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Research paper

Calculation and analyze of the thermal load from the Diva Saraiva Library from Campus I from the FACTHUS – Uberaba/MG

Cálculo e análise da carga térmica da Biblioteca Diva Saraiva do Campus I da FACTHUS – Uberaba/MG

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ABSTRACT: The climatization of environments aims to control the climate of a closed environment, conditioning the air to adjust the temperature, humidity, velocity, and purity to standards of thermal comfort and control of pollutants, established by resolutions and technical norms. At the Diva Saraiva Library on Campus I of the Faculty of Human Talents, located in the city of Uberaba/MG, thermal discomfort was noticed by most users. Books and other library files are exposed to fluctuations in temperature, and humidity that favor the proliferation of fungi, which consequently accelerate the processes of deterioration files papers. This work presents an approach to the thermal load calculation of a building, from three critical situations: maximum solar radiation, maximum external temperature and a maximum occupancy of people. The greatest thermal load was found in the position of the maximum temperature of the outdoor air, the value of 38760.95 W, with the largest portions, were heat conduction and the envelope air renewal. It has been proposed to install a VRF cooling system containing 7 evaporator units, 1 air exchange system, and also the acquisition of 2 portable dehumidifiers to ensure relative humidity appropriate meeting the demands of the building found, accompanied by the acquisition costs (R$ 122,608.00), installation (R$ 50,000.00) and maintenance of equipment (R$ 2,800.00 monthly).

Keywords: Air Conditioning of Libraries; Thermal Comfort; Solar Irradiation, Ventilation.

RESUMO: *A climatização de ambientes visa controlar o clima de um ambiente fechado, condicionando o ar de forma a ajustar a temperatura, umidade, velocidade e pureza, para padrões de conforto térmico e de controle de poluentes, estabelecidos por resoluções e normas técnicas. Na Biblioteca Diva Saraiva do Campus I da Faculdade de Talentos Humanos, situada na cidade de Uberaba/MG, foi notado desconforto térmico por grande parte dos usuários. Os livros e demais arquivos da biblioteca encontram-se expostos a flutuações de temperatura e umidade, que favorecem a proliferação de fungos, que por consequência, aceleram os processos de deterioração de arquivos em papéis. O presente artigo apresenta uma abordagem do cálculo de carga térmica de uma edificação, a partir de três situações críticas: máxima irradiação solar, máxima temperatura externa e máxima ocupação de pessoas. A maior carga térmica encontrada foi na situação de máxima temperatura do ar externo, com o valor de 38.760,95 W, sendo que as maiores parcelas foram de condução de calor pela envoltória e renovação de ar. Foi proposta a instalação de um sistema VRF de climatização contendo 7 unidades evaporadoras, sistema de renovação de ar e também a aquisição de 2 desumidificadores portáteis para garantir a umidade relativa apropriada atendendo às demandas encontradas da edificação, acompanhado dos custos de aquisição (R$ 122.608,00), instalação (R$ 50.000,00) e manutenção dos equipamentos (R$ 2.800,00 mensais).*

Palavras-chave*: Climatização de Bibliotecas; Conforto Térmico; Irradiação Solar; Ventilação.*

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INTRODUCTION

Refrigeration appears in various human activities and can be used for domestic, commercial, and industrial purposes such as, for example, refrigerators, food freezing and air conditioning, etc. (SILVA, 2010).

According to Silva (2010), acclimatizing an enclosed space is an air treatment process to simultaneously control the temperature, humidity, purity, and air movement in the environment. The Thermal Load (TL) consists of all the heat that needs to be removed from a climate-controlled environment, to maintain constant, the desired internal temperature and humidity conditions, through mechanical means. Refrigeration is the name given to this removal of heat from the environment.

The main climatic variables that are analyzed for thermal comfort standards are humidity, temperature, air velocity and incident solar radiation, as they are related to the functioning of the human body, whose mechanism is complex and can be generally compared with a machine that produces heat according to its activity. A healthy human being releases heat to maintain their internal body temperature of 37 °C. When this happens without great effort, it causes a feeling of thermal comfort (FROTA; SCHIFFER, 2001).

Another great source of heat for an environment to be acclimatized is the temperature and movement of the outside air, which ends up transmitting heat by convection, in addition to thermal radiation from the neighborhood, penetrating through thermal conduction to the internal environment (SACHT; ROSSIGNOLO; SANTOS, 2010).

Humans have a better life condition when their bodies can function without fatigue or stress, which can be generated by several factors, including excessive heat and cold. Therefore, architecture has as one of its functions to provide thermal comfort conditions inside civil constructions, regardless of the external climate conditions (FROTA; SCHIFFER, 2001).

Some technologies currently introduced in civil construction raise doubts about the quality of life in buildings. Housing must provide comfort and security to its inhabitants. Over the past few years, several countries have strived to increase the scientific foundation to improve the performance of air conditioning in buildings. In Brazil, importance is being given to this topic, as there is a great concern with a minimum performance in buildings and it was expressed in a documental manner in the publication of the Brazilian Regulatory Standard (NBR) 15575 of 2013, which establishes minimum requirements for performance, useful life and guarantee for the main systems that make up the buildings (SORGATO et al., 2014).

The lack of concern with the climate in civil constructions highlights problems such as the aesthetics of facades and the thermal discomfort of building users (BRAGA; AMORIM, 2004).

The analysis of thermal load peaks in buildings has a direct influence on the correct sizing of an artificial thermal conditioning system, and in Brazil little importance has been given to the construction and orientation of walls and roofs, which ends up causing a wall to act as a radiant panel at certain times of the day (GRANJA; LABAKI, 2004).

According to Cassares (2000), the acclimatization of closed environments that have a large amount of paper documents, such as in a library, the non-observance of norms related to heat and humidity, contribute to the deterioration of documents. The speed at which deterioration takes place is doubled with each increase of 10°C and the increase in humidity provides conditions that contribute to this acceleration. These situations provide conditions that are favorable to trigger chemical and physical reactions in paper materials,

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as pollutants, as well as biological agents (insects, rodents, and fungi) need moisture for their survival and proliferation, which significantly contribute to the deterioration of collections and files.

