

INI-C simplified thermal comfort assessment method: performance and limitations

Método simplificado de avaliação de conforto térmico da INI-C: desempenho e limitações

Método simplificado de evaluación del confort térmico INI-C: prestaciones y limitaciones

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Author contributions: Concepcion; Methodology; Supervision; Writing – review and editing: DE SOUZA, Roberta V.G.; Concepcion; Data curation; Data collection; Methodology; Validation; Visualization; Writing – original draft: MEDEIROS, Helder G.; Writing – original draft: GERALDO, Beatriz C.A.; Writing – original draft: CAMILO, Alice S.d.S.; Writing – original draft: PINTO, Maria Angélica V.

Conflicts of interest: The authors certify that there is no conflict of interest.

Funding: Productivity grant from Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq.

Ethics approval: The authors certified that there was no need for Ethics Committee approval.

Use of AI: The authors certify that there was no use of artificial intelligence in the preparation of the work.

Editors: Daniel Sant’Ana (Editor-in-Chief); Joara Cronemberger (Associate Editor); Sarah Adorno Blanco Vencio (Editorial Assistant).

Abstract

Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service, and Public Buildings, INI-C, published in 2021, incorporated a simplified method for evaluating the Percentage of Hours in Thermal Comfort (PHOCT) for naturally ventilated spaces through a Metamodel developed in Python. This article aims to verify its applicability and for this purpose, 82 buildings on the UFMG campus were analysed, classified into three groups according to the method's applicability: 1) applicable, 2) applicable with adjustments, and 3) not applicable. Only 16% of the buildings fell into Group 1. The simplified method was applied with modifications to three buildings in Group 2, and the results were compared with computer simulations in EnergyPlus. It was found that the PHOCT values obtained by the Metamodel are close to those generated by simulation, with a maximum difference of 5.7%. Finally, it is considered that the new method can support a general evaluation of naturally ventilated buildings; however, adjustments should be considered to broaden its applicability.

Key-words: Natural Ventilation; Thermal Comfort; Simulation Method; Simplified Method; School Buildings.

Resumo

A Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas, INI-C, publicada em 2021 incorporou um método simplificado para avaliação do Percentual de Horas em Conforto Térmico (PHOCT) para espaços naturalmente ventilados através de um Metamodelo desenvolvido em Python. Este artigo objetiva verificar a aplicabilidade deste método utilizando para tal, 82 edificações do campus da UFMG, classificadas em três grupos conforme a aplicabilidade do método: 1) aplicável, 2) aplicável com ajustes e 3) não aplicável. Apenas 16% das edificações enquadraram-se no Grupo 1. O método simplificado foi aplicado com modificações em três edificações do Grupo 2, e os resultados foram comparados com simulação computacional no Energy Plus. Verificou-se que os valores de PHOCT obtidos pelo Metamodelo são próximos aos gerados por simulação, com diferença máxima de 5,7%. Por fim, considera-se que o novo método pode promover uma avaliação geral de edificações ventiladas naturalmente, porém devem ser considerados ajustes no mesmo para ampliar a sua aplicabilidade.

Palavras-chave: Ventilação Natural; Conforto térmico; Método de Simulação; Método Simplificado; Edificações Escolares.

Resumen

La Instrucción Normativa de Inmetro para la Clasificación de Eficiencia Energética de Edificios Comerciales, de Servicios y Públicos, INI-C, publicada en 2021, incorporó un método simplificado para evaluar el Porcentaje de Horas en Conforto Térmico (PHOCT) para espacios naturalmente ventilados mediante un Metamodelo desarrollado en Python. Este artículo tiene como objetivo verificar su aplicabilidad usando para ello, 82 edificios del campus de la UFMG, clasificados en tres grupos según la aplicabilidad del método: 1) aplicable, 2) aplicable con ajustes y 3) no aplicable. Solo 16% de los edificios correspondieron al Grupo 1. El método simplificado se aplicó con modificaciones en tres edificios del Grupo 2, y los resultados se compararon con simulaciones computacionales en EnergyPlus. Se observó que los valores de PHOCT obtenidos por el Metamodelo son cercanos a los generados por la simulación, con una diferencia máxima del 5,7%. Finalmente, se considera que el nuevo método puede promover una evaluación general de edificios ventilados naturalmente; sin embargo, deben considerarse ajustes para ampliar su aplicabilidad.

Palabras-clave: Ventilación Natural; Conforto Térmico; Método de Simulación; Método Simplificado; Edificios Escolares.

1 Introduction

In the global energy outlook, the growing demand for electricity is a feature that has driven economic growth and the increase in electrification end uses, such as electric cars and the increase in demand for data centers. The forecast is that between 2018 and 2050, the increase in global energy consumption will be approximately 50% (Mostafazadeh, Eirdmousa and Tavakolian, 2023). The final consumption of electricity's share currently represents 20% with a forecast to increase to 26% in 2035 in the Declared Policies Scenario (STEPS), 29% in the Announced Promises Scenario (APS) and 36% in the Net Zero Emissions Scenario (NZE) (IEA, 2024). The buildings sector is currently responsible for 40% of the world's energy consumption, with space heating and cooling accounting for 34% of this consumption (Prabhakar et al, 2020). In the European Community, energy consumption reductions of up to 60% have been observed in the building sector in the member states when energy efficiency regulations have become stricter, showing that building labelling has a positive effect on the energy performance of the built stock (Wong and Krüger, 2017).

In Brazil, according to the 2023 National Energy Balance (BEN), the public and commercial sectors together consumed 24.2% of the electricity (Brasil, 2023). With the insertion of design strategy measures, it is expected that in Brazil the application of energy efficiency concepts has the potential to reduce energy consumption by 50% in new buildings and 30% in renovated buildings (Procelinfo, 2014).

In addition to being favorable to health, natural ventilation reduces the need for the use of artificial air conditioning and, consequently, the energy consumption of buildings, especially in mild and hot climates (Báez et al., 2017). Nevertheless, Veloso, Andrade Filho, and Souza (2023) stated that there is a growing trend in Brazil for new office buildings to be designed in accordance with international trends and green certification codes, which promote the use of fully conditioned open-plan offices and often disregard the potential benefits of natural ventilation. This trend can lead to significant increases in electricity consumption in this sector, ranging from 11% to 123%, when compared to buildings that incorporate natural ventilation as an adaptive measure. Thus, considering the particularities of each location, natural ventilation can be used as a strategy to provide greater thermal comfort and reduce building energy consumption (Báez et al., 2017).

School environments often have inadequate temperatures for those who occupy them, and this factor directly influences student learning, which can impair attention and the ability to solve activities a situation that is not different in Brazil (Puteh et al., 2012; Garcia et al., 2021). It is also noted that air quality is a factor that must be considered when designing a school building, since users spend a large part of the day inside learning spaces and in this sense, natural ventilation should be encouraged (Almeida and Freitas, 2014; Garcia, Souza and Silva, 2023).

