Review

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Desiccant Technologies for Improving Air Quality: An Overview of the Brazilian Scenario and Comparison of Available Design Software

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Desiccant Technologies for Improving Air Quality: An Overview of the Brazilian Scenario and Comparison of Available Design Software

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Abstract: A review of desiccant dehumidification technologies for improving air-quality has been presented, especially focusing on alternatives for air conditioning systems for minimizing the Sick Building Syndrome. The principles and types of desiccant wheels, as well as the existing selection software for these types of equipment, were reviewed and comparatively evaluated. The study focuses on the Brazilian context, therefore, information about air condition systems and laws of this country were evaluated. Possible applications of desiccant wheels are also analyzed, such as their integration into cooling cycles and the sensible heat wheel. Finally, several commercial desiccant wheel selection software were evaluated, which are useful in many situations. Nevertheless, it was evidenced that the available softwares are not capable of performing an operation analysis for only a specific period. Therefore, it is essential to create computational tools to select desiccant wheels, considering the data from the different Brazilian regions for a year.

Keywords: dehumidification; desiccant wheels; air quality; air conditioning systems

1. Introduction

In air conditioning design, it is essential to consider the addition of external air to closed environments such as offices, schools, hospitals, malls, among others. The American Society for Heating, Refrigeration and Air Conditioning Engineering (ASHRAE) establishes that if a building has more than 20% of people with symptoms of some disease or discomfort when exposed to this environment, it is considered a building that fits a Sick Building Syndrome (SBS) situation [1].

The lack of indoor air renewal causes the accumulation of chemical pollutants (carbon monoxide and dioxide, sulfur dioxide and formaldehyde, ammonia, among others) and biological contaminants (fungi, algae, protozoa, bacteria, and mites), which makes the air hazardous for human health, being a risk factor for people with respiratory diseases [2]. Environments with high levels of these pollutants are conventionally called SBS, where the World Health Organization (WHO) recognized this problem in 1982 [3].

In the 1970s, an energy crisis spread globally due to conflicts between oil exporting countries in the Middle East. As a result, oil suffered a reduction in production and a price increase, reaching 400% in 1973. In the same period, engineers, looking for alternatives to reduce the consumption of electric energy [4], reduced the external air supply to buildings [5,6]. Consequently, the first reports of SBS [7] were seen.

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Fungal exposures are receiving increasing attention as an occupational and public health problem due to the high prevalence of fungal contamination in buildings [8]. Moisture and moisture-related problems are significant sources of fungal contamination in homes, buildings, and schools [9]. Indoor fungi can be inhaled, and the presence of such particles has been linked to many illnesses and symptoms (infections, allergic reactions, or toxic responses) among occupants of moisture-damaged buildings [10]. On the other hand, moisture damage in buildings could alter various components of building materials, which can be another source of deterioration in indoor air quality (IAQ) [11]. Fungal growth is associated with moisture content, defined as the ratio between the material's free water and its dry weight [12].

Some studies indicate a relation between humidity, indoor-measured visible biological contaminant growth, and its effects on human health. Sterling et al. [13] analyzed the humidity impact on contaminants (such as viruses, bacteria, and fungi) and the possible impacts on human health. The authors observed, at room temperature, that the required humidity range for minimizing risks to human health by biological contaminants was between 40 and 60%, as shown in Figure 1.

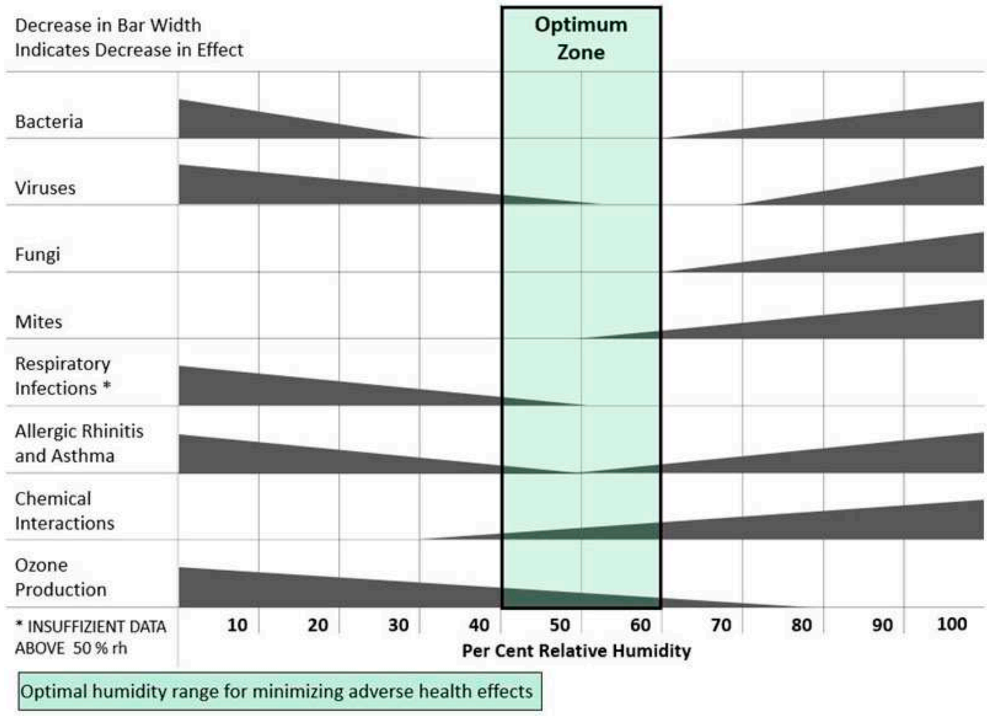

Figure 1. Optimal humidity range for minimizing risks to human health. Source: [13].

In 1984, the WHO estimated that up to 30% of buildings could be affected by SBS. In the early 1980s, the concept of SBS was correlated with environmental problems. Table 1 shows some of the main symptoms associated with SBS. However, the concept evolves and includes psychological aspects, economic implications, energy savings, and climate change [14].

Brasche [15] observed that women suffer more from SBS when compared to men, with 44.3% of women suffering from SBS, while only 26.2% of men face this problem, as shown in Table 2. However, this percentage difference between genders is due to position within the company; in the same study, when men and women are in environments with the same IAQ, the rates of occurrence of SBS are similar.

Table 1. Symptoms associated with SBS. Source: [14].

