v. 4, n. 8, 2024

Journal of
Engineering
Research

APPROACH TO DESICCANT WHEELS IN BRAZIL AND TECHNOLOGY PAY BACK

Alexandre Fernandes Santos
Faculdade Profissional – FAPRO,
Curitiba - Paraná - Brazil.
https://orcid.org/0000-0001-5306-6968

Heraldo José Lopes de Souza
Faculdade Profissional – FAPRO,
Curitiba- Paraná - Brazil.
https://orcid.org/0000-0002-8471-7804

Darlo Torno
Esp. Fapro – Professional College.
Curitiba, Parana

Daiane Busanello
Esp. Fapro – Professional College.
Curitiba, Parana

Natalia Tinti
Esp. Fapro – Professional College.
Curitiba, Parana
https://orcid.org/0000-0002-8471-7804

Márcia Cristina de Oliveira
Esp. Fapro – Professional College.
Curitiba - Paraná

Sandro Adriano Zandona
Esp. Fapro – Professional College.
Curitiba, Parana
https://orcid.org/0000-0002-8471-7804

Eliandro Barbosa de Aguiar
MSc. Fapro – Professional College.
Curitiba, Parana

Sariah Torno Fapro
Esp. Fapro – Professional College.
Curitiba, Parana

Abstract: Desiccant/enthalpy wheels are technologies that adhere to everything that connects with thermal energy efficiency. This article addressed the importance of enthalpic/desiccant wheels and generated a payback simulation in some Brazilian cities.
Keywords: Dessicant wheel, enthalpy wheel, thermal load, heat recovery.

INTRODUCTION

The improvement of the energy performance of buildings has become a cornerstone of energy policies, aiming to pursue the so-called sustainability tripod, formed by the physical environment, economic processes, and social organizations. (SILVA apud CSILLAG, 2007). The main purpose is the rational use of energy consumption, and this objective is pursued through techniques to increase the energy efficiency of the air conditioning system, as it is one of the fastest-growing infrastructures worldwide and has high electricity consumption. (Teixeira, 2021).

According to the Brazilian Association of Refrigeration, Air Conditioning, Ventilation, and Heating ABRAVA (2022), the Brazilian air conditioning and refrigeration sector represented a turnover of approximately R$37.98 billion in 2021, with a growth rate of 9.8% compared to 2020, while the growth expectation for 2022 is 5.5%. The quantity of Split-type air conditioners produced in 2021 exceeded 3.5 million units.

This significant increase in sales in the HVAC sector will result in an increase in energy consumption. According to the International Energy Agency, by 2050, the projection is that 10 air conditioning units will be sold every second worldwide, and air conditioning systems will consume the equivalent of all the energy used by Japan, the United States, and the European Union combined in 2018. This value could be halved if energy efficiency measures are taken. The number of air conditioning units is expected to skyrocket from 1.6 billion to 5.6 billion by 2050. (ASHRAE. 2020).

According to the Department of Energy, the cost of energy used in commercial buildings in the United States increased by over 200% between 1979 and 1995. The department also predicts an additional increase of 46% between 2001 and 2025. HVAC systems consumption, on average, 39% of the energy used in commercial buildings. Energy-efficient HVAC systems represent significant savings in building operational costs. The increase in ventilation rates, necessary to meet the ventilation standard set by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.1-2019, results in higher energy expenditure for conditioning outdoor air. (ASHRAE. 2020).

Energy regulations are a means that some countries have found to encourage the construction of new buildings with better energy efficiency. There are policies adopted in each country, each with a different name for the policy or certification, but with the same objective: to establish a set of requirements to make buildings more energy-efficient, without compromising the comfort or productivity of occupants. (PÉREZ-LOMBARD, J., & C., 2007).

When improving energy efficiency in an air conditioning system is mentioned, energy recovery is often mentioned. This occurs because it exchanges air in the environment at the same time as it transfers energy, reducing the difference in external temperature when the air enters the environment. All devices operate on the same principle, using exhaust air to condition supply air through energy transfer (ASHRAE. 2020).

To size the thermal load of a space, the heat dissipation of people, equipment and the amount of external air that must be removed and inserted into the environment are taken into account. According to ASHRAE, at least 20% of the thermal load comes from the renewal of air in the environment (Handbook, 2012). To reduce the thermal load and, consequently, the electrical consumption of the air conditioning system, equipment is used that recovers heat for air renewal (O. & Fisk, 2002).

In Brazil, enthalpic wheel technology is already used in several buildings. The main interest of customers when requesting this technology is to promote sustainability and obtain certifications, which is becoming an incentive for the market. However, there is still a long way to go in terms of public policies and financial exemptions for those who wish to purchase an enthalpic wheel for their ventures. This is because purchase values tend to increase when it comes to air renewal items, but decrease when they relate to air conditioning equipment and energy consumption.

STATE OF ART

The concept of solid desiccant dehumidifiers used in air conditioning applications is not new. The first works in this field were conducted by (CLARK; MILLS; BUCHBERG, 1981), (LAVAN et al., 1980), (GUNDERSON; HWANG; RAILING, 1978) (B, (PESARAN; MILLS, 1987a, 1987b), and (BISWAS ; KIM; MILLS, 1984; KIM; BISWAS; MILLS, 1985) which were developed between the 1970s and 1980s.

Carl Munters filed a patent for a desiccant wheel-based drying system. He realized the potential of the attraction capacity of 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 (MUNTERS, 2020).

Desiccant wheels are used in various heating applications, such as in residential environments to prevent the growth of mold and mildew. In hot and humid climates, desiccants are responsible for removing moisture load (latent heat), as conventional air conditioning systems have limitations when used for this purpose. (ASHRAE, 2019).

The most widespread technology is the vertical desiccant rotor, where in Figure 1 shows the operating principle of this equipment, which has two air flows, the first of which occupies ¾ of the wheel and is responsible for adsorbing all excess moisture from the air and, after the air passes through the rotor, the air is already supplied with low moisture content. The second air flow, called regeneration air, occupies ¼ of the rotor and is responsible for extracting moisture in vapor form from the desiccant rotor, using a heated air flow. The rotor structure is made in the shape of a bee hive, to increase the area of the hygroscopic material in contact with the air. The hygroscopic material can be silica gel or a mixture of silica gel and zeolites (MUNTERS, 2019).