During the COVID-19 pandemic, studies have shown that efficient ventilation in spaces for collective use reduces the risk of contamination by respiratory diseases (Morawska and Milton, 2020; Garcia, Souza and Silva, 2023). In view of this, the Brazilian Federal University of Minas Gerais, UFMG determined a biosafety protocol with adjustments to the functioning of the university during the pandemic. Among them, the enhancement of natural ventilation was highlighted, with the opening of doors and windows (UFMG, 2020).

1.1 Building labeling in Brazil

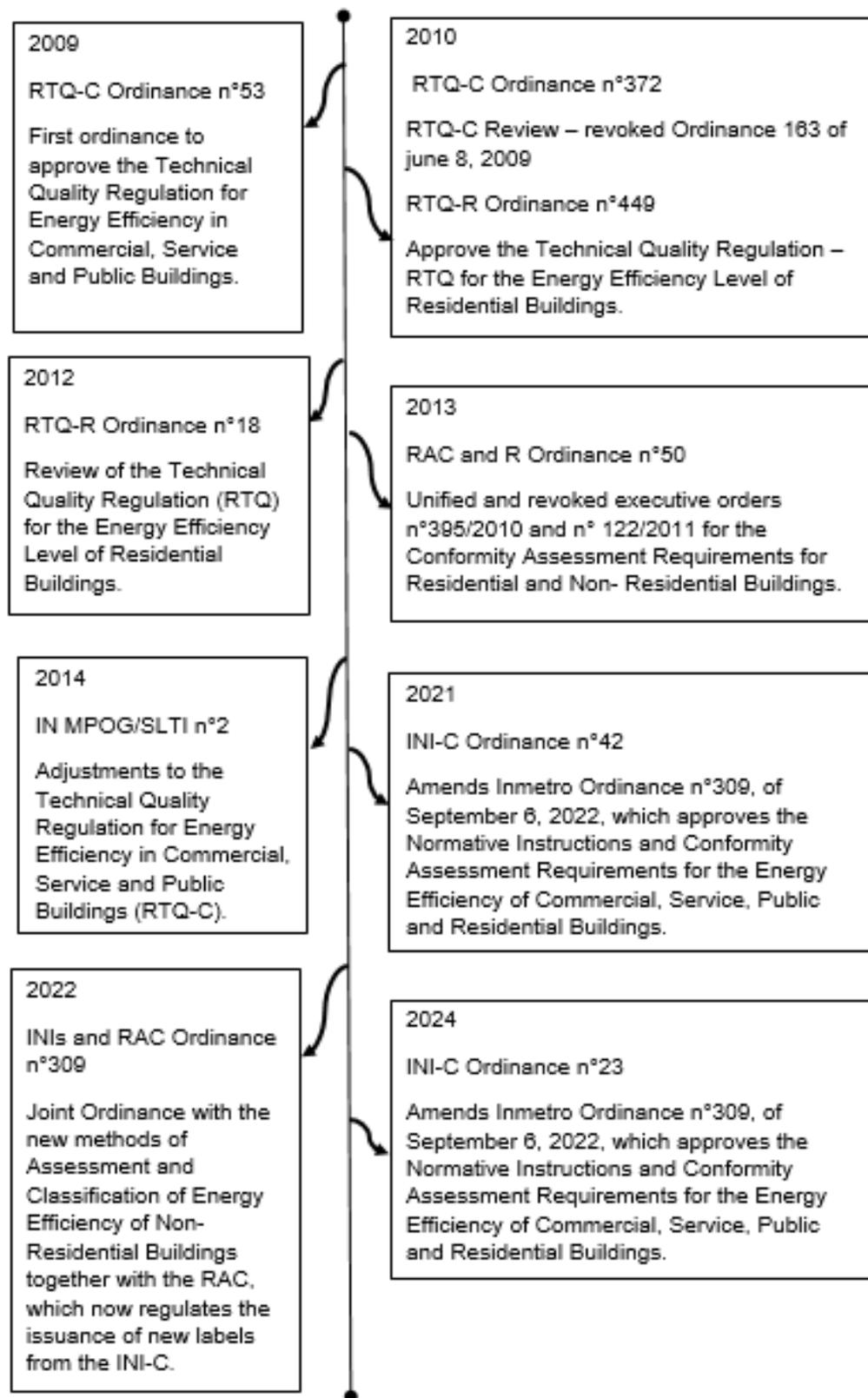
In 1984, INMETRO began discussions about the creation of evaluation programs that would contribute to the rationalization of energy use in Brazil, and provide information on the energy efficiency of equipment available in the national market (PBE Edifica, 2024).

From 1985 to 2005, the Ministry of Mines and Energy established the National Program for the Conservation of Electric Energy, PROCEL (PBE Edifica, 2024), laws no. 9.991 and n°. 10,295 and Decree No. 4,059 (Brazil 2000; Brasil 20011), the Management Committee of Indicators and Levels of Energy Efficiency - CGIEE, the Technical Group for Energy Efficiency in Buildings in the Country - GT-Edificações, PROCEL EDIFICA and; the Technical Secretariat - ST-Edificações and the Technical Commission - CT-Edificações. The last one, regularized by Inmetro, defined the process of obtaining the National Energy Conservation Label ENCE (PBE Edifica, 2024).

From that moment on, within the scope of the Brazilian Labeling Program (PBE), the Technical Quality Regulation for the Energy Efficiency Level of Commercial, Service and Public Buildings (RTQ-C), the Technical Regulation for the Quality of the Energy Efficiency Level of Residential Buildings (RTQ-R) and its related documents were prepared. Among these documents are the Conformity Assessment Requirements for Energy Efficiency of Buildings (RAC) and the Manuals for the application of RTQ-C and RTQ-R (PBE Edifica, 2024).

Finally, in 2017, aiming at the energy performance of buildings with a focus on the use of primary energy, the Brazilian Center for Energy Efficiency in Buildings (CB3E) and PROCEL Edifica, launched the proposal for a new approach (Brasil, 2021) to evaluate, which promoted the creation of the Inmetro Normative Instruction for the Classification of Energy Efficiency of Commercial Buildings, of Public Services (INI-C) in 2021. INI-C is, in practice, an update of the old Technical Quality Regulation for the Energy Efficiency Level of Commercial, Service and Public Buildings (RTQ-C) (Brazil, 2021). The change in name occurred to reflect the transition from a technical regulation to a more comprehensive normative instruction in line with the current needs for energy efficiency assessment and certification in the country. These steps are illustrated in a timeline in Figure 1.

Figure 1: Timeline that identifies publications and highlights the deadlines and transitional provisions between RTQs and INIs.