Symptoms	Occurrence (%)
Lethargy	57
Stuffy nose	47

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Dry throat	46
Headache	43
Itchy eyes	28
Dry eyes	27
Runny nose	23
Flu	23
Breathing difficulty	9
Chest pain	9

Table 2. Gender-related differences in SBS. Source: [15].

	Women		**Men**	
	People	%	People	%
With Symptoms	393	44.3	151	26.2
Without Symptoms	495	55.7	426	73.8
Total	888	100	577	100

In the mid-1990s, when the issue of indoor air quality began to gain importance in Brazil, air conditioning systems became a main subject for maintaining cleanliness and conservation. In 1998, with the death of the then Minister of Communications Sérgio Motta, attributed mainly to the bacterium Legionella, the then minister of Health José Serra announced the formation of a study group to publish legislation that obliges those responsible for air conditioning systems to maintain clean systems, therefore preventing diseases in the Brazilian population [16].

The Ministry of Health published in 1998 the ORDINANCE N°3523 [17], which defines values and definitions to maintain IAQ as described in Art. 4, the definition of Sick Building Syndrome. From Art. 5, it is possible to mention the need to meet a minimum level of air renewal (27m^3/h/person) and a minimum filtration of class G1. On the other hand, the Brazilian Ministry of Health published in 2003 RESOLUTION No. 09 (RE-09) [18], which presents additional information from ORDINANCE No. 3,523/98. One of the definitions given in RE-09 is the concept of air conditioning, which corresponds to the air treatment process intended to maintain the IAQ requirements of the conditioned space, controlling variables such as temperature, humidity, speed, particulate matter, biological particles, and carbon dioxide content.

RE No. 09 also presents parameters related to the maximum recommended values for microbiological contamination, which is 750 cfu/m^3 (Colony-forming unit/cubic meter), and chemical contamination, being 1000 ppm for the concentration of carbon dioxide (CO_2) and 80 μg/m^3 of aero dispersoids. In addition to these parameters, there are recommended operating ranges for temperature, humidity, air speed, air renewal rate, and the degree of air purity that must comply with the Brazilian Regulatory Standard NBR 16401-3 for indoor air quality [19].

An essential point for maintaining IAQ is to keep the equipment in full operation, and for this, it was necessary to create a Maintenance, Operation, and Control Plan (MOCP). In Brazil, the Civil House published Law No. 13,589 of 2018 [20], which obliges public and collective buildings to keep the MOCP active, thus guaranteeing the ranges established for a good IAQ. Just increasing air renewal in buildings without proper treatment does not solve all the problems associated with IAQ. According to Che et al. [21], this methodology can increase indoor humidity, which can also substantially raise the potential for microbiological growth, as this increase in ventilation can augment the concentration of pollutants in the environment. However, the practice of increasing the rates of air renewal has established itself among designers [22]. Outdoor air recommendations are stipulated for each type of design, where designers seek to increase the speed of outdoor air to the maximum allowed according to NBR 16401-3 and obtain systems that provide temperature,

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humidity, and specific filtration control for the condition of the environment in question. If necessary, it could consider using total heat exchangers as enthalpy wheels, which can provide energy savings to the building.

According to Pargeter [23], the energy consumption required by conventional air treatment practices for air-conditioning in commercial buildings represents an average of 10% of all energy spent in the United States. The author also noted that a large part of the energy consumption for air conditioning in these commercial buildings is due to air renewal, as this is a different condition from the internal comfort conditions. In addition to electricity consumption, the higher rate of air renewal leads to greater investments and maintenance costs of this Heating, Ventilation, and Air Conditioning (HVAC) system.

One alternative to conventional refrigeration systems is the so-called desiccant cooling cycles [24,25], which employ active desiccant rotors for dehumidifying the outdoor air and running the produced dry air through evaporative coolers to provide the refrigeration effect. The main advantage of such technology is that no special refrigerant fluids are required, and that its mainly driven by thermal energy, which means that solar or thermal waste energy can be used to power these cycles. On the other hand, the COP of this cycle is quite low, which could not be a big issue considering that a renewable source or waste energy is being used as a source of power. These alternatives can also be used alongside other cooling systems, as previously demonstrated [26,27]

This research aims to analyze alternatives for air HVAC systems for minimizing Sick Building Syndrome and improving air quality considering international programs/standards. For this purpose, an alternative technology known as desiccant wheels was studied, analyzing the principles and types of them, as well as the existing selection software for these types of equipment. In addition, energy efficiency programs worldwide and in the Brazilian context were analyzed, aiming at implementing strategies in which the use of desiccant wheels is appropriate. Finally, some commercial software for desiccant wheels were compared aiming to identify the different tool available in the air conditioning market.

2. Materials and Methods

The International Energy Agency [28] estimated that about 2/3 of homes worldwide will have an air conditioner installed by the year 2050, representing sales of 10 air conditioners per second within the next 30 years. There is an expectation that air cooling systems could account for more than 20% of the world's electrical energy demand growth, provided that no alternative technologies for air conditioning are available. According to the Brazilian Association of Refrigeration, Air Conditioning, Ventilation, and Heating (ABRAVA) [29], the Brazilian air conditioning and refrigeration sector in the year 2021, presented a percentage growth of 9.8% by the year 2020, while the amount of Split type air conditioners that were produced in 2021, exceeded 3.5 million units. This significant increase in sales in the HVAC sector results in an increase in energy consumption. Therefore, programs aimed at energy efficiency were created to obtain better results regarding air conditioning systems, increase in renewal air, and electricity consumption.

2.1. World

The first climate zoning initiatives for building energy efficiency programs were mainly performed in countries (Sweden and Norway) dominated by heating with extreme weather conditions [30]. Nowadays, several countries, such as Australia [31], China [32], Germany [33], India [34], Japan [35], Saudi Arabia [36], the United Kingdom [37], and United States [38], are subject to climate zoning for energy efficiency analysis in buildings. In Brazil, the first definition of climatic zones was made by Roriz et al. [39]. These climate zones are used for various purposes, supporting thermal regulations with prescription-based and performance-based requirements, standardized data for building energy calculation, energy standards, voluntary labeling programs, and design guidelines [40].

The number of zones needed to characterize a country is essential for the success of building energy efficiency programs [41]. Too many zones lead to complicated energy efficiency programs for

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buildings, making their use and adoption difficult. A low number leads to extensive zones with significant climatic variations, making them unsuitable for any building energy efficiency program [42].