According to Branco (2016), the correct conservation of paper documents is complex, due to the reactions that naturally deteriorate them. By maintaining adequate levels of certain parameters, it is only possible to delay this degradation process. Knowing the age of the documents that are stored is of paramount importance, because in a library where only books are read, the care taken to preserve the collections is different when compared to an important archive/museum containing older and rarer works. Cuts in expenses and conservation costs are common to a building project when it exceeds the defined project value, and these cuts are often directed to the HVAC system, harming it in such a way that, in some cases, it becomes the worse than not having an air conditioning system.

In this context, the objective of the present work was to calculate the TL of the Diva Saraiva Library under three critical situations, in moments of: maximum solar irradiation; maximum outdoor temperature and maximum occupancy. Therefore, propose the installation of an air conditioning system that meets the parameters required by the building, informing the costs of acquisition, installation, and maintenance of the equipment.

LITERATURE REVISION

The RTSM (Radiant Time Series Method) calculation method corresponds to the one described by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in its publication HVAC Fundamentals between the years 2001 to 2013.

According to Nardelli (2018), the RTSM method does not require iterative calculations, however it offers a reliable result as an answer. The main objective is to obtain the total hourly thermal load. For this, the previously calculated convective fractions of the TL are added to the fractions by radiant heat gain through solar transmission, conduction through surfaces and internal heat sources for a given hour analyzed.

Authors such as Creder (2004), Silva (2010), Lamberts, Dutra, and Pereira (2014), among others, use ASHRAE HVAC Fundamentals as a reference in their thermal load calculation methodologies. The installments that make up the TL are:

- **Sunstroke**: Heat that penetrates the internal environment due to solar radiation that falls on the opaque and translucent surfaces of the building envelope.
- **Conduction**: Heat that penetrates the internal environment through opaque and translucent surfaces due to the temperature difference between the external and internal parts of the building.
- **People**: Heat released by occupants of the environment.
- **Artificial lighting and equipment**: Heat released by lamps and electrical equipment installed inside the enclosure.
- **Air infiltration**: Corresponds to the air that enters the internal environment through cracks in doors and windows.
- **Air renewal**: The renewal thermal load corresponds to the amount of air that needs to be inserted/removed mechanically into the environment to dilute the concentration of pollutants (physical, chemical, and biological) in the air, keeping it at acceptable levels (NBR 16401- 1, 2008).

According to Creder (2004), the total thermal load can also be divided into sensitive and latent. The sensitive part represents the heat energy that needs to be removed from the environment to keep the internal temperature at the desired value. The latent part represents the amount of water vapor that needs to be removed from the environment to maintain the internal relative humidity within the stipulated parameters.

According to Trinkley (2001), the construction or renovation program of a library must provide air conditioning equipment that helps the preservation of bibliographic materials, maintaining appropriate levels of temperature and humidity, providing clean and filtered air, contributing to the reduction of pollutants in the air. The recommended temperature and relative humidity parameters for a library are respectively 18°C to 24°C and 45% to 55%.

Installing one or more dehumidification equipment is the most effective strategy when the user needs better control of relative humidity. The air conditioning, controlled by a thermostat, and the dehumidifier, controlled by a humidistat, independently control the temperature and humidity parameters, ensuring an adjusted control without wasting energy (ALMEIDA, 2018).

METHOD

To analyze and propose an HVAC system for the Diva Saraiva Library on Campus I of the Faculty of Human Talents in Uberaba/MG, a survey of all relevant data for the project's calculations was carried out, so that the most accurate estimate possible could be made. to the actual CT model of the building.

The **climatic database** and the **location** of the building were the first information verified to start the acclimatization project. The Diva Saraiva Library on Campus I of the Faculty of Human Talents is located in the city of Uberaba-MG, at 230 Manoel Gonçalves Rezende street in the São Cristóvão neighborhood. The location and geographic orientation information is shown in **Tab. 1** and **Fig. 1.**

Table 1. Geographical position of the library.

Location	Latitude	Longitude	Elevation
Diva Saraiva Library	-19,776º	-47,938º	809 m

Source: Google Maps, 2019.

Figure 1. Wall orientations.

Source: Adapted from Google Maps, 2019.

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Current climate data from the automatic meteorological station of the Federal University of Triângulo Mineiro (UFTM), located in the city of Uberaba/MG, were collected on the website of the National Institute of Meteorology (INMET, 2019).

As a reference for climate data, the period between 2018-09-01 and 2019-03-31 was analyzed, in which they present the highest days of insolation and temperature in Uberaba/MG (INMET, 2019). This period was chosen knowing that the project must be dimensioned for the most critical situations of the year, thus meeting the periods with lower TL rates.

The table of data generated by INMET was reclassified into three parts: Situation 1 constituted moments of maximum solar irradiation. Situation 2 were moments of maximum temperature. Situation 3 moments of maximum occupancy for the Diva Saraiva Library.

As the maximum irradiation does not occur at the time of maximum temperature, which is also not at the same time of maximum occupancy, it became pertinent to analyze from these three points of view to identify how the envelope behaves in each one of them, defining which is the most impactful for the highest CT values.

After organizing the tables in descending order, and according to the study of interest, only the first 50 lines of each condition were selected. **Tab. 2** brings a sample of the data. This decision was because prolonging the selection would not add value to the final analysis of the thermal load, since the data is organized in a descending way, focusing on the most critical moments.

Table 2. Sample of climate data arranged descendingly by temperature.

Date	Actual time	Temperature [°C]	Humidity [%]	Solar radiation [W/m²]
2018-09-24	4:00 pm	35.2	21	566.11
2018-09-24	2:00 pm	35.0	20	927.78
2018-09-24	3:00 pm	34.9	20	785.56
2018-09-24	1:00 pm	34.6	23	921.94
2019-02-01	2:00 pm	34.3	32	1066.11
2018-09-25	3:00 pm	34.3	28	798.33
2019-01-31	4:00 pm	34.3	34	583.89
2019-01-31	3:00 pm	34.1	33	987.50
2019-02-01	4:00 pm	34.0	31	807.78
2018-09-26	4:00 pm	34.0	27	585.28

To work with the building's constructive data, the library was divided into two separate spaces, Part A, which comprises the area where books, desktop computers and most of the occupants are located, and Part B, which corresponds to the two small rooms with glass partitions located to the right of the building, as seen in **Fig. 2**. Their respective measurements are shown in **Tab 3**.