There are more than 20 variables that can affect the performance of the desiccant, however, it is customary for manufacturers to adopt good practices by setting variables to obtain constant performance. The main variables that change from project to project are: inlet dry bulb temperature, inlet absolute humidity, speed at the desiccant face, with which it is possible to calculate the process and regeneration air flow. Every project to be developed must consider these variables that are influenced by climate variation. (ASHRAE, 2020).

On the other hand, the rotating desiccant wheel is the most commonly used technology in desiccant solid dehumidifiers. This technology is advantageous as it can provide air with uniform humidity at the outlet, in addition to eliminating batch mode operation (i.e., with simultaneous lateral adsorption and desorption processes), allowing continuous rotation. However, some common disadvantages associated with this technology are: (i) pressure drops, (ii) pore blockage caused by the binder polymers, which reduces the overall mass transfer performance, (iii) noise and lower compactness due to the parts rotating wheels and (iv) need for extra electricity to drive the motor that rotates the wheel. To improve the efficiency of the thermodynamic cycle, several wheels, such as desiccant and heat recovery wheels, can be used together (SHAMIM et al., 2021).

"AIR-AIR" TYPE HEAT EXCHANGERS

Air-to-air " type heat recuperators are responsible for transferring temperature and/ or humidity between two different air flows. The introduction of external air into buildings is essential to maintain good indoor air quality (IAQ), reducing the spread of diseases inside the environment. The woodburner can reduce excess moisture in the outside air, which, if left untreated, can cause the growth of bacteria, mold and allergies. (ASHRAE, 2020).

The United Nations Intergovernmental Panel on Climate Change (IPCC-UN) is seeking measures to reduce carbon dioxide emissions from energy use. ASHRAE's strategic plan is to encourage the adoption of " air-to-air " type heat exchangers in all projects that use electrical energy for air conditioning. " Air-to-air " heat exchangers are capable of supplying large quantities of external air with an advantageous cost-benefit ratio, in addition to meeting the minimum ventilation requirements established by ASHRAE Standards 62.1 and 62.2 (ASHRAE, 2020).

Table 1 _ (a) and (b) present the technical characteristics of all types of " air-to-air " heat recuperators described in ASHRAE, demonstrating flow operating ranges, system load loss, performance of each equipment, operating temperature range, technical

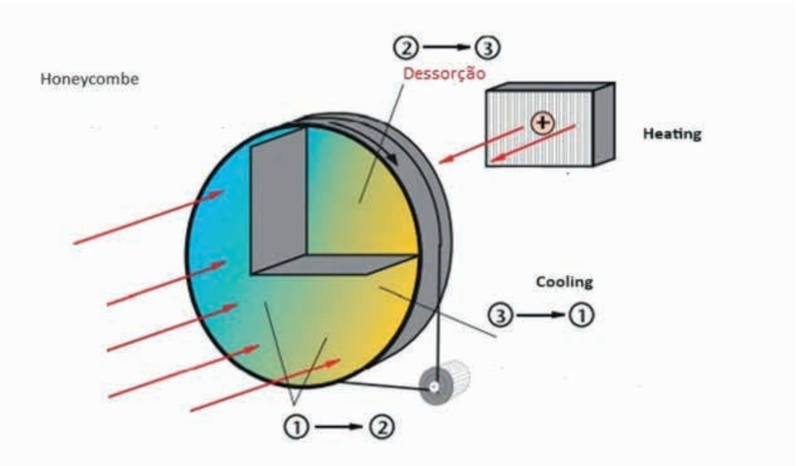


Figure 1 – Vertical Desiccant Rotor – Honeycomb Type. SOURCE: (Munters, 2019)

	FIXED PLATE a	MEMBRANE PLATE a	ENTHALPIC WHEEL	SENSITIVE WHEEL
AIRFLOW DIRECTION	Crossflow Counterflow	Crossflow Counterflow	Parallel flow Counterflow	Against flow
EQUIPMENT OPERATING RANGE (L/s)	Minimum 25	Minimum 25	25 to 35,000	25 to 35,000
TYPICAL EFFECTIVENESS SENSITIVE(Ms =Me), %c	50 to 75	55 to 75	65 to 80	65 to 80
TYPICAL LATENT EFFICACY, * %c	0	25 to 60	50 to 80	0
TOTAL EFFECTIVENESS, * %c	20 to 50	35 to 70	55 to 80	25 to 60
FACE SPEED, m/s	1 to 5	1 to 3	2.5 to 5	2 to 5
LOSS OF LOAD, Pa	100 to 1000	100 to 500	100 to 300	100 to 300
OACF%	0 to 2	0 to 5	0.5 to 10	0.5 to 10
OACF	0.97 to 1.06	0.97 to 1.06	0.99 to 1.1	1 to 1.2
TEMPERATURE RANGE, °C	-60 to 800	-40 to 60	-55 to 800	-55 to 800
TYPICAL PURCHASE MODE	-Exchanger only; -Exchanger with protective accessory;-Exchangers and fans;-Complete system;	-Exchanger only; -Exchanger with protective accessory;-Exchangers and fans;-Complete system;	-Exchanger only; -Exchanger with protective accessory;-Exchangers and fans;-Complete system;	-Exchanger only; -Exchanger with protective accessory;-Exchangers and fans;-Complete system;
	FIXED PLATE	**MEMBRANE PLATE**	**ENTHALPIC WHEEL**	**SENSITIVE WHEEL**
BENEFITS	-No moving parts; -Low pressure loss;-Easy cleaning;	-No moving parts; -Low pressure loss;-Low air leakage-Moisture/mass transfer;	-Moisture/mass transfer; -Large and compact sizes;-Low pressure loss;-Available on all ventilation system platforms;	-Large and compact sizes; -Low pressure loss;-Easy cleaning;
LIMITATIONS	-Large size for large airflows;	-Few suppliers; - Long-term maintenance and unknown performance;	- Supply air may require additional heating or cooling; -Some OACF do not have purge;	-Some OACF do not have purge;

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.317482406037

HEAT RATE CONTROL METHODS (CTR)	- Bypass and duct dampers	- Bypass and duct dampers	- Bypass and wheel dampers with speed control;	- Bypass and wheel dampers with speed control;

Table 1 (a) - Types and characteristics of " air-to-air " heat exchangers. Source: (ASHRAE,2020).