The United States of America (US) has a national building code applicable to its total territory but also has state-level building regulations that address smaller fractions of its territory [43]. According to the International Energy Conservation Code [44] and Standard 90.1-2019 of ASHRAE [38], the US is divided into 17 zones. The low-resolution national climate zoning of the US is contrasted with the climate zoning of the State of California, where significant energy efficiency efforts have recently been implemented. The State of California has a higher [38].

On the other hand, Tunisia has two climate classifications, one for thermal regulation purposes and another for passive construction design guidelines, based on performance metrics such as energy consumption in HVAC and thermal comfort in buildings without HVAC. However, climate zoning developed for thermal regulation purposes has minor sensitivity to some climatic variables, such as wind speed and direction [45]. Climate zoning is usually adopted to guide requirements for civil construction, having a high economic impact. However, in some countries, such as Brazil, climate zoning took more time to become part of building requirements due to the slow transition from voluntary to mandatory requirements [46]. Another factor that complicates the implementation of climate zoning is an arbitrary number of zones, especially in the case of neighboring areas with similar climates but located on opposite sides of the boundaries between adjacent zones. For example, on the border between Argentina, Brazil, and Uruguay, recommended values for coverage based on climate zoning range from 0.5 to 2 W/m2K depending on which side of the border the building is located, despite negligible climatic variations in this region [40].

The European Union has developed two strategies to combat CO_2 emissions and promote building energy efficiency. Initially, energy performance certification was created in the 1990 decade as an essential method for reducing energy use and CO_2 emissions. Subsequently, countries adopted an Energy Policy Strategy called Horizon 20-20 ("H2020") to reduce greenhouse gas emissions. European Union countries have been implementing various methods, laws, and projects to achieve the targets prescribed by H2020; however, the main focus has been on building efficient new buildings and renovating older ones [47]. In China, mandatory minimum standards for home appliances have been adopted, and an increase in regulation and enforcement of these standards is noticeable. This country promotes a voluntary energy efficiency labeling program for devices and uses EU-adopted labeling conventions. Corporate income tax incentives encourage energy-efficient technologies and measures [48].

2.2. Brazil

Due to the importance of air conditioning and the associated energy consumption, programs were created to optimize the electricity consumption of buildings, especially HVAC systems. Thus, programs have emerged aimed at studying technologies that aim to improve the energy efficiency of an air treatment system. According to Xu et al. [49], in 2001, Brazil suffered the biggest energy crisis that had ever been seen, a fact that led the population and institutions to mobilize and seek alternatives to save electricity. Therefore, different energy efficiency programs were implemented in Brazil.

2.2.1. National electric energy conservation program

With the increasing concern about energy consumption, a discussion in Brazil on the energy issue started in 1984 by The National Institute of Metrology, Standardization, and Industrial Quality (INMETRO). This institution contributed to creating the Brazilian Labeling Program (PBE in Portuguese), which works through informative labels to inform the consumer about the energy efficiency of the item in question [50]. The PBE gained strength by adding two partners: the National Energy Conservation Program (PROCEL in Portuguese) and the National Program for the Rationalization of the Use of Petroleum and Natural Gas Derivatives (CONPET in Portuguese) [51].

In 1993, the PROCEL Seal was created to inform consumers about more efficient equipment (mainly air conditioners, freezers, and refrigerators). Thus, it serves to identify the level of energy efficiency of appliances, based on tests in laboratories certified by INMETRO and classified according to their level of energy consumption. Those that are classified as A are the ones that have better energy efficiency, that is, they consume less energy [52].

Considering that buildings consume approximately 50% of Brazil's energy, the Federal Government in 2003 created the PROCEL EDIFICA seal. This strategy seeks to evaluate parameters in commercial, residential, and public service buildings to prepare buildings with the lowest possible energy expenditure by considering the facade, lighting, and air conditioning system [53]. In buildings that are structured from their conception to have the PBE EDIFICA seal, they present an energy reduction of up to 50% compared to buildings that have not adopted the PBE EDIFICA methodology. In buildings that have undergone significant retrofits, the percentage of energy reduction goes up to 30% [54].

Figures 2 and 3 present the results of annual investments and historical results obtained by PROCEL from 2008 to 2020, where there was an exponential increase in energy savings, while investments after 2011 decreased.

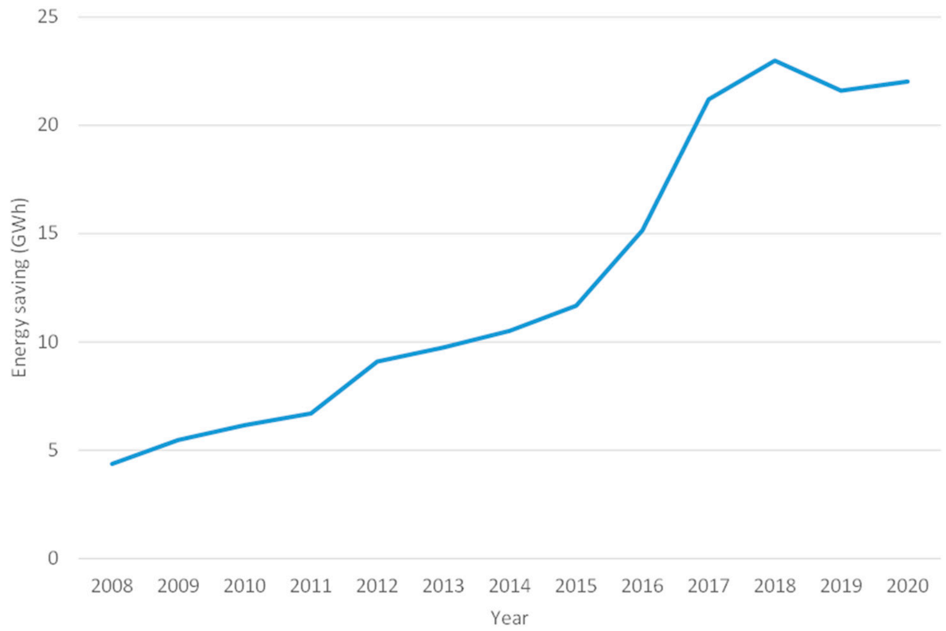

Figure 2. Energy savings generated by PROCEL 2008 to 2020. Source: adapted from [55].

