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STANDARD ASSESSMENT FOR ENERGY SAVING STRATEGIES OF INDUSTRIAL AIR-CONDITIONING SYSTEMS

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Abstract: *Industrial energy efficiency is a critical factor for the success of energy transition efforts. That demand enhances industry concerns on energy awareness and management, along with its economic benefits, but energy efficiency opportunities are not yet broadly exploited. Heat, Ventilation, and Air conditioning (HVAC) is a significant energy consumer at most industrial facilities and holds relevant energy savings potential, often neglected by managers. In this context, this paper searches to propose a direct and standardized method to evaluate the performance of industrial air conditioning systems based on regular and easy to assess information from the installation. Air-conditioning systems are decomposed into installed equipment factors and system operation energy factors, which are evaluated based on quantitative data from the literature research. The best available techniques (BAT) approach is applied, along with considerations from national regulations concerning efficiency levels of air conditioning equipment and technical literature. The identified equipment factors are the energy efficiency label and the application of supporting systems. The operation factors identified are the operating temperature, proper maintenance, and application of system automation measures. The energy factors' information is assembled into a set of conditions and results in levels of performance, defined by Key Performance Indicators (KPIs). The final system efficiency is calculated by the indirect method, considering each factor condition, and correlated with the available benchmark, allowing for a suitable diagnosis of the energy performance. The evaluation outcomes are demonstrated by the application in three hypothetical cases, indicating that it enables the comparison between different air-conditioning system configurations performances and supports the identification of improvement opportunities on air-conditioning systems. It is expected that decision-makers from different industries will be able to properly identify their main priorities and define energy savings strategies.*

Keywords: *Energy management, Air-conditioning efficiency, Industrial facilities, Energy savings potential.*

1. INTRODUCTION

Energy efficiency has been being recognized globally as a critical factor for sustainable development and the success of energy transition. International institutions consider the development of non-polluting and resource-efficient management models and processes as fundamental elements for international conventions, such as Paris Agreement and the 2030 Agenda (UN, 2015). In Brazil, the manufacturing industry's share of the GDP is 11.3% (IBGE, 2020), while its share of national electricity consumption is 35.9% (EPE, 2020). The discussion about promoting energy efficiency has been intensified due to the growing concern with sustainability. The National Confederation of Industry (Confederação Nacional da Indústria, CNI) considers energy efficiency improvement measures as an industry contribution to the Paris Agreement mechanisms. The institution notes that about half of the projects of certified emission reductions were applied in the industry, with energy efficiency as one of the main topics (CNI, 2019). In the context of the Sustainable Development Mechanism (SDM), the Brazilian industry plan, Plano Indústria, also has among its five main ambitions the energy efficiency and conservation (CNI, 2018).

Despite such efforts, the implementation of energy efficiency measures and strategies in companies face many barriers for broader adoption. In the European Union, 18,9% of large enterprises and 4% of small and medium-sized enterprises have a comprehensive energy efficiency system (Cagno and Trianni, 2014). In Brazil, the large energy conservation technical potential of energy-intensive industrial branches estimated by Bajay *et al.* (2009) was not yet exploited (De Mello Santana and Bajay, 2016). Information-related issues compose one category of the important barriers for the implementation of energy efficiency projects (Henriques and Catarino, 2016; Cagno and Trianni, 2014). The lack of information of consumption patterns and efficiency measures levels of the plant, lack of knowledge of energy-saving opportunities, and also lack of training and knowledge from the technical personnel (Henriques and Catarino, 2016)

restrain the exploration of such opportunities.

To meet the need to evaluate different industrial sectors' energy profiles and identify potential energy savings, the industry and researchers have developed different methods for energy efficiency management. These tools have the objective of establishing an awareness of energy consumption in industrial and auxiliary plant processes, in addition to evaluating their effects on production and productivity. Studies in energy analysis, according to Menghi *et al.* (2019), seek to systematically investigate how energy is consumed in the plant through energy audits and benchmarks. Zanardo *et al.* (2018) proposed an energy performance diagnosis model for industrial plants based on Key Performance Indicators (KPI) and Hierarchical Process Analysis (AHP). Studies in energy-saving measures, on the other hand, develop methods that explore energy-saving measures in specific sectors or processes. Kluczek (2014), for example, identified opportunities to implement Best Available Techniques (BAT) solutions in a Polish factory, while Svensson and Paramonova (2017) identified solutions to increase the process energy efficiency of three industrial units by Value Stream Mapping.