	HEATING TUBE	ROTATING SPIRAL	THERMOSYPHON	DESSICANT LIQUID	FIXED BED REGENERATOR
AIRFLOW DIRECTION	Parallel flow Counterflow	-	Counterflow allele flow	-	Against flow
EQUIPMENT SIZE RANGE (L/s)	Minimum 50	Minimum 50	Minimum 50	-	Minimum 25
TYPICAL EFFECTIVENESS SENSITIVE(Ms =Me), %c	40 to 60b	45 to 65b	40 to 60b	40 to 60	80 to 90c
TYPICAL LATENT EFFICACY, * %c	0	0	0	50 to 75 b,d	60 to 80 with desiccant coating
TOTAL EFFECTIVENESS, * %c	15 to 35	-	-	40 to 75d	50 to 80c
NOMINAL SPEED, m/s	2 to 4	1.5 to 3	2 to 4	1.5 to 2.2	1 to 2.5
LOSS OF LOAD, Pa	150 to 500	150 to 500	150 to 500	170 to 300	50 to 300
OACF, %	0 to 1	0	0	0	3 to 5c
OACF	0.99 to 1.01	1.0	1.0	1.0	0.90 to 1c
TEMPERATURE RANGE, °C	-40 to 93	-45 to 500	-40 to 40	-40 to 46	-55 to 60
	HEATING TUBE	ROTATING SPIRAL	THERMOSYPHON	DESSICANT LIQUID	FIXED BED REGENERATOR
TYPICAL PURCHASE MODE	-Exchanger only; -Exchanger with protective accessory;-Exchangers and fans;-Complete system;	-Serpentine type heat exchanger; -Complete system;	-Exchanger only; -Exchanger with protective accessory;	-Complete system;	-Exchanger and damper ; -Complete system;
BENEFITS	-No moving parts, except inclined parts; -Location of the engine is not critical;-Allowable pressure differential up to 15kPa;	-Exhaust airflow can be separated from supply airflow; -Engine location is not critical;	-No moving parts; -exhaust airflow can be separated from the supply airflow;-Engine location is not critical;	-Remote airflow latent transfer; -Efficient microbiological cleaning of exhaust and supply air streams;	-Some moving parts; -No defrosting strategy required;-Easy maintenance-Easy cleaning-Moisture/ mass transfer, if desiccant is coated;
LIMITATIONS	-Effectiveness limited by load loss and cost; -Few suppliers;	-Previous performance may require a more accurate simulation model;	-Effectiveness limited by load loss and cost; -Few suppliers;	-Few suppliers; -Maintenance and unknown performances;	-Indoor units may require airflow/ damper selector to control OACF; -Has some OACF;

HEAT RATE CONTROL METHODS (CTR)	-Incline angle below 10% at maximum heat rate;	-By-pass valve or pump speed control;	-Control valve above full range;	-Valve control or pump speed control above full range;	- Bypass and duct damper ; -Recovery period;

air-to-air ” heat recuperators. Source: (ASHRAE,2020).

	SYSTEM 1	SYSTEM 2
Equipment	Insufflation fan	Insufflation fan
	Cooling Coil	Cooling Coil
	Resistances	Resistances
	Exhaust Fan	Exhaust Fan
	-	Heat recover
	Chiller	Chiller

Table 2 – Equipment used in each system to be analyzed. Source: (The Authors)

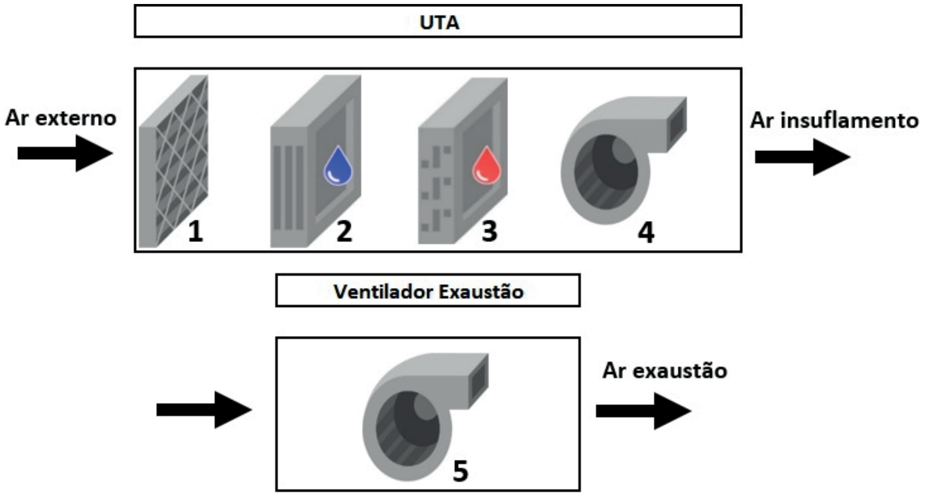


Figure 2 - Composition of system 1

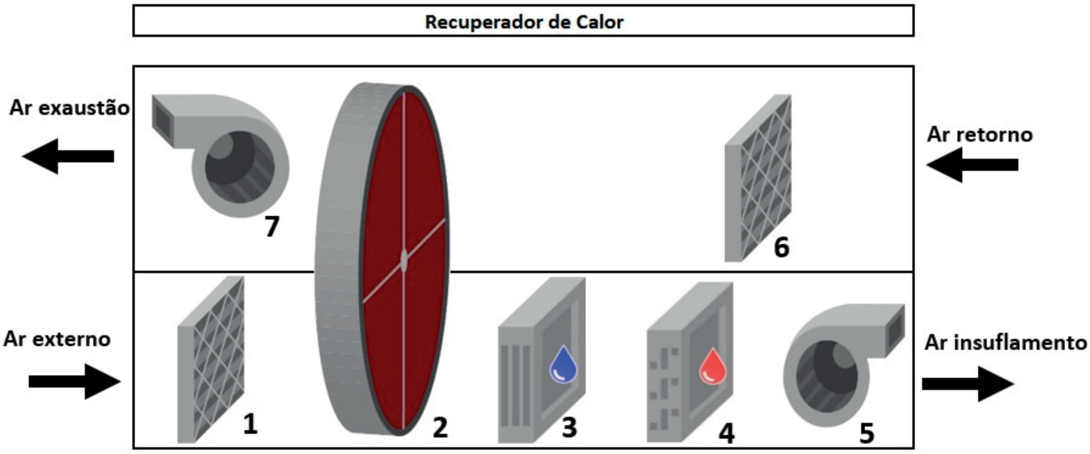


Figure 3 - Composition of system 2

advantages and disadvantages, in addition to other relevant points.