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Figure 2. Parts A and B of the library.

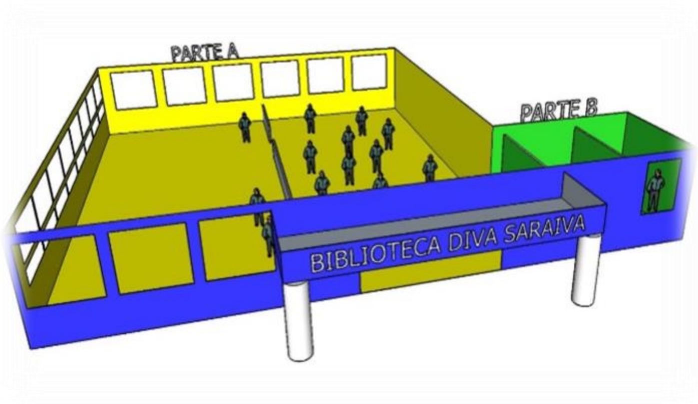

Table 3. Areas and ceiling height of the library.

Area of Part A (m²)	Area of Part B (m²)	Total area (m²)	Ceiling height (m)
402.8	35.1	437.9	3.8

All data were subdivided according to true north, being the Southwest (SO), Southeast (SE), Northeast (NE) and Northwest (NO) sides. In both parts, measurements were taken of the area and height of the site, size of windows and doors.

There is a glass door located on the NE wall of Part A, with a width of 5.8 m and height of 2.45 m, where it was recommended that it be closed to avoid great heat penetration into the environment by the outside air. The door should be opened when an occupant passes by and closed immediately afterwards.

Figure 3. Right Side (SE) of the Library.

It is important to emphasize that the NO wall of Part A and the SW wall of Part B border on a climate-controlled environment at the same temperature (administrative center of the college). This means that there is no heat transfer by conduction and insolation. Consequently, these walls are disregarded from the TL calculation. The external walls, roof and internal space are shown in **Fig. 3** to **5**.

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Figure 4. Library Background (SO).

Figure 5. Library internal space.

Thermal Insolation Load (Q_ins)

According to Lamberts, Dutra and Pereira (2014), the amount of heat transferred by insolation (Q_{ins}) in Watts that enters an enclosure differs between opaque and translucent surfaces and are given by equations (1) and (2).

$$Q_{ins}(opaques) = U * A * (\alpha * R_{es} * I) \quad (1)$$

where, *U* represents the global thermal transmittance coefficient (W/m².K); A is the Surface Area (m²); *α* is the Absorbance of the external surface; R_{es} is the external surface resistance where the sun's rays strike (m².K/W) and *I* is the solar irradiation incident on the surface (W/m²).

$$Q_{ins}(translucents) = A * (SF * I) \quad (2)$$

where, SF represents the Solar Factor of the material and the sun protection.

The amount of solar irradiation (I) that falls on all surfaces of the envelope, depending on the time and day of the year, was calculated following the methodology of Creder (2004).

The construction of the walls of the Diva Saraiva Library is composed of: concrete block (1.4 x 10-1 m); mortar plaster (2.5 x 10-2 m); painting. These conditions fall within the type of wall nº 8 of General Annex V, of Ordinance 50/2013 of Inmetro, having a global coefficient of thermal transmittance (U) of 2.87 W/m².K.

The library's roof is composed of thermo-acoustic tile (zinc sheet 1.00 x 10-3 m, molded polystyrene 3.00 x 10-2 m, zinc sheet 1.00 x 10-3 m); air chamber (> 5.00 x 10-2 m) with downward heat flow and not ventilated; Styrofoam board lining (3.00 x 10-2 m). The global transmittance coefficient for this type of coverage was not found in the literature, therefore, it was calculated using data from **Tab. 4**, presenting a coefficient (U) of 4.7 x 10-1 W/m².K.

Table 4. Properties of roofing materials.

Material	λ (W/m.K)	R_{ar}(m².K/W)
Zinc	1.12 x 10^{2}	-
Expanded polystyrene Molded	4.00 x 10^{-2}	-
Air Chamber > 5 cm, not ventilated, downward heat flow.	-	6.10 x 10^{-1}

Source: Adapted from NBR 15220, 2003.

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At the Diva Saraiva Library, the roof, and the southeast walls (SE) are tinted in ice white with an α coefficient of 37.2; the southwest walls (SO) are tinted close to canary yellow, corresponding to an α of 29.3; and the northeast walls (NE) have an imperial blue dye with α = 66.9 (INMETRO, 2013).

The translucent surfaces of the library are formed by glass with an average thickness of 5 mm, SF of 0.85 and coefficient (U) of approximately 6.0 W/m².K. The windows facing southeast (SE) and southwest (SO) are protected by opaque awnings at 45º, SF of 0.2. As for the northeast (NE) orientation, there is an opaque coverage of the building facade and trees that cover approximately 50% of the glazed area.

Conducting Thermal Load (Q_{cond})

For conduction TL, according to Lamberts, Dutra and Pereira (2014), the conduction heat transfer rate **(**Q_{cond}**)** for walls, roofs and windows is expressed by equation (3):

$$Q_{cond} = U * A * (T_{ext} - T_{int}) \tag{3}$$

where, T_{ext} represents the external temperature of the environment (°C); $T_{int}$is the internal ambient temperature (°C).

The global coefficients of thermal transmittance (U) of the walls, roof and windows of the library were the same used for the insolation TL. These already include the internal and external convection coefficients of the surfaces according to the direction of heat flow and wind speed.