Source: Adapted from PBE Edifica (2004).

1.2 INI-C

In 2022, the Brazilian Labeling Program (PBE) published Inmetro Ordinance No. 309, regarding the Normative Instructions and Conformity Assessment Requirements for the Energy Efficiency of Residential Buildings (INI-R) and for Commercial, Service and Public Buildings (INI-C) (Brazil, 2022), which is the object of this work.

As with its predecessor, the RTQ-C, all systems (wraps, air conditioning, lighting and water heating) are evaluated. However, this new method directly uses the consumption of electrical or thermal energy used in each of the building's evaluated systems, which are added and compared with the reference conditions. In addition, the proposal takes into account carbon dioxide (CO₂) emissions, the rational use of water, local generation of renewable energy, and the estimated consumption of equipment (Brasil, 2021).

The INI-C allows the application of both a simplified method and a simulation method for each item evaluated, except for water heating, as shown in Chart 1 (Brazil, 2021).

Table 1: Possible combinations between the individual systems and the simplified evaluation and simulation methods.

Possible combinations between the individual systems and the simplified evaluation and simulation methods.			Simulation method					
			Envelope		Daylighting	Lighting	Cooling	Heating
			AC Build	NV Build				
Simplified Method	Envelope	AC Build	---	✓	✓	✓	X	X
		NV Build	✓	---	✓	✓	X	X
	Daylighting	✓	✓	-----	✓	X	X	
	Lighting	✓	✓	✓	-----	✓	X	
	Air conditioning	X	X	✓	✓	-----	X	

Source: Brasil (2021, p. 15).

1.3 Building Envelope in INI-C

The evaluation of the envelope is given by the percentage of reduction of the total annual thermal load (RedCgTT), which is obtained by the ratio between the total annual thermal load of the real building envelope (CgTTreal) and the reference condition (CgTTref). For the actual condition, the total annual thermal load shall be found on the basis of the sum of the annual cooling thermal loads (actual CgTR in kWh/year), taking into account all artificially conditioned thermal zones. The thermal load estimate is based on a metamodel, a simpler mathematical model that represents the answer of a more complex simulation model, which is available online (BRASIL, 2021).

In cases where the building is fully ventilated naturally or uses a combination of natural ventilation and artificial air conditioning, the Percentage of Occupied Hours in Thermal Comfort, PHOCt (%) should be evaluated. The fraction of excess hours per heat (FHdesc) throughout the year for the occupation period should be used to calculate the approximate PHOCt (BRASIL, 2021). For FHdesc estimation, a metamodel can be used, available at <http://www.pbeedifica.com.br/NaturalComfort>.

1.4 Metamodel for FHdesc

The simplified FHdesc estimation method uses a meta-model in which parameters should be incorporated to determine the thermal comfort conditions in naturally ventilated buildings. Among these parameters, 9 (nine) refer to the climate of the region and 29

(twenty-nine) refer to the characteristics of the evaluated building (Rackes, Melo and Lamberts, 2016). Table 1 shows the limits of the input parameters used in the Natural Ventilation Metamodel.

Table 2: Limits of the Metamodel input parameters for natural ventilation.

Input data	Unit	Values		
		Min.	Max.	
I	Average annual outdoor temperature (Tar)	°C	10	30
II	Annual average of the diff. between the max. and min. daily temp. (TarMD)	°C	3	15
III	Diff. between the max. and min. of the annual external seasons (TarMA)	°C	3	28
IV	Cooling Degree-Days to Base Temp. of 18°C (CDD18)	K.day	0	3800
V	Cooling Degree-Days for 25°C base temp. (CDD25)	K.day	0	1600
VI	Average of annual normal direct solar radiation (MRDR)	W/m ²	40	200
VII	Average of annual diffuse solar radiation in the horizontal plane (MRDH)	W/m ²	70	130
VIII	Average of annual outdoor air velocity (VMV)	m/s	0	50
IX	Altitude	m	0	2000
X	Total length (largest dimension between the sides of the building)	m	13	200
XI	Total depth (smallest dimension between the sides of the building)	m	8	50
XII	Height between floors	m	2,75	4,25
XIII	Number of floors	-	1	5
XIV	Average area of occupied rooms	m ²	9	400
XV	Total fraction of the building area allocated to stairs	-	0	0,28
XVI	WWR (Fraction of façade opening)	-	0,05	0,7
XVII	Average Vertical Shading Angle	°	0	45
XVIII	Average solar absorption of the outer walls	-	0,2	0,8
XIX	Average thermal capacity of the walls	kJ/m ² .K	40	500
XX	Average solar absorption of the roof	-	0,2	0,8
XXI	Average thermal transmittance of the roof	W/m ² .K	0,1	5
XXII	Average Thermal capacity of the roof	kJ/m ² .K	10	400
XXIII	SHGC (solar gain coefficient of glass)	-	0,2	0,8
XXIV	Thermal transmittance of glass	W/m ² .K	1	6
XXV	Average of the combination between dens. of pot. of llum. and equipment in the long-stay rooms	W/m ²	1	25
XXVI	Average of the combination between dens. lighting power and equipment in the transitional areas	W/m ²	1	15
XXVII	Occupancy density	occup./m ²	0.01	1
XXVIII	Occupancy start time	h	6	10
XXIX	Occupancy end hour	h	14	22
XXX	External air velocity correction factor	-	0,10	0,40
XXXI	Surrounding Obstacles	-	0,3	1,0
XXXII	Average of the maximum opening fraction of all windows	-	0.2	1
XXXIII	WWRnight (fraction of opening of the façade of windows intended for night ventilation)	-	0	0.17
XXXIV	Relationship between the width and height of primary windows	-	0,1	50
XXXV	Discharge coefficient of primary windows	-	0,40	0,8
XXXVI	Effective flow area between the occupied spaces and shared permanence areas, by shared wall comp.	-	0,000	0,4
XXXVII	Increasing air velocity from ceiling fans	m/s	0	0,9

Source: Adapted from Rackes, Melo and Lamberts (2016).

According to Rackes, Melo and Lamberts (2016), the Metamodel aims to facilitate the validation of passive ventilation systems, having been developed after carrying out more than 50 thousand thermoenergetic simulations. Developed based on school buildings, it is able to quantify their thermal performance through the annual fraction of occupied hours exceeding the comfort limit suggested by ASHRAE 55-2017. Factors such as the increase in the built area, the number of floors, the density of occupation and the density of installed power can increase the discomfort in the building (Rackes, Melo and Lamberts, 2016).

