RGSA – Revista de Gestão Social e Ambiental
ISSN: 1981-982X
Submission date: 12/30/2024
Acceptance date: 03/31/2025
DOI: https://doi.org/10.24857/rgsa.v19n4-028
Organization: Interinstitutional Scientific Committee
Chief Editor: Ana Carolina Messias de Souza Ferreira da Costa
Assessment: Double Blind Review pelo SEER/OJS

STUDY OF AIR CONDITIONING TECHNOLOGIES AND SIZING OF A REFRIGERATION SYSTEM

João Vitor Ferreira Araujo [1]
Fernando Nunes Belchior [2]
Janine Cavalcante de Oliveira [3]
Gradisca de Oliveira Werneck de Capistrano[4]
John Edward Neira Villena[5]

ABSTRACT

Objective: The objective of this article is to conduct a study on Brazilian public policies regarding Energy Efficiency and how they apply to different types of air conditioning technologies available on the market.

Theoretical Framework: The main concepts and theories that support the research were presented. The focus includes the different types of air conditioning units and their technologies, as well as the necessary calculations for their proper sizing.

Method: A bibliographic review was conducted, followed by the development of a model and its subsequent validation. Data collection was carried out by selecting the environments to be analyzed. Finally, the tool was applied in two case studies.

Results and Discussion: The findings revealed that the sizing of air conditioning systems yielded satisfactory results when validated through alternative models available in bibliographic sources. Possible discrepancies and study limitations are also considered in this section.

Research Implications: The practical and theoretical implications of this research are discussed, providing insights into how the results can be applied or influence practices in the field of proper air conditioning unit sizing and the energy efficiency involved in their operation.

Originality/Value: This study contributes to the literature by creating a detailed calculation spreadsheet for air conditioning unit sizing. The relevance and value of this research are highlighted by enabling, in a simple and didactic manner, the pursuit of energy efficiency through the correct sizing of this equipment.

Keywords: Air Conditioners, Energy Efficiency, Thermal Load, Dimensioning.

[1] Universidade Federal de Goiás, Goiânia, Goiás, Brazil. E-mail: joaovitor.fa@outlook.com
Orcid: https://orcid.org/0009-0005-4147-8945
[2] Universidade Federal de Uberlândia, Uberlândia, Minas Gerais, Brazil. E-mail: fnbelchior@ufg.br
Orcid: https://orcid.org/0000-0002-1385-3374
[3] Universidade Federal de Goiás, Aparecida de Goiânia, Goiás, Brazil.
E-mail: janinecavalcanteoliveira@gmail.com Orcid: https://orcid.org/0000-0002-9261-8566
[4] Universidade de São Paulo, São Carlos, São Paulo, Brazil. E-mail: gradisca@ufg.br
Orcid: https//orcid.org/0000-0002-6966-8987
[5] Universidad Católica de Santa Maria, Arequipa, Arequipa, Perú. E-mail: johnneirav@ufg.br
Orcid: https://orcid.org/0000-0003-2281-6505

ESTUDO DAS TECNOLOGIAS DE CONDICIONADORES DE AR E DIMENSIONAMENTO DE UM SISTEMA DE REFRIGERAÇÃO

RESUMO

Objetivo: O objetivo deste artigo é realizar um estudo a respeito das políticas públicas brasileiras sobre Eficiência Energética e como elas se aplicam aos diferentes tipos de tecnologias de condicionadores de ar disponíveis no mercado.

Referencial Teórico: Foram apresentados os principais conceitos e teorias que fundamentam a pesquisa. Destacam-se os tipos de aparelhos de ar condicionado e suas tecnologias, além de cálculos necessários para o seu correto dimensionamento.

Método: Foi realizada a pesquisa bibliográfica, e a seguir foi elaborado o modelo, seguido pela validação do mesmo. A coleta de dados foi realizada por meio da seleção dos ambientes a ser analisados. Por fim, a aplicação da ferramenta foi feita em dois estudos de casos.

Resultados e Discussão: Os resultados obtidos revelaram que o dimensionamento de sistemas de ar condicionado obteve resultados satisfatórios quando validado através de modelos alternativos disponíveis em fontes bibliográficas. Possíveis discrepâncias e limitações do estudo também são consideradas nesta seção.

Implicações da Pesquisa: As implicações práticas e teóricas desta pesquisa são discutidas, fornecendo insights sobre como os resultados podem ser aplicados ou influenciar práticas no campo do dimensionamento correto de aparelhos de ar condicionado e a eficiência energética envolvida no funcionamento destes equipamentos.

Originalidade/Valor: Este estudo contribui para a literatura ao criar uma planilha de cálculo para o dimensionamento de aparelhos de ar condicionado, de maneira bem detalhada. A relevância e o valor desta pesquisa são evidenciados por permitir, de maneira simples e didática, a busca pela eficiência energética, obtida através do dimensionamento correto deste equipamento.

Palavras-chave: Energia Térmica, Ar Condicionado, Eficiência Energética, Dimensionamento.