With all the existing technologies presented in Table 1 (a) and (b), knowledge will then be deepened on one of the types of “ air-to-air ” heat recovery devices, type Enthalpic Wheel.

MATERIALS AND METHODS

In Brazil, the heat recovery concept is still not widespread and, to understand the limitations in relation to the application of this technology, a case study will be carried out in a Call Center. In this case, external air charge will always be necessary and operation will occur during all hours of the year. For this study, two external air treatment systems will be adopted, composed as indicated in Table 2.

In both systems, Figure 2 and Figure 3 will illustrate the components and air flows of system 1 and system 2 respectively.

Where the components of system 1 are:

1. Filter
2. Cooling coil
3. Warming bench
4. Insufflation fan
5. Exhaust fan

Where the components of system 2 are:

1. Filter
2. Enthalpic wheel
3. Cooling coil
4. Warming bench
5. Insufflation fan
6. Exhaust filter
7. Exhaust Fan

In system 1, we have a supply fan and an exhaust fan, a heat exchanger responsible for cooling the external air and a bank of resistances for heating. In system 2, the same components are used, with the addition of the Enthalpic Wheel manufactured by ERI Corporation, which shows the performance of their enthalpic rotors for ripple sizes of 2mm in Figure 4. We will use this information to calculate the efficiency of the heat recovery unit., which was calculated at 71% for the case studies carried out.

ANALYSIS AND DISCUSSION

To compare the systems’ operation and simple *payback*, we will use the psychrometric data provided by *Ashrae Data Viewer* (ASHRAE, 2021b). In the case study, we need to take into account some premises, such as the presence of 600 people in the workplace and an area of 1000m². It is important to determine the external air flow required by NBR 16401-3 (ABNT, 2008) for this environment, in order to maintain pollutant concentration levels at acceptable levels.

Thus, using the methodology presented in ABNT NBR 16401-3 (ABNT, 2008) to determine the external flow, we have Equation 1.

Equation 1 :

$$V_{ef} = P_z * F_p + A_z * F_a$$

Where:

V_{ef} is the effective flow of external air, expressed in (L/s)

F_p is a flow factor per person, expressed in (L/s*people)

F_a is the flow per occupied useful area, expressed in (L/s*m²)

P_z is the maximum number of people per ventilation zone

A_z is the useful area occupied by people, expressed in m²

Using Equation 1 presented and the reference factors for this Call Center application available in NBR 16404-3 which are F_p= 5.7 and F_a = 0.9, could determine the. That said, you get:

$$V_{ef}=600*5{,}7+1000*0{,}9=4.320L/s \text{ ou } 15.552m^3/h$$

The study will include five cities as reference: Brasília (central-west region), Curitiba (southern region), Manaus (northern region), Salvador (northeast region) and São Paulo (southeast region), with the psychrometric

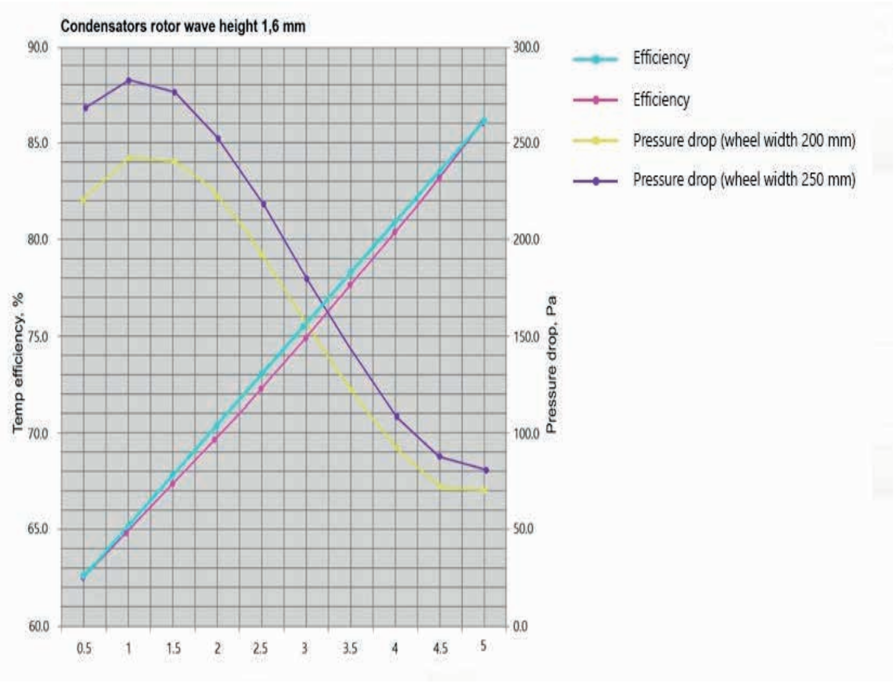


Figure 4 - ERI performance diagram. Source: (ERI CORPORATION, 2023)

conditions of these locations throughout the 8760 hours of the year. The internal comfort condition adopted will be a dry bulb temperature (DBT) of 23°C and enthalpy of 47.8 kJ/kg (ASHRAE, 2013). To treat the thermal load of external air in the Call Center, the equipment will have to cool the external air to a condition of 23°C and enthalpy of 47.8 kJ/kg. Furthermore, air density will be considered constant in all regions of Brazil, being ρ=1,2kg/m^3.

When surveying the thermal load of external air, the methodology presented in NBR 16655-3 Installation of residential air-conditioning systems — Split and compact Part 3: Method for calculating residential thermal load (ABNT, 2018) where the heat total outside air is expressed by Equation 2.

Equation 2 :

$$qt_{ae} = \frac{\rho * V_{ef} * (h_{ae} - h_{ins})}{3600}$$

Where,

qt_{ae} = Total thermal heat of external air expressed in kW

V_{ef} = Air flow rate expressed in m³/h

h_{ae} = Enthalpy of external air expressed in kJ/kg

h_{ins} = Enthalpy of the inflation condition expressed in kJ/kg

With the flow data, the cities, the internal and inflation conditions and the methodology for calculating the total thermal load of the external air already defined, the Call Center case study for each location will be presented below.