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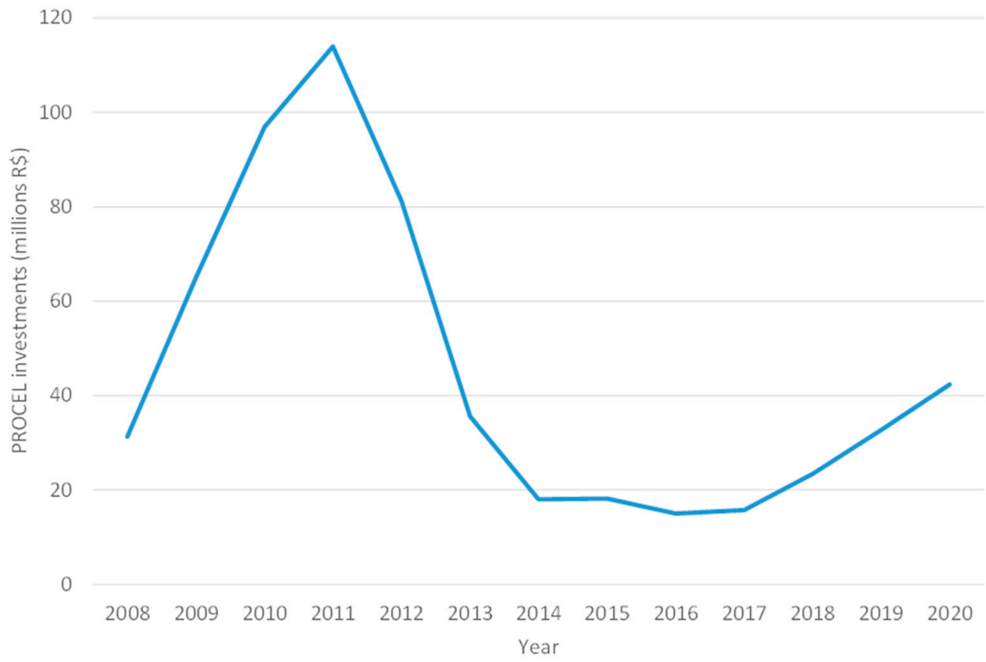

Figure 3. The investment made in PROCEL. Source: adapted from [55].

2.2.2. Other programs

In addition to PROCEL, other programs and mechanisms were created with the support of the Ministry of Mines and Energy, as well as laws and decrees in order to promote energy efficiency and energy conservation at the national level. Among all, the main programs adopted are briefly presented:

- National Program for the Rationalization of the Use of Petroleum and Natural Gas Derivatives (CONPET): CONPET is a Ministry of Mines and Energy program that Petrobras subsidizes through technical, administrative, and financial resources. It is a program instituted by decree in 1991 and is responsible for designing, operationalizing strategies, promoting institutional articulation, and disseminating the Program's actions. Initially, it aimed to encourage the efficient use of non-renewable sources in the economy;
- Law No. 9,478, of August 6, 1997: establishes the principles and objectives of the National Energy Policy, which aims to protect the environment and promote energy conservation. In addition, this Law also created the National Energy Policy Council (CNPE). The purpose of CNPE creation is to generate the rational use of the country's energy resources. It will support regulatory agencies such as the National Electric Energy Agency (ANEEL) and the National Agency of Petroleum, Natural Gas, and Biofuels (ANP);
- Law No. 9,991, of July 24, 2000: establishes percentages of net operating revenue (NOR) of electric energy distributors to encourage the development of energy efficiency projects aimed at use at the final point of consumption. In addition, seek the transformation of the electric energy market through equipment and new technologies;
- Law No. 10,295, of October 17, 2001 (regulated by Decree No. 4,059, of December 19, 2001): Law No. 10,295, also known as the Energy Efficiency Law, establishes the procedures to determine the electrical consumption of machines and energy-consuming appliances, whether they are manufactured or only marketed in the country, and target programs for each type of equipment. The main objective is to promote structural transformations in the market of energy-consuming equipment;
- Decree N° 4,059 also defines the procedures and responsibilities to establish the indicators and levels of energy efficiency. For this purpose, it instituted the Management Committee of Indicators and Energy Efficiency Levels (CGIEE), composed of the main institutions in the

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energy sector, such as the Ministry of Mines and Energy; Ministry of Development, Industry, and Foreign Trade; Ministry of Science and Technology and Innovation; ANEEL; ANP, among others;

- Law No. 13,280, of May 3, 2016: reserve 20% of the resources of electric energy companies destined for energy efficiency for application in PROCEL. This law also creates the Energy Efficiency Management Committee, transferring to ANEEL the power to define the collection schedule, fines, penalties, and payment method for the resources invested in PROCEL;
- Sectoral Funds: they were created to provide financial resources to research, development, and innovation projects in Brazil and to contribute to the national advance in technology, science, and innovation in their areas of activity, such as energy, water, mineral, oil, and natural gas. Sectoral funds use resources from the National Fund for Scientific and Technological Development (FNDCT), created in 1969;
- PROESCO: intended to finance energy efficiency projects and was approved in 2006 by the National Bank for Economic and Social Development. The program also supports the implementation of projects that present evidence that will contribute to energy savings, with the main focus on lighting, compressed air, air conditioning and ventilation, refrigeration and cooling, and other sectors.

3. Desiccant dehumidifiers

According to Kavanaugh [56], several improvements have already been implemented over the years in terms of the energy efficiency of air conditioning equipment. However, other technologies can reduce energy consumption, including desiccant wheels, enthalpy wheels, and crossflow heat exchangers used to treat external air in buildings.

3.1. Background

In 1951, Carl Munters filed a patent for a desiccant-based drying system. He realized the potential for attracting water molecules and materials such as silica gel. It was from this concept that the process and development of drying technology using desiccant wheels began [57].

Desiccant wheels (Figure 4) are based on a wheel with desiccant crystals impregnated and grown on a fiberglass substrate. The lightweight wheel has a high surface area to airflow ratio [58]. The desiccant wheel is known as a passive desiccant wheel or enthalpy wheel when there is no regeneration air heater, while it is called an active desiccant wheel when it is provided with an air heater, and the regeneration and process air side are slatted apart. The wheel is installed with thermal insulation and air-proof material so that there is no exchange of mass and energy with the surroundings [59].

