Environmental Sustainability in Traditional University Libraries: Contributions from BIM/BES Integration to the Thermal Performance and Books Conservation

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Abstract As a spreader of knowledge, universities must be practical examples of sustainable applications, including building or intervening in their buildings. However, some authors point out that universities focus more on the social dimension of sustainability than the environmental one, emphasizing the need for research aimed at environmental sustainability in these places. In this context, university campuses present emblematic buildings with historical and architectural relevance with more than 20 years old and still need analyses in terms of thermal performance. Among these traditional buildings on university campuses are the libraries, usually proposed in open floor plans, with spaces for collaborative study and an integrated collection of books. However, both spaces must meet different criteria of thermal performance and conservation of books, which is associated with the internal microclimate and consequently with the adequacy of climatic conditions. The main objective of this research was to analyze the environmental sustainability in iconic libraries through transdisciplinary procedures, where the thermal performance and conservation of books from the Library of the Federal University of Uberlândia (UFU Library), Brazil, were jointly evaluated. The analyzed spaces have open floor plans with natural ventilation, a communal study area, and a collection of related books for consultation. The method adopted was the hygrothermal simulation

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based on the BIM/BES data transfer, having as parameters the operating temperature ranges according to (ASHRAE 55 (2020) Thermal environmental conditions for human occupancy. ASHRAE, Atlanta) and the isoperm method of (Sebera in Isoperms an environmental management tool. Comission on Preservation and Access, Washington (1997)). We concluded that the hygrothermal simulation contributes to environmental sustainability since it allows the analysis of the current scenario of the library, as well as the creation of new scenarios. Regarding the thermal performance, we observe that the appropriate scenario is the current one, as it presented service between 82.15% and 86.88% of the occupied periods throughout the year. The proposed scenario with double glazing did not present significant temperature differences concerning the current scenario. Regarding the book conservation, we concluded that the current scenario is unsatisfactory, with isosperms between 0.28 and 1. That corresponds to the longevity of the paper between 12.6 and 45 years. Unfortunately, the data transfer between BIM/BES could have been finer since there were errors in the transfer of geometry, thermal properties, and information such as usage, occupation, and scheduling.

Keywords Simulation-based architectural design · Campus architecture · Library · Building information modeling · Building energy simulation

1 Introduction

After World War II, with the spending on energy and the oil crisis in the 1970s, it became necessary to invest in innovations for energy efficiency in several areas, including buildings and constructions (Mitchell 2010; Papadopoulos 2016). In the same period, the first conferences about energy and environment at a global level emerged, such as the Stockholm Conference in 1972 and the Brunktland Commission in 1980, which corroborated the concept of sustainability (Keeler and Burke 2009). In the 1990s, the first BES (Building Energy Simulation) software for energy simulations rose to assist the decision-making in the design process, which helped in sustainable design alternatives (Crawley et al. 2000).

In 2015 the 2030 Agenda was created with 17 sustainable development goals to be achieved globally by 2030. In this sense, universities as a spreader of knowledge must be practical examples of sustainable applications, including building or intervening in their buildings. However, Leal Filho et al. (2021) point out that universities focus more on the social dimension of sustainability than the environme‘ntal one, emphasizing the need for research aimed at environmental sustainability in these places. In this context, several University Campuses have iconic buildings with historical and architectural relevance, which, mainly because they are more than 20 years old, have not been analyzed in terms of thermal performance. In addition, these buildings must be suited to functional realities and sustainable goals to be enjoyed today and preserved for future generations. Among the sustainable objectives, which include intervention in existing assets, is target 11.4, to protect the world's cultural and natural heritage, and 7.3, which values global energy efficiency. It should be noted that in addition to aesthetic and historical values, these buildings must meet various regulations and their peculiarities, and according to (Keeler and Burke 2009), sustainable projects must be, above all, integrated, that is, they must have a holistic view and multidisciplinary design solutions.

Among these traditional buildings on university campuses are the libraries, usually proposed in open floor plans, with spaces for collaborative study and an integrated collection of books. However, both spaces must meet different criteria of thermal performance and conservation of books, which is associated with the internal microclimate and consequently with the adequacy of climatic conditions. For the analysis of existing libraries, some authors used energy simulation, as is the case of the research by Tronchin and Fabbri (2017), who analyzed the conservation of books in a historical library in Italy using the IES VE software, and the research by Waddicor et al. (2016) who analyzed the thermal and energy performance of a library in Italy in different scenarios through simulation with the IDA ICE software. In addition, BIM (Building Information Modeling) platform software, pointed out by authors such as Jalaei et al. (2020) and Haidar et al. (2018), is efficient for sustainable analysis and decisions based on parametric modeling.

In this sense, the main objective of this research was to analyze the environmental sustainability in iconic libraries through transdisciplinary procedures, where the thermal performance and conservation of books from the Library of the Federal University of Uberlândia (UFU Library), Brazil, were jointly evaluated. The analyzed spaces have open floor plans with natural ventilation, a communal study area, and a collection of related books for consultation. The method adopted was the hygrothermal simulation based on the BIM/BES data transfer, having as parameters the operating temperature ranges according to ASHRAE 55 (2020) and the isoperm method of Sebera (1997).

2 Recent Developments

Recent scientific research has sought to analyze library buildings, or even specific sectors of these buildings, in order to compare their thermal performance measured in loco with the limits proposed both by the standards: ASHRAE (2007) and EN 15757 (2010), and by other comparison índices (Silva and Henriques 2014). Recent measurements produced in more severe conditions of temperate climates, such as in Greece (Drougka et al. 2020), demonstrate how temperature and humidity, albeit restricted to summer, have proved to be the most critical threats to book conservation. Recent research in Italian libraries has established comparisons with different standards, demonstrating that 80% of the acceptable values concerning humidity (Andretta et al. 2016), but that, thus, the climatic conditions monitored typically in the summer could lead to the loss of the collections in 300 years (Verticchio et al. 2020). In the same region, recent estimates at the Biblioteca Classense in Ravenna showed that the predicted durability of the most recent books is about half that of

19th-century collections (Coppola et al. 2020). Diulio et al. (2015) and Diulio et al. (2019) observed similar results in libraries in Argentina. They presented better conditions in the autumn and spring seasons than UNI 10,829, concluding that the most influential parameters on thermal performance were the adjacency with other spaces, followed by the global transmittance and the transparency of the openings.

Also, having on-site measurement and comparisons with indexes as a fundamental scientific method, studies have verified inadequate conditions for the conservation of books and, therefore, have proposed architectural solutions to improve these conditions. In the European context, Sahin et al. (2017) and Boeri et al. (2022) have considered passive design alternatives without introducing heating or air conditioning systems. They found situations where archival assets were stored without any air conditioning system, producing microclimatic conditions to ensure their preventive conservation. In simultaneous searches in libraries in Portugal, Schito et al. (2019a) demonstrated the effectiveness of thicker walls in smoothing and delaying changes in the external climate but that the need to reduce relative humidity at specific and identified parts represents a limit for the production of excellent conditions Schito et al. (2019b). In the Asian context, Liu and Lu (2009) argued that although HVAC systems can be expensive, monitoring systems for temperature and humidity data are simple, reliable, and inexpensive solutions, which can decisively contribute to the selection of sustainable design strategies.