- BRASILIA DF

Table 3 _ presents the operational data of system 1 over the 8760 hours of a year. In this same table it is also possible to observe the thermal load data from the external air weighted by its operating time as well as the number of hours that the system will be in operation.

Table 4 presents a summary of the operation of system 1, having a weighted thermal heating load of 42.62 kW in 1346.71 hours of operation and a weighted thermal cooling load of 10.63 TR in 7413.29 hours of operation..

Just like system 1, system 2 is presented in Table 5 following the same analysis, but with the difference of showing the performance of the enthalpic wheel point by point throughout all hours of the year.

weighted heating load of 30.26 kW over 1346.71 hours of operation and a weighted thermal cooling load of 7.54 TR over 7413.29 hours of operation.

- MANAUS/AM

Table 7 _ presents the operational data of system 1 over the 8760 hours of a year. In this same table it is also possible to observe the thermal load data from the external air weighted by its operating time as well as the number of hours that the system will be in operation.

The Table 8 presents a summary of the operation of system 1, where the heating process does not occur and a weighted cooling thermal load of 40.71 TR over 8760 hours of operation.

Just like system 1, system 2 is presented in Table 9 following the same analysis, but with the difference of showing the performance of the wheel enthalpy point by point throughout all hours of the year, thus resulting in thermal load from the air external weighted.

A Table 10 presents a summary of the operation of system 2, where the heating process does not occur and a weighted cooling thermal load of 28.91 TR over 8760 hours of operation.

And finally, Graph 1 presents in graphic form the simple *payback information* for the systems proposed for the case study.

Outdoor Air Condition		Room condition		Hours of the year(h)	Thermal savings (kW)	Thermal load of External air Heating (kW)	Thermal load of External Air Refrigeration (Ton)	Thermal load of External air Heating weighted by time (kW)	Thermal load of External air Time-weighted refrigeration (Ton)
DBT (°C)	Coincident Enthalpy (kJ/kg)	DBT Coincident (°C)	Coincident Enthalpy (kJ/kg)						
0.00	11.00	23.00	47.80	0.04	190.77	190.77	0.00	7.66	0.00
4.00	17.67	23.00	47.80	0.12	156.21	156.21	0.00	18.82	0.00
5.00	19.17	23.00	47.80	0.24	148.44	148.44	0.00	35.77	0.00
6.00	21.52	23.00	47.80	0.84	136.22	136.22	0.00	114.89	0.00
7.00	23.25	23.00	47.80	2.61	127.29	127.29	0.00	332.37	0.00
8.00	25.29	23.00	47.80	5.90	116.68	116.68	0.00	688.98	0.00
9.00	27.16	23.00	47.80	13.22	106.98	106.98	0.00	1413.92	0.00
10.00	29.12	23.00	47.80	29.17	96.82	96.82	0.00	2824.10	0.00
11.00	30.92	23.00	47.80	54.68	87.53	87.53	0.00	4786.23	0.00
12.00	32.90	23.00	47.80	89.76	77.24	77.24	0.00	6933.02	0.00
13.00	34.91	23.00	47.80	128.02	66.84	66.84	0.00	8557.14	0.00
14.00	36.96	23.00	47.80	164.23	56.20	56.20	0.00	9229.45	0.00
15.00	39.46	23.00	47.80	212.07	43.23	43.23	0.00	9168.20	0.00
16.00	41.91	23.00	47.80	272.38	30.54	30.54	0.00	8319.26	0.00
17.00	45.23	23.00	47.80	373.41	13.31	13.31	0.00	4970.31	0.00
18.00	48.91	23.00	47.80	576.76	5.74	0.00	1.63	0.00	940.01
Outdoor Air Condition		Room condition		Hours of the year(h)	Thermal savings (kW)	Thermal load of External air Heating (kW)	Thermal load of External Air Refrigeration (TR)	Thermal load of External air Heating weighted by time (kW)	Thermal load of External air Time-weighted refrigeration (TR)
DBT (°C)	Coincident Enthalpy (kJ/kg)	DBT (°C)	Coincident Enthalpy (kJ/kg)						
19.00	52.54	23.00	47.80	866.32	24.56	0.00	6.98	0.00	6044.37
20.00	54.90	23.00	47.80	984.72	36.80	0.00	10.45	0.00	10293.79
21.00	55.72	23.00	47.80	785.26	41.07	0.00	11.67	0.00	9161.40
22.00	55.98	23.00	47.80	647.71	42.38	0.00	12.04	0.00	7798.42
23.00	55.87	23.00	47.80	559.46	41.84	0.00	11.89	0.00	6649.61
24.00	55.97	23.00	47.80	541.35	42.37	0.00	12.04	0.00	6516.88
25.00	56.20	23.00	47.80	525.34	43.56	0.00	12.38	0.00	6501.07
26.00	56.31	23.00	47.80	500.82	44.14	0.00	12.54	0.00	6280.11
27.00	56.74	23.00	47.80	448.56	46.34	0.00	13.16	0.00	5904.84
28.00	57.15	23.00	47.80	368.31	48.47	0.00	13.77	0.00	5071.20
29.00	57.11	23.00	47.80	266.12	48.24	0.00	13.70	0.00	3646.78
30.00	56.55	23.00	47.80	171.46	45.37	0.00	12.89	0.00	2209.83
31.00	55.40	23.00	47.80	95.66	39.38	0.00	11.19	0.00	1070.20
32.00	53.98	23.00	47.80	49.15	32.06	0.00	9.11	0.00	447.60
33.00	53.78	23.00	47.80	19.90	30.98	0.00	8.80	0.00	175.12
34.00	54.07	23.00	47.80	5.76	32.50	0.00	9.23	0.00	53.13
35.00	54.15	23.00	47.80	0.56	32.94	0.00	9.36	0.00	5.27
38.00	58.00	23.00	47.80	0.08	52.88	0.00	15.02	0.00	1.20

Subtitle	
(blue)	Cooling
(orange)	Heating

Table 3 - Study of system 1 for Brasília. Source: The authors

	System 1	
	Heating	Cooling
Hours in the year	1346.71	7413.29
Time-weighted average thermal load of external air	42.62 kW	10.63 Ton

Table 4 - Summary of system operation. Source: The Authors.