ESTUDIO DE LAS TECNOLOGIAS DE ACONDICIONADORES DE AIRE Y DIMENSIONAMIENTO DE UN SISTEMA DE REFRIGERACIÓN

RESUMEN

Objetivo: El objetivo de este artículo es realizar un estudio al respecto de las políticas públicas brasileras sobre Eficiencia Energética y como estas se aplican a los diferentes tipos de tecnologías de acondicionadores de aire disponibles en el mercado.

Marco Teórico: En este tópico, se presentan los principales conceptos y teorías que fundamentan la investigación. Se destacan los tipos de aparatos de aire acondicionado y sus tecnologías, además de cálculos necesarios para su dimensionamiento correcto.

Método: Fue realizada la búsqueda bibliográfica, y después fue elaborado el modelo, seguido por la validación del mismo. La colecta de datos fue realizada por medio de la selección de los ambientes a ser analizados. Finalmente, se aplicó la herramienta en dos estudios de caso.

Resultados y Discusión: Los resultados obtenidos revelaron que el dimensionamiento de sistemas de aire acondicionado obtuvo resultados satisfactorios cuando se validó a través de modelos alternativos disponibles en fuentes bibliográficas. Posibles discrepancias y limitaciones del estudio también son consideradas en esta sección.

Implicaciones de la investigación: Las implicaciones prácticas y teóricas de esta investigación son discutidas, proporcionando informaciones sobre como los resultados pueden ser aplicados o influenciar prácticas en el campo del dimensionamiento correcto de aparatos de aire acondicionado y la eficiencia energética involucrada en el funcionamiento de esos equipamientos.

Originalidad/Valor: Este estudio contribuye para la literatura al crear una planilla de cálculo para el dimensionamiento de aparatos de aire acondicionado, de manera bien detallada. La relevancia y el valor de esta investigación son evidenciados por permitir, de manera simple y didáctica, la búsqueda por la eficiencia energética, obtenida a través del dimensionamiento correcto de este equipamiento.

Palabras clave: Carga Térmica, Acondicionadores de Aire, Eficiencia Energética, Dimensionamiento

1 INTRODUCTION

The concept of air conditioning was already applied centuries ago, where water from aqueducts was circulated through the walls of houses to cool them. For a long time, man tried to get rid of the heat, using fans, storing ice from the winter and various other methods that did not prove commercially viable.

The basic principle of an air conditioning unit is to use a fluid that will be cooled to a lower temperature than the environment to be cooled and to facilitate the exchange of heat between the air and this fluid. Thus, air conditioners have four main components that work in a closed cycle: compressor, condenser, expansion valve and evaporator (SHAPIRO e MORAN, 2009).

Population growth, economic development in southern countries and increasing resource consumption are possible reasons to justify the increase in electricity consumption. According to Kammen e Sunter, (2016), the well-being, cultural and social aspects and economic competitiveness of a population are directly affected by its energy capacity. On the other hand, the environmental damage caused by the increase in the production of energy resources makes countries seek increasingly efficient energy use.

In this context, this paper aims to conduct a study on Brazilian public policies on Energy Efficiency and how they apply to the different types of air conditioning technologies available on the market, through the construction of a calculation base that provides the correct dimensioning of an air conditioning system for a given environment. A validation of the model will be carried out based on the work carried out by De Almeida (2016)and Inácio, (2014).

2 THEORETICAL FRAMEWORK

2.1 PUBLIC POLICIES ON ENERGY EFFICIENCY

In the early 1970s, in contrast to US support for Israel in the Yom Kippur War, Kippur , the Arab countries of the Organization of the Petroleum Exporting Countries (OPEC) suspended oil supplies to countries supporting Israel, constituting the first oil shock. Later, in 1978 and 1979, as a result of the Iranian Revolution and the rise of the Shiite government of Ayatollah Khomeini, the second suspension of oil supplies by the Arab countries that are members of OPEC occurred. In the face of both stoppages, the price of oil reached its highest historical highs, directly impacting the world economy (MARINHO, 2010).

At the same time, discussions about the environmental impact of greenhouse gas emissions resulting from the use of fossil fuels were gaining relevance. Cardoso (2012)states that, given this scenario of international instability regarding the supply of oil and with the environmental issue gaining strength, countries are beginning to develop public policies for the rational use of energy resources, reduction of waste and development of alternative energy sources.

Brazil ranks 22nd on the list of most energy-efficient countries indicated by ACEEE, behind countries such as India, Thailand and South Africa (ACEEE, 2016). According to data from the 2020 National Energy Balance (EPE, 2020), Brazil was among the ten countries with the largest installed electricity generation capacity in the world and between 2016-2017 alone there was an increase of 4.3%, the 4th largest variation among the ten countries on the list. However, studies indicate that the conversion rate of primary energy into useful energy is around 33%, indicating a great potential for improvement by making processes and equipment more efficient (GOLDEMBERG e VILLANUEVA, 2003).