Lighting Thermal Load (Q_{light})

As for artificial lighting, 48 fluorescent lamps with a power of 110 W were counted. Part B has only 2 lamps of 110 W. For calculation purposes, it was considered that the lamps are 100% on during the entire working hours of the library, which goes from 7:30 am to 10:00 pm.

Equipment Thermal Load (Q_{equip})

At the Diva Saraiva Library, the amount of equipment turned on at the same time varies according to the day and time, however, as the amount of electrical equipment in the library is relatively small, for calculation purposes, it was considered that all equipment is turned on during the period analyzed.

In Part A, 11 desktop model computers, 1 HP Laser Printer model M401DNE, and an estimate of 10 notebook computers were counted. Part B has an estimate of 2 notebooks. The average heat dissipated by office/library equipment can be seen in **Tab. 5**.

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Table 5. Typical rates of office equipment heat dissipation

Equipament	Continuous use (W)
Computers (with high safety coefficient)	75
Monitors (19 to 20 in.)	80
Laser printers (large, office size)	550

Source: Adapted from NBR 16401-1, 2008.

Thermal Load of People (Q_{peo})

The Brazilian Regulatory Standard (NBR) 16401-1 (2008) shows an estimate of the sensible and latent heat released per occupant, according to the level of activity and internal temperature of the environment. The sensible and latent heat portions can vary according to the temperature, but the total dissipated heat will always be the same for the same activity condition. Typical rates of heat released by people are shown in **Tab. 6**.

Table 6. Typical rates of heat transfer released by people.

Activity Level	Local	Total Heat (W)	Sensitive Heat(W)	Latent Heat (W)
Sitting in the theater	Matinee theater	95	65	30
Sitting in the theater at night.	Night Theater	105	70	35
Sitting down, light work.	Offices, hotels.	115	70	45

Source: Adapted from NBR 16401-1, 2008.

After an interview with library staff, **Fig. 6** shows the estimated occupancy of the library throughout the day. The maximum capacity of the Diva Saraiva Library was estimated at 84 people, with 76 people in Part A and 8 in Part B. For the purposes of calculation, an occupancy value was considered according to time bands, which can be seen in **Tab. 7**.

Figure 6. Total occupancy throughout library opening hours.

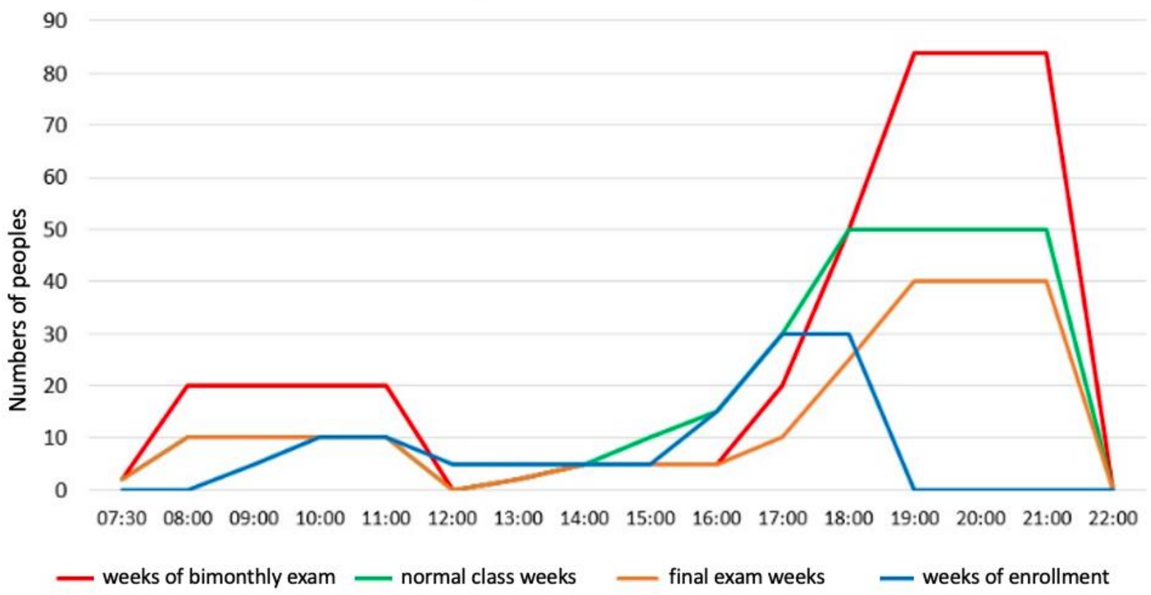

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Table 7. Occupation of Parts A and B of the library.

Time(h)	11am to 4pm	4pm to 6pm	6pm to 10pm
Number of people (Part A)	10	30	76
Number of people (Part B)	2	4	8

According to NBR 16401-2 (2008), the feeling of thermal comfort is essentially subjective, that is, it varies from person to person. The environment is in thermal comfort when the air conditions satisfy at least 80% of the occupants who have been in the enclosure for more than 15 minutes. As a reference, the thermal comfort parameters are shown in **Tab. 8.**

Table 8. Thermal comfort parameters.

Season	Temperature (ºC)	Humidity (%)
Summer	22.5 to 25.5	65
Winter	21 to 23.5	60

Source: Adapted from ABNT 16401-2, 2008.

As a reference for all TL calculations, the following air conditions for the internal environment of the library were considered: Dry bulb temperature (DBT) 24 ºC; Relative humidity (RH) of 65%.

Infiltration/Air Renewal Thermal Charge $(Q_{inf/renew})$

The renewal of air in installations larger than 5 Tons of Refrigeration, which is equivalent to 17,572 kW, is mandatory regardless of the type of environment or use, according to Ordinance 3523/98 of the Ministry of Health and Resolution 09/2003 of the National Agency of Sanitary Surveillance (ANVISA, 2003). These ordinances establish that the minimum flow for external air renewal is 27 m³/h per person for environments with low turnover of people, which is the case of the Diva Saraiva Library.

When this renovation is done only with the addition of outside air, that is, without the mechanical removal of inside air, the pressure of the internal air in the environment tends to be greater than the external one, which inhibits the entry of infiltration air through the gaps of doors and windows.