Outdoor Air Condition		Return air condition		Air condition after Enthalpica Wheel	Room condition		Hours of the year(h)	Thermal savings (kW)	Thermal load of External air Heating (kW)	Thermal load of External Air Refrigeration (TR)	Thermal load of External air Heating weighted by time (kW)	Thermal load of External air Time-weighted refrigeration (TR)
DBT (°C)	Coincident Enthalpy (kJ/kg)	DBT coincident (°C)	Coincident Enthalpy (kJ/kg)	Coincident Enthalpy (kJ/kg)	DBT (°C)	Coincident Enthalpy (kJ/kg)						
0.00	11.00	23.00	47.80	21.67	23.00	47.80	0.04	135.45	135.45	0.00	5.44	0.00
4.00	17.67	23.00	47.80	26.41	23.00	47.80	0.12	110.91	110.91	0.00	13.36	0.00
5.00	19.17	23.00	47.80	27.47	23.00	47.80	0.24	105.39	105.39	0.00	25.39	0.00
6.00	21.52	23.00	47.80	29.14	23.00	47.80	0.84	96.71	96.71	0.00	81.57	0.00
7.00	23.25	23.00	47.80	30.37	23.00	47.80	2.61	90.37	90.37	0.00	235.99	0.00
8.00	25.29	23.00	47.80	31.82	23.00	47.80	5.90	82.84	82.84	0.00	489.18	0.00
9.00	27.16	23.00	47.80	33.15	23.00	47.80	13.22	75.95	75.95	0.00	1003.88	0.00
10.00	29.12	23.00	47.80	34.54	23.00	47.80	29.17	68.75	68.75	0.00	2005.11	0.00
11.00	30.92	23.00	47.80	35.81	23.00	47.80	54.68	62.15	62.15	0.00	3398.22	0.00
12.00	32.90	23.00	47.80	37.22	23.00	47.80	89.76	54.84	54.84	0.00	4922.44	0.00
13.00	34.91	23.00	47.80	38.65	23.00	47.80	128.02	47.46	47.46	0.00	6075.57	0.00
14.00	36.96	23.00	47.80	40.10	23.00	47.80	164.23	39.90	39.90	0.00	6552.91	0.00
15.00	39.46	23.00	47.80	41.88	23.00	47.80	212.07	30.69	30.69	0.00	6509.42	0.00
16.00	41.91	23.00	47.80	43.62	23.00	47.80	272.38	21.69	21.69	0.00	5906.68	0.00
17.00	45.23	23.00	47.80	45.98	23.00	47.80	373.41	9.45	9.45	0.00	3528.92	0.00
18.00	48.91	23.00	47.80	48.59	23.00	47.80	576.76	4.07	0.00	1.16	0.00	667.41
19.00	52.54	23.00	47.80	51.16	23.00	47.80	866.32	17.44	0.00	4.95	0.00	4291.50
20.00	54.90	23.00	47.80	52.84	23.00	47.80	984.72	26.13	0.00	7.42	0.00	7308.59
21.00	55.72	23.00	47.80	53.42	23.00	47.80	785.26	29.16	0.00	8.28	0.00	6504.59
22.00	55.98	23.00	47.80	53.60	23.00	47.80	647.71	30.09	0.00	8.55	0.00	5536.88
23.00	55.87	23.00	47.80	53.53	23.00	47.80	559.46	29.70	0.00	8.44	0.00	4721.22
24.00	55.97	23.00	47.80	53.60	23.00	47.80	541.35	30.09	0.00	8.55	0.00	4626.98
25.00	56.20	23.00	47.80	53.77	23.00	47.80	525.34	30.93	0.00	8.79	0.00	4615.76
26.00	56.31	23.00	47.80	53.85	23.00	47.80	500.82	31.34	0.00	8.90	0.00	4458.88
27.00	56.74	23.00	47.80	54.15	23.00	47.80	448.56	32.90	0.00	9.35	0.00	4192.44
28.00	57.15	23.00	47.80	54.44	23.00	47.80	368.31	34.41	0.00	9.78	0.00	3600.55
29.00	57.11	23.00	47.80	54.41	23.00	47.80	266.12	34.25	0.00	9.73	0.00	2589.21
30.00	56.55	23.00	47.80	54.01	23.00	47.80	171.46	32.21	0.00	9.15	0.00	1568.98
31.00	55.40	23.00	47.80	53.19	23.00	47.80	95.66	27.96	0.00	7.94	0.00	759.84
32.00	53.98	23.00	47.80	52.19	23.00	47.80	49.15	22.76	0.00	6.47	0.00	317.80
33.00	53.78	23.00	47.80	52.04	23.00	47.80	19.90	22.00	0.00	6.25	0.00	124.34
34.00	54.07	23.00	47.80	52.25	23.00	47.80	5.76	23.07	0.00	6.55	0.00	37.73

35.00	54.15	23.00	47.80	52.31	23.00	47.80	0.56	23.39	0.00	6.64	0.00	3.74
38.00	58.00	23.00	47.80	55.04	23.00	47.80	0.08	37.54	0.00	10.67	0.00	0.85

Subtitle	
(blue)	Cooling
(orange)	Heating

Table 5 - Study of system 2 for Brasília. Source: The authors

	System 2	
	Heating	Cooling
Hours in the year	1346.71	7413.29
Time-weighted average thermal load of external air	30.26 kW	7.54Ton

Table 6 - System operation summary. Source: The Authors.