In 1984, in a protocol signed between the Brazilian Association of the Electrical and Electronic Industry (ABINEE), the MIC and the Ministry of Mines and Energy (MME), the Electric Energy Conservation Program for home appliances was created, which, from 1992 onwards, became known as the Brazilian Labeling Program (PBE) (MME, 2011). The PBE is coordinated by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO), and its main objective is to inform the end consumer about characteristics such as energy efficiency, capacity and noise of appliances, enabling more informed choices. This consists of classifying products into categories from “A” to “E”, according to their efficiency, considering the relationship between energy consumption and capacity (CARDOSO, 2012).

Figure 1a shows an example of the National Energy Conservation Label (ENCE), which provides consumers with information such as the type of equipment, manufacturer's name, commercial logo, model indication, indication of the model's energy efficiency rating, indication of energy consumption, additional information relevant to the consumer and INMETRO's signature. Among all its initiatives, the Procel Seal Program , created in 1993 in a joint action between Procel and INMETRO (PROCEL, 2012), stands out as being responsible for 98% of the gains. Figure 1b shows an example of the Procel Seal .

Figure 1

(a) National Energy Conservation Label and (b) Procel Seal

(the) (b)

Source: INMETRO, Regulamento específico para uso da etiqueta nacional de conservação de energia – ENCE. Linha de fogões e fornos a gás, 2006andPROCEL, Procel Info, 2020

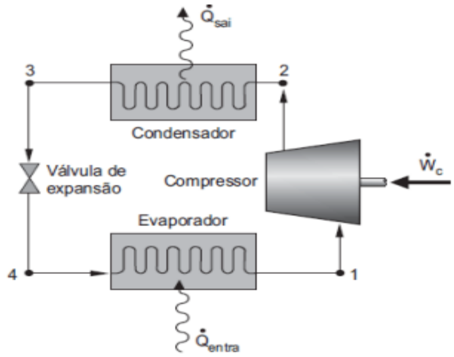
2.2 AVAILABLE AIR CONDITIONER CONFIGURATIONS

The basic principle of an air conditioning unit is to use a fluid that will be cooled to a temperature lower than the temperature of the environment to be cooled and to facilitate the exchange of heat between the air and this fluid. Thus, air conditioners have four main components that operate in a closed cycle: compressor, condenser, expansion valve and evaporator (SHAPIRO e MORAN, 2009). Figure 2 shows an air conditioning system.

The cycle begins in the compressor unit, which is responsible for increasing the pressure and temperature of the refrigerant fluid. In phase 2, the fluid passes through the condenser unit, which forces heat exchange between the fluid and the external environment, forcing the fluid to change its physical state to a liquid state. In phase 3, the fluid passes through the expansion valve, which restricts its passage, reducing the system pressure, causing the fluid to boil and, consequently, lowering its temperature. Finally, in the evaporator, the fluid, at a lower temperature than the environment to be cooled, circulates through a system of coils, absorbing heat from the air (SHAPIRO e MORAN, 2009).

Figure 2

Representation of an air conditioning system



Source: SHAPIRO, H. N., e MORAN, M. J. Princípios da Termodinâmica para Engenharia, 6th ed., 2009.

2.2.1 Window Type

The device has a compact structure that houses both the condensing unit and the evaporator unit, and is installed on the wall, which makes it less flexible, produces a considerable amount of noise and has lower energy efficiency. The model has the advantages of being easy to install, having a lower market value than others and easy maintenance.

2.2.2 Split Type

It is mainly characterized by having the condensing unit separate from the evaporating unit, with the condensing unit installed in the external environment and the evaporator in the internal environment to be air-conditioned. Its advantages include lower noise levels, a varied *design* and installation flexibility (CREDER, 2011).

split air conditioners , as (DUFRIO, 2017)can be highlighted:

a) *High- wall* or Wall: its main feature is the installation of the evaporator unit at a high point on the wall. It is ideal for small to medium-sized environments, i.e., places with low foot traffic.
b) *Multi-split* They are characterized by having only one condensing unit that supplies more than one evaporator unit. For this reason, it is a good option for places where space to allocate several condensing units is limited.

c) Cassette: Its evaporator unit is installed on the ceiling, in the central region of the place where you want to cool, and has four air outlets. It has a limitation regarding the height of the plaster recess, requiring at least 35 centimeters for its installation.

d) Floor to ceiling: can be installed either close to the floor or on the ceiling. It is recommended for commercial use due to its high cooling capacity.

2.2.3 Inverter **type**

inverter technology refrigeration system is characterized by controlling the compressor rotation, regulating the flow of refrigerant fluid, thus maintaining control of the room temperature practically constant. In contrast to conventional systems that turn off the motors once the desired temperature is reached and turn them on again when there are variations. For this reason, as stated Rezende (2012), air conditioners that have the *inverter system* can have an energy consumption up to 40% lower than conventional systems.