Given the context presented, the energy consumption of air conditioning systems is quite significant, representing from 10% to 20% of final energy consumption in many industries (Cagno and Trianni, 2014). These systems maintain the temperature and humidity levels of an environment within comfort conditions or production process demands. Energy efficiency should be considered both in the design and in the operation and maintenance of the system, with retrofit being an opportunity for energy savings in old facilities. It is a system that holds great potential for energy savings, that may vary by type of installation and equipment. These considerations should be included by facility managers in the efforts for increasing energy performance.

This work seeks to establish a standardized methodology for evaluating the energy performance of the Air-Conditioning systems in the industry. The analysis takes into account the condition of the installed HVAC equipment, the operation patterns, and its contribution to the final energy consumption of the plant, based on the existing technical literature. As a result, it seeks to identify the energy consumption and performance of the air-conditioning system of the industrial facility, thus supporting decision-making in factory environments. The work is part of a project that establishes a standardized evaluation for multiple sectors in industries facilities based on Key Performance Indicators and performance-based benchmarks. This paper searches to propose a direct and standardized method to evaluate the performance of industrial air conditioning systems. Its application is meant to be based on regular and easy to assess information from the system installation. Recognizing that energy savings are not generalizable, it may serve as a support for companies and managers to deal with knowledge and organizational barriers, achieving energy awareness without complex analyses outside the scopes of their normal practices. The evaluated system is decomposed into the installed equipment, the system operation patterns, and its energy consumption, which is evaluated based on quantitative data from the literature research.

2. AIR-CONDITIONING SYSTEMS

The air-conditioning system can be isolated or centralized and with direct or indirect expansion. Isolated systems consist of unitary air conditioners of a single environment, while centralized systems provide conditioning in more than one room. In systems with direct expansion, the air is directly cooled by the refrigerant. These systems may be isolated or centralized, being installations of small to medium capacities (up to 50 TR) (Pena, 2002). The main systems are listed:

- Window Air Conditioning units: Isolated compact unit (MMA, 2017).
- Split Air Conditioning units: Isolated compact unit for one to two environments (MMA, 2017), for 3 TR to 50 TR (Pena, 2002).
- Self-Contained systems: Centralized systems, installed outside of the conditioned environments (MMA, 2017), for 5 TR to 40 TR (Pena, 2002).
- Rooftop system: Centralized systems, vastly used in supermarkets, malls, and warehouses (MMA, 2017), for 5 TR to 40 TR (Pena, 2002).
- Variable Refrigerant Flow (VRF) systems ou Multi-Split: Centralized system for multiple environments, but it relies on complementary systems for thermal comfort and indoor air quality (MMA, 2017). For 10 to 40 TR (MMA, 2017).

In centralized systems with indirect expansion, liquid cooling units are applied, the chillers. Because of the complexity of those systems, they apply to larger buildings, typically with a thermal load greater than 285 TR up to 4000 TR (MMA, 2017). Besides the chillers, the installed equipment are Air Handling Units (AHU) or Fan Coils (MMA, 2017). There are air, water, and evaporative condensed chiller, with the subcategories of screw-driven chillers, centrifugal chillers, and alternative chillers (Pena, 2002; MMA, 2017).

3. APPLIED METHOD

The overall objective of the proposed energy performance evaluation of the industrial air-conditioning units is to establish a diagnostic model based on multiple performance factors. This work extends Zanardo *et al.* (2018), addressing in more detail the air-conditioning industrial system with quantitative assessments based on data from the literature and demanding accessible information from the facility. The methodology steps are distributed into three stages, as presented in Fig.1: problem structuring, model building, and application. These stages are developed in the subsequent sections.

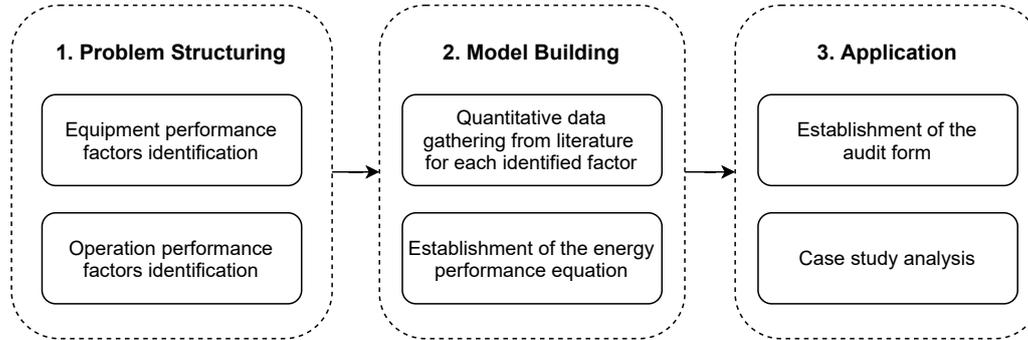


Figure 1. Energy performance assessment method. The three stages are explained in detail in the following sections.