Outdoor Air Condition		Room condition		Hours of the year(h)	Thermal savings (kW)	Thermal load of External air Heating (kW)	Thermal load of External Air Refrigeration (Ton)	Thermal load of External air Heating weighted by time (kW)	Thermal load of External air Time-weighted refrigeration (Ton)
DBT (°C)	Coincident Enthalpy (kJ/kg)	DBT coincident (°C)	Coincident Enthalpy (kJ/kg)						
18.00	48.99	23.00	47.80	0.19	6.18	0.00	1.75	0.00	0.33
19.00	52.00	23.00	47.80	0.71	21.77	0.00	6.18	0.00	4.37
20.00	54.99	23.00	47.80	1.42	37.28	0.00	10.59	0.00	14.99
21.00	58.38	23.00	47.80	5.16	54.84	0.00	15.58	0.00	80.44
22.00	63.11	23.00	47.80	32.15	79.39	0.00	22.55	0.00	725.06
23.00	67.24	23.00	47.80	238.30	100.77	0.00	28.63	0.00	6822.04
24.00	70.37	23.00	47.80	825.26	116.99	0.00	33.24	0.00	27428.81
25.00	72.82	23.00	47.80	1425.56	129.72	0.00	36.85	0.00	52535.35
26.00	74.62	23.00	47.80	1394.61	139.02	0.00	39.49	0.00	55078.70
27.00	75.96	23.00	47.80	1148.77	146.01	0.00	41.48	0.00	47650.10
28.00	76.95	23.00	47.80	910.33	151.10	0.00	42.93	0.00	39078.18
29.00	77.82	23.00	47.80	757.63	155.62	0.00	44.21	0.00	33494.19
30.00	78.60	23.00	47.80	676.93	159.66	0.00	45.36	0.00	30704.36
31.00	79.27	23.00	47.80	526.79	163.16	0.00	46.35	0.00	24417.19
32.00	79.71	23.00	47.80	409.81	165.42	0.00	46.99	0.00	19258.15
33.00	79.97	23.00	47.80	236.81	166.77	0.00	47.38	0.00	11219.40
34.00	80.59	23.00	47.80	118.16	169.96	0.00	48.28	0.00	5705.33
35.00	80.21	23.00	47.80	41.79	168.03	0.00	47.74	0.00	1994.75
36.00	78.94	23.00	47.80	7.56	161.45	0.00	45.87	0.00	346.81
37.00	78.29	23.00	47.80	1.62	158.06	0.00	44.90	0.00	72.57
38.00	87.18	23.00	47.80	0.27	204.14	0.00	57.99	0.00	15.85
39.00	89.00	23.00	47.80	0.09	213.58	0.00	60.68	0.00	5.60
40.00	90.00	23.00	47.80	0.09	218.76	0.00	62.15	0.00	5.60

Subtitle	
(blue)	Cooling
(orange)	Heating

Table 7 - Study of system 1 for Manaus. Source: The authors

	System 1	
	Heating	Cooling
Hours in the year	0.00	8760.00
Time-weighted average thermal load of external air	0.00 kW	40.71 Ton

Table 8 - System operation summary. Source: The Authors.

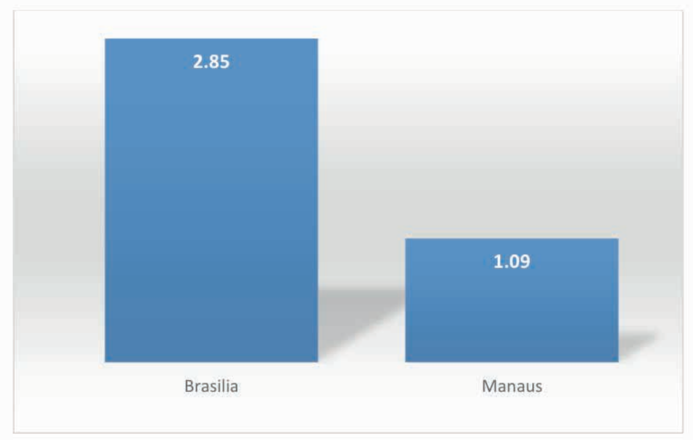
Outdoor Air Condition		Return air condition		Air condition after Enthalpica Wheel	Room condition		Hours of the year(h)	Thermal savings (kW)	Thermal load of External air Heating (kW)	Thermal load of External Air Refrigeration (Ton)	Thermal load of External air Heating weighted by time (kW)	Thermal load of External air Time-weighted refrigeration (Ton)
DBT (°C)	Coincident Enthalpy (kJ/kg)	DBT (°C)	Coincident Enthalpy (kJ/kg)	Coincident Enthalpy (kJ/kg)	DBT (°C)	Coincident Enthalpy (kJ/kg)						
18.00	48.99	23.00	47.80	48.65	23.00	47.80	0.19	4.39	0.00	1.25	0.00	0.23
19.00	52.00	23.00	47.80	50.78	23.00	47.80	0.71	15.45	0.00	4.39	0.00	3.10
20.00	54.99	23.00	47.80	52.91	23.00	47.80	1.42	26.47	0.00	7.52	0.00	10.64
21.00	58.38	23.00	47.80	55.31	23.00	47.80	5.16	38.93	0.00	11.06	0.00	57.11
22.00	63.11	23.00	47.80	58.67	23.00	47.80	32.15	56.37	0.00	16.01	0.00	514.79
23.00	67.24	23.00	47.80	61.60	23.00	47.80	238.30	71.55	0.00	20.33	0.00	4843.65
24.00	70.37	23.00	47.80	63.82	23.00	47.80	825.26	83.06	0.00	23.60	0.00	19474.45
25.00	72.82	23.00	47.80	65.57	23.00	47.80	1425.56	92.10	0.00	26.17	0.00	37300.10
26.00	74.62	23.00	47.80	66.84	23.00	47.80	1394.61	98.70	0.00	28.04	0.00	39105.88
27.00	75.96	23.00	47.80	67.80	23.00	47.80	1148.77	103.66	0.00	29.45	0.00	33831.57
28.00	76.95	23.00	47.80	68.50	23.00	47.80	910.33	107.28	0.00	30.48	0.00	27745.51
29.00	77.82	23.00	47.80	69.11	23.00	47.80	757.63	110.49	0.00	31.39	0.00	23780.87
30.00	78.60	23.00	47.80	69.67	23.00	47.80	676.93	113.36	0.00	32.20	0.00	21800.10
31.00	79.27	23.00	47.80	70.15	23.00	47.80	526.79	115.84	0.00	32.91	0.00	17336.21
32.00	79.71	23.00	47.80	70.46	23.00	47.80	409.81	117.45	0.00	33.37	0.00	13673.29
33.00	79.97	23.00	47.80	70.64	23.00	47.80	236.81	118.41	0.00	33.64	0.00	7965.78
34.00	80.59	23.00	47.80	71.08	23.00	47.80	118.16	120.67	0.00	34.28	0.00	4050.78
35.00	80.21	23.00	47.80	70.81	23.00	47.80	41.79	119.30	0.00	33.89	0.00	1416.27
36.00	78.94	23.00	47.80	69.91	23.00	47.80	7.56	114.63	0.00	32.56	0.00	246.24
37.00	78.29	23.00	47.80	69.45	23.00	47.80	1.62	112.22	0.00	31.88	0.00	51.53
38.00	87.18	23.00	47.80	75.76	23.00	47.80	0.27	144.94	0.00	41.18	0.00	11.25
39.00	89.00	23.00	47.80	77.05	23.00	47.80	0.09	151.64	0.00	43.08	0.00	3.97
40.00	90.00	23.00	47.80	77.76	23.00	47.80	0.09	155.32	0.00	44.13	0.00	3.98

Subtitle	
	Cooling
	Heating

Table 9 - Study of system 2 for Manaus. Source: The authors

	System 2	
	Heating	Cooling
Hours in the year	0.00	8760.00
Time-weighted average thermal load of external air	0.00 kW	28.91 TR

Table 10 - System operation summary. Source: The Authors.