According to Silva (2010), the total volumetric flow of renovation air is given by equation (4).

$$V_{renew} = n * V_{peo} \quad (4)$$

where, V_{renew} represents the total renewal air flow (m³/h); *n* is the number of occupants of the room; V_{peo} is the air flow rate per person (m³/h).

To calculate the air renewal flow, it was considered that the library's renovation system always works at maximum flow to meet the maximum number of occupants of parts A and B of the library.

Creder (2004) proposes that the amounts of sensible and latent heat transfer that are added to the environment by air infiltration/renewal are given by equations (5) and (6).

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$$Q_{sensible} = \dot{m} * cp * (T_{ext} - T_{int}) \quad (5)$$

where, $Q_{sensible}$ represents the Amount of Sensitive Heat Transfer (kW); m is the renewal air mass flow (kg/s); cp is the Specific heat of water at constant pressure (kJ/kg.K); T_{ext} is the external ambient temperature (K); T_{int} = Internal room temperature (K).

$$Q_{latent} = \dot{m} * h_{lv} * (\omega_{ext} - \omega_{int}) \quad (6)$$

where, Q_{latent} represents the Latent Heat Transfer Amount (kW); h_{lv} is the Latent Heat of vaporization of water (kJ/kg); ω_{ext} is the Absolute Outdoor Air Humidity (kg/kg) and ω_{int} is the Absolute Indoor Air Humidity (kg/kg).

Total Thermal Load

To estimate the total thermal load, after calculating all the parcels, the sum of these represents the total TL value of the environment.

In order to meet possible heat penetration into the enclosure, as a safety measure, a Security Coefficient (SC) of 10% must be added to the calculations (CREDER, 2004).

The entire TL calculation methodology was applied equally to the three critical analysis situations: maximum solar irradiation; maximum outdoor temperature; maximum occupancy of people. The situation which results in the greatest thermal load values is the maximum amount of heat that must be removed from the environment, and sets the air conditioning system of the reference. Knowing the details about the TL parcels, characteristics of the building can be found that can attenuate or accelerate the heat propagation to the interior of the environment.

RESULTS AND DISCUSSION

Among the three analysis perspectives, the first to be worked on was Situation 1 (instants of maximum solar irradiation). The calculations of all portions of the building's TL were made taking into account all the climatic, construction and occupancy parameters for these moments.

The results with the maximum, average and minimum thermal load of Parts A and B of the library are shown in **Table 9**.

Table 9. Thermal load of Parts A and B for Situation 1.

	Part A Total TL (W)	Part A Total TL with CS (W)	Part B Total TL (W)	Part B Total TL with SC (W)
Maximum TL	3.7432×10^4	4.1175×10^4	3.6009×10^3	3.9610×10^3
Average TL	2.8913×10^4	3.1805×10^4	2.6475×10^3	2.9123×10^3
Minimum TL	2.0378×10^4	2.2415×10^4	1.7214×10^3	1.8935×10^3

It is noticed that Part A of the library represents the largest portion of the total thermal load of the building, as the construction area, number of people, lamps, equipment and renewal air flow are greater compared to Part B.

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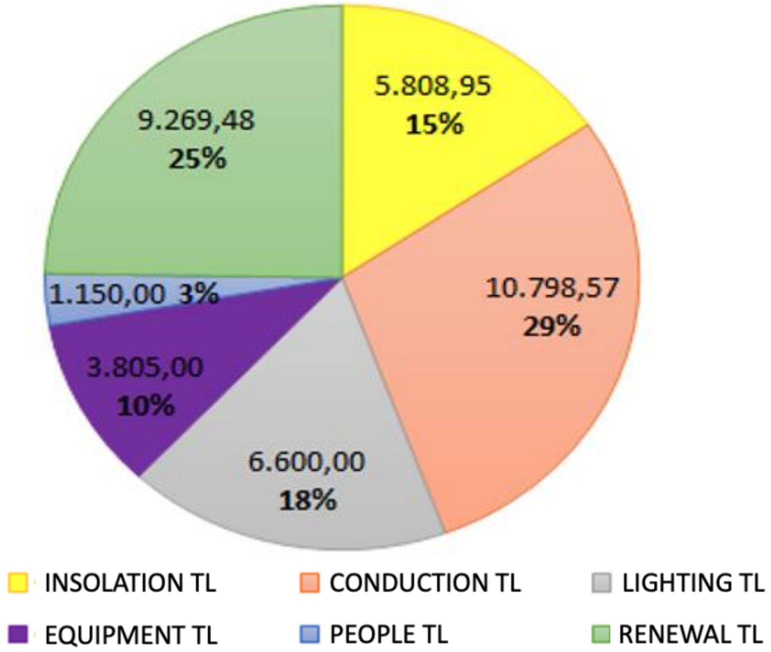
The maximum thermal load for Situation 1 occurred on 02/03/2019 at 1:00 pm. The graph with the maximum TL portions of Part A, which represents approximately 91% of the total load, is shown in **Fig. 7**.

Figure 7. Maximum thermal load (W) plots from Part A to Situation 1.



It could be observed from the results that the largest portions of TL are respectively conduction, air renewal and insolation. It is also noticed that despite the solar irradiation being potentially higher in Situation 1, the share of heat from insolation in the building envelope corresponded to only 15% of the total thermal load. This fact can be explained by the following factors: library does not receive insolation on all NO-oriented surfaces; low solar absorbance of the ice white color of the roof and low thermal transmittance coefficient of the roof; outdoor sunshades for windows in NE, SE, SW orientations and NE tree shading.

For **Situation 2** (instants of maximum external temperature) the results of the TL Parts A and B are shown in **Tab. 10**.

Table 10. Thermal load of Parts A and B for Situation 2.