Compromising human comfort levels with thermal performance to conserve books is not a simple task. As evaluated by Krüger and Diniz (2011) in full-scale models reproducing three Brazilian library buildings in cities with different climates, there is a significant difference between the conditions of book storage, although there are similarities in the conditions of internal thermal comfort. Recently, Turhan et al. (2021) shared a similar inference that about 90% of library users in Turkey are satisfied with thermal sensation, while at the exact location, thermal performance results point to a high risk of degradation. In certain regions with some design alternatives, there may be a convergence between thermal comfort and book conservation, which raises the need for further studies on this subject.

Computer simulations aiming to delineate the condition of indoor climates have allowed relevant conclusions regarding the reduction of energy expenditure with cooling and heating in libraries. Simulations performed directly in BIM modeling applications have demonstrated potential tools for reducing building heating and cooling loads (Sadeghifam et al. 2021; Liu and Wang 2022). In applications aimed explicitly at thermo-energetic simulations, research with the IDA ICE (Equa, Inc.) has sought to reduce the computational effort through simplifications without significant distortions about more complex models (Verticchio et al. 2020) or with metamodels (Bracht et al. 2021; Amaral et al. 2022) leading to objective conclusions on reduced energy consumption (Waddicor et al. 2016). Likewise, the design driven by simulation models in IES VE (Integrated Environmental Solutions Limited, Inc.) clearly outlines the energy consumed by the environment (Hussin et al. 2019) and proposes allocating books according to conditioning criteria attested by the application (Tronchin and Fabbri 2017). In addition, analyses of the impact of specific systems on building energy consumption, such as lighting power density, could be more accurately outlined in eQUEST, Inc. (Song et al. 2015).

Considering that humidity and temperature are the variables that most interfere with the conservation of books, recent studies have revealed crucial impacts of air exchanges on indoor environments' humidification and dehumidification processes (Kupczak et al. 2017). In this sense, passive strategies such as controlling natural ventilation by opening doors and windows in the summer can represent a strategy that determines the collection's durability (Stoakes et al. 2011). Among the most critical factors to be considered as design strategies is the determination of the risks of books degradation by chemical, mechanical or biological means (Coşkun et al. (2017) and the definition of air renewal rates in line with thermal comfort and indoor air quality (Conceição et al. 2019).

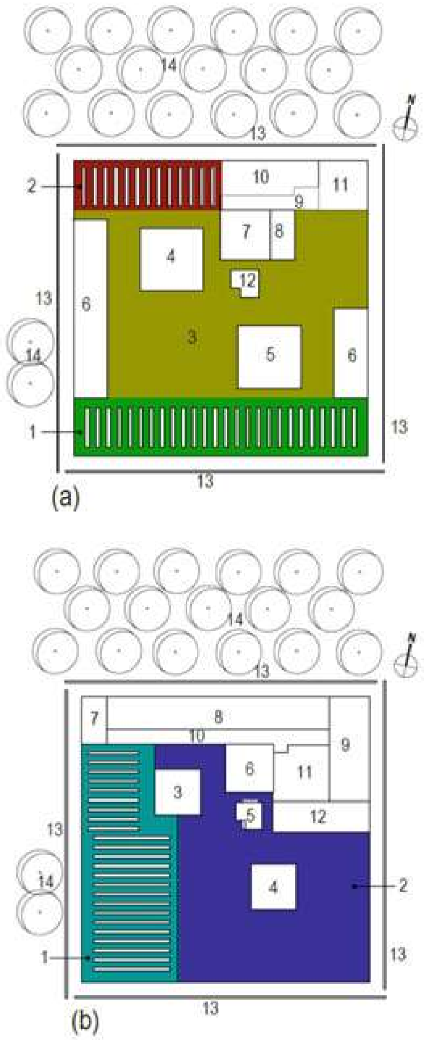
3 Qualitative Sample: UFU Library, Brazil

The library of the Federal University of Uberlândia at Santa Mônica Campus (UFU Library) is located in Uberlândia, a countryside city in Brazil (18.92S, 48.26W), a tropical wet and dry climate in Köppen–Geiger climate classification system. Finished in 1991, designed by the architects Paulo Zimbres and Luís Antônio Almeida Reis, it is an iconic example of the campus and the city, with architectural and social relevance (Fig. 1).

According to Luís Antônio Almeida Reis, the designers propose natural ventilation, and subsequently, new environments were added and artificially conditioned. The spaces analyzed in the research (Fig. 2) are located in open floor plans with book collections and communal study areas interconnected and naturally ventilated. Among the passive strategies of the building are: shading provided by the ceramic cobogós that permeate the entire glazed facade, trees on the facades that receive sunlight, cross ventilation through large openings and atriums, as well as the chimney effect provided by several dormer vents. The collection of the analyzed

(a) (b)

Fig. 1 **a** UFU Library overview, **b** second-floor view with spaces for collaborative study and books storage. (Authors 2022)



1.	Book collection 1
2.	Book colletcion 2
3.	Collective study area
4.	Mezzanine
5.	Atrium with windows
6.	Individual study rooms
7.	Bathrooms
8.	Audiovisual room
9.	Circulation
10.	Offices
11.	Records and book colletcion
12.	Stairs
13.	Brise soleil
14.	Trees

1.	Book collection
2.	Collective study area
3.	Mezzanine
4.	Atrium with windows
5.	Stairs
6.	Bathroom
7.	Meeting room
8.	Offices
9.	Cataloguing room
10.	Circulation
11.	Deposit
12.	Rare collection
13.	Brise soleil
14.	Trees

Fig. 2 Spaces analyzed in the hatch, **a** 1st-floor plan, **b** 2nd-floor plan. (Authors 2022)

spaces consists of books for loan, with rare books being found indoors with artificial control of temperature and humidity.

4 Method

This research sought to verify the joint service of thermal performance and conservation of books in libraries with passive strategies in the qualitative sample UFU Library. Based on hygrothermal simulation methods with BIM/BES workflow, three steps were defined: the definition of thermal performance requirements, the definition of book conservation requirements, and hygrothermal simulation using Revit 2021 (Autodesk, Inc.) and DesignBuilder software version 7.0.1.006 (Software Ltd.), the last one being validated by ASHRAE 140 (2017). Three scenarios were analyzed:

the current scenario with open windows, the current scenario with closed windows, and the scenario with double glazing and open windows.

4.1 Thermal Performance Requirements

Chapter 5.4.2.2 of ASHRAE 55 (2020) presents thermal performance requirements for naturally ventilated buildings by determining an acceptable operating temperature range. We define the operating temperatures with the acceptability limit of 80% of users from Eq. 01.

To define the acceptable operating temperature ranges for the library, the average monthly temperatures outside Uberlândia were collected based on the simulation in DesignBuilder from the meteorological file provided by (ABNT TR 15,575–1-1 (2021), and applied in the sequence with Eq. 01. As a result, we define the acceptable operating temperature ranges for each month, according to Table 1.

$$\begin{aligned} \text{Upper acceptability limit of } 80\% &= 0,31\,\text{tpma(out)} + 21,3 \\ \text{Lower acceptability limit of } 80\% &= 0,31\,\text{tpma(out)} + 14,3 \end{aligned} \quad (1)$$

Table 1 Acceptable operative temperature ranges for naturally ventilated spaces in Uberlândia. (Authors 2002)