Inverter systems are characterized by reaching the ideal temperature more quickly, have less temperature fluctuation, are more efficient in energy consumption and are quieter, as they operate at low speeds (FUJITSU, 2016).

2.3 AIR CONDITIONING INSTALLATION PROJECT

Creder (2011)describes a method for the correct preparation of an air conditioning project, considering important factors such as walls and roofs, transmission of heat from the sun through windows, circulation of people, lighting and electrical equipment. In addition, the author provides the theoretical set to calculate the thermal load of each of the variables described and, thus, enables the dimensioning of the system to be installed. In addition, the Brazilian Standard (NBR) of the Brazilian Association of Technical Standards (ABNT) 16401 of 2008, provides the reference values to be used in the calculation (ABNT, 2008).

2.3.1 Thermal comfort

According to Fanger (1970), thermal comfort is understood as the different combinations between types of clothing, metabolic activity, and environmental thermal conditions that result in a better feeling of comfort for the majority of people. *American Society of Heating , Refrigeration , and Air- Conditioning Engineers* - (ASHRAE, 2005)the concept of thermal comfort can also be interpreted as a state of mind that expresses well-being with the thermal environment. According to Brazilian standard (NBR) 16401, the environmental factors that affect the sensation of thermal comfort are temperature, humidity and air speed. (CREDER, 2011)proposes ranges of temperature and air humidity for different locations and purposes of use, as shown in Table 1.

Table 1

Comfort Conditions

Purpose	Location	Temperature (°C)	Relative Humidity (%
Comfort	Residences, Hotels, Offices, Schools	23 to 25	40 to 60
Short-term occupancy stores	Banks, Barber shops, Hairdressers, Shops, Supermarkets	24 to 26	40 to 60
Environments with high heat load	Theaters, Auditoriums, Temples, Cinemas, Bars, Cafes, Restaurants, Libraries	24 to 26	24 to 26

Source: Adapted fromCREDER, H., Instalações de ar condicionado, 6th ed., Livros Tecnicos e Cientificos, 2011.

2.3.2 Walls and roofs

Solar energy falling on opaque surfaces such as walls and roofs is transmitted to the internal environment by both conduction and convection. The energy flow can be defined as a function of the temperature of the external environment, the internal temperature of the environment, the surface area, the coefficient of thermal resistance and an addition to the characteristic temperature differential of the surface (CREDER, 2011), as per equation 1.

$$Q_s = A * U[(t_e - t_i) + \Delta t] \tag{1}$$

where:

Q_s = Surface heat load in Watts;

t_e = External temperature in °C;

t_i = Internal temperature in °C;

A = Surface area in m²;

Δt = Addition to the temperature differential given in the table;

U = Overall heat transfer coefficient.

The coefficient of thermal resistance U is defined as Creder (2011)the heat flow per hour through one square meter of surface. In situations where there are different materials that make up the surface, the total coefficient U is the inverse of the sum of the resistances of each material. The total resistance is calculated in the same way as series resistances in an electrical circuit. Thus, to calculate the total resistance of a common wall, Equation 2 can be used.

$$R = \frac{1}{h_e} + \left(2 * \frac{1}{C_r}\right) + \frac{1}{h_i} + \frac{1}{k_t} \tag{2}$$

where:

h_e = Convective coefficient of the outside air;

h_i = Convective coefficient of indoor air;

C_r = Conductance of the plaster;

k_t = Conductivity of common brick.

Accordingly Creder (2011), the reference values to be considered for most common building materials are shown in Table 2.

Table 2

Heat Transmission Coefficient of Building Materials

Material	Coefficient (kcal/h * m² * °C)
Common brick (k_t)	1.11
Plaster (C_r)	2.39
Outside air film (h_e)	19.5
Indoor air film (h_i)	7.13

Source: Adapted fromCREDER, H., Instalações de ar condicionado, 6th ed., Livros Tecnicos e Cientificos, 2011.

Thus, the thermal resistance coefficient U is given by Equation 3.

$$U = \frac{1}{R} \tag{3}$$

Finally, Creder (2011)it states that to determine the value of the thermal load transmitted by opaque surfaces, the following reference values must be considered for the addition to the temperature differential shown in Table 3.

2.3.3 Heat transmission from the sun through windows

According to Creder (2011), the energy transmitted through sunlight to transparent surfaces is divided into a portion that is reflected, another that is absorbed by the material and the portion that penetrates the environment. Thus, for design purposes, only the amount of energy that passes through the surface is considered. In addition, the presence of curtains, awnings and blinds causes a reduction in the amount of heat and, for this reason, must also be considered. Tables 4 and 5 show, respectively, the coefficient of solar heat transmission through transparent surfaces and the reduction coefficients due to protection factors.

Table 3

Addition to temperature differential for medium colors

Surface	Δt (°C)
Roof	16.6
Wall facing east or west	11.1
North facing wall	5.5
South facing wall	0

Source: Adapted fromCREDER, H., Instalações de ar condicionado, 6th ed., Livros Tecnicos e Cientificos, 2011.