The structuring of the evaluation begins with an exploratory literature search on energy efficiency in industrial air-conditioning facilities, identifying the factors that impact the system performance. First, the factors related to the installed equipment are explored. Then the factors related to its operation are identified.

In section 2, data collection of the energy impact of the identified factors is carried out by the bibliographical research. This research used academic literature and technical reports, such as the best available techniques reference documents from the European Commission (EIPPCB, 2009), reports from the National Electricity Conservation Program, and reports from companies from different industrial sectors. This research identifies the quantitative information on the energy impact to define the performance indicators and establish the performance equation.

The last stage of the energy performance assessment method comprises the application. It consists of the questions to the person in charge of the industrial unit. Finally, the final application of the evaluation is the filling out of the developed audit form with data from a case study, to obtain the system's energy efficiency.

4. AIR-CONDITIONING ASSESSMENT

4.1 PROBLEM STRUCTURING

The exploratory research to structure the proposed evaluation was performed, based on technical reports and academic literature on air-conditioning equipment and operation. The identified main performance factors regarding the installed equipment are their efficiency level and supporting systems. Regarding the operation adopted, the performance factors are the operation temperature, system automation, and system maintenance. Figure 2 presents these considerations for the air-conditioning energy performance assessment of industrial units, presenting each critical factor.

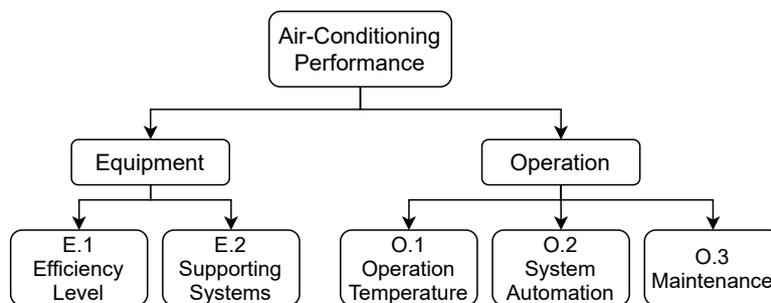


Figure 2. Energy performance factors structure for the air-conditioning assessment.

The equipment performance E_P may be defined as presented in Eq.1, E_1 being the performance indicator for the equipment efficiency level, E_2 being the performance indicator for the supporting systems.

$$E_p = E_1 E_2 \quad (1)$$

The operation performance O_P may be defined as presented in Eq.2, O_1 being the performance indicator for the operation temperature, O_2 being the performance indicator for the system automation, and O_3 being the performance indicator for the system maintenance.

$$O_p = O_1 O_2 O_3 \quad (2)$$

Finally, the final system performance F_P may be defined as presented in Eq.3.

$$F_p = O_p E_p \quad (3)$$

4.2 MODEL BUILDING: EQUIPMENT FACTORS

4.2.1 Equipment Efficiency Level

For isolated systems, using window or split type air conditioners, INMETRO regulation defines energy efficiency classes (Diário Oficial da União, 2020), from class A to class F. The minimum efficiency requirements are regulated and presented in Tab. 1, for the window-type cooling system, and in Tab. 2, for split cooling systems.

Table 1. Energy Efficiency Coefficient for Window Type Conditioners - IDRS (Wh/Wh) (with a manufacturing and import suitability deadline of 31/12/2022) (Diário Oficial da União, 2020).

Efficiency Class	Category 1 (Up to 2.6 kW)	Category 2 (2.6 to 4.1 kW)	Category 3 (4.1 to 5.8 kW)	Category 4 (Above 5.8 kW)
A	3.1	3.21	2.95	2.89
B	3.01	3.12	2.87	2.81
C	2.93	3.03	2.79	2.72
D	2.84	2.94	2.71	2.65

Table 2. Energy Efficiency Coefficient for Split Type Conditioners - IDRS (Wh/Wh) (with a manufacturing and import suitability deadline of 31/12/2022) (Diário Oficial da União, 2020).

