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DIAGNOSTIC AND APPLICATION OF DMAIC METHODOLOGY FOR AIR CONDITIONER MAINTENANCE MANAGEMENT: A CASE STUDY IN A HIGHER EDUCATION INSTITUTION.

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Abstract. *Proper maintenance of air conditioning systems is essential to ensure thermal comfort in various environments, such as homes, businesses, and schools. Lack of maintenance can affect the respiratory health of users, as well as reduce performance, reliability, and increase energy consumption. This case study at the Federal Institute of Education, Science and Technology of Bahia - Jequié Campus uses the Define, Measure, Analyze, Improve, and Control (DMAIC) methodology to manage the maintenance of air conditioning systems and ensure a safe environment. The objectives include diagnosing the management of air conditioning systems and applying the DMAIC methodology. The procedure involves a checklist based on legislation to identify non-conformities, using tools such as the "5W" and the cause and effect matrix. Based on the data, an action plan was developed associated with the Gravity, Urgency, and Tendency (GUT) prioritization matrix. In addition to solving the air conditioning system maintenance problem, this project sought to improve the energy efficiency and maintenance processes of the Institute. It is expected that this proposal will contribute to the protection of air quality and user health, as well as promote the importance of planning and improving maintenance.*

Keywords: *Checklist, Academic environment, Thermal systems.*

1. INTRODUCTION

Maintenance management is a crucial aspect to ensure the efficiency and lifespan of equipment in an organization. Specifically, the maintenance of air conditioners is of utmost importance in enclosed environments as it directly affects air quality and user comfort. According to Garcia (2022), one of the benefits of performing regular maintenance is the prevention of failures in the physical facilities of the production environment Garcia *et al.* (2022).

It is important to highlight that inadequate maintenance of air conditioning systems and ducts can have serious financial and legal consequences for companies and institutions, such as fines exceeding R\$ 200,000 and lawsuits for non-compliance with regulations regarding employees, teachers, and students (Falcão, 2022). Furthermore, maintenance related to Indoor Air Quality (IAQ) has not evolved in the same way as production machinery, as building construction previously aimed only to provide suitable conditions for human activities, without considering IAQ (Silva *et al.*, 2020).

During hotter and colder periods, the use of air conditioning significantly increases, leading to a rise in maintenance requests. This occurs due to the lack of natural air circulation in enclosed spaces, which allows pollutants to accumulate in the filters, turbines, and coils of the equipment. To prevent respiratory diseases caused by these pollutants, it is essential to perform periodic maintenance on the equipment, clearing the filters and increasing the efficiency of the systems (Nascimento, 2021).

Authors such as Nascimento (2021) and Cutrim *et al.* (2019) have mentioned the existence of various methodologies and tools that can be employed in the quality management process to assist in maintenance. These include DMAIC (Define, Measure, Analyze, Improve, and Control), data collection techniques like the Pareto diagram, Ishikawa diagram, and the 5W2H method for action planning. Such tools play a crucial role in understanding quality management and are essential for implementing improvements in an institution's maintenance program.

Therefore, it becomes essential to conduct studies to identify problems and failures in maintenance management. In this context, the use of DMAIC, an internationally recognized methodology, along with tools such as data collection techniques, the GUT matrix, the Ishikawa diagram, and the 5W2H method for action planning, become relevant for

understanding quality management and implementing improvements in an institution’s maintenance program. It is crucial for companies and institutions to perform regular maintenance on air conditioning equipment to prevent respiratory diseases caused by the accumulation of pollutants in the filters, turbines, and coils of the equipment. Additionally, inadequate maintenance can result in severe financial and legal consequences. Therefore, it is necessary to invest in efficient maintenance management to ensure equipment efficiency, longevity, air quality, and user comfort.

1.1 OBJECTIVES

1.1.1 GENERAL OBJECTIVE

To analyze the maintenance management of air conditioning systems in a higher education institution (HEI) through the application of the DMAIC methodology in order to identify inconsistencies and propose technical recommendations.

1.1.2 SPECIFIC OBJECTIVES

- 1.To develop a diagnosis of the maintenance management of air conditioning systems in a higher education institution;
- 2.Enhance the management of air conditioning system maintenance at the higher education institution through the implementation of the DMAIC methodology as an organizational approach to quality tools;
- 3.To propose technical improvements through the implementation of the 5W2H action plan focused on maintenance.

2. MATERIALS AND METHODS

The present research consists of a case study of air conditioning equipment maintenance management in an HEI through the application of the DMAIC methodology. Therefore, in the initial stage, research was conducted in databases such as Scielo, CAPES, and Web of Science to gather information on maintenance management for the analysis of the HEI from January 2019 to June 2023 (Moreira *et al.*, 2019).