Table 4

Coefficient of solar heat transmission through glass

Days of the year vs Face of the building	S	IF	AN D	NE	N	NO DE	TH E	ON LY	SKYLIGHT
December 22nd	98	420	474	222	49	217	440	430	740
January 21st to November 21st	65	384	480	245	57	250	443	384	734
February 22nd to October 23rd	38	342	489	343	114	334	448	342	691
March 22nd to September 22nd	38	255	458	418	229	418	439	225	636

Source: Adapted fromCREDER, H., Instalações de ar condicionado, 6th ed., Livros Tecnicos e Cientificos, 2011.

Table 5

Heat reduction coefficient by protective suit

Protection	Reduction coefficient
Awnings or blinds	0.15 – 0.20
Internal and reflective blinds	0.50 – 0.66
White (blackout) interior curtains	0.25 – 0.61

Source: Adapted fromCREDER, H., Instalações de ar condicionado, 6th ed., Livros Tecnicos e Cientificos, 2011.

To determine the amount of heat in kcal/h that passes through the windows, Creder (2011)he related the area of the window glass and the heat transmission coefficient using Equation 4.

$$Q_v = A * U \tag{4}$$

Once the amount of solar energy transmitted has been defined, simply multiply the value by the reduction coefficient for cases where there are awnings, blinds or curtains (CREDER, 2011).

2.3.4 Movement of people

According to Creder (2011), an important factor to be considered in the design is the number of people occupying the environment. This is because, during the body temperature regulation mechanism, the body exchanges heat with the environment. Thus, once the environment is below 15.6 °C, sensible heat is transferred from the human body to the external environment. On the other hand, if the environment is above 37 °C, the environment gives off heat to the human body, causing perspiration and the elimination of water vapor during breathing, adding latent heat to the environment. Creder (2011)states that, if the environment is at a temperature between 15.6 °C and 37 °C, the human body exchanges heat with the environment in the form of sensible and latent heat according to (NBR 16401-1 ABNT, 2008).

It is important to emphasize that the temperature of the environment only interferes with the proportion between latent heat and sensible heat emitted by the human body, not affecting the amount of total heat (NBR 16401-1 ABNT, 2008). Therefore, the amount of total heat or the influence of the number of people occupying the environment is given by Equation 5, in which n is the number of people and Q is the total amount of heat transmitted from the human body to the environment for each level of activity (CREDER, 2011).

$$Q_{ps} = n * Q \tag{5}$$

2.3.5 Lighting and electrical equipment

Second Creder (2011), the heat generated during the operation of the room lighting, as well as electrical equipment, must be considered in the design. Therefore, it is necessary to calculate the thermal load of these equipment so that it can be removed from the room by the air conditioning system. Another important point is the number of hours that these equipments remain on, since equipments that remain on for less time also have less influence.

When the actual electrical power is known, it is possible to calculate the thermal load using Equation 6, in which k is the correction factor for the use of fluorescent lamps given by Creder (2011)due to the use of ballasts and 3.4 is the conversion factor from Watts to BTU.

$$n° \; de \; lâmpadas * potência * k * 3.4 \tag{6}$$

Still according to NBR 16401-1 ABNT (2008), the estimate for heat dissipation of electrical equipment is carried out in a manner analogous to the calculation for the circulation of people using equation 1, the reference values are given in Table 6.

According to Creder, (2011), the calculation can also be done using the equipment's power, which is known through Equation 5.

Table 6

Typical heat dissipation rates of various equipment

Various equipment	Recommended dissipation (W)	Recommended Dissipation (BTU)
Computer	65	222
Small monitor (13" to 15")	55	188
Medium Monitor (16" to 18")	70	239
Large monitor (19" to 20")	80	273
Desktop printer	100	341
Small office printer	160	546
Large Office Printer	275	938
Desktop copier	85	290
Office copier	400	1365
Cash registers	48	164
Coffee machine (10 cups)	1500	5118
Refrigerator (0.71 to 2.1 m³)	310	1058
Microwave oven	600 to 1400	2047 to 4777
Refrigerated drinking fountains	700	2388

Source: ABNT, NBR 16401: Instalações de ar condicionado – Sistemas Centrais e Unitários, 2008.

3 METHODOLOGY

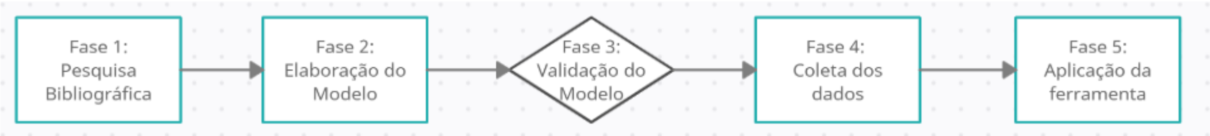
This work aimed to be an exploratory, methodological and applied research. The exploratory nature is due to the search for knowledge in relation to the historical facts that led to public policies focused on energy efficiency and also a survey of the main types of air conditioning technologies present in the market. Methodological because it used the method developed by Creder (2011)for calculating the thermal load to be removed from an environment to be cooled for the correct dimensioning of air conditioning systems. Finally, applied research, because it aims to contribute to the community by endorsing knowledge that will assist in more conscious purchases from the perspective of energy efficiency.