Efficiency Class	Energy Efficiency (IDRS)
A	5.5
B	5.0
C	4.5
D	4.0
E	3.5
F	3.1

To define the performance impact of isolated systems equipment efficiency level, it is possible to find its efficiency coefficient with Tab. 1 and Tab. 2. Therefore, it is necessary to know the equipment capacity (kW), the efficiency class (A, B, C, D, E, or F), and equipment type (window or split) from the installed systems. The performance impact is therefore calculated in comparison with efficiency class A from its capacity category and equipment type.

In the case of centralized systems, PROCEL (2013) defines minimum efficiency requirements for different equipment. The regulation presents efficiency requirements for equipment of different energy efficiency classes (class A to class D), different thermal capacities (equipment from 19 kW up to 1055 kW), and different air-conditioning systems (VRF systems, Multi-split, multiple chiller types, etc.). To establish a common performance factor, the efficiency values are analyzed by capacity categories. Four capacity categories are defined, as presented in Tab. 3. For each of them, Tab. 3 presents the lower and higher possible efficiency requirements for different equipment.

Table 3. Higher and lower efficiency requirement for different capacity classes (PROCEL, 2013).

Capacity Category	Higher Efficiency Class A	Lower Efficiency Class D
Up to 5 TR	5.5 IDRS	2.65 IDRS
5 to 50 TR	3.81 COP	2.4 COP
50 to 400 TR	5.5 COP	3 COP
Above 400 TR	6.17 COP	5.2 COP

For centralized systems, it is necessary to consider the equipment capacity (TR), efficiency class (A, B, C, or D), and the type of system (VRF systems, Multi-split, multiple chiller types, etc). It is, therefore, possible to define its minimum efficiency requirement from PROCEL (2013), and its performance impact is calculated in comparison with the higher efficiency coefficient for its capacity.

The performance indicator of the Equipment Efficiency Level is calculated as presented in Eq.4, E_1 being the performance indicator, $ER_{Equipment\ class}$ being the minimum efficiency requirement for the analyzed equipment, and $ER_{Higher\ Efficiency}$ being the higher efficiency coefficient for the capacity category. In the case of isolated systems, if the equipment is a window type conditioner, Tab. 1 is consulted, and if the equipment is a split type conditioner, Tab. 2 is consulted. For centralized systems, the minimum efficiency requirement can be obtained from PROCEL (2013) for the capacity category defined in Tab. 3.

$$E_1 = \frac{ER_{Equipment\ class}}{ER_{Higher\ Efficiency}}. \quad (4)$$

If the installed equipment has the highest efficiency for its capacity category, $E_1 = 1$ and the Equipment Efficiency Level performance factor will not reduce the system performance. On the other hand, if it has a lower efficiency class, its impact on the system performance depends on its ratio to the highest efficiency. The most severe factor impact would be for the lowest efficiency class, resulting in an impact by 50%.

4.2.2 Supporting Systems

The application of different operating systems can also increase the efficiency of the HVAC system. The installation of a single circuit with a variable flow rate in existing systems is very effective, with noticeable results of improved operational control and reduction of annual energy consumption of over 25% in specific systems (MMA, 2017). Moreover, the installation of a Dedicated Outdoor Air System (DOAS) improves air quality in air-conditioned environments. It decouples dehumidification and conditioning of ventilation air from sensible cooling and heating in the zone (ASHRAE, 2019). In addition, it brings an efficiency gain in the chilled water system compared to the traditional application, since it allows existing air conditioners to operate with a reduced total load. There may be an efficiency gain between 10% and 15% in the chilled water system (MMA, 2017). In the case of split air conditioners with rotary compressors, the inverter technology is applied for efficiency gains and energy savings. Equipment operating with the inverter technology can reduce consumption of up to 40% (Lima, 2017).

To define this performance factor, it is necessary to have the information of the application of supporting systems such as a single circuit with variable flow rate, DOAS, or the inverter technology. The energy impact of supporting systems is defined to be the conservative value of 10% of efficiency gain. The performance indicator of Supporting Systems is calculated as presented in Eq.5, E_2 being the performance indicator, f_{SS} being the factor for the application ($f_M = 0$) or not ($f_{SS} = 1$) of a single circuit with variable flow rate, DOAS, or the inverter technology.

$$E_2 = 1 - 0.1f_{SS}. \quad (5)$$

4.3 MODEL BUILDING: OPERATION FACTORS

4.3.1 Operation Temperature

Increasing the operating temperature of the air conditioner by 1°C can reduce energy consumption by about 5 - 10%, depending on the temperature difference between indoors and outdoors (European Commission, 2009). The comfort temperature determined by regulation can be defined as the temperature reference for air-conditioning applications, indicating the possibility of consumption reduction. Thus, Tab. 4 presents the operating temperatures of thermal comfort according to ABNT (2008).