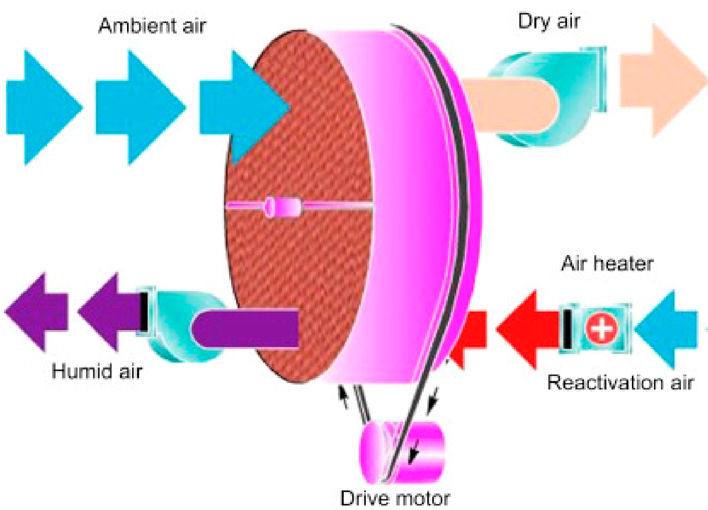

Figure 4. Desiccant wheel [59].

In operation, the wheel rotates continuously and the desiccant cycles through adsorption, regeneration, and cooling every 4–5 minutes. Drying air is constantly regenerated in a closed circuit. The hot regeneration air passes through the desiccant medium, and the released moisture is released into the atmosphere [60]. No ambient air is introduced into the process, as desiccant cooling is done using dry air. The desired dew point is achieved by changing the spin speed and other dryer variables without excessively drying thermally sensitive materials [61]. Desiccant wheels are used in various heating and residential environments to prevent the growth of mold and mildew. Desiccants remove moisture (latent energy) in hot and humid climates, as conventional air conditioning systems are limited [62].

3.2. Types of desiccant dehumidification systems

Generally speaking, there are five types of desiccant dehumidification systems; however, the most widespread technology is the vertical desiccant rotor. Each of these technologies is described below.

3.2.1. Spray drying tower

The spray drying tower (Figure 5) has two tanks corresponding to the condenser and the regenerator. In this system, the humid air enters the segment of the condenser, passing through a saline fog that will capture the humidity of the air, where the dry air is inflated for the process. At the bottom of the condenser tank, the saline solution is pumped to the second tank (regenerator), through which the second flow of high temperature external air passes, causing the saline solution to lose moisture to the regeneration air. Thus, the hygroscopic material returns to the condenser tank [63].

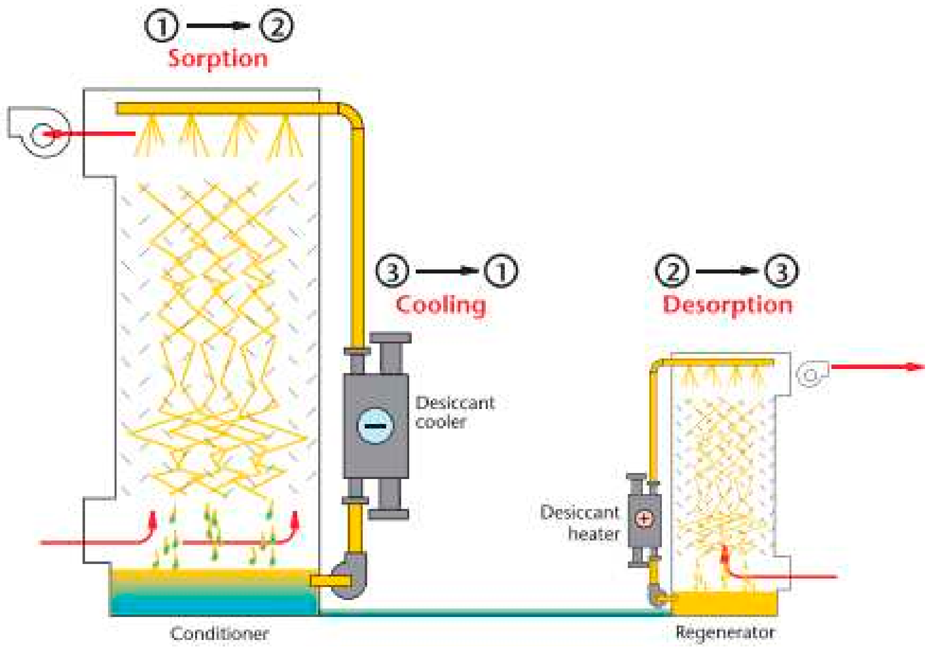

Figure 5. Spray drying tower scheme. Source: [64].

3.2.2. Dual tower desiccant dryers

The Dual tower desiccant dryers have two vessels (one for process and another for regeneration), as shown in Figure 6; each vessel has solid silica gel inside. Moist air passes through the first pressurized cylinder, trapping moisture in the silica gel until it saturates the hygroscopic material. After the saturation of the first cylinder, the direction of the process air to the second cylinder is reversed, the first being regenerated with external and heated air [65].