The complexity of the application of simulation methods occurs due to the programs, which in addition to presenting non-didactic interfaces, require from the user not only the ability to configure the tools, but also the understanding of the physical and chemical phenomena involved, as well as a good understanding of numerical solutions (Versteeg and Malalasekera, 1995). Thus, this process usually involves professionals from different areas to develop the model and feed the database for simulation, since both the decision of the input data and the interpretation of the model's results require mastery of the theme (Meusel and Wetsphal, 2017). Another problem that can invalidate the use of thermoenergetic simulation programs for Brazilian buildings is the adaptation of the programs to the Brazilian reality, such as real climate data, topographies and topologies, and graphical interfaces in Portuguese, which becomes inaccessible to the entire Brazilian population (Medeiros and Souza, 2019).

On the other hand, simplified evaluations, despite providing an estimated value, most of the time present results close to the results of computer simulations, thus being sufficient to provide quick perceptions, without requiring so much data and presenting a faster and less complex application.

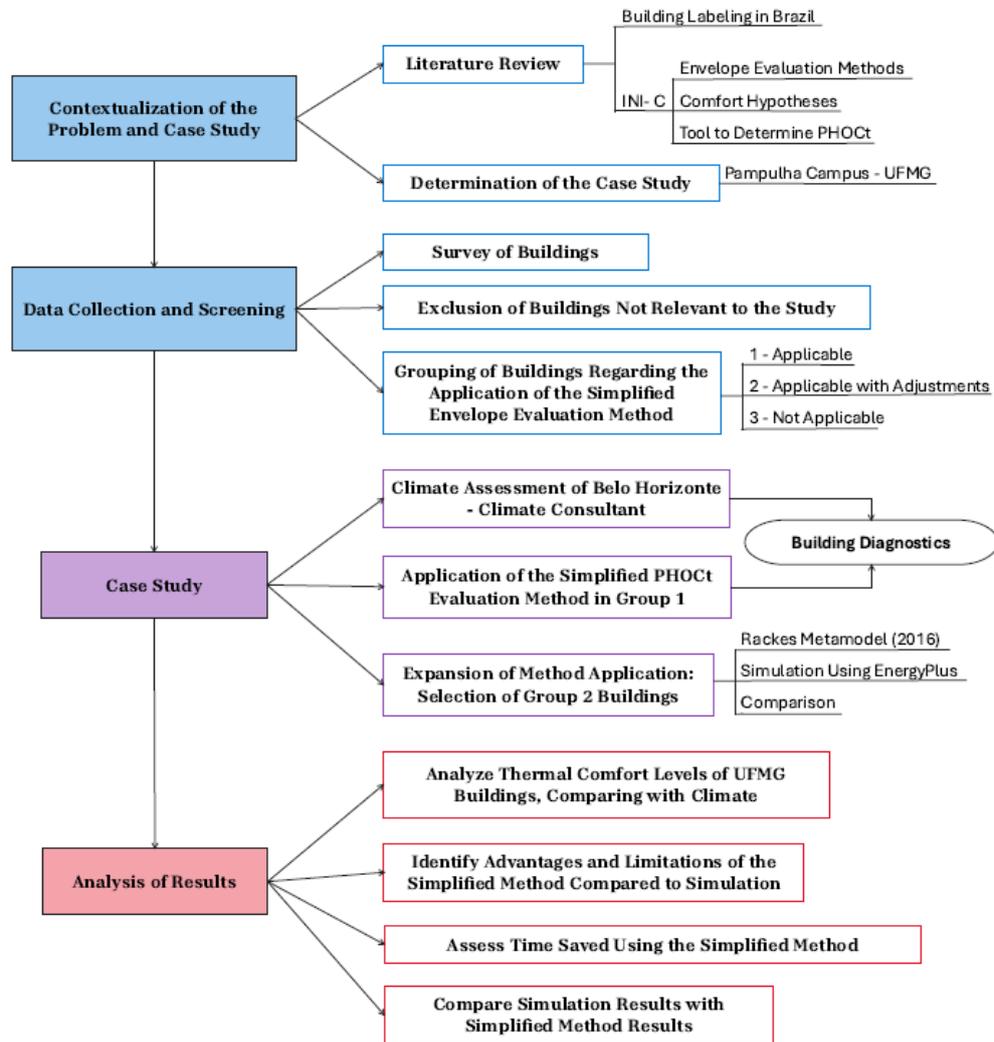
The present work, the result of a master's dissertation (Medeiros, 2021), sought to identify possible limitations of the new evaluation system, proposing recommendations to expand the use of the INI-C thermal comfort assessment tool, having as object of study the buildings of the Pampulha Campus of the Federal University of Minas Gerais.

Por outro lado, as avaliações simplificadas, apesar de preverem um valor estimado, na maioria das vezes apresentam resultados próximos aos resultados das simulações computacionais, sendo assim suficientes para o fornecimento de percepções rápidas, sem exigir tantos dados e apresentando uma aplicação mais rápida e menos complexa.

2 Methodology

Two PHOCT evaluation methods were used to comprehensively analyze the simplified method of evaluation of naturally ventilated buildings of the INI-C, the simplified method and the computer simulation having as a case study buildings of the Pampulha Campus of UFMG. In both methods, the comfort condition used to define the acceptable thermal conditions for a naturally ventilated environment was based on the ASHRAE 55-2017 adaptive comfort model. To achieve the proposed objectives, the methodological procedures were followed, as shown in Figure 2.

Figure 2: Research steps.



2.1 Case Study

With 699,630m² of built area, the object of study are the buildings of the Federal University of Minas Gerais, more specifically the Pampulha Campus, formed by buildings/complexes aimed at research and support and administration of academic units.

Architectural plans of 47 buildings were surveyed, divided into 111 blocks. Architectural projects and types of uses and occupation were surveyed and analyzed through the university's collection, in order to screen the buildings of interest for the research and grouping in relation to the applicability of the Metamodel. Of these, 29 blocks or buildings were considered of no interest for the research carried out, because they are not naturally ventilated or ventilated in a hybrid way and because they have a different functioning from offices, or academic rooms. Each building block was analyzed separately and then evaluated as a building.

The buildings considered to be of interest for the research were evaluated in compliance with the limits established by the INI-C for the application of the simplified method: parallelepipedal format; length between 13 m and 200 m; width between 8 m and 50 m; ceiling height between 2.75m and 4.25m; maximum of five floors; a ratio between length

and width less than four, maximum total height of 16m; area variation of up to 10% between the rooms and space of the APPs.

As few buildings/blocks fit the pattern, it was considered to make small modifications for the possibility of application in the simplified model, such as: changing the length and width ratio, which should not exceed the limit of 4, maintaining the original area.

Thus, three groups were defined according to the applicability of the method: 1) buildings in which the simplified method can be applied without adjustments, 2) buildings in which the simplified method can be applied with adjustments, and 3) buildings in which the simplified method is not applicable.