Month	Acceptability limit OF 80% (°C)	
	Upper limit	Lower limit
Jan	0,31.22,97 + 21,3 = 28,42 °C	0,31.22,97 + 14,3 = 21,42 °C
Feb	0,31.23,39 + 21,3 = 28,55 °C	0,31.23,39 + 14,3 = 21,55 °C
Mar	0,31.24,65 + 21,3 = 28,94 °C	0,31.24,65 + 14,3 = 21,94 °C
Apr	0,31.23,77 + 21,3 = 28,66 °C	0,31.23,77 + 14,3 = 21,66 °C
May	0,31.21,05 + 21,3 = 27,82 °C	0,31.21,05 + 14,3 = 20,82 °C
Jun	0,31.20,65 + 21,3 = 27,70 °C	0,31.20,65 + 14,3 = 20,70 °C
Jul	0,31.20,39 + 21,3 = 27,62 °C	0,31.20,39 + 14,3 = 27,62 °C
Aug	0,31.21,97 + 21,3 = 28,11 °C	0,31.21,97 + 14,3 = 21,11 °C
Sep	0,31.24,69 + 21,3 = 28,95 °C	0,31.24,69 + 14,3 = 21,95 °C
Oct	0,31.24,24 + 21,3 = 28,81 °C	0,31.24 + 14,3 = 21,81 °C
Nov	0,31.23,42 + 21,3 = 28,56 °C	0,31.23,42 + 14,3 = 21,56 °C
Dez	0,31.24,22 + 21,3 = 28,80 °C	0,31.24,22 + 14,3 = 21,80 °C

4.2 Requirements of Books Conservation

The combinations between temperature and relative humidity are internal variables that directly influence book conservation (Sebera 1997; Michalski 2016). Sebera (1997) presents methods of isoperms elaborated from pairs of temperature and relative humidity that are associated with the longevity of the paper, that is, the time required for its deterioration. In this research, the Sebera isoperm method was used, which uses enthalpy ranges of 20–35 kcal to create various combinations of temperature and relative humidity, associating these with the permanence index (PI), an index mentioned by Krüger and Diniz (2011) obtained from Eq. 2. Sebera (1997) defines permanence as the time required for the paper to deteriorate.

$$\frac{P_2}{P_1} = \left(\frac{UR_1}{UR_2}\right)\left(\frac{T_1 + 460}{T_2 + 460}\right)10^{+394\Delta H^{\neq}\left(\frac{1}{T_2+460} - \frac{1}{T_1+460}\right)} \quad (2)$$

For instance, PI = 1.00 corresponds to temperature and relative humidity combinations of 20 °C and 50% and paper longevity of 45 years, as well as the combination of 22.2 °C and 30%, presents the same result as shown in Fig. 3. On the other hand, combinations that result in a PI of 5 indicate a book life expectancy of 225 years and PI of 0.33, an expectation of 15 year.

The enthalpy of 25 kcal/mole was adopted for the study, referencing the research by Assis and Bastos (2007). Thus, the Sebera chart shows an enthalpy of 25 kcal/mol, adapted for this research, as shown in Fig. 4. The Sebera diagram also

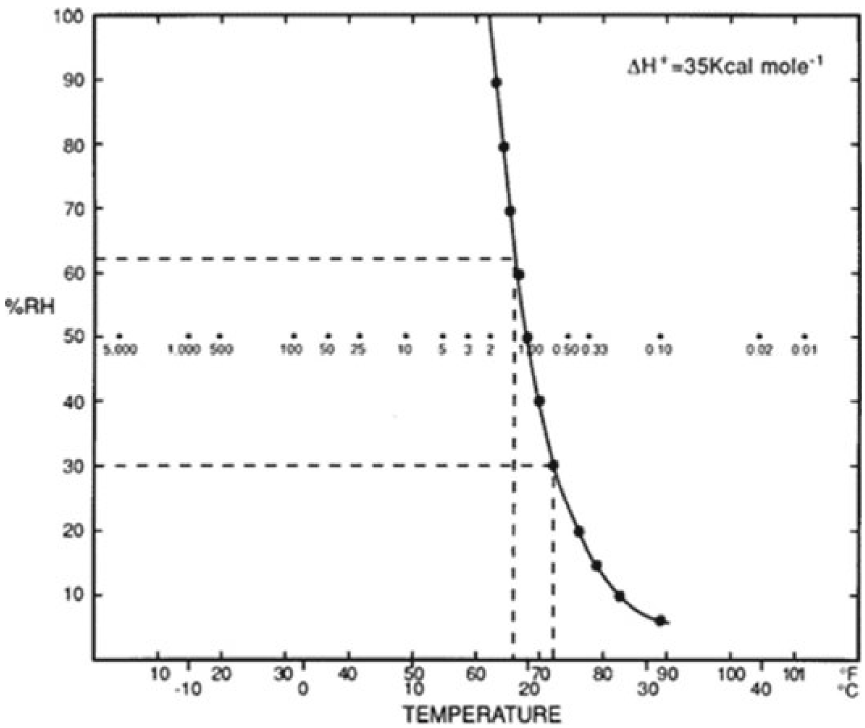


Fig. 3 Combinations of temperature and relative humidiy with PI = 1,00. (Sebera 1997)

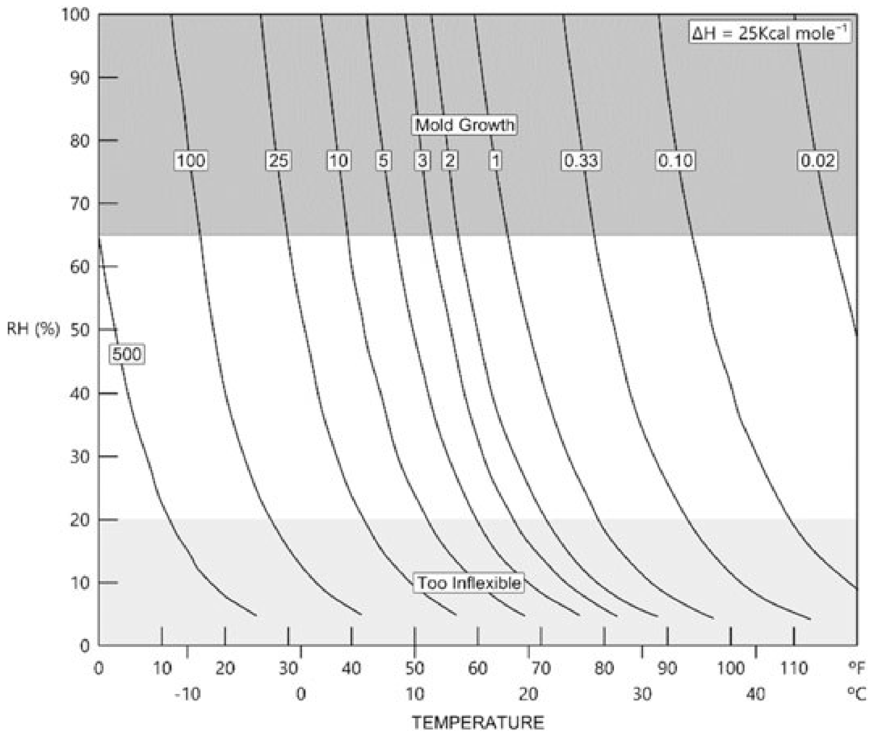


Fig. 4 Sebera diagram used on this research. (Adapted from Sebera 1997)

shows the zones where indoor relative humidity influences mold development or stiffness on paper.

From the hygrothermal simulation, pairs of internal temperature and relative humidity could be plotted on the graph to verify the longevity of the papers.