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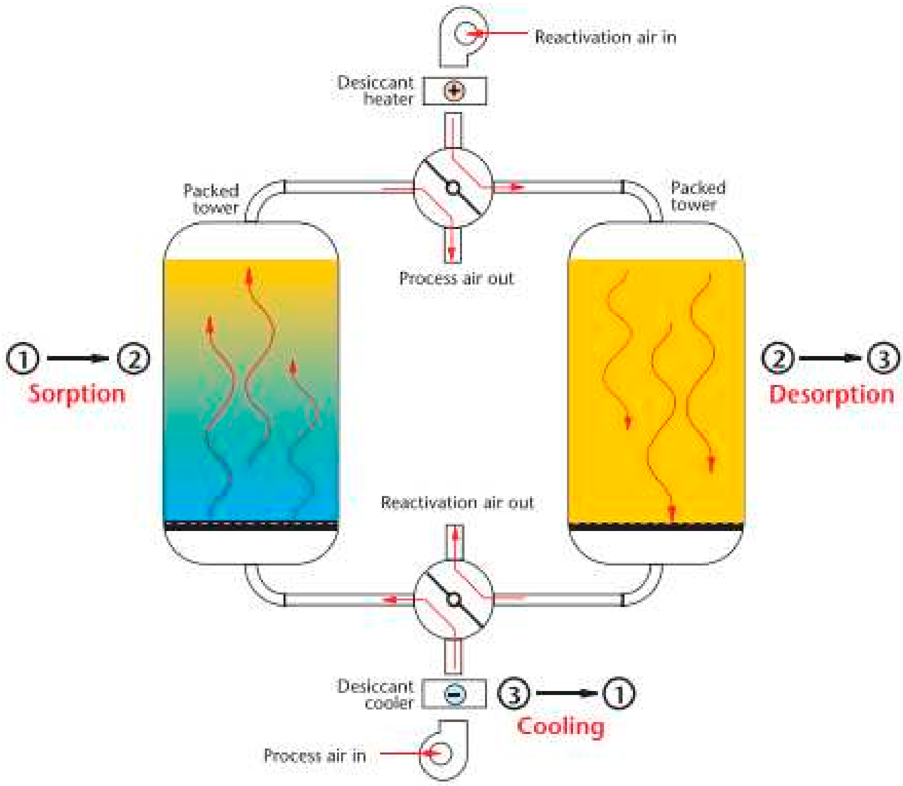

Figure 6. Dual tower desiccant dryer scheme. Source: [64].

3.2.3. Tray dryer

The spray dryer has two air flows (process and regeneration), as presented in Figure 7. The hygroscopic material responsible for capturing the humidity from the air is arranged in trays, the humid air will pass through the process air sector, and the external air of the regeneration will pass through 1/ 4 of the trays. The trays will rotate, so the silica gel passes from the process to the regeneration sector [66].

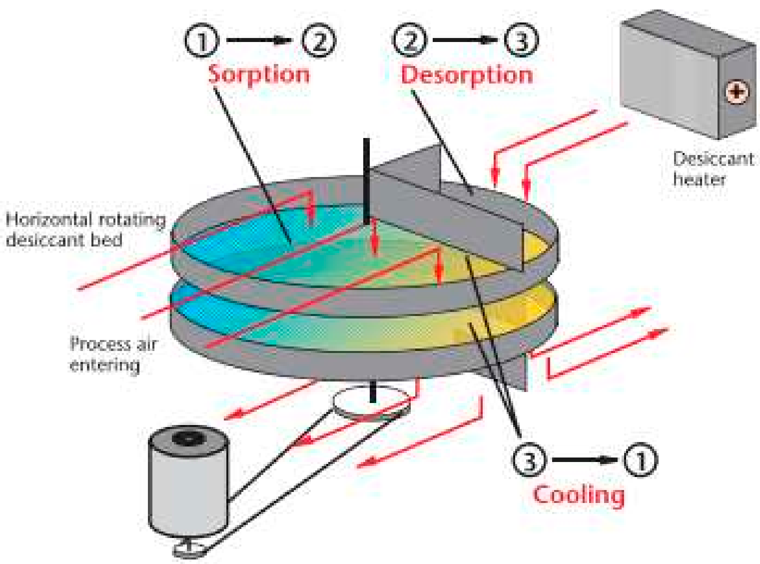

Figure 7. Tray dryer scheme. Source: [64].

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3.2.4. Multi-belt dryer

The multi-belt dryer has two streams of trays arranged vertically (Figure 8), where the granular hygroscopic material is installed, and the humid process air passes through the trays. After the silica gel saturation, the tray rotates to the regeneration sector, where the moisture impregnated on the silica gel is eliminated [67].

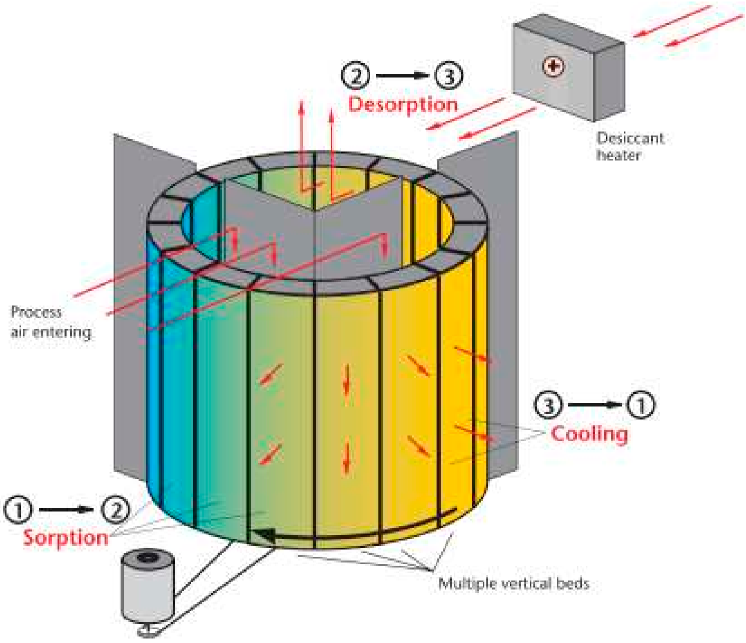

Figure 8. Multi-belt dryer scheme. Source: [64].

3.2.5. Desiccant dehumidifier

Figure 9 shows the working principle of the desiccant dehumidifier, which has two air flows, the first occupying ¾ of the wheel and is responsible for adsorbing all excess moisture from the air. After the air passes through the rotor, it is inflated with low moisture content [68].

The second airflow, called regeneration air, occupies ¼ of the rotor and is responsible for extracting moisture in a vapor state from the desiccant rotor using a flow of heated air. The rotor structure is made in the shape of a beehive to have the largest possible area of hygroscopic material in contact with the air [69]. The hygroscopic material may be silica gel or a mixture of silica gel and zeolites [70].