In this context, three buildings were selected so that it was possible to test the expansion of the applicability of the Metamodel, which make up Group 2, namely, Dance Annex of the School of Fine Arts, EBA, Block 2 of the Faculty of Education, FAE and Block H Institute of Biological Sciences, ICB. These buildings were selected for the analysis because they use different construction technologies and because they require adjustments for the application of the Metamodel.

It is worth mentioning that these case studies were chosen for analysis due to the difference in volumetry and format, in addition to the use of diversified construction materials.

To evaluate the PHOCt of the buildings in Group 1, the Metamodel was used. As the survey was carried out in 2022, before the publication of INI-C Ordinance No. 309/2022, the values of 14.1 W/m² and 23.8 W/m² were adopted for the installed power density in areas of transient and prolonged permanence, respectively, as recommended by INMETRO Ordinance No. 248, of July 10, 2018 (BRAZIL, 2018), as shown in Table 3, below:

Table 3: Input data fixed by the Ordinance INMETRO n° 248/2018.

Input data	Unit	Fixed values
Measurement of the combination between the power density of lighting and equipment in long-stay rooms	W/m ² .K	School – 23,8 Office - 25
Measurement of the combination between the power density of lighting and equipment in the transient dwell areas (corridors and stairs)	W/m ² .K	School – 14,1 Office - 15
Occupancy density	ocup./m ²	School – 0,667 Office - 0,1

Source: Brasil (2018).

The Belo Horizonte climate file INMET 2012 was used for all evaluations because it is the file used by the natural ventilation metamodel. In addition, the presence of ceiling fans with air velocity of 0.35m/s in all the buildings under analysis was also considered.

Table 4: Input data related to the INMET climate file for Belo Horizonte used in the simplified method.

Input data	Unit	Value
1 Average annual external temperature (Tar)	°C	21,8
2 Annual average of diffs. between the max. temp. and min. Daily (TarMD)	°C	9,4
3 Diff. between the max. and min. annual external temp. (TarMA)	°C	13,6
4 Cooling Degree-Days to Base Temp. of 18°C (CDD18)	K.dia	1483
5 Cooling Degree-Days for 25°C base temp. (CDD25)	K.dia	164
6 Média anual da radiação solar direta normal (MRDR)	W/m ²	95
7 Average annual diffuse solar radiation in the horizontal plane (MRDH)	W/m ²	91
8 Average Annual Outdoor Air Velocity (VMV)	m/s	2,2
9 Altitude	m	869

Finally, another variable used is the opening hours of the buildings. In this case, it was necessary to make an adjustment, since Metamodelo has a limit from 06:00 am to 22:00 pm, while the actual opening hours of the blocks are from 7:30 am to 22:45 pm. Thus, it was necessary to consider the hours from 8:00 am to 10:00 pm.

In view of the greater detail of the data in the Python interface and the possibility of evaluating more than one building simultaneously, this program was chosen for the evaluation of the Group 1 blocks instead of the INI-C web interface. This is justified because the web interface does not allow you to view the climatic parameters used - the user only selects the city, without knowing from which climatic file the data was extracted. In the Python interface, it is necessary to manually enter the nine parameters that make up the chosen climate file, providing greater precision in the results.

2.2 Expanding the applicability of the Metamodel

In order to attest to the feasibility of expanding the Metamodel, the following buildings of Group 2 were selected for thermoenergetic evaluation: Dance Annex of the School of Fine Arts, Block H of the Institute of Biological Sciences and Block 2 of the Faculty of Education.

When analyzed by the simplified method, these buildings had their parameters adjusted due to some impediments of the Metamodel, as shown in Table 5:

Table 5: Parameters adjusted for use with the Metamodel.

Building	Parameter	Measured	Adjusted	Reason
Dance Annex - EBA	Ceiling height	3,75m	3,19m	Limit of 16m total height
	Installed power in APP	39,9 W/ m ²	25,0 W/m ²	25 W/m ² limit
	Width	10,62m	12,73m	Non-rectangular shape
Block H - ICB	Thermal capacitance of the roof	457,9 kJ/m ² .K	400,0 kJ/m ² .K	Limit of 400.0 kJ/m ² . K
	Number of floors	4	4 e 3	First floor is pilotis
Block 2 - FAE	Length	108,6m	102,8m	Length x width ratio
	Width	24,4m	25,7m	Length x width ratio
	Ceiling height	Variable	3,1m	Only one ceiling height value must be entered
	Roof absorption	0,85	0,80	Limit of 0.8

It should be noted that no building met the requirement "area variation of up to 10% between the rooms and space of the APPs (Extended Stay Environment), for this reason this requirement was ignored.

From a model of Sketchup Make 2017, and the Euclid plug-in 0.9.3, the buildings were produced three-dimensionally to evaluate whether the adjustments made for the use of the Metamodel were significant for the result of the PHOCT.

After completing the volumetry, it is necessary to incorporate data into the model, such as physical characteristics of the materials used, occupation and equipment of the environments, in addition to lighting routines and window and door openings. In the following figures, it is possible to compare the volumes of the satellite images of the buildings and their respective 3D model.

Figure 3: Aerial image of FAE's Block 2



Figure 4: FAE's Block 2 3D model

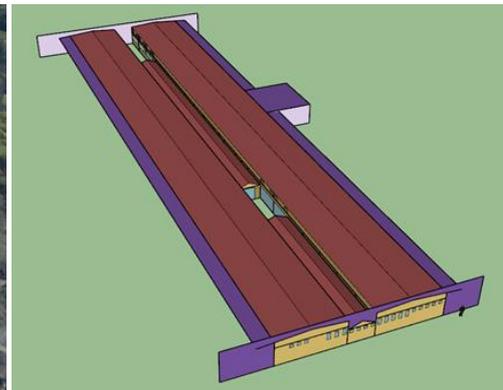


Figure 5: EBA Dance Annex aerial image



Figure 6: EBA Dance Annex 3D Model

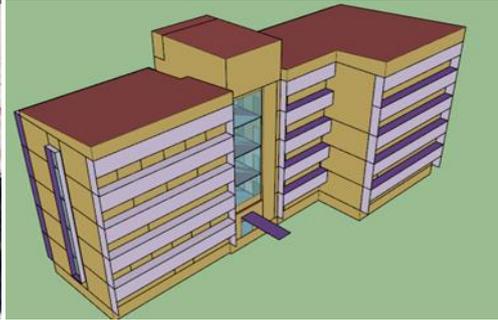


Figure 7: ICB aerial image

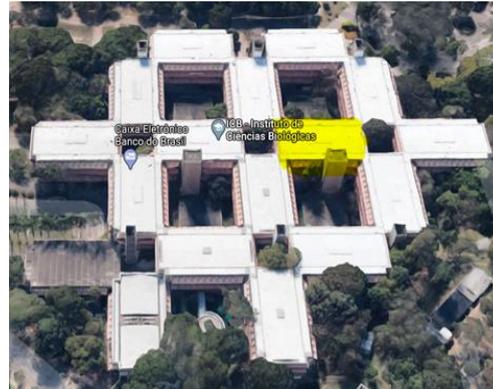


Figure 8: ICB 3D model

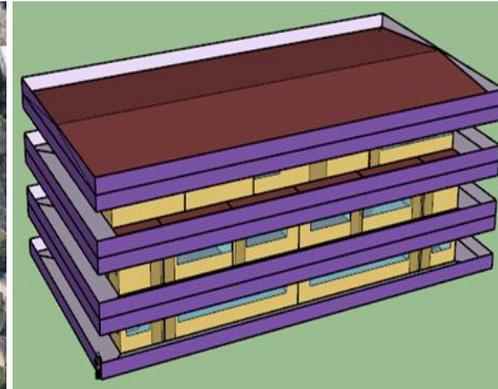


Table 6 shows the characteristics of the simulated buildings, which resulted in temperature data for each of the environments analyzed for each period of the year.