Table 1 presents the stages carried out in the case study, using the DMAIC methodology, which is a widely used tool for continuous process improvement. In the **first stage (D-Define)**, the problem was identified and defined through brainstorming, aiming to collect the stakeholders’ perception of the process. In the **second stage (M-Measure)**, data related to the identified problems in the management of air conditioning equipment maintenance were collected from various sources, such as records, reports, checklists, technical inspections, and direct observations. In the **third stage (A-Analyze)**, the collected data were analyzed, and process non-conformities were identified using tools such as cause-and-effect diagrams, prioritization matrices, and the 5 Whys technique. In the **fourth stage (I-Improve)**, based on the collected information and the analyses performed, an action plan was developed to achieve the previously established objectives. This action plan was built sequentially to optimize the entire process of implementing the planned actions. In the **fifth and final stage (C-Control)**, the implementation of the Maintenance, Operation, and Control Plan (MOCP) in the Institute is aimed. This stage aims to ensure the effectiveness of the implemented actions through the execution of a continuous control and monitoring system.

Table 1: DMAIC Application Schedule.

D	M	A	I	C
Define	Measure	Analyze	Improve	Control
Brainstorm	Brainstorm Process Mapping and Recognition	Brainstorm	Action Plan	MOCP
		5 Whys		
		Ishikawa Diagram		
		GUT Prioritization Matrix		

Source: Authors (2023).

In order to obtain the required data for the case study, techniques and tools from Six Sigma quality were employed. Among them, brainstorming stands out, which is a group technique that seeks to generate a large number of ideas in a short period of time. Process mapping was also used, which allows for the visualization of the sequence of activities and the identification of improvement points. Another technique used was the checklist, which was applied to the maintenance coordination of the mentioned campus, as well as to each department that has an installed air conditioning system, in order to identify the main non-conformities and improvement points. This form was developed based on the applicable legislation Resolution-RE No. 09/2003 (BRASIL, 2003) and Law No. 13,589/2018 (BRASIL°, 2018), which allowed for the collection of information such as equipment mapping, maintenance program, inspection analysis regarding cleanliness,

training, and documentation survey.

After applying the checklist, the analysis of the main causes that have led to inconsistencies in the maintenance management of the mentioned equipment was carried out. For this purpose, the cause-and-effect diagram method (Ishikawa diagram), commonly known as the fishbone diagram, developed by Kaoru Ishikawa in 1943, was used. This method allows for the identification of secondary causes of a problem or evaluated situation based on the primary causes (6Ms - Machine, Manpower, Environment, Material, Method, Measurement) Ishikawa and Loftus (1990).

The 5 Whys method, developed by Taiichi Ohno, was used as a complementary technique to the Cause-and-Effect Diagram analysis, aiming to identify the underlying root cause of the analyzed situation Ohno (1982).

The method mentioned above consisted of a sequence of five questions, each one thoroughly exploring the causes behind the identified problem. The focus of the questions presented in Table 2 was directed towards identifying the root cause of the problem in order to establish effective and sustainable corrective measures.

Table 2: 5W Matrix (WHYS) Questions.

WHYS Matrix Questions
Problem: Lack of maintenance of air conditioners in an educational institution
Why is the maintenance of air conditioners not carried out in the educational institution?
Why doesn't the institution have a team for the maintenance of air conditioners?
Why wasn't there an investment in hiring or training employees for the maintenance of air conditioners?
Why is the maintenance of air conditioners not considered a priority or there are no financial resources available?
Why are there other more urgent needs or the allocation of resources for the maintenance of air conditioners was not budgeted?

Source: Authors (2023).

In order to enhance decision-making capabilities in complex scenarios, the GUT Matrix was employed as a prioritization tool. This matrix consists of three factors: Gravity, Urgency, and Tendency. By analyzing these factors, it is possible to calculate the criticality of each situation or problem. The use of the GUT Matrix is widely disseminated in courses and training programs offered by the National School of Public Administration (ENAP) for the development of public servants, as it provides a clear view of priorities and facilitates the decision-making process (Ribeiro *et al.*, 2020).

In the last phase of the research, an action plan called 5W2H was established with the aim of addressing the main identified root causes. In this stage, the activities to be performed, the individuals responsible for each action, deadlines, and required resources were defined.

3. RESULTS AND DISCUSSION

3.1 Checklist - Mapping and Process Recognition

The results of the analysis of the *checklist*, presented simply in Figure 1, and in a comprehensive manner in the table 3, revealed a concerning scenario for the current situation of air conditioning maintenance at the IES (Higher Education Institution), as there is no designated team for this purpose, and out of the 25 analyzed topics, only 3 items are in compliance. As a result, most of the already installed air conditioning units have not received the necessary maintenance. Silva *et al.* (2021) states that this situation has led to frequent problems for students and teachers related to thermal discomfort in classrooms, laboratories, and other environments. Furthermore, the lack of proper maintenance can lead to an accumulation of dirt and bacteria, which can compromise the users' health.

Table 3: Comprehensive checklist of the diagnostic research on the HEI's situation.

Article Itens	Access Link
Checklist	https://abrir.link/c8RXx

Source: Authors (2023).

Moreover, the situation worsens with the 33 units that still need to be installed. Without the presence of a specialized team for installation, it is possible that the new equipment will experience malfunctions already in their first use.

Indoor thermal comfort is a crucial factor, as thermal discomfort can have a significant impact on the quality of life of individuals using these spaces. Additionally, this situation can negatively affect both the learning environment and productivity, resulting in direct consequences for students' performance and the work of teachers Celarino *et al.* (2023). Furthermore, the lack of proper maintenance can result in an accumulation of dirt and bacteria, which can compromise the users' health (BRASIL, 2003).