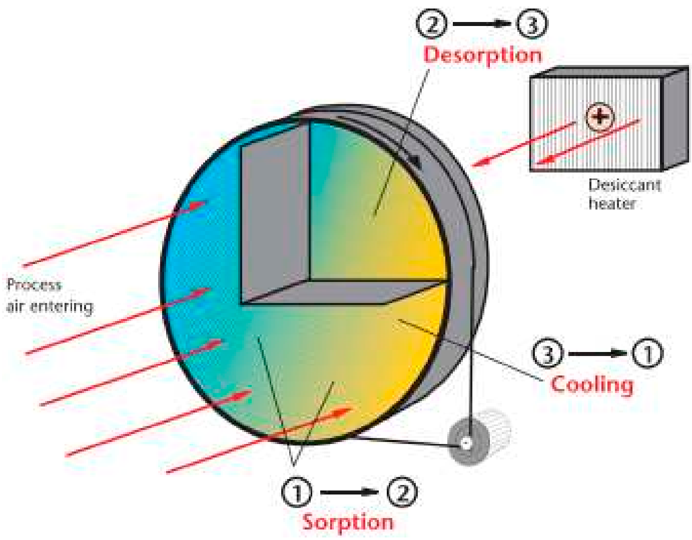

Figure 9. Desiccant dehumidifier scheme. Source: [64]

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3.3. Desiccant dehumidification by heat recovery wheel

The heat recovery wheels have different operating characteristics from the desiccant wheels; their main objective is to promote the transfer of heat and humidity between the two existing air flows in the equipment [71]. These types of equipment also can minimize cross-contamination that can occur due to exhaust and supply airflows and provide high efficiency systems with a low pressure drop in the airflows [72]. Thus, some technologies were developed, such as cross-flow heat exchangers and enthalpy wheels [73].

3.3.1. Enthalpy wheels

The rotary heat exchanger (Figure 10), commonly known as enthalpy wheels, is an "air-air" type heat exchanger that works on the principle of sensible heat (temperature) and latent heat (humidity) exchange between the flow of renewal air and the flow of exhaust air [74]. Enthalpy wheels can be classified as sensible heat wheels and enthalpy wheels. The denomination for these two models is due to their application, where the sensible heat wheels act with the function of only exchanging the sensible heat, while the enthalpy wheel works completely between the energies of the air, being the sensible heat and the latent heat. These two processes occur between the two air masses that travel through the equipment [75].

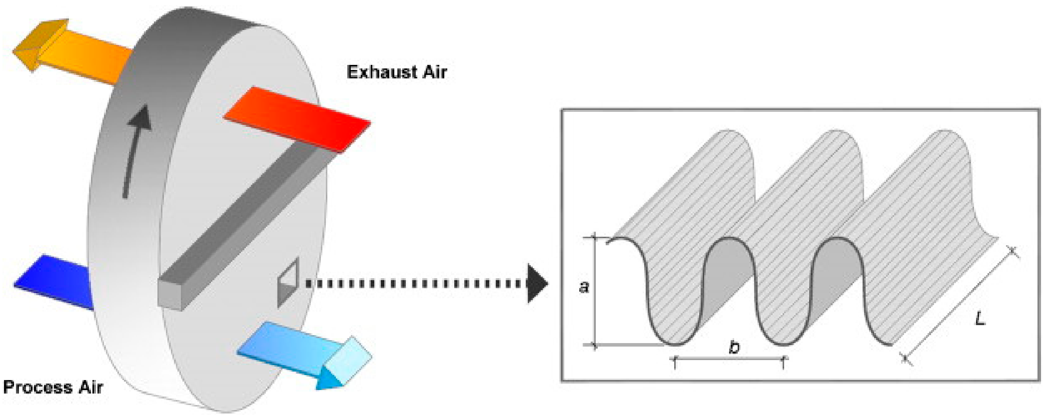

Figure 10. Enthalpy wheel [74].

The enthalpy wheel is an essential piece of equipment for building air treatment systems and has some advantages and disadvantages. As an advantage, it can be mentioned that it is a technology that reaches efficiencies of around 50% to 80% [76]. It's operation and high operating flows provide energy savings since the cooling system that works after the enthalpy wheel can have a lower cooling load than the conventional one (without using the enthalpy wheel) [77]. For any design to meet the Green Building certifications, some minimum assumptions must be met, and one of them is the rate of air renewal of the central systems. Thus, it is possible to reduce the size of the cooling or heating coils of the air treatment units [78]. Its main disadvantage is the initial investment in the system, however, this value has a low payback period [79].

3.3.2. Cross-flow heat exchangers

The cross-flow heat exchanger is an “air-to-air” static heat exchanger. Like the enthalpy wheel, the cross-flow heat exchanger can be classified into two models [80] The sensible cross-flow heat exchanger performs the function of only sensible heat exchange between the two air masses, and the conventional cross-flow heat exchanger (Figure 11), which is to exchange sensible heat and latent heat during the thermal exchange process of the equipment [81].

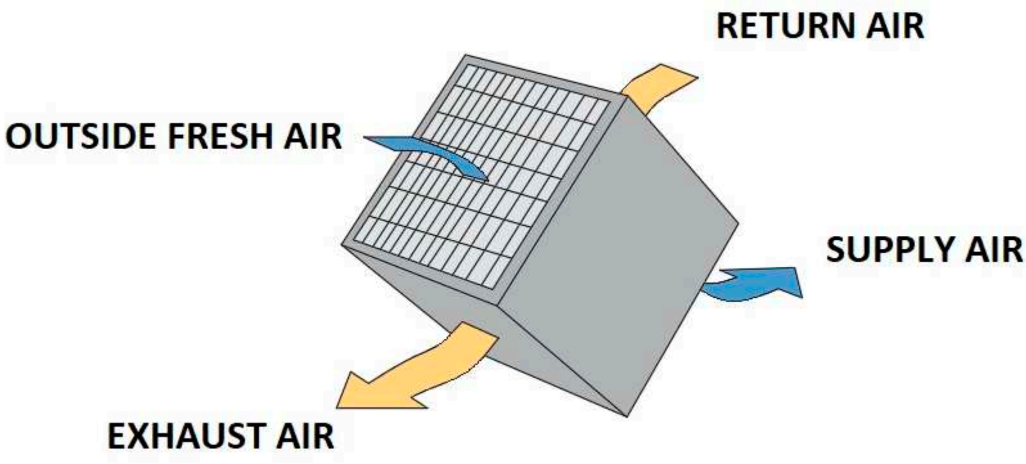

Figure 11. Cross-flow heat exchangers.

Cross-flow heat exchangers are generally used for gas-to-liquid heat transfer applications where the gas is on the outside, and the liquid is on the tube side of the heat exchanger. Most of these exchangers have fins that increase the surface area and consequently improve heat transfer. In most sensible heat transfer applications, the external fluid is treated as unmixed flow, while the tube-side fluid is treated as mixed flow [82]. Nasif [83] found that cross-flow heat exchangers significantly reduce energy consumption. It reduces the latent load in hot and humid environments and provides 100% external air to the environment in question.