Table 6: Characteristics of the simulated buildings.

	Building		
	Block 2 - FAE	Block H- ICB	Dance Annex - EBA
Transmittance of external walls (W/m ² .K)	Aluminum frame with cement plate and masonry 5,54 e 1,85	Masonry 1,85	Masonry 1,85
Roof transmittance (W/m ² .K)	Asbestos roof and PVC lining 1,76	Slab, waterproof insulation and sandwich tile 0,56	Slab, waterproof insulation and metal tile 1,87
Area	2600 m ²	2880 m ²	1680 m ²
Flor number	1	5	4
Total height	3,1 m	18,8 m	16,0 m
Type of use	Classroom, library and administrative rooms	Offices, library, dance and administrative rooms	Classroom and seminar room
Colors and absorption of the walls	White 0,2	Yellow and white 0,2 e 0,3	White 0,2
Conception	-	2010	1968-1969
Inauguration	1965	In bidding	1973

Source: Adapted from the Planning and Projects Department (2020).

With this data, it was possible to treat them considering the limits of ASHRAE 55-2017, to determine the PHOCT of each environment. Thus, a comparison was made between the PHOCT obtained by the Metamodel and the one extracted by the simulation method, to verify whether the adjustments made in the Metamodel were significant for the result.

2.3 Data analysis

The main results obtained in this research refer to the verification of the applicability of the simplified method for natural ventilation analysis, proposed in the INI-C, and to the development of a proposal for simplification of volumes, with the objective of enabling the application of the metamodel. For this, the survey of the set of buildings of the UFMG Campus was used as a sample. The relevance of the proposals was evaluated by comparing them with the results of computer simulations.

According to the applicability of the Metamodel proposed by Rackes, Melo and Lamberts (2016), 16% of the blocks fall into the group of applicable, 61% into the group of applicable with adjustments and 23% into the group of non-applicable buildings (Medeiros, 2021). The reasons for the restriction in the application of the simplified method proposed by INI-C are: non-rectangular shape, presence of zenith openings; building on stilts; floors that are different from each other, the length of the building or block greater than four times its width, the presence of voids inside the building or block; building with more than five floors, building with the presence of a basement, ceiling height varies along the floor, length of the building or block less than 13 m, environments with double ceilings, total height of the building exceeds 16m, part of the building has auditoriums and presence of external stairs (Medeiros, 2021).

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3.1 Group 1 – Application of the metamodel

After the evaluation of 13 (thirteen) buildings in Group 1 by the simplified method, the PHOCT values were obtained, which vary between 96.8% and 52.8%. The results obtained

showed that there is a great difference between the comfort levels of the buildings analyzed. In this way, an overview of the comfort levels of the buildings of the UFMG Campus Pampulha was obtained. Table 7 shows the estimate of the hours in heat discomfort obtained in this simulation.

Table 7: Estimate of the fraction of discount hours in relation to the occupancy hours obtained through the metamodel for the Group 1 buildings.

Building	FHdesc (%)	PHOCt considered
ICB – Block B	30,4	69,6
ICB – Block C	47,1	52,9
ICB – Block E	46,6	53,4
ICB –Block F	43,9	56,1
ICB –Block I	38,8	61,2
ICB – Block L	35,5	64,5
ICB – Block M	19,1	80,9
ICB –Block P	3,2	96,8
ICB – Block Q	27,0	73,0
ENG-CPDE	5,5	94,5
VET – Block 13	47,8	52,2
PRA-DGA	6,9	93,1
EBA – Engraving Annex	16,6	83,4

Source: Brasil, 2018.

3.2 Grup 2 – Expanding the applicability of the metamodel

The results presented for the EBA Dance Annex, in relation to the estimate of the fraction of hours in heat discomfort were: FHdesc=10.9% and PHOCt= 89.1%. In this study, the use of ceiling fans was not considered, and the air velocity $V_{ar}=0$ m/s. The justification for the disregard of the use of fans was due to the fact that the project did not provide for the equipment.

In Block H of the ICB, there was an adaptation of the pilotis, as there is no provision in the Metamodel of how to act in the case of buildings on pilotis. The building has 4 floors and the first is pilotis. For this reason, there were two studies, considering the building with 3 floors and then it was done considering 4 floors. The estimated fraction of hours in heat discomfort were: ICB Block H (3 floors) FHdesc=12.3% and PHOCt= 87.7%; ICB Block H (4 floors) FHdesc=15.6% and PHOCt= 84.4%.

Block 2 of the FAE presented the results presented for the estimation of the fraction of hours in heat discomfort: FHdesc=31.6% and PHOCt= 61.4%.

4 Results analysis

The Metamodel proposed by INI-C is an easier and faster process in relation to the simulation method, but to be truly efficient and encourage its use for the labeling of naturally ventilated or hybrid buildings, it is necessary to increase its scope. Changing the parameters of buildings to suit the tool can be an alternative.

The PHOCt result of the 13 (thirteen) buildings that can be evaluated by the Metamodel without the need for adjustments had large variations, between 96.8% (ICB-Block P) and

52.2% (VET-Block 13). This difference is justified by the fact that the variation in the area and the number of floors are factors of great influence on thermal performance (Rackes et al. 2016).

To expand the applicability of the Metamodel, it was necessary to make adjustments to the input data, resulting in the possibility of evaluating 63 buildings within the Campus. With the changes, it was verified that the results obtained by the Metamodel are close to those obtained by the simulation method. These simulations were carried out in three buildings, namely: EBA Dance Annex, FAE Block 2 and ICB Block H.

The results showed that, despite small differences, the Metamodel provided estimates close to those of the simulation, especially in buildings whose configurations were within the limits of applicability of the simplified method. The mean deviation was approximately -1.95%, indicating a good correlation between the two methods.

Table 8: Comparison between the PHOCT values obtained by the metamodel and by computer simulation.