To compose the work, the relevant bibliographic sources were initially surveyed, read and indexed through books, monographs, theses, dissertations and periodical articles. The research database was carried out, in particular, in the CAPES/MEC Periodicals Portal.

Subsequently, the project for dimensioning the thermal load was made using the *software Microsoft Excel* . The model followed the methodology developed by Creder (2011) and used the equations and tables presented in chapter 2.3. The reference numbers used in the calculation were taken from ABNT NBR 16401 (ABNT, 2008)and the book Air Conditioning Installations by Creder (2011). The model was validated through a comparative analysis between the developed tool and the works of De Almeida (2016)and Inácio, (2014). Figure 3 presents a flowchart of the research procedure adopted.

Figure 3

Research procedure



Source: Own Authorship

4 RESULTS AND DISCUSSIONS

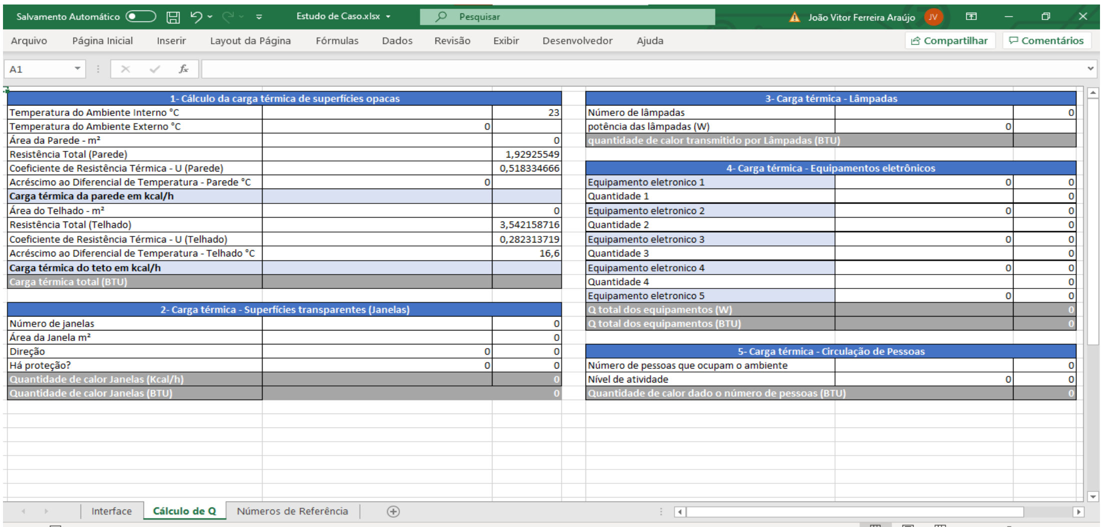
This study presents a tool using *Microsoft Excel* to calculate the thermal load of environments depending on characteristics such as location, orientation, dimensions, structural characteristics, occupancy and presence of electronic equipment. The book "Installations of Air Conditioning" by Helio (CREDER, 2011)and the reference numbers contained in the ABNT NBR 16401 standard (ABNT, 2008). For validation purposes, the work of De Almeida (2016), as well as the dissertation of , were used Inácio (2014).

4.1 THE PROJECT

The project was designed to calculate the thermal load of environments in an intuitive way for the user. After entering all the data into the system, the influence of each of the variables on the amount of thermal load of the environment will be automatically calculated in the ' *Q Calculation* ' tab. Figure 4 shows how these calculations were organized.

Figure 4

System for calculating thermal load



1- Cálculo da carga térmica de superfícies opacas		
Temperatura do Ambiente Interno °C		23
Temperatura do Ambiente Externo °C	0	
Área da Parede - m²		0
Resistência Total (Parede)		1,92925549
Coeficiente de Resistência Térmica - U (Parede)		0,518334666
Acréscimo ao Diferencial de Temperatura - Parede °C	0	
Carga térmica da parede em kcal/h		
Área do Telhado - m²		0
Resistência Total (Telhado)		3,542158716
Coeficiente de Resistência Térmica - U (Telhado)		0,282313719
Acréscimo ao Diferencial de Temperatura - Telhado °C		16,6
Carga térmica do teto em kcal/h		
Carga térmica total (BTU)		

2- Carga térmica - Superfícies transparentes (Janelas)		
Número de janelas		0
Área da Janela m²		0
Direção	0	0
Há proteção?	0	0
Quantidade de calor Janelas (Kcal/h)		0
Quantidade de calor Janelas (BTU)		0

3- Carga térmica - Lâmpadas		
Número de lâmpadas		0
potência das lâmpadas (W)	0	
quantidade de calor transmitido por Lâmpadas (BTU)		