4.3 Hygrothermal Simulation Based on BIM/BES Workflow

Hygrothermal simulations simulate indoor temperatures and relative humidity. In this research, these variables were calculated according to the BIM/BES workflow from modeling and data transfer from a BIM software, Revit, and exported to the selected BES software, DesignBuilder, for hygrothermal simulation. Thus, the simulation was approached in 3 steps: modeling in BIM, input data in BIM, and exporting to BES software. Figure 5 shows the building and models in 4 moments: (a) photograph of the building, (b) detailed modeling in Revit, (c) simplification of the model in Revit, and (d) model imported into DesingBuilder.

4.3.1 Building Information Modeling

To produce the hygrothermal simulation of the spaces analyzed in the library, we model the detailed geometry in Revit from consultations with the original project

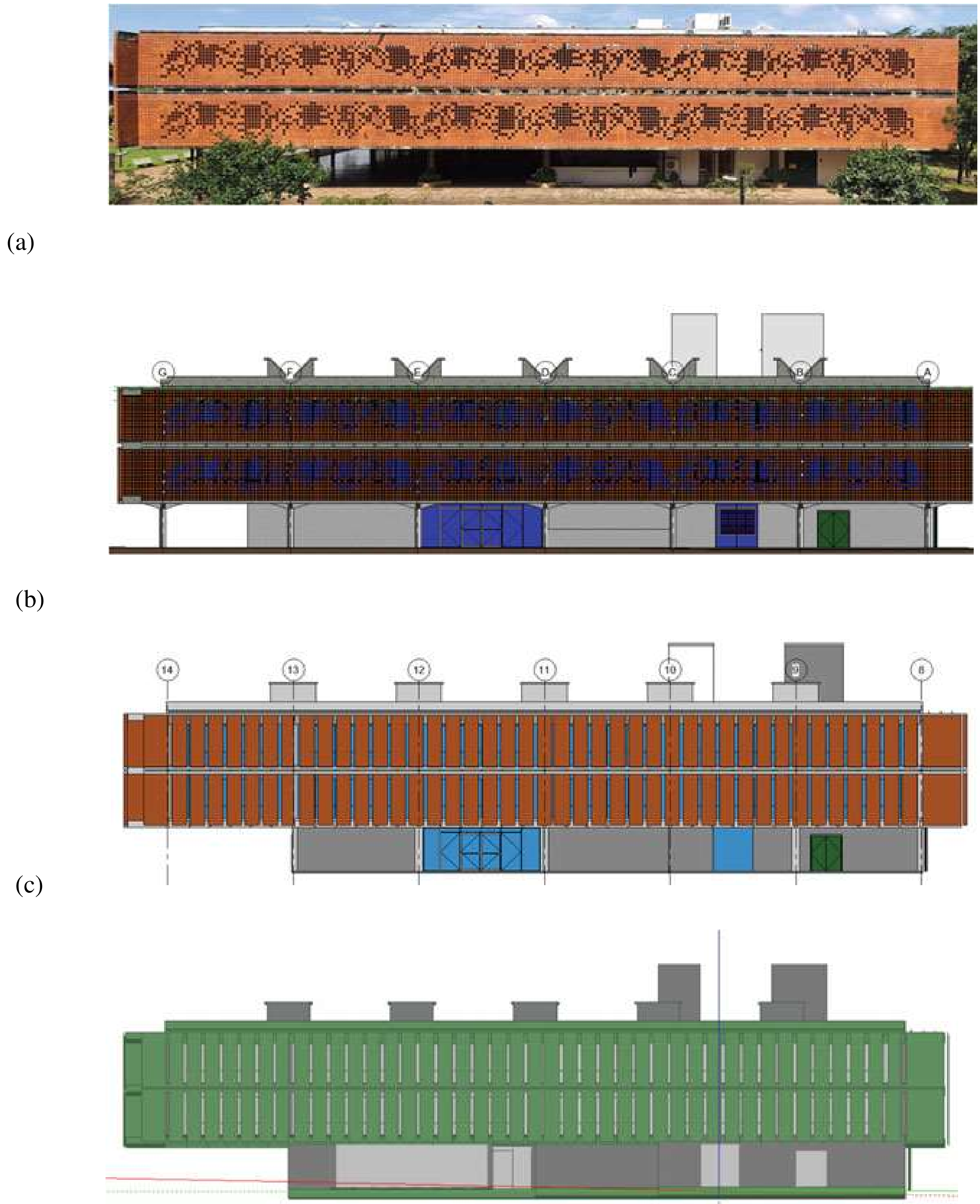


Fig. 5 **a** Photo of the building, **b** detailed modeling in Revit, **c** simplification of the model in Revit, **d** model imported into DesignBuilder. (Authors 2022)

and on-site. This step required considerable time since it was necessary to investigate the materials used and their thermal properties since the original projects provided by the University Campus City Hall were incomplete. In order to model the brise soleil in ceramic, it was necessary to map the hollow elements from on-site visits.