Table 4. Comfort temperatures determined by ABNT (2008)

Season	Operating Temperature (°C)	Relative Humidity
Summer (Humid)	22.5 to 25.5	65%
Summer (Dry)	23 to 26	35%
Winter (Humid)	21 to 23.5	60%
Winter (Dry)	21.5 to 24	30%

Therefore, knowing the operating temperature of air-conditioning in the different rooms of the industrial unit, it is possible to encounter the energy impact of the operation temperature factor. For each degree Celcius lower than presented in Tab. 4, 21°C for winter, and 22.5°C for summer, the efficiency of the system is reduced by 5%. The performance

indicator of the Operation Temperature is calculated as presented in Eq.6, O_1 being the performance indicator, T_{op} being the operation temperature ($^{\circ}\text{C}$).

$$O_1 = 1 - 0.05(21 - T_{op}). \quad (6)$$

4.3.2 System Automation

System automation and control measures' impacts on the system's energy consumption are the subject of multiple studies. By the modeling of actual buildings constructions in simulation tools, energy savings resulting from the adoption of one or multiple measures were acquired for different scenarios (Jiru, 2014; Fasiuddin and Budaiwi, 2011; Mathews *et al.*, 2001; European Commission, 2009).

The strategy of a setback control, a reduction of how often the cooling system operates by measures such as the implementation of time-of-day schedule, occupancy sensors, or CO_2 sensors, achieves significant savings. Its application for demand-controlled ventilation achieves up to 8% savings in different climate zones scenarios (Jiru, 2014). Time schedule operation is a simple strategy with great potential for energy savings, turning the system off during unoccupied periods as periods without production or on vacant days. Limiting the air-conditioning reduces up to 40% of the consumption of a plant that works 8 hours a day (European Commission, 2009). The application of a time schedule with a 2 hours lag and lead time resulted in energy savings by 20%, in the case of (Fasiuddin and Budaiwi, 2011). Zone-based temperature control is also relevant in the energy consumption of centralized climate control systems. It reduces energy consumption by limiting climate control when it is not needed in certain zones. Fasiuddin and Budaiwi (2011) encountered energy savings by 8% by multi-zone system operation.

Therefore, the considered system automation measures are the zone-based temperature control and setback control, defined by either the installation of occupancy or CO_2 sensors or a time schedule operation. The assumed energy savings are 8% and 10%, respectively. The performance indicator of the Operation Temperature is therefore calculated as presented in Eq.7, O_2 being the performance indicator, f_{ZC} being the factor for the existence ($f_{ZC} = 0$) or not ($f_{ZC} = 1$) of a zone-based temperature control, and f_{SC} being the factor for the existence ($f_{SC} = 0$) or not ($f_{SC} = 1$) of a setback control.

$$O_2 = 1 - 0.08f_{ZC} - 0.1f_{SC}. \quad (7)$$

4.3.3 Maintenance

Regular maintenance of HVAC systems can both increase their efficiency and avoid important energy losses. Therefore, the facility has to follow strictly an appropriate maintenance program. A maintenance program following ASHRAE Standard (Paxson *et al.*, 2018) explains how maintenance will be managed to preserve the condition of the HVAC system, defining maintenance objectives. It includes, among others, a maintenance plan defining the effort for performing inspection and maintenance work, establishing planning, organizing, and control, and a process for periodic review, being capable of continuous improvement. The report presents the minimum required inspection and maintenance tasks and their frequencies.

Institute for Building Efficiency (2012) summarizes studies results on the potential energy savings from maintenance practices, considering system monitoring, water treatment program, the follow up of manufacturer instructions, regular testing, repairing, and other solutions. The energy-saving estimations on maintenance impact over whole-building system range from 5% to 20% in commercial buildings. The energy-savings average value from the studies is 15%.

Given this information, it should be demanded from the facility an appropriate maintenance program following ASHRAE Standards, with an established maintenance plan and conformity to maintenance inspection and tasks frequencies, at least quarterly. The adoption of these requirements is assumed to impact 15% of the system's efficiency. The performance indicator of Maintenance is therefore calculated as presented in Eq.8, O_3 being the performance indicator, f_M being the factor for the existence ($f_M = 0$) or not ($f_M = 1$) of an appropriate maintenance program following ASHRAE Standards.

$$O_3 = 1 - 0.15f_M. \quad (8)$$

4.4 APPLICATIONS

Table 5 summarizes the considerations for the air-conditioning performance assessment, presenting each critical factor and its energy impact. Regarding the general impact on the system's performance, the most important factor is the equipment efficiency level, indicating that low-efficiency equipment may be the main responsible for a low-performance system, followed by the adoption of an appropriate maintenance program following ASHRAE Standards. The evaluation determines the system performance by the indirect method, and each consideration from Tab. 5 represents a loss in performance. A system equipped with the best equipment for its capacity category, applying suitable supporting systems and that follows operation benchmark would have a resulting performance of 100%.

