding to 25,37 ºC and 13,34 ºC, respectively. When compared to São Paulo, results correspond to 24,73º C and 17,07ºC, which are once again more acceptable in terms of complying to a comfortable temperature range.

Conclusions show that Brazilian dynamic simulation method presents permissible results when applied in Portugal: in terms of building thermal performance labelling, minimum level (mandatory) was reached for all scenarios both in São Paulo and Lisbon despite discrepancies on $PHFT_{UH}$, $Tomax_{UH}$ and $Tomin_{UH}$ values. Thus, construction solutions equally applied for both case studies impact differently on results considering climate varieties between countries. Having in mind that winter season in Portugal is more severe, reference model used for Brazilian climate is not applicable to Portuguese climate: it should address construction systems with more efficient parameters mainly to avoid heat losses during winter.

- *Conclusions on how applying Portuguese seasonal method impacts on Brazilian case study.*

Whereas implementing Brazilian dynamic method in Portugal shows satisfactory results with mandatory labelling level based on NBR 15.575: 2021 reached for all simulated scenarios, seasonal method applied to São Paulo case study also shows satisfactory results for all strategies, particularly for north façades, ranging from B- to B class, which is ideally required for new buildings. For south-oriented façades, classification ranges from C to B-. Results indicate that using insulation on external walls for São Paulo (M1) is not necessary and that the best strategy for reducing annual energy demand in São Paulo would be through ventilation.

Seasonal method applied in Portugal shows that the same construction solutions lead to different results: scenarios calculated by Itecons spreadsheet are only acceptable for north-oriented façades when applying ETICS 60 mm white polystyrene board to external walls and when combining all improvement measures. For south orientation, results are acceptable when applying ETICS, with more efficient glazings and combined solutions. Classification ranges from E to C on north façades and from D to B on south façades. Again, similarly to dynamic simulation applied in Portugal, results for seasonal method indicate that construction solutions equally applied for both case studies impact differently on results considering climate varieties between countries, being less acceptable for Portuguese case study.

6. LIMITATIONS AND SUGGESTIONS FOR FUTURE WORKS

Firstly, as expected, data input is not the same for Portuguese and Brazilian calculation methods: Brazilian dynamic method is carried by comparing reference and real models. Besides, NBR 15.575: 2021 requires data with respect to occupation and internal loads, such as occupancy patterns, lightning and equipment parameters, occupants' metabolic rate and radiant ratio, as well as specific information respective to characteristics of transparent elements, window frames, natural ventilation, and infiltration by cracks. Whereas seasonal method is based on a single model and does not require the same parameters related to occupation and internal loads, lightning, equipments and ventilation/infiltration as Brazilian standard (although this method also requires data input for ventilation which is calculated according EN 15242 and comply with SCE - *Manual of Buildings Energy Certification System*). Therefore, comparison between the two methods may lead to slightly different conclusions. Dynamic method outputs are "diluted" throughout a year timespan, whereas seasonal method is specific for each cooling season. In Brazil, it may not be necessary to evaluate winter and summer seasons separately as winter temperatures are not similarly rigorous as most cities of Europe.

In future works, investigation should be carried in detail to assess impacts of cooling and heating thermal loads on both seasonal and dynamic methods, which are used for evaluating attendance to non-mandatory intermediate and upper levels according to NBR 15.575:2021. This provision aims at evaluating total thermal load of housing units in the simulation model without use of natural ventilation.

Investigations should also be carried to validate users' comfort with construction solutions which are attending mandatory thresholds according to Brazilian standards: in practice, does minimum criteria satisfies users thermal comfort? Furthermore, future studies can evaluate whether and how Portuguese standards are discussing provisions for assessing buildings performance data beyond energy needs, particularly related to users' comfort as approached by NBR 15.575: 2021.

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