4. Software for selecting desiccant wheels

Selecting a proper desiccant requires that the involved dehumidification process be simulated. This can be quite time-consuming depending on the level of detail required for a specific simulation, as well as required a considerable number of operating and construction data related to the wheel, as shown in previous works [84–87]. As a result, commercial software became available for facilitating the selection process. This section presents some software for selecting desiccant wheels, while some characteristics are analyzed.

4.1. Novel Aire

Novel Aire Technologies, based in the United States, is a company that has been operating in the dehumidification market for approximately 20 years with energy conservation products and desiccant wheels and has more than 500 customers in 25 countries around the world. The characteristics of Novel Aire software are presented in Table 3.

Table 3. Noval Aire software.

Airflow	**340 m³/h up to 59,500 m³/h**
Diameter rotors	250 mm up to 3.050 mm
Main input data	Process airflow

4.2. Munters

Munters was founded by Carl Munters in 1955 and is based in Sweden, belongs to the dehumidification and air conditioning market serving thousands of customers, having about 3500 employees, 17 factories around the world, and an installed base of 320 thousand air treatment systems. The characteristics of Munters software are presented in Table 4.

Table 4. Munters software.

Airflow	120 m³/h up to 170,000 m³/h
Diameter rotors	N/A
Main input data	Process airflow
	Regeneration airflow

4.3. Rotor Source

Rotor Source was founded in 1999 and is headquartered in the United States. It is currently in the dehumidification market, focusing on selling desiccant wheels to manufacturers of dehumidification equipment. The characteristics of rotor source software are presented in Table 5.

Table 5. Rotor source software.

Airflow	200 m³/h up to 150,000 m³/h
Diameter rotors	220 mm up to 3,300 mm
Main input data	Process airflow
	Regeneration airflow

4.4. Puresci

Puresci is a China-based company with over ten years of experience in the desiccant rotor field. It has projects with more than 1000 clients around the world. The characteristics of the rotor source Puresci are presented in Table 6.

Table 6. Puresci software.

Airflow	N/A
Diameter rotors	350 mm up to 3,050 mm
Main input data	Process airflow
	Regeneration airflow

4.5. Comparison between software

Several companies that develop heat recovery technologies by desiccant wheels are recognized by international organizations such as Eurovent, AHR Exhibition; and by Brazilian organizations such as ABRAVA and Southern Brazilian Association of Refrigeration, Air Conditioning, Heating and Ventilation (ASBRAV), were studied.

The research on commercial software for the technologies studied (Table 7) does not present a careful analysis of the operating results over a year; in most cases, the software only shows the efficiency and output data. In addition, it is necessary that in all software, the user use external knowledge in thermal engineering to be able to analyze a project.

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Table 7. This is a table. Tables should be placed in the main text near to the first time they are cited.

	Noval Aire	Munters	Rotor source	Puresci
Input data				
Process inlet dry bulb temperature	X	X	X	X
Absolute humidity entering the process	X	X	X	X
Regeneration inlet dry bulb temperature	X	X	X	X
Absolute inlet humidity in regeneration	X	X	X	X
Dry bulb temperature after heating in regeneration.	X	X	X	X
Output data				
Output dry bulb temperature in the process	X	X	X	X
Output absolute humidity in the process	X	X	X	X
Dry bulb temperature after regeneration output	X	X	X	X
Output absolute humidity at regeneration output	X	X	X	X
Moisture removal charge	X	X		

Therefore, it is suggested that software would need to incorporate an updated database, such as the ASHRAE weather data viewer, into their source code to cover as many locations as possible with updated data. It is also necessary for the software to be able to perform a dynamic analysis of the total hours of the year and not just a one-off analysis.

5. Conclusions

This work presented options for reducing electrical energy consumption in air conditioning and refrigeration systems using desiccant dehumidification technologies. Initially, the importance of air renewal in buildings was analyzed, and it was observed that the circulation lack of renewed air could contribute to the environment being a favorable place for spreading respiratory diseases, which is a risk factor for a worker of any organization. Thus, a building with a high level of pollutants falls under the sick building syndrome.

Subsequently, it was observed that the consumption of conventional air conditioning systems in countries such as the United States and Brazil may require up to 10% of the electricity demand of these countries. Therefore, programs aimed at energy efficiency were created or strengthened to obtain better results when referring to air conditioning systems, increase in renewal air, and electric energy consumption. For example, European Union countries adopted an energy policy is known as Horizon 20-20 to reduce greenhouse gas emissions, being implemented various laws and projects to achieve the Horizon 20-20 objectives.

In Brazil, since 1984, the Brazilian Labeling Program has been implemented, which indicates an item's energy efficiency through informative labels. This program gained strength by adding two policies: the National Energy Conservation Program and the National Program Rationalization of the Use of Petroleum Derivatives and Natural Gas. Other guidelines, such as Law No. 9,478 of 1997, Law No. 9,991 of 2000, and Law No. 10,295 of 2001, were implemented to promote efficiency and energy conservation in Brazil. All these programs were created to meet the current and future markets that will demand high energy consumption, however, it is necessary to explore new technologies, such as desiccant dehumidification, which showed promising results in terms of energy efficiency.

It is worth noting that a desiccant dehumidification system has a coating applied for airflow dehumidifying. As the wheel turns, the desiccant alternately passes through the incoming air, where humidity is adsorbed, and through a regeneration zone, where the desiccant is dried, and humidity is expelled. The wheel continues to rotate, and the adsorption process is repeated. Several variables can affect desiccant performance, such as inlet dry bulb temperature, absolute inlet humidity, speed on the desiccant face, among others, so the selection of desiccant wheels is fundamental depending on the project to be developed. Thus, several desiccant wheel selection software were investigated to list and present the main characteristics of each one. It was observed that the multiple software studied do not present a detailed analysis of the annual operation and usually only show the output data. Therefore, the selection software could be improved by incorporating a database update, considering ASHRAE weather data viewer to cover more locations, especially in Brazil.

For future studies, it is suggested to develop software focused on measuring energy and economic benefits when using the technology of desiccant/enthalpic wheels in the recovery of energy from the renewal air and that contemplates improvements concerning the software researched in this work.

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