Table 5. Audit information and performance impact for each defined performance factor.

Performance Factor	Audit Required Informations	Performance Impact
Efficiency Level (E_1)	System type	Up to 50%
	Equipment type	
	Refrigeration Capacity and Power	
	PROCEL Efficiency Class	
Supporting Systems (E_2)	Application of a Dedicated Outdoor Air System (DOAS)	10%
	Application of a Variable Primary Chilled Water System	
	Application of Inverter Technology	
Operation Temperature (O_1)	Operation Temperature	5% per °C
System Automation (O_2)	Application of Zone-based Temperature Control	8%
	Application of Setback control	10%
Maintenance (O_3)	Appropriate Maintenance Program	15%

The standardized performance evaluation is to be applied in a case study of an operating industrial facility HVAC system. To demonstrate its application and outcomes, the analysis of three hypothetical cases of air conditioning systems is presented. The cases are meant to represent different configurations of commercial and industrial air-conditioning systems.

Case 1 represents a general warehouse for a company in the retail sector, composed of a storeroom of 200 m² and office rooms that sum up to 50 m². The air-conditioning system is Multi-split conditioning sized for a refrigeration capacity of 15 TR, assuming the need for 1 TR for each 17 m². There are no supporting or automation systems, the maintenance program is neglected, and the employees set the operating temperature below 20 °C. On the other hand, case 2 represents a large industrial manufacturing facility, whose air-conditioning system provides thermal comfort for employees working among operating machines. With an area of 4500 m², there is a scroll chiller of 280 TR. There is a Dedicated Outdoor Air System (DOAS), time schedule setback control, and the operation temperature is managed to stay within comfort temperatures. Besides that, there is an appropriate maintenance program. Finally, the air conditioning system from case 3 is composed of eight isolated systems on an office building, with Split conditioning equipment. Three of the offices are equipped with efficiency class B, and the five others, C. The operation temperature varies, but the employees have affirmed to maintain it on average at 20 °C. The considered attributes are presented in Tab. 6.

Table 6. Considered audit information responses for three application cases.

Audit Required Informations	Case 1	Case 2	Case 3
System type	Centralized	Centralized	Isolated
Equipment type	Multi-split (air)	Scroll Chiller	8x Split
Refrigeration Capacity	15 TR	280 TR	8x 5 kW
PROCEL Efficiency Class	A	C	3 x B, 5 x C
Application of a Dedicated Outdoor Air System (DOAS)	No	Yes	No
Application of a Variable Primary Chilled Water System	No	No	No
Application of Inverter Technology	No	No	No
Operation Temperature	19°C	23°C	20°C
Application of Zone-based Temperature Control	No	No	No
Application of Setback control	No	Yes	No
Appropriate Maintenance Program	No	Yes	No

Regarding case 1, a 12 TR Multi-split (air condensation) with a PROCEL efficiency class A presents a minimum efficiency requirement of 3.22 COP (PROCEL, 2013). Even if it is class A, the higher efficiency encountered for equipment from 5 TR to 50 TR is of 3.81 COP (Tab. 3). Therefore, $E_1 = 0.85$. Since there is no supporting system, $E_2 = 0.9$. For an operation temperature of 19°C, $O_1 = 0.9$. Finally, since it does not apply any system automation and does not present an appropriate maintenance program, $O_2 = 0.82$ and $O_3 = 0.85$. The equipment performance is $E_p = 0.76$ and operation performance is $O_p = 0.63$. The final system performance is $F_p = 0.48$.

On the other hand, the 280 TR Scroll Chiller from case 2 presents a minimum efficiency requirement of 4.9, and the higher efficiency encountered for equipment from 50 TR to 400 TR is 5.5 COP (Tab. 3). Therefore, $E_1 = 0.89$. The application of a DOAS system defines that $E_2 = 1$. For an operation temperature of 23°C, $O_1 = 1$. For the application of Setback control, $O_2 = 0.92$. Finally, there is an appropriate maintenance program and $O_3 = 1$. The equipment performance is $E_p = 0.89$ and operation performance is $O_p = 0.92$. The final system performance is $F_p = 0.82$.