Graph 1 - Simple *Payback* (in years) by city. Source: The Authors

CONCLUSION

air-to-air " energy recovery to condition air in buildings is a timely initiative to promote a sustainable built environment, aligned with guidelines from ASHRAE and the United Nations International Panel on Climate Change, which aim to reduce carbon dioxide emissions related to energy use.

The literature review highlights that desiccant wheels are widely used for heating in various environments and to prevent the growth of mold and mildew in homes. In hot and humid climates, desiccant wheels remove the moisture load as conventional air conditioning systems are limited for this purpose. For the implementation of this technology, the investigation of heat and mass transfer mechanisms is essential, including the evaluation of the performance of new polymeric composite desiccant materials, which have become an area of research. Selection of the appropriate wheel depends on careful analysis of the heat and mass transfer mechanisms and the performance of the desiccant material.

On the other hand, new desiccant wheel design concepts were observed, such as a rotating desiccant wheel integrated with the wind tower, a desiccant-integrated mobile air conditioning system, and rotating desiccant wheel systems with a conventional heat pump system. Therefore, it can be seen that desiccant wheels can be coupled to different types of systems, which shows great versatility.

Improving the performance of desiccant wheels using multistage cooling has also been widely analyzed. These multi-stage cooling systems are used because of their ability to achieve isothermal dehumidification. Several researchers have investigated the performance of a single-wheel multi-partition desiccant cooling system. However, multi-stage systems can be designed with a single wheel with more than two partitions or with two conventional wheels, which showed that multiple wheels can be used for this multiple cooling concept.

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.317482406037

REFERENCES

ABNT. Installation of residential air conditioning systems – Split and compact. *NBR,16655 part 3,* 2018.

ABNT, AB de NT *NBR_16401-3_2008.pdf,* 2008.. Available at: <http://www.ductbusters.com.br/normas/NBR_16401-3_2008.pdf>.

ASHRAE. *Ashrae Handbook Fundamentals.* [sl:sn]

ASHRAE. *2019 ASHRAE Handbook_ HVAC Applications CH35.pdf.* [sl:sn]

ASHRAE. *2020 Ashrae Handbook.* [sl:sn]

ASHRAE. AIR-TO-AIR ENERGY RECOVERY EQUIPMENT. In: ASHRAE (Ed.). *ASHRAE Handbook -- HVAC Systems and Equipment.* 1st ed. Washington DC: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2021a. P. 38.

ASHRAE. *ASHRAE DATA VIEWER.* Available at: <https://www.techstreet.com/standards/weather-data-viewer-2021-basic-subscription?product_id=2248129>.

ASHRAE. *ASHRAE 139-2022: Method of Testing for Rating Desiccant Dehumidifiers Utilizing Heat for the Regeneration Process.* [sl: sn].

BISWAS, P.; Kim, S.; MILLS, AF A Compact Low-Pressure Drop Desiccant Bed for Solar Air Conditioning Applications: Analysis and Design. *Journal of Solar Energy Engineering,* vol. 106, no. 2, p. 153–158, 1 May 1984. Available at: <https://doi.org/10.1115/1.3267572>.

CLARK, J.E.; MILLS, AF; BUCHBERG, H. Design and Testing of Thin Adiabatic Desiccant Beds for Solar Air Conditioning Applications. *Journal of Solar Energy Engineering,* vol. 103, no. 2, p. 89–91, 1 May 1981. Available at: <https://doi.org/10.1115/1.3266230>.

ERI CORPORATION. *ERI CORPORATION.* Available at: <ERI CORPORATION>. Accessed on: 3 Mar. 2023.

Kim, S.; BISWAS, P.; MILLS, AF A Compact Low-Pressure Drop Desiccant Bed for Solar Air Conditioning Applications—2: Bench Scale Tests. *Journal of Solar Energy Engineering,* vol. 107, no. 2, p. 120–127, 1 May 1985. Available at: <https://doi.org/10.1115/1.3267664>.

LAVAN, Z. et al. Development of a solar desiccant dehumidifier. In: Solar energy: International progress; Proceedings of the International Symposium-Workshop, AA(Illinois Institute of Technology Chicago), AB(Illinois Institute of Technology Chicago), AC(Illinois Institute of Technology Chicago), AD(Illinois Institute of Technology Chicago), AE(Illinois Institute of Technology Chicago), AF(Illinois Institute of. *Proceedings...* AA(Illinois Institute of Technology Chicago), AB(Illinois Institute of Technology Chicago), AC(Illinois Institute of Technology Chicago), AD(Illinois Institute of Technology Chicago), AE (Illinois Institute of Technology Chicago), AF (Illinois Institute of: 1 Jan. 1980. Available at: <https://ui.adsabs.harvard.edu/abs/1980seip.conf..898L>.

MEN, Y. et al. Novel flue gas waste heat recovery system equipped with enthalpy wheel. *Energy Conversion and Management,* vol. 196, p. 649–663, 2019. Available at: <https://www.sciencedirect.com/science/article/pii/S019689041930696X>.

MUNTERS. *Munters' desiccant rotor – industrial dehumidification at its best.* Available at: <https://www.munters.com/en/about-us/history-of-munters/history-news2/munters-desiccant-rotor--industrial-dehumidification-at-its-best/>. Accessed on: 11 Jul. 2022.

O., S., & Fisk, W. (2002). Association Of Ventilation System Type With SBS Symptoms In Office Workers.

SHAMIM, JA et al. A review of solid desiccant dehumidifiers: Current status and near-term development goals in the context of net zero energy buildings. *Renewable and Sustainable Energy Reviews,* vol. 137, no. September, p. 110456, 2021. Available at: <https://doi.org/10.1016/j.rser.2020.110456>.

TEIXEIRA, AR (2021). Assessment of Air Conditioning Solutions applied in a Commercial and Services Building to achieve nZEB Classification.