4- Carga térmica - Equipamentos eletrônicos		
Equipamento eletronico 1	0	0
Quantidade 1		0
Equipamento eletronico 2	0	0
Quantidade 2		0
Equipamento eletronico 3	0	0
Quantidade 3		0
Equipamento eletronico 4	0	0
Quantidade 4		0
Equipamento eletronico 5	0	0
Q total dos equipamentos (W)		0
Q total dos equipamentos (BTU)		0

5- Carga térmica - Circulação de Pessoas		
Número de pessoas que ocupam o ambiente		0
Nível de atividade	0	0
Quantidade de calor dado o número de pessoas (BTU)		0

Source: Own Authorship

In Figure 4, the upper left-hand table (1) calculates the heat load transmitted to the environment through opaque surfaces (walls and ceiling) and, for this, Equations 1, 2 and 3 were used. Next, there is table 2 (below table 1) which uses Equation 4 to calculate the amount of heat that passes through transparent surfaces (windows). In tables 3 and 4 (right-hand side of figure 5) the influence of lamps and electronic equipment is calculated using Equations 6 and 5, respectively. Finally, in table 5 (bottom right), the heat load transmitted to the environment due to occupancy is calculated using Equation 5. The total heat load is given by the sum of the other loads plus a safety factor of 10%, as per Creder (2011).

4.2 MODEL VALIDATION

The first reference used was the work De Almeida (2016), in which an air conditioning system was designed to serve room A-03, located in block A of the UFG School of Engineering, in Goiânia-GO. The room has an area of 25 m², 3.5 m of ceiling height, and a window with an area of 5 m² without any type of protection facing southeast. The environment has the following electronic equipment: 8 40W lamps, 1 desktop computer, 1 22-inch monitor and a printer. An occupancy of 5 people with a moderate level of physical activity in office work (130 W/person) was considered.

Next, the reference was used Inácio (2014)in which the *software was considered Energy Plus* was used to calculate the ideal thermal load for the classrooms of the Instituto Federal Fluminense (IFF) Itaperuna Campus . In order to validate the designed model, room B18 of block B was used, whose characteristics are: area of 41.47 m², ceiling height of 3 m, 1 window with dimensions of 4.85 m wide and 1.46 m high facing north and without protection, 2 640 W lamps and occupancy of 36 people with activity level "walking, standing still" (140 W/person). Figures 5 and 6 show the program screen with the result of validation 1 and 2, respectively.

As can be seen in Table 7, the results returned by the model were satisfactory since they presented an error of +8.29% compared to the model of De Almeida (2016)and -0.72% compared to that presented by Inácio (2014). Thus, it is clear that the initial objective of developing a program to be used to calculate the thermal load of different environments was achieved.

Table 7

Comparison of the project in relation to the model developed byDe Almeida (2016)

Proposed Model	Peter Henry (2016)	Difference (%)
16,419.21 BTUs	15,058 BTUs	+8.29
Proposed Model	William Ignatius (2014)	Difference (%)
32,359.57 BTU	32,594 BTU	-0.72

Source: Own Authorship

Figure 5

Model validation 1 result

Projeto de Instalação de Ar Condicionado		
1.	Orientação da Parede	Parede voltada para o leste ou oeste
2.	Largura	5
3.	Comprimento	5
4.	Altura do pé direito	3,5
5.	Cidade	Goiânia (GO)
6.	Número de janelas (tipo 1)	1
7.	Largura da Janela - m (tipo 1)	2,5
8.	Altura da Janela - m (tipo 1)	2
8.	Direção (tipo 1)	SE
6.	Número de janelas (tipo 2)	
7.	Largura da Janela - m (tipo 2)	
8.	Altura da Janela - m (tipo 2)	
8.	Direção (tipo 2)	
9.	Há algum tipo de proteção nas janelas?	Não
10.	Número de lâmpadas	8
11.	Potência (W)	40
12.	Selecione o equipamento eletrônico:	Computador
13.	Quantidade:	1
14.	Selecione o equipamento eletrônico:	Monitor grande (19 pol. a 20 pol.)
15.	Quantidade:	1
16.	Selecione o equipamento eletrônico:	Impressora de escritório pequena
17.	Quantidade:	1
18.	Selecione o equipamento eletrônico:	
19.	Quantidade:	
20.	Outro equipamento eletrônico:	
21.	Potência	
22.	Quantidade de Pessoas que ocupam o ambiente:	5
23.	Nível de atividade física	Atividade moderada em trabalhos de escritório
24.	Resultado	16419,21 BTU