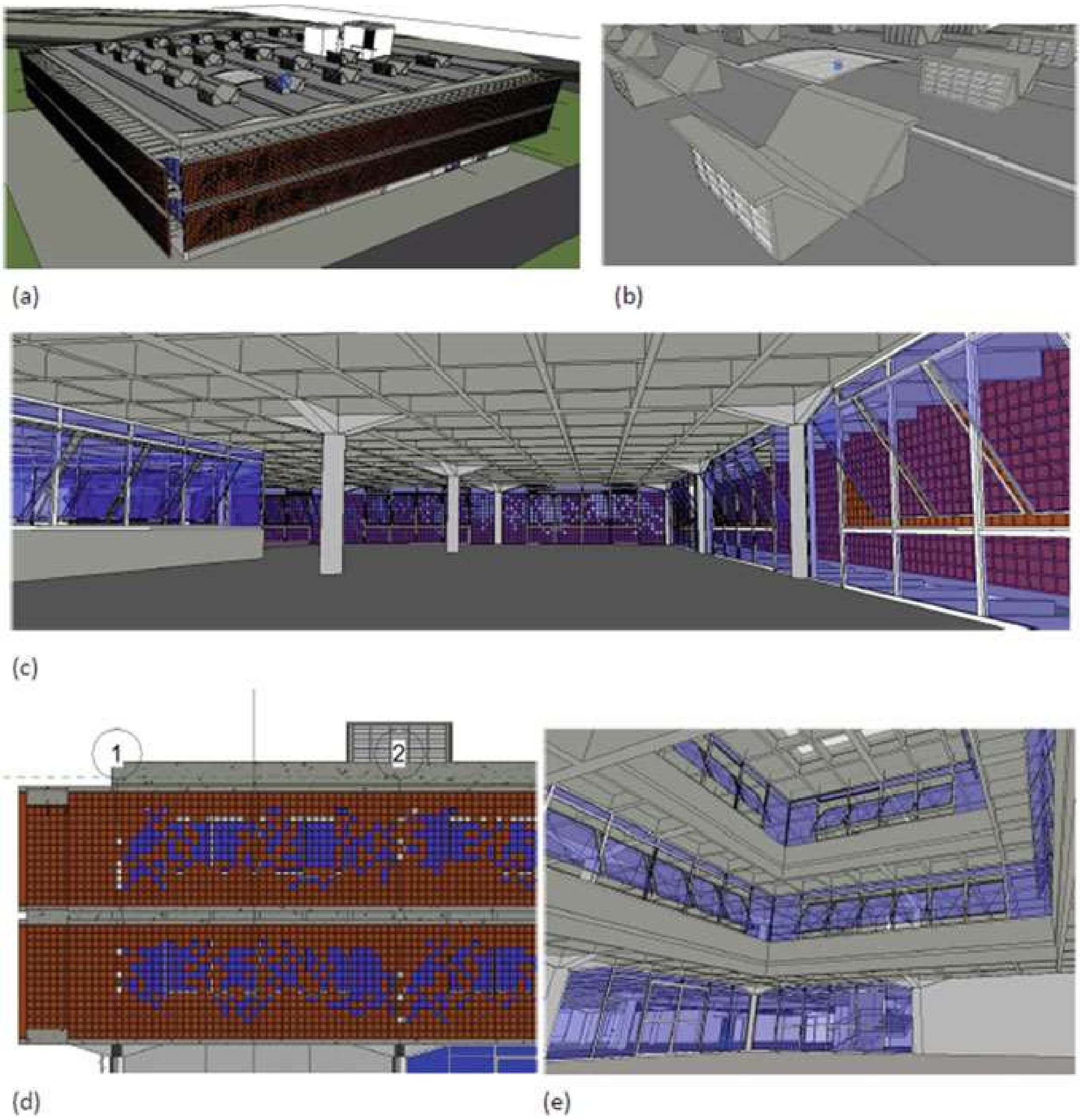


Fig. 6 Detailed geometry modeled in Revit software. **a** extern view, **b** roof with dormer vents and skylight, **c** internal view of the open plan of the first floor, **d** detail of the brise soleil with cobogós, and **e** external atrium. (Authors 2022)

Figure 6 shows the detailed model in BIM/BES data transfer using an existing BIM model.

Figure 6 shows the details of the external geometry, such as hollow brick walls and a roof with dormer vents and skylight, as well as the open floor plan of the interior with frames with fixed and tilting leaves, pillars with capitals, and an atrium with frames.

4.3.2 Input in Revit (Autodesk, Inc.)

Input data is information entered into the BIM model for further hygrothermal simulation in the BES software. In Revit, spaces with their respective uses and information such as geometry with thermal properties of materials, location, orientation, and spaces with internal heat gains. International standards, as well as Brazilian standards and authors, were used as a reference to better adapt to the Brazilian reality. In Table 2, we show the thermal properties of the materials, and in Table 3, the internal heat gains such as occupation, lighting power densities, and equipment, as well as air change per hour, outdoor air per person, and outdoor air per area.

ASHRAE 90.1 (2016) was a reference for preparing an occupancy, lighting, and equipment schedule. For this, the building area type was in the standard, and the schedule index C referring to the library was selected to fill the respective schedules. The frame operation is unavailable in Revit, so the input of this information was entered into the DesignBuilder software.

4.3.3 Protocols

For BIM/BES protocols need to transfer information between them (Eastman et al. 2018). The recommended protocol between Revit and DesignBuilder is *.gbxml, as this is more suitable for thermal energy analysis (DesignBuilder 2022). Figure 7 shows the workflow between the software, in which the BIM model supplies the data necessary for the thermal simulation. The energy analysis was modeled in Revit through the spaces and environments mode and then exported to DesignBuilder through the *.gbxml protocol.

5 Results and Discussion

Based on the outcomes, we conclude that the BIM/BES data transfer is not satisfied. There were several failures on the first attempt when exporting the detailed model from Revit, including:

- geometry transfer errors (as shown in Fig. 8)
- failure to transfer thermal properties data
- no transfer of occupation and gains schedule of internal heat.

Thus, we performed several tests to simplify the model in Revit. Figure 9 compares the detailed model, simplification, and imported into DesignBuilder. The main simplifications were: roofing, louvers, external frames, and dormer vents. Different alternatives to model the louvers in Revit were exported to DesignBuilder to verify if the geometry simplification would be compatible with the BES software. Thus, we modeled the louver with the same permeability as the detailed model. Despite simplifying geometry, the Venetian blind of the dormer vents requires their modeling in DesignBuilder with a central wall to simulate the sloping roof of the dormer vents since this provides a ventilation block between the two shutters. As for the coverage, it had to be elaborated in a single slab to be modeled in Revit and calculated manually, taking into account all the layers and their thermal properties, applying the

Table 2 Library´s material thermal properties. (Authors 2022)

System	Material	Thichness (mm)	λ (w/m.k)	c (kJ/kg.k)	ρ (kg/m³)	FS	Tvis	U (w/m².k)	α
8-hole brick wall plastered on both sides (a)	Mortar	25	1,15	1	2000	–	–	–	0,2
	Ceramic	13	0,9	0,92	1600	–	–	–	
	Air space	64	0,356	10,035	–	–	–	–	
	Ceramic	13	0,9	0,92	1600	–	–	–	
	Mortar	25	1,15	1	2000	–	–	–	
Ceramic brises	Ceramic	–	1200	0,92	0,7	–	–	–	
Dormer vents with policarvonate	Alvelolar policarbonate [b] [d]	6	0,2	1,26	1200	0,565	0,42	5	0,2
Glass windows	Colourles glass [b]	6	–	–	–	0,87	0,87	5,7	0,3
Concrete colunm	Concrete [b]	150	1,75	1	2300	–	–	–	0,7
MDF partitions	MDF [b]	40	0,2	2,3	850	–	–	–	–
Drywall	Plasterboard [b]	12,5	0,35	0,84	750	–	–	–	–
	Air space	75	0,468	1	1,2	–	–	–	
	Plasterboard [b]	12,5	0,35	0,84	750	–	–	–	
Interior slabs	Vinyl floor [c]	2	0,27	1,5	2300	–	–	–	–
	Subfloor [b]	20,8	1,15	1	2000	–	–	–	
	Concrete [b]	10	1,15	1	2000	–	–	–	
Simplified roof = thermoacoustic tile + waterproofed slab	Steel [b]	0,43	55	0,46	7800	–	–	–	0,3962
	Expanded polystyrene [b]	30	0,04	1,42	35	–	–	–	
	Steel [b]	0,43	55	0,46	7800	–	–	–	
	Air space	4	0,356	10,035	–	–	–	–	
	Layer of protection [b]	30	1,15	1	2000	–	–	–	
	Waterproofing [b]	0,4	0,23	1,46	1000	–	–	–	
	Regularization [b]	20	1,15	1	2000	–	–	–	
	Concrete [b]	100	1,75	1	2300	–	–	–	

(continued)

Table 2 (continued)

System	Material	Thichness (mm)	λ (w/m.k)	c (kJ/kg.k)	ρ (kg/m^3)	FS	Tvis	U (w/m^2.k)	α
	White alvelolar Policarbonate [b] [d]	6	0,2	1,26	1200	0,565	0,42	5	–
Simplified roof = skylight	Air space	75	0,356	10,035	–	–	–	–	
	Simple glass [b]	6	1,1	0,84	2500	–	–	–	

[a] equivalent to an eight-hole ceramic block, as Weber et al. (2017), p. 45
[b] ABNT NBR 15,220–2 (2005)
[c] Weber et al. (2017), p. 44
[d] Balsamo et al. (2019)

Table 3 Occupancy, power density, air changes per hour, outdoor air per person, and outdoor air per área. (Authors 2022)

Input	Value	Unity	Source
Occupancy	9,29	m^2/person	ASHRAE 90.1 (2016)
*Lighting power density	8,1	W/m^2	André et al. (2022)
*Equipment power density	9,7	W/m^2	
Air changes per hour	1	ac/hour	ISO 17772–1 (2017)
Outdoor air per person	14	l/s	
Outdoor air per area	1,4	l/(sm^2)	

*It was used by André et al. (2022) in offices in Brazil and adopted as a reference for the research, as they are better suited to the Brazilian reality