	Part A Total TL (W)	Part A Total TL with CS (W)	Part B Total TL (W)	Part B Total TL with SC (W)
Maximum TL	3.8761×10^4	4.2637×10^4	3.6001×10^3	3.9601×10^3
Average TL	3.3578×10^4	3.6935×10^4	3.1318×10^3	3.4449×10^3
Minimum TL	3.0298×10^4	3.3328×10^4	2.9070×10^3	3.1977×10^3

The maximum thermal load for Situation 2 occurred on 2019-01-19 at 3:00 pm. The graph with the maximum thermal load portions of Part A is shown in **Fig. 8**.

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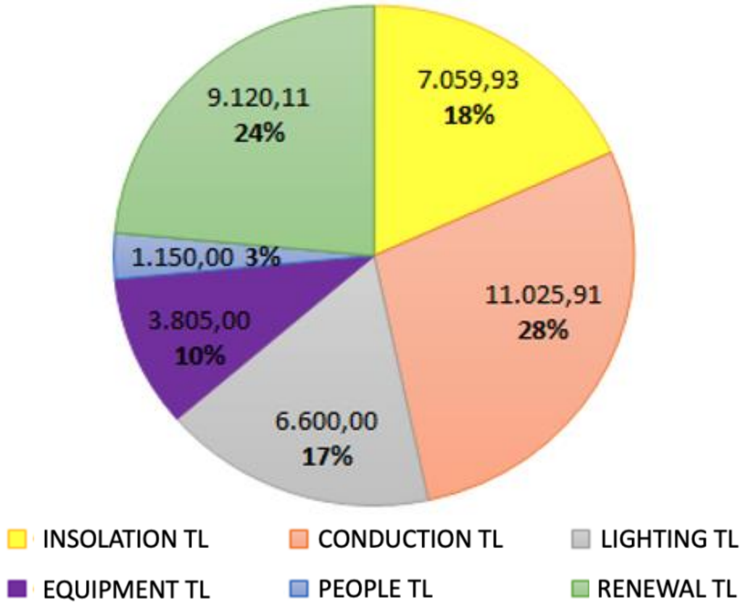
Figure 8. Maximum thermal load (W) plots from Part A to Situation 2.



With these results, it was noticed that the maximum TL for the temperature was slightly higher than in Situation 1. However, the average and the minimum were considerably higher, as observed in **Tabs. 9 to 11**. As the amount of people, lighting, equipment and renewal air flow are constant in both situations, it is evident that the climatic parameters on days with higher external temperature significantly contribute to a higher TL.

It is also noted that the insolation portion in Situation 2 was 18% and in Situation 1 it was 15%, which can be explained by the difference in time of the measured instants. In Situation 2, the maximum TL occurred at 3 pm, where the greatest incidence of the sun's rays is on the SW surface. In Situation 1, the maximum TL occurred at 1:00 pm, the time when the solar irradiation focuses more on the library roof. However, with the good insulation imposed by the building's roof, due to the low solar absorbance of the white color and the low thermal transmittance of the elements, this insolation is considerably attenuated.

For **Situation 3** (times of maximum occupancy), the days with the highest outdoor temperature and the 8:00 pm time were considered, which is among the times of greatest occupancy. The TL results for parts A and B are shown in **Tab. 11**.

Table 11. Thermal load of Parts A and B for Situation 3.

	Part A Total TL (W)	Part A Total TL with CS (W)	Part B Total TL (W)	Part B Total TL with SC (W)
Maximum TL	3.1117×10^4	3.4228×10^4	2.9425×10^3	3.2367×10^3
Average TL	2.4316×10^4	2.6748×10^4	2.1334×10^3	2.3468×10^3
Minimum TL	1.6611×10^4	1.8272×10^4	1.2593×10^3	1.3853×10^3

The maximum TL for Situation 3 occurred on 01/22/2019 at 8:00 pm. The graph with the thermal load portions of Part A is shown in **Fig. 9**.

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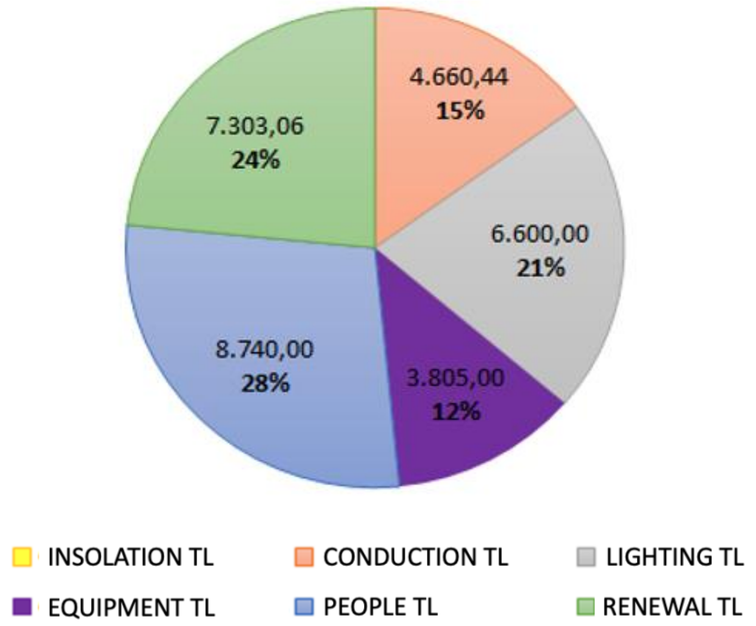
Figure 9. Maximum thermal load (W) plots from Part A to Situation 3.



It is observed by the results that at moments of greater occupation there is no longer the presence of the insolation portion, since at 8 pm the solar irradiation has already ceased. The outdoor air temperature at this time is lower compared to the afternoon, resulting in lower TL of conduction and renewal. It is also noted that due to maximum occupancy, the largest portion of the TL was people.

For a better perspective of the importance of periodic and detailed TL analysis, a hypothetical Fourth Situation (Maximum Everything) was calculated, where maximum irradiation, temperature, humidity, and occupancy for the library were considered simultaneously. A situation that, despite being hypothetical, can often be mistakenly used by calculators. The maximum solar irradiation does not coincide with the same moment of the highest external temperature, which also does not coincide with the moment of greatest occupation of the environment. Considering these moments of maximum simultaneously without evaluating the due day and time in which they occur, leads to a result that is highly overestimated in the TL and out of the reality of the building. The calculated values of the "All Maximum" Situation are shown in **Tab. 12**.