The analysis of case 3 is simpler because isolated systems do not operate with supporting or automation systems,

or regulated maintenance programs. However, the efficiency for the three equipment class B is 5 IDRS and for the five equipment class C is 4.5 IDRS (Diário Oficial da União, 2020). It results in $E = 0.85$. For the operation temperature, $O = 0.95$. The resulting system performance is $F_p = 0.80$.

The results are presented in Tab. 7.

Table 7. Results for the three application cases.

	Case 1	Case 2	Case 3
Final System Performance	48%	82%	80%
Equipment Performance	76%	89%	85%
Operation Performance	63%	92%	95%

The air-conditioning performance assessment can be applied to distinct configurations and support an evaluation of its different performances. It is possible to identify from Tab. 7 that the disregard the facility from case 1 provides for operation performance interfere in their system. The system from case 2 is more steady but the equipment could be replaced for higher performance. The analysis of the system from case 3 is direct, for its lower sizing. However, their equipment may also be replaced for better results. There may be important energy savings potential for these cases in comparison with a high-performance system, the $F_p = 1$ benchmark. Further investments would be required in the considered systems to achieve such energy savings potential. This strategic decision is endorsed by the presented standardized performance assessment of air-conditioning systems.

5. CONCLUSIONS

This paper proposes an evaluation model for measuring the level of energy performance in air-conditioning industrial systems, based on the Key Performance Indicators (KPI) method. The evaluation is direct and standardized, based on easy to access information from the system installation, to deal with energy management barriers related to the lack of information from the facility management. The system is evaluated separately between the equipment performance factors and the operation performance factors, and it is structured by academic and technical literature research. The identified equipment factors are the equipment efficiency level and the adoption of supporting systems. The considered supporting systems are Dedicated Outdoor Air System (DOAS), variable primary chiller water system, or inverter technology. The operation factors are the operation temperature, the adoption of an appropriate maintenance program, and automation systems as zone-based temperature control or setback controls. The factors with higher energy impact are the equipment efficiency level and the adoption of a maintenance program. The proposed air-conditioning assessment supports decision-making in manufacturing environments and enables the comparison between different industrial units.

6. REFERENCES

- ABNT, 2008. “NBR 16 401: Instalações de ar-condicionado - Sistemas centrais e unitários Parte 2: Parâmetros de conforto térmico”.
- ASHRAE, 2019. *Advanced Energy Design Guide for Small to Medium Office Buildings Achieving Zero Energy*. Atlanta. ISBN 9781936504053.
- Bajay, S.V., Gorla, F.D. and Bordoni, O.F.J.G., 2009. “Os Segmentos Industriais Energo-Intensivos De Maiores Potenciais Técnicos De Conservação De Energia No Brasil”. *Revista Brasileira de Energia*, Vol. 15, pp. 89–107.
- Cagno, E. and Trianni, A., 2014. “Evaluating the barriers to specific industrial energy efficiency measures: An exploratory study in small and medium-sized enterprises”. *Journal of Cleaner Production*, Vol. 82, pp. 70–83. ISSN 09596526. doi:10.1016/j.jclepro.2014.06.057. URL <http://dx.doi.org/10.1016/j.jclepro.2014.06.057>.
- CNI, C.N.d.I., 2018. *Mudança do clima e indústria brasileira: iniciativas e recomendações estratégicas para implementação e financiamento da NDC do Brasil*. Brasília. ISBN 9788579571626.
- CNI, C.N.d.I., 2019. *Contribuição da indústria ao mecanismo de desenvolvimento sustentável no acordo de paris*. Brasília.
- De Mello Santana, P.H. and Bajay, S.V., 2016. “New approaches for improving energy efficiency in the Brazilian industry”. *Energy Reports*, Vol. 2, pp. 62–66. ISSN 23524847. doi:10.1016/j.egy.2016.02.001. URL <http://dx.doi.org/10.1016/j.egy.2016.02.001>.
- Diário Oficial da União, 2020. “PORTARIA Nº 234, DE 29 DE JUNHO DE 2020”.
- EPE, E.d.P.E., 2020. *Balanço Energético Nacional 2020: Ano base 2019*.
- European Commission, 2009. “Reference document on best available techniques for energy efficiency”. Technical Report February.
- Fasiuddin, M. and Budaiwi, I., 2011. “HVAC system strategies for energy conservation in commercial buildings in Saudi Arabia”. *Energy and Buildings*, Vol. 43, No. 12, pp. 3457–3466. ISSN 03787788. doi:10.1016/j.enbuild.2011.09.004.