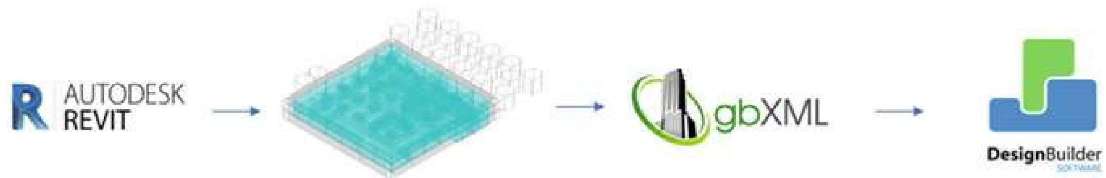
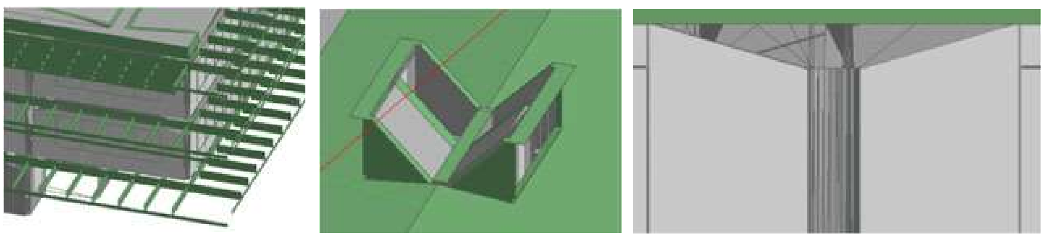
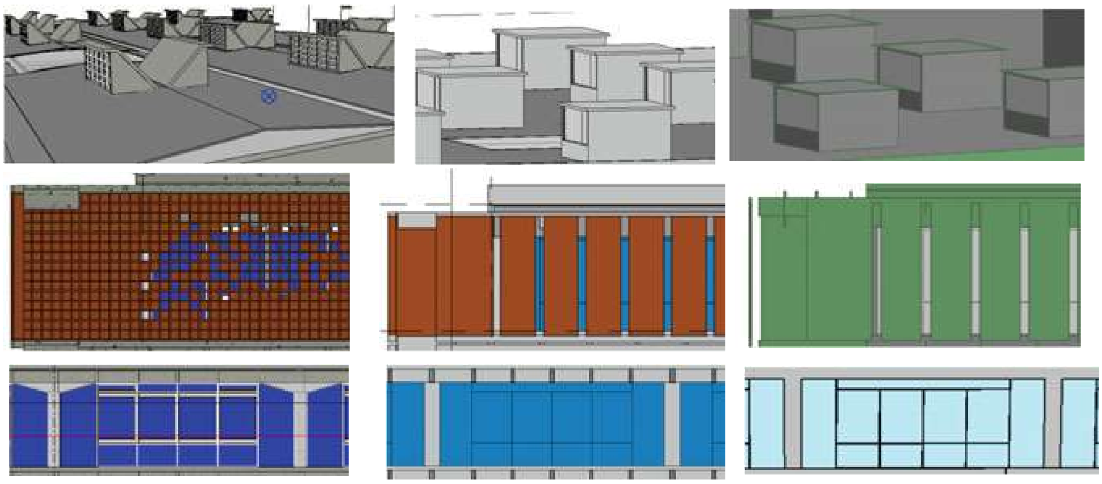


Fig. 7 The BIM/BES workflow. (Authors 2022)



(a) (b) (c)

Fig. 8 Geometry transfer errors between Revit and DesignBuilder. **a** Brises were not imported, **b** Dormer vents with errors, **c** Errors in the columns. (Authors 2022)



(a) (b) (c)

Fig. 9 **a** Detailed model in Revit, **b** Simplifying geometry in Revit, **c** Simplified BIM model imported into DesingBuilder. (Authors 2022)

weighted average of the roofs with waterproofed slabs, and the waterproofed slab with thermoacoustic tile. Another error was in the import of voids from the mezzanine, atriums, and dormer vents necessary to open the holes in the energy software itself. As for the import of thermal properties, there was a failure to transfer only the air chambers and absorbances, requiring manual correction of these items in the BES software.

The tipper windows were set for opening according to the library's occupancy schedule with an opening percentage of 30%, temperature setpoint of 21,45 °C (temperature indicated for natural ventilation for Uberlândia by the Climate Consultant 6.0 software, and operation of the windows when the internal temperature is higher than the external one. Another limitation of the BIM software was the impossibility of inserting the weather file. Therefore, this was inserted directly into the DesignBuilder software, as well as it was necessary to model. Regarding compliance with Thermal Performance, the spaces analyzed did not fully meet the ranges recommended by ASHRAE 55 (2020), but their performance was considered satisfactory since percentage of operative temperature in the occupied periods reached 82,15% to 86,88%. There are high-temperature peaks in the afternoon, mainly in March and September.

Figure 10 shows the spaces that presented the best percentage of service to the operating temperature range in ocupation periods are located on the first floor and are, respectively: reading area with 86.88%, book collection 2 with 86.73%, and book collection 1 with 85.75%. The fact that the study area showed better thermal performance might be due to the lower glazing on the facades. The spaces that presented lower thermal performance were located on the upper floor: book collection and collaborative study area, with 82,15%. Lower performance may be due to proximity to coverage. These two spaces presented the same result due to a limitation in the simulation that required the union of voids, and these two spaces have dormer vents with voids in common. These spaces are blue in Figs. 10 and 11.

In the collection of books, one on the first floor, there is 14,25% non-compliance with the operating temperature ranges, with 5,60% below the lower limits and 8,65% above the upper limits. In book collection two on the first floor, there is 13,27% non-compliance with the operating temperature ranges, with 2,70% below the lower limits and 10,57% above the upper limits. In the communal study area on the first floor, there is 13,12% non-compliance with the operating temperature ranges, with 3,12% below the lower limits and 9,99% above the upper limits. On the upper floor, in the book collections and collaborative study area, there is 17,85% non-compliance with the operating temperature ranges, with 2,01% below the lower limits and 15,84% above the upper limits.

Due to the lack of full compliance with the operating temperature ranges, we simulate two more scenarios for comparison with the current scenario, shown in Fig. 11, namely: single glass/open windows (current scenario); single glass/closed windows; and double glazing/open windows (with change from standard clear glazing (U = 5.7 w/m^2.k) to double glazing with solar control (U = 1.9 w/m^2.k, FS = 0.37, and Light Transmission = 0.47), according to Inmetro 50 (2013). The proposed scenario

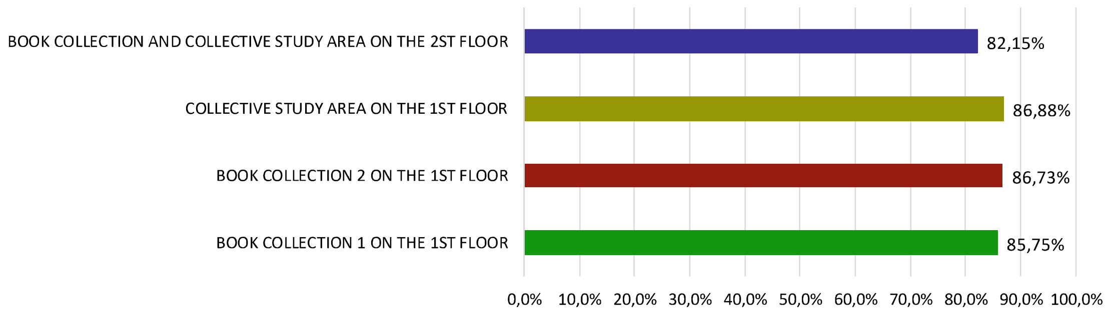


Fig. 10 Accordance of operative temperature range in the occupied periods of each space in the current scenario. (Authors 2022)