Table 12. Thermal Load of Part A for the "All Maximum" Situation.

Part A	Total LT (W)	Total LT with SC (W)
Maximum TL	5.1026×10^4	5.6128×10^4

All the maximum Thermal Loads of the four situations for Part A are shown in descending order in **Fig. 10**.

After analyzing all the situations, Situation 2 was defined as a reference for the HVAC system suggestion. It is justified by the fact that this calculation situation obtained the highest TL for both Part A and Part B of the library, and given the TL of that situation, all other situations 1 and 3 analyzed will also be covered.

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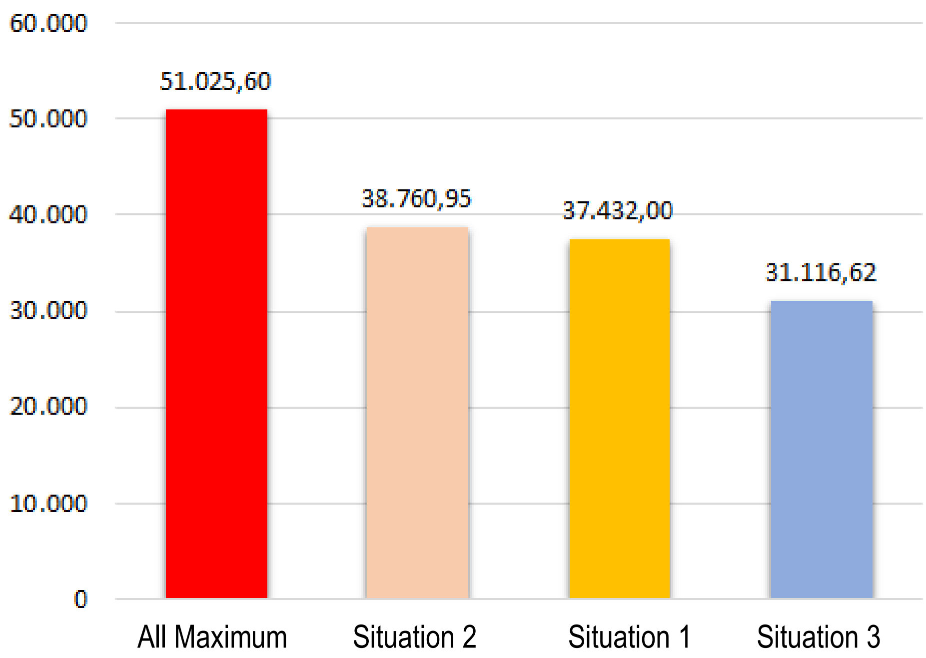
Figure 10. Thermal Loads (W) from Part A for the four situations.



Following all calculations, the minimum power (BTU/h) and air flow (m³/h) that needs to be met by the HVAC system for parts A and B of the library were defined. The BTU/h unit was chosen because the air conditioning manufacturers use it in the equipment specification. This information is shown in **Tab. 13**.

Table 13. Minimum power and air flow suggested for the climatization system.

	Part A	Part B	Total
Total Thermal Load (BTU/h)	145,485.00	13,515.00	159,000.00
Sensitive (BTU/h)	119,911.00	10,747.00	130,658.00
Latent (BTU/h)	25,573.00	2,769.00	28,342.00
Renewal air flow (m³/h)	2,05200	216.00	2,268.00

Among the alternative types of air conditioning systems, Split, Variable Refrigerant Flow (VRF) and Self-Contained systems were compared, in the parameters of electrical power consumed and coefficient of performance (COP), meeting a minimum refrigerating power of 159,000.00 BTU/h demanded by the library. The values for each system are shown in **Table 14**.

Table 14. Electric power consumed and COP.

System Type	Eletrical Power (W)	COP
Split	15.79	4.45
VRF	13.51	3.88
Self-Contained	26.99	2.81

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According to Corrêa (2013), the VRF system has advantages that, among them, are the energy savings provided by the compressor with capacity variation. This variation allows the HVAC system to adapt to the variation in TL throughout the day. Another feature of this system is the ease of adaptation to different building architectures, as the indoor units (evaporators) are modular and there are only one or a few outdoor units (condensers), bringing greater simplicity in assembly and disassembly in a possible change in the building layout. It is worth mentioning the built-in electronics that allow you to set different comfort temperatures for independent environments and the adjustment of operating hours, which can also be remotely controlled via the Internet.

With the VRF having the lowest energy consumption among the types of systems compared, a COP of 3.88, and all the advantages mentioned by Corrêa (2013), this HVAC system was chosen for the Diva Saraiva Library.

To better control the relative humidity, a budget was made with a company from São Paulo-SP, specialized in dehumidification equipment. The objective was to meet the following parameters: relative humidity around 50% (TRINKLEY, 2001); area of 402.8 m² (Part A where the bookshelves are located); ceiling height of 3.8 meters; flow 2052 m³/h of external air from the air conditioning system. The dimensioning performed by the company resulted in 2 dehumidification equipment shown in **Table 15**.

Table 15. Portable air dehumidification equipment.

Item	Qty.	Unit price (R$)
DESIDRAT PLUS 15.000 – 220V (LCD)	2	32,800.00
TOTAL VALUE ∑(quant. x unit price)		65,600.00

Then, the sketch was drawn with the arrangement of the evaporator, condenser, and the dehumidification equipment units in the Diva Saraiva Library. The length of the interconnection pipes of the indoor units with the outdoor unit was calculated in the amount of 63.5 m, as shown in **Fig. 11**.

In the next step, the price quotation was carried out in a refrigeration company located in the city of Uberaba/MG with the specifications of the air conditioning system calculated for that library. The best proposal presented showed the greatest amount of information about the components necessary for the installation and was chosen for this work. The manufacturer's proposal with all the necessary equipment to meet the HVAC system is shown in **Table 16**.