URL <http://dx.doi.org/10.1016/j.enbuild.2011.09.004>.

- Henriques, J. and Catarino, J., 2016. “Motivating towards energy efficiency in small and medium enterprises”. *Journal of Cleaner Production*, Vol. 139, No. 2016, pp. 42–50. ISSN 09596526. doi:10.1016/j.jclepro.2016.08.026.
- IBGE, I.B.d.G.e.E., 2020. *Indicadores IBGE - Contas nacionais trimestrais*, Vol. 8. ISBN 8524008806. URL <http://www.ibge.gov.br/1989>.
- Institute for Building Efficiency, 2012. “Energy Savings from Maintenance”. Technical Report 233, Institute for building efficiency, Washington.
- Jiru, T.E., 2014. “Combining HVAC energy conservation measures to achieve energy savings over standard requirements”. *Energy and Buildings*, Vol. 73, pp. 171–175. ISSN 03787788. doi:10.1016/j.enbuild.2014.01.009. URL <http://dx.doi.org/10.1016/j.enbuild.2014.01.009>.
- Kluczek, A., 2014. “Application of best available techniques in an enterprise producing heating devices”. *Journal of Cleaner Production*, Vol. 83, pp. 444–453. ISSN 09596526. doi:10.1016/j.jclepro.2014.07.056. URL <http://dx.doi.org/10.1016/j.jclepro.2014.07.056>.
- Lima, L.F.D., 2017. “Estudos de Eficiência Energética em Aparelhos Condicionadores de Ar e Técnicas para Redução da Carga Térmica nas Edificações”. p. 132.
- Mathews, E.H., Botha, C.P., Arndt, D.C. and Malan, A., 2001. “HVAC control strategies to enhance comfort and minimise energy usage”. *Energy and Buildings*, Vol. 33, No. 8, pp. 853–863. ISSN 03787788. doi:10.1016/S0378-7788(01)00075-5.
- Menghi, R., Papetti, A., Germani, M. and Marconi, M., 2019. “Energy efficiency of manufacturing systems: A review of energy assessment methods and tools”. *Journal of Cleaner Production*, Vol. 240. ISSN 09596526. doi:10.1016/j.jclepro.2019.118276.
- MMA, M.d.M.A., 2017. *Ar Condicionado: Guia Prático sobre Sistemas de Água Gelada*. ISBN 9788577383412.
- Paxson, T.L., Langston, D.R., Danks, R.A., Benito, B.R., Friedman, G., Gallagher, M.W., Heinemeier, K.H., Lawing, M.J., Lipscomb, B.E., London, P., Prather, D., Ray, G.A., Rodriguez, G., Rossi, D.T., Roth, R.J., Sturgeon, J.O., Warfield, J., Forner, P., Galbreath, D., Halel, D., Pacella, J., Emmerich, S.J., Brundage, D.M., Ferguson, J.M., Gallagher, M.W., Grondzik, W.T., Hedrick, R.L. and Humble, J., 2018. “ANSI/ASHRAE/ACCA Standard 180-2018: Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems”. Technical report, ASHRAE.
- Pena, S.M., 2002. “Sistemas De Ar Condicionado E Refrigeração Procel Programa Nacional De Conservação De Energia Elétrica”. Technical report, PROCEL.
- PROCEL, 2013. “Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas”. Technical report, MINISTÉRIO DO DESENVOLVIMENTO, INDÚSTRIA E COMÉRCIO EXTERIOR, Brasília.
- Rocha, L.R.R. and Monteiro, M.A.G., 2005. *Gestão Energética*. Rio de Janeiro.
- Svensson, A. and Paramonova, S., 2017. “An analytical model for identifying and addressing energy efficiency improvement opportunities in industrial production systems – Model development and testing experiences from Sweden”. *Journal of Cleaner Production*, Vol. 142, No. June 2014, pp. 2407–2422. ISSN 09596526. doi:10.1016/j.jclepro.2016.11.034. URL <http://dx.doi.org/10.1016/j.jclepro.2016.11.034>.
- UN, U.N., 2015. “Transforming our world: the 2030 Agenda for Sustainable Development”. doi:10.1163/157180910X12665776638740.
- Zanardo, R.P., Siluk, J.C.M., de Souza Savian, F. and Schneider, P.S., 2018. “Energy audit model based on a performance evaluation system”. *Energy*, Vol. 154, pp. 544–552. ISSN 03605442. doi:10.1016/j.energy.2018.04.179. URL <https://doi.org/10.1016/j.energy.2018.04.179>.

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