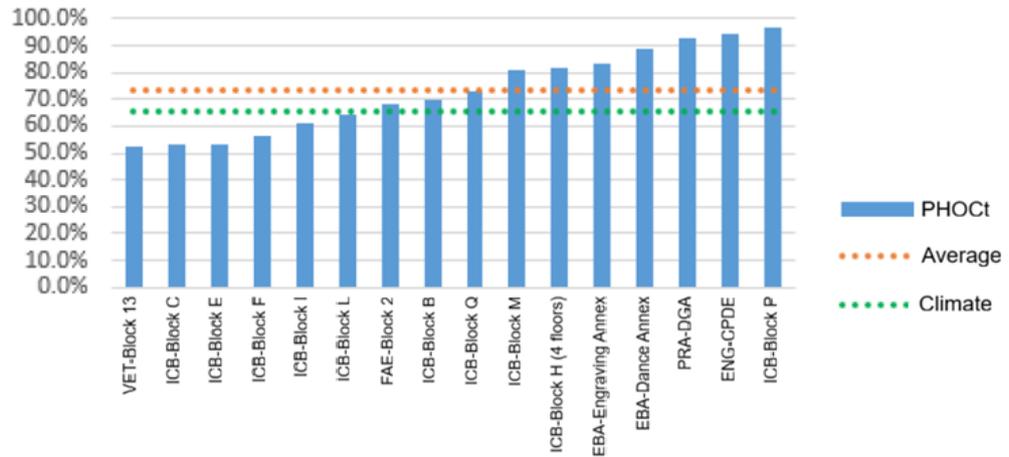
Building	PHOCT metamodel	PHOCT computer simulation	Percentage difference
EBA dance annex	89,1%	91,7%	-2,6%
ICB Block H	87,7% (3 flr.)	85,6%	2,1%
	84,4% (4 flr.)		-1,6%
FAE Block 2	68,4%	74,1%	-5,7%

However, for buildings with more extreme characteristics or that exceed the limits of the Metamodel, the deviation tends to increase, reflecting the limitations inherent to the simplified method.

These analyses demonstrate that the potential of the Metamodel for evaluating the thermal comfort of buildings is considerable, especially when its application limits are respected.

The evaluation of 16 buildings showed a large variation in the levels of thermal comfort, so in Figure 10 below it is possible to see that the buildings have a level of comfort within the expected, with 65.6% being the expected value for the climate of Belo Horizonte, as indicated by the Climate Consultant 6.0 software. In the image, it is noticeable that 6 buildings are below the expected levels.

Figure 10: Thermal Comfort Levels of the evaluated buildings of the Pampulha Campus.



Finally, it is worth mentioning that the difference in analysis time between the simulation method and the Metamodel is a determining factor for the choice of the method to be used. While Metamodelo performed the evaluation between 2 and 3 hours, the simulation method required 20 to 40 hours for each building.

5 Final Considerations

The present study aimed to verify the applicability of the Metamodel in the labeling process using as object of analysis the buildings of the Pampulha Campus of the Federal University of Minas Gerais. Limitations of the new evaluation system were identified, and recommendations were proposed to expand the use of the INI-C thermal comfort assessment tool.

The results analyzed showed that of the 82 buildings evaluated, only 13 of them can be evaluated by the simplified method. The main limitations that prevent the use of the metamodel are: variation of 10% in the PPAs, floors that are different from each other, non-rectangular shape, and length x width ratio.

Among the limitations imposed in the INI-C, the fact that buildings are evaluated by the simplified method only when all their long-stay environments have an area difference of up to 10% between them should be removed, since this restriction makes the use of the metamodel unfeasible. In the study, only one building met this requirement.

The limitation imposed in the INI-C of evaluating buildings by the simplified method only when all their environments of prolonged stay have an area difference of up to 10% between them should be removed, since this restriction makes the use of the Metamodel unfeasible. In the study, only one building met this requirement.

The normative instruction INI-C could also provide acceptable adequacy guides in the modeling of buildings, so that the parameters could be inserted within the range of the Metamodel, extending its application and thus promoting the use of naturally ventilated buildings. In this research, suggestions for adjustments in three buildings of Group 2 were presented, both in volumetry, that is, ceiling height, length and width of the blocks, as well as in thermal characteristics of the constructive elements and power of the equipment, due to the limits established by INI-C for the application of the simplified method. The results indicate that even with these modifications, the PHOCT values obtained by the

Metamodel were close to those generated by simulation, with a maximum difference of 5.7%.

Therefore, the simplified method of evaluation of naturally ventilated buildings is considered an efficient and agile method, but of restricted application due to its limitations. For its broad implementation, it is necessary to evaluate procedures to make its use more flexible and thus facilitate the process of labeling buildings in Brazil.

References

ALMEIDA, R. M. S.; FREITAS, V. P. Indoor environmental quality of classrooms in Southern European climate. **Energy and Buildings**, v. 81, p 127-140, 2014. DOI: <https://doi.org/10.1016/j.enbuild.2014.06.020>

BÁEZ, M. G.; PADURA, A. B; HUELVA, M. M.; CHACARTEGUI, R., Natural ventilation systems in 21st-century for near zero energy school buildings, **Energy**, v. 137, p. 1186-1200, 2017. DOI: <https://doi.org/10.1016/j.energy.2017.05.188>

BRASIL. Portaria n.º 248, de 10 de julho de 2018 - **Aperfeiçoamento do Regulamento Técnico da Qualidade para a Classe de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos**. Available at: <http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC002520.pdf>. Portuguese.

BRASIL. Lei n. 9991, de 24 de julho de 2000. **Dispõe sobre realização em investimento em pesquisa e desenvolvimento e em eficiência energética por parte das empresas concessionárias, permissionárias e autorizadas do setor de energia elétrica, e dá outras providências**. Available at: https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2019/decreto/D9991.htm. Accessed on: 16 jul. 24. Portuguese.

BRASIL. Lei n. 10.295, de 17 de outubro de 2001. **Dispõe sobre a Política Nacional de Conservação e Uso Racional de Energia e dá outras providências**. Diário Oficial da União: seção 1, Brasília, DF, ano 138, n. 200, p. 1, 18 out. 2001. Available at: <http://www.inmetro.gov.br/qualidade/pdf/lei10295.pdf>. Accessed on: 16 jul. 24. Portuguese.

BRASIL. Portaria Inmetro nº 372, de 17 de setembro de 2010. **Aprovar a revisão dos Requisitos Técnicos da Qualidade para o Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos (RTQ) por “BRASIL. Ministério de Minas e Energia. Empresa de Pesquisa Energética. Balanço Energético Nacional 2023 – Ano base 2022: Relatório Final. Rio de Janeiro, 2023**. Available at: <https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2021>. Portuguese.