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Figure 11. Sketch of the layout of the units.

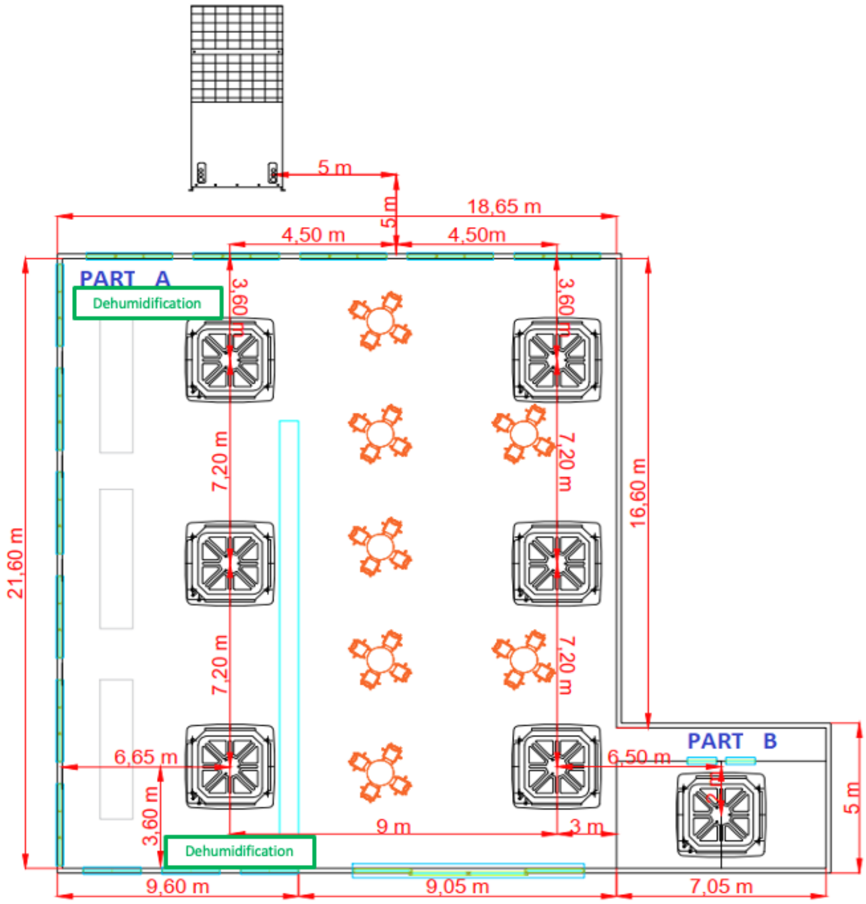

Table 16. Manufacturer's commercial proposal

Item	Qty.	Unit price R$
4TVH0170D6000AA - Cond. modular 100% Inverter 170 MBH 220V/3F - TVR LX R- 410 A	1	35,164.00
4TVC0027B1000AA - Evap. cassete (4 vias) 27 MBH - TVRII R-410 A , 220V 60HZ 1F	6	2,086.00
4TVC0018B1000AA - Evap. cassete (4 vias) 18 MBH - TVRII R-410 A , 220V 60HZ 1F	1	1,618.00
RAYPANELWHT001 – White panel 4-way cassette- TVRII	7	678.00
TCONTRM01WA – White remote-control TRANE – TVRII	7	138.00
TRDK225HP - Kit RefNet Evap. de 112 até 225 MBH – TVR	6	254.00
TCONTCCM09A – Central Control w/o Software/BAS - 64 Evaporators- TVRII	1	474.00
TOTAL VALUE ∑(quant x unit PRICE)		57,008.00

Source: TRANE, 2019.

The refrigeration company from Uberaba/MG informed the equipment installation and maintenance costs, which are shown in **Tab. 17**.

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Table 17. Equipment installation and maintenance costs.

Description	Value R$
Installation of all system units, piping, electrical and others, with all necessary materials included. Startup and guidance on the functioning and operation of the system.	50,000.00
Monthly cost forecast with preventive and corrective maintenance	2,800.00

Source: TRANE, 2019

CONCLUSIONS

Due to the aspects addressed throughout the work, to determine the thermal load of the Diva Saraiva Library and propose an HVAC system, it was possible to verify that the situation of analysis that resulted in the highest value of total thermal load was that of instants of highest outdoor air temperature, with 38,760.95 W, also resulting in the highest average value among the analyzed instants, 33,577.57 W. As the outdoor air temperature is directly related to the thermal loads of conduction and renewal of the air, this This condition was shown to be the most significant in maintaining the highest TL values.

The analysis situation of the moments of greatest solar irradiation, with an average of 28,913.29 W, showed that this insolation was attenuated by the opaque awnings installed on the translucent surfaces and by the low solar absorbance of the white roof.

The moments with the highest occupation of the library resulted in the lowest mean TL value, with 24,316.26 W. Although the thermal load of people is higher in this situation, at 20 h the temperature of the outdoor air is lower compared to the period of late, and there is no longer the presence of the insolation portion.

The methodologies used in this work with the analysis of critical situations, the calculations performed hourly, and the use of current climate data found results that are understood to be the closest to the reality of the building.

The VRF air conditioning system suggested by this work has great advantages compared to other air conditioning systems, among which the following stand out: the possibility of renovation; varying the capacity of the compressor to adjust to partial thermal loads; and a lower energy consumption. In the quotation made, the acquisition cost of the air conditioning equipment was R$57,008.00, and the installation cost was R$50,000.00. The monthly cost of preventive and corrective maintenance, estimated at R$ 2,800.00, was also budgeted. The relative humidity control to preserve the library's paper collections was quoted in two portable dehumidifying equipment for R$ 32,800.00 each, totaling R$ 65,600.00. The total calculated to have all systems installed and operating was R$ 172,608.00.

The analyzes and calculations of thermal load, the suggestion of the air conditioning and air dehumidification system carried out in this work presented a proposal for a library environment with thermal comfort for the occupants, preservation of books and other paper collections, meeting the recommendations of the literature and current technical standards in the country.

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