Source: Own Authorship

Figure 6

Validation result 2

Projeto de Instalação de Ar Condicionado		
1.	Orientação da Parede	Parede voltada para o leste ou oeste
2.	Largura	8,424
3.	Comprimento	5
4.	Altura do pé direito	2,5
5.	Cidade	Rio de Janeiro (RJ)
6.	Número de janelas (tipo 1)	1
7.	Largura da Janela - m (tipo 1)	4,85
8.	Altura da Janela - m (tipo 1)	1,46
8.	Direção (tipo 1)	N
6.	Número de janelas (tipo 2)	
7.	Largura da Janela - m (tipo 2)	
8.	Altura da Janela - m (tipo 2)	
8.	Direção (tipo 2)	
9.	Há algum tipo de proteção nas janelas?	Não
10.	Número de lâmpadas	2
11.	Potência (W)	640
12.	Selecione o equipamento eletrônico:	
13.	Quantidade:	
14.	Selecione o equipamento eletrônico:	
15.	Quantidade:	
16.	Selecione o equipamento eletrônico:	
17.	Quantidade:	
18.	Selecione o equipamento eletrônico:	
19.	Quantidade:	
20.	Outro equipamento eletrônico:	
21.	Potência	
22.	Quantidade de Pessoas que ocupam o ambiente:	36
23.	Nível de atividade física	Caminhando, parado em pé
24.	Resultado	32359,57 BTU

Source: Own Authorship

5 CONCLUSION

This work enabled the development of technical skills for the preparation of refrigeration projects, taking into account the main factors for determining the thermal load of environments. A tool was developed for calculating the thermal load to be removed from an environment by an air conditioning system with an accuracy of 9.09% compared to the work developed by De Almeida (2016)and 0.26% compared to the dissertation prepared by Inácio (2014) in which *software was used Energy Plus* , made available by the United States Department of Energy.

Therefore, since the tests performed obtained results that differed by less than 10%, it can be concluded that the tool developed is reliable for estimating the thermal load of environments and, therefore, dimensioning the ideal cooling capacity for an air conditioning system. A cooling system was dimensioned for one of the rooms in the new Classroom Center of the Faculty of Science and Technology of UFG, thus obtaining a satisfactory result, since the structural characteristics of the environment, the installed electrical equipment, the occupancy rate and the climatic characteristics of the location were taken into account.

REFERENCES

ABNT. (2008). *ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 16401: Instalações de ar condicionado – Sistemas Centrais e Unitários*.

ACEEE. (2016). *American Council for an Energy-Efficiency Economy*. The 2016 International Energy Efficiency Scorecard. https://www2.aceee.org/l/310911/2018-01-05/glrw9

ASHRAE. (2005). *Handbook Fundamentals – Thermal comfort*.

CARDOSO, R. B. (2012). *Estudo dos impactos energéticos dos Programas Brasileiros de Etiquetagem Energética: Estudo de caso em refrigeradores de uma porta, condicionadores de ar e motores elétricos*. Universidade Federal de Itajubá.

CREDER, H. (2011). *Instalações de ar condicionado* (6th ed.). Livros Tecnicos e Cientificos.

DE ALMEIDA, P. H. S. (2016). *Impactos da instalação e manutenção de ar condicionado no consumo energético.* Universidade Federal de Goiás.

DUFRIO. (2017). *Conheça os principais tipos de ar-condicionado e suas diferenças*.

EPE. (2020). *Empresa de Pesquisa Energética. Balanço Energético Nacional 2020*.

FUJITSU. (2016). *Ar condicionado tecnologia inverter*.

GOLDEMBERG, J., & VILLANUEVA, L. D. (2003). *Energia, meio ambiente e desenvolvimento* (3rd ed.).

INÁCIO, W. dos S. (2014). *Dimensionamento da carga térmica de resfriamento de ambientes: estudo de caso no Instituto Federal Fluminense Campus Itaperuna*. Universidade Candido Mendes.

INMETRO. (2006). *Instituto Nacional de Metrologia e Normalização e Qualidade Industrial, Regulamento específico para uso da etiqueta nacional de conservação de energia – ENCE. Linha de fogões e fornos a gás*.

KAMMEN, D. M., & SUNTER, D. A. (2016). City-integrated renewable energy for urban sustainability. *Science*, *352*(6288), 922–928.

MARINHO, H. A. de M. P. (2010). Estados Unidos: o contexto dos anos 1970 e as crises do petróleo. *Revista Eletrônica História Em Reflexão*, *4*(7).

MME. (2011). *Plano Nacional de Eficiência Energética - Premissas e diretrizes básicas*. https://antigo.mme.gov.br/documents/36208/469534/Plano+Nacional+Efici%C3%AAncia+Energ%C3%A9tica+%28PDF%29.pdf/899b8676-ebfd-c179-8e43-5ef5075954c2?version=1.0

PROCEL. (2012). *Resultados PROCEL 2012, Ano base 2011*.

PROCEL. (2020). *Procel Info. 2020.* http:/www.procelinfo.com.br

REZENDE, P. H. O. (2012). *Uma proposta de modelagem de condicionadores de ar split visando a análise de pedidos de ressarcimento por danos elétricos*. Universidade Federal de Uberlândia.

SHAPIRO, H. N., & MORAN, M. J. (2009). *Princípios da Termodinâmica para Engenharia* (6th ed.). LTC.