BRASIL. Portaria n.º 299, de 19 de junho de 2013. **Aperfeiçoamento do Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos (RTQ-C)**. Diário Oficial da União de 19 de junho de 2013, seção 01, páginas 79 e 80. Portuguese.

BRASIL. Portaria n.º 248, de 10 de julho de 2018 - **Proposta de texto da Portaria Definitiva referente ao Regulamento Técnico da Qualidade para a Classe de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos**. Diário Oficial da União

- de 12 de julho de 2018, seção 01, página 335. Available at: <http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC002520.pdf>. Portuguese.
- BRASIL. Portaria nº 42, de 24 de fevereiro de 2021a. **Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas (INI-C)**. Diário Oficial da União: de 09 de março de 2021, seção 01, página 44. Available at: <http://sistema-sil.inmetro.gov.br/rtac/RTAC002989.pdf>. Portuguese.
- BRASIL. Portaria nº 309, de 6 de setembro de 2022. **Instruções Normativas e os Requisitos de Avaliação da Conformidade para a Eficiência Energética das Edificações Comerciais, de Serviços e Públicas e Residenciais - Consolidado**. Diário Oficial da União: de 06 de setembro de 2022, seção 01, páginas 30 a 89. Portuguese.
- CARLO, J. C., LAMBERTS, R. **Parâmetros e métodos adotados no regulamento de etiquetagem da eficiência energética de edifícios – parte 1: método prescritivo**. Ambiente Construído, Porto Alegre, v. 10, n. 2, p. 7-26, 2010. Portuguese.
- GARCIA, M.S.; SOUZA, R. V. G. SILVA, F. J. **Towards Health and Comfort: Architectural Design and Indoor Air Quality in Naturally Ventilated Classrooms**. In: Lecture Notes in Civil Engineering. 1ed.: Springer Nature Switzerland, 2024, v., p. 403-413. DOI: https://doi.org/10.1007/978-3-031-48461-2_36.
- GARCIA, M. S.; SOUZA, R. V. G.; OLIVEIRA, I. C. F.; REIS, I. A. Eficiência energética e conforto térmico em edifícios universitários: a importância de uma perspectiva integrada para a adaptação aos novos tempos. **Revista da Universidade Federal de Minas Gerais**, v. 28, p. 149-179, 2021. DOI: <https://doi.org/10.35699/2316-770X.2021.26714>. Portuguese.
- HENSEN J. L. M., LAMBERTS, R. (Ed.). **Building performance simulation for design and operation**. London: Routledge, 2011.
- INTERNATIONAL ENERGY AGENCY, IEA. **Energy intensity – SDG7: Data and Projections – Analysis** -, (n.d.). Available at: <https://www.iea.org/reports/sdg7-data-and-projections/energy-intensity>. Accessed on: 17 jul. 2024.
- MEDEIROS, H. G. **Método simplificado de avaliação de conforto térmico para ambientes ventilados naturalmente ou híbridos do INI-C: desempenho e limitações**. Dissertação (Programa de Pós-Graduação em Ambiente Construído e Patrimônio Sustentável) - Universidade Federal de Minas Gerais, 2022. Portuguese.
- MEDEIROS, M. M. X. DE L., SOUSA, L. L. DE L. **Análise de uso de softwares de simulação termoenergéticas em edificações**. Trabalho de conclusão de curso Bacharelado em Ciência e Tecnologia. Universidade Federal do Semiárido Ufersa campus Mossoró-RN, 2019. Portuguese.
- MEUSEL, M. D. Z. V.; WESTPHAL, F. **Barreiras para a introdução de simulação computacional à prática de projeto arquitetônico: O caso de um edifício institucional em Curitiba-PR**. In: ENCAC 2017. Balneário Camboriú, 2017. Portuguese.
- MORAWSKA, L.; MILTON, D. K. **It is time to address airborne transmission of COVID-19**. Clinical Infectious Diseases, ciaa939, 2020. DOI: <https://doi.org/10.1093/cid/ciaa939>.

- MOSTAFAZADEH, F., EIRDMOUSA, S. J., TAVAKOLAN, M. Energy, economic and comfort optimization of building retrofits considering climate change: a simulate-based NSGA-III approach. **Energy and Buildings**, vol. 280, 2023, 112721, Elsevier. DOI: <https://doi.org/10.1016/j.enbuild.2022.112721>.
- PBE EDIFICA. Sobre o PBE Edifica. Disponível em <https://pbeedifica.com.br/sobre> Accessed on: 17 jul. 2024. Portuguese.
- PRABHAKAR; M., SAFFARI, M., GRACIA, A. DE, CABEZA, L. F. Improving the energy efficiency of passive PCM system using controlled natural ventilation. **Energy and Buildings**, vol. 228, December 2020, 110483, Elsevier. DOI: <https://doi.org/10.1016/j.enbuild.2020.110483>.
- PUTEH, M.; IBRAHIM, H. M.; ADNAN, M.; CHEAHMAD, C. N.; NOH, N. M. Thermal comfort in classroom: constraints and issues. **Procedia Social Behavior Science**, n. 46, p. 1834-1838, 2012. DOI: <https://doi.org/10.1016/j.sbspro.2012.05.388>.
- PROCELINFO. PROCEL Edifica – **Eficiência energética nas edificações**. Available at: <http://www.procelinfo.com.br/data/Pages/LUMIS623FE2A5ITEMIDC46E0FFDDBD1240197D2587926254722LUMISADMIN1PTBRIE.htm> 2021. Accessed on: 9 jul. 2024.
- RACKES, A., MELO, A. P., LAMBERTS, R. Naturally comfortable and sustainable: Informed design guidance and performance labeling for passive commercial buildings in hot climates. **Applied Energy**, n. 174, p. 256-274, 2016. DOI: <https://doi.org/10.1016/j.apenergy.2016.04.081>.
- UNIVERSIDADE FEDERAL DE MINAS GERAIS (UFMG). **Protocolo de Biossegurança e Adequação do Espaço Físico na UFMG**. 2020. Available at: https://ufmg.br/storage/b/d/4/b/bd4b2cf83ed9619099eff5a389184f7a_16020949808844_1676750974.pdf. Portuguese.
- VELOSO, A. C. O., ANDRADE FILHO, C. R., SOUZA, R. V. G. The Potential of Mixed-Mode Ventilation in Office Buildings in Mild Temperate Climates: An Energy Benchmarking Analysis. **Energy and Buildings**, vol. 297, 2023. DOI: <https://doi.org/10.1016/j.enbuild.2023.113445>.
- WONG I. L., KRÜGER, E. Comparing energy efficiency labelling systems in the EUA and Brazil: implications, challenges, barriers and opportunities. **Energy Policy** v. 109, p. 310 – 323, 2017. DOI: <https://doi.org/10.1016/j.enpol.2017.07.005>.