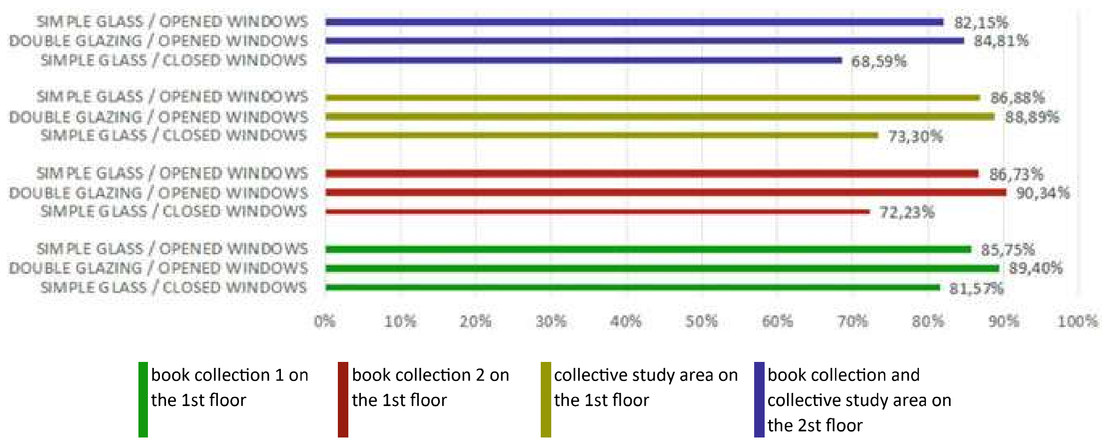


Fig. 11 Accordance of operative temperature range in the occupied periods in the three scenarios of the analyzed spaces. (Authors 2022)

took into account the lack of characterization of the building. We proposed a scenario preserving the translucent elements. Thus, in this scenario, the one-layer glass was replaced by the glass with lower thermal transmittance.

It can be seen in Fig. 11 that the scenario with closed windows had the worst thermal performance, as well as showing the importance of natural ventilation in the building. Although the scenario with double glazing improves the thermal performance of the analyzed spaces, it still did not fully meet the operating temperature range since this scenario did not significantly attenuate the maximum and minimum operating temperatures. The hottest periods are in March and September, so, as a way of evaluating this scenario, the operating temperatures in the periods occupied in September in the collection of books two on the first floor in the three scenarios shown in Fig. 12. The double-glazed/open window scenario was excluded from the analysis as the results were very close to the current scenario. Note the importance of natural ventilation in the scenario with closed windows. It can be seen in Fig. 12 that there was a difference in the operating temperature between the scenario with open and closed windows, reaching a difference of 1.56 °C, causing the scenario with open windows not to reach the upper limit at times. Even with high temperatures in September, this space attended 72.73% of the time in the current scenario. There were no hours below the lower operating temperature limit and 27,27% above the upper operating temperature limit.

Regarding book conservation, the results are the internal operating temperatures of 8760 h of the three collection spaces in the current scenario (single glass/open windows) plotted on the Sebera graph (Figs. 13, 14, and 15). In this, the year was divided into seasons through four colors: winter (blue), spring (green), autumn

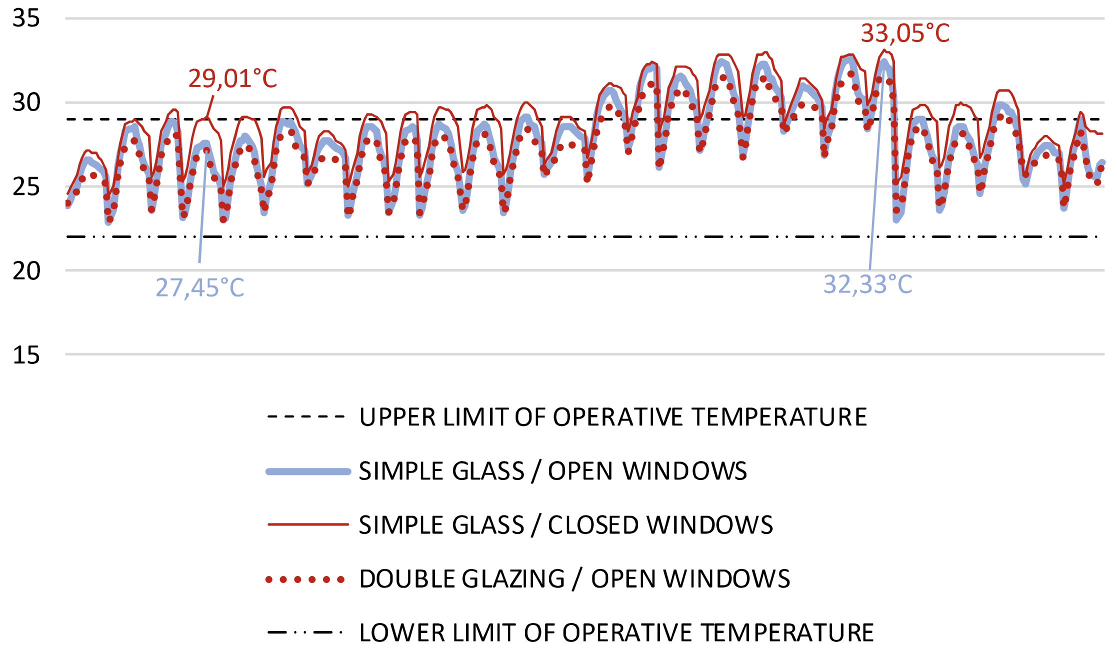


Fig. 12 Operative temperature in occupied periods in the book collection 2 on the 1st-floor in the three scenarios. (Authors 2022)

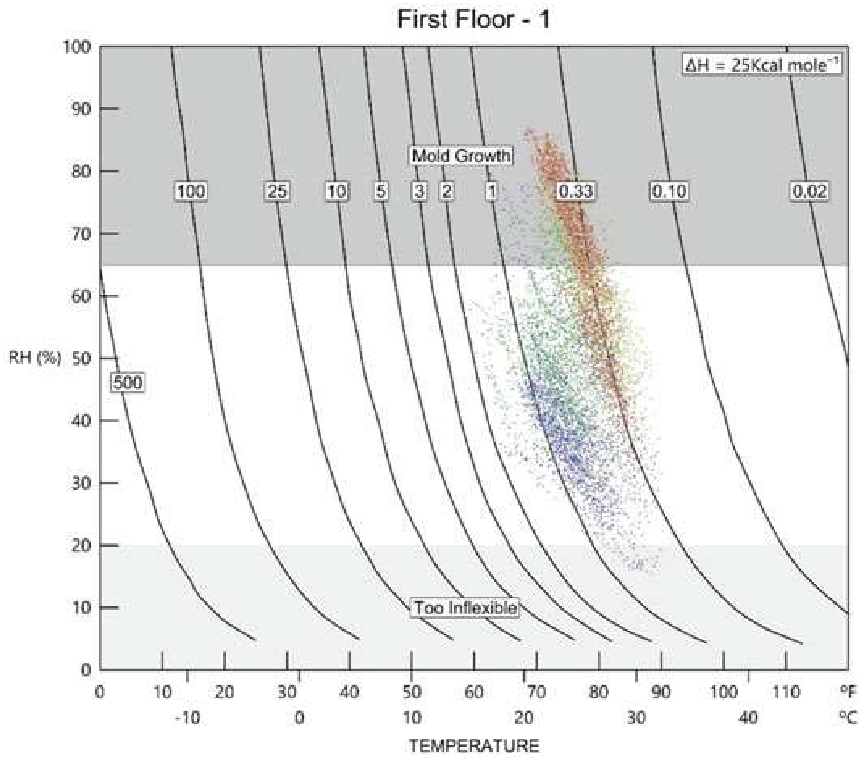


Fig. 13 Sebera diagram for book collection 1 on the 1st floor. (Authors 2022)

(yellow), and summer (red). It is observed that the internal microclimate is not suitable for the conservation of books since all spaces have surpassed the mold zone due to the high humidity inside, which may be due to the shading strategies using brise-soleil and trees, as well as ventilation blocking due to the louvers, bookshelves, and partitions allocated later.

The best conservation conditions occur in winter and spring, and the autumn and summer periods are more harmful due to the high humidity and temperatures. The temperature and humidity pairs close to PI = 0.28 and 1 indicate a low expectation of the books, around 12,6 to 45 years. Also, the collections on the first floor (Figs. 13 and 14) are more susceptible to mold, as they are closer to the ground and suffer from solar and ventilation blocks. It happens in periods of paper of low humidity in winter. Besides, we observe lower humidity in the second-floor collection (Fig. 15), mainly in summer and autumn.

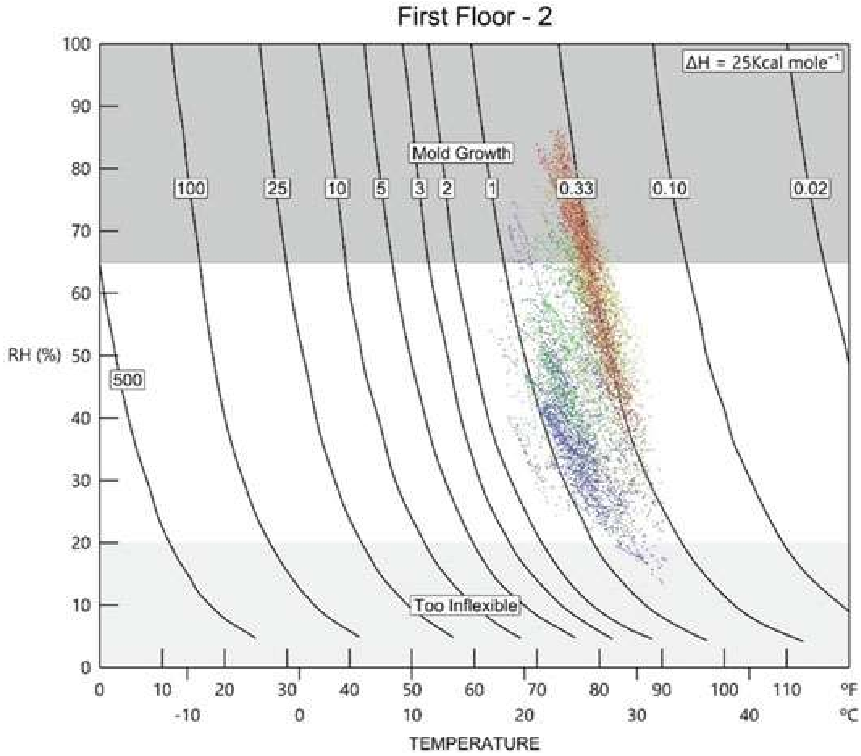


Fig. 14 Sebera diagram for book collection 2 on the 1st-floor. (Authors 2022)

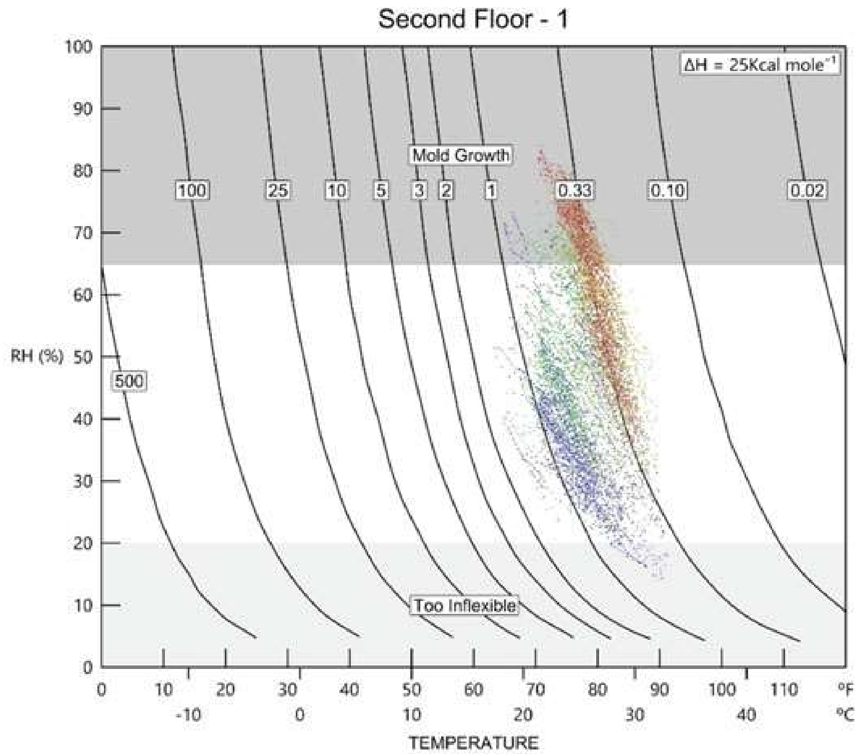


Fig. 15 Sebera diagram for book collection 1 on the 2st floor. (Authors 2022)

6 Conclusion

This research contributed to environmental sustainability by investigating, through hygrothermal simulation, naturally ventilated environments of an iconic university building in the current and future scenarios. It also contributed to the analysis of the feasibility of transferring BIM/BES data as an instrument for the microclimatic analysis of buildings. Another contribution of the research was a holistic view of the property, which allowed analyzing not only the thermal performance but the conservation of books, as well as proposing scenarios to improve the thermal performance without de-characterizing the building, which is in line with SDG 11.4 and 7.3. A hygrothermal simulation is an effective tool for environmental sustainability analysis regarding thermal performance and book conservation.

Regarding the thermal performance of the current scenario of the spaces analyzed, it was satisfactory since the operating temperature range in the occupied periods was between 82.15% and 86.88%. The scenario proposed to improve the thermal performance of the presets (double glass and open windows) was insignificant since it did not present significant differences in maximum and minimum temperatures in the current scenario. The scenario with closed windows presented higher temperatures, demonstrating the importance of natural ventilation for thermal performance. Thus, the appropriate scenario for the thermal performance of the analyzed building was the current scenario, despite the lack of full service.

The current scenario is unsuitable for conservation and books since isosperms are between 0.28 and 1, which means low longevity of the paper, between 12.6 and 45 years. Besides, the BIM/BES data transfer remains errors in geometry, thermal properties, and information such as usage, occupation, and scheduling. In this research, environmental sustainability focused on the microclimatic analysis of thermal performance and conservation of building books. However, the meaning of sustainability is broader. In this sense, future work related to energy efficiency analysis using BIM/BES integration in the exact scenarios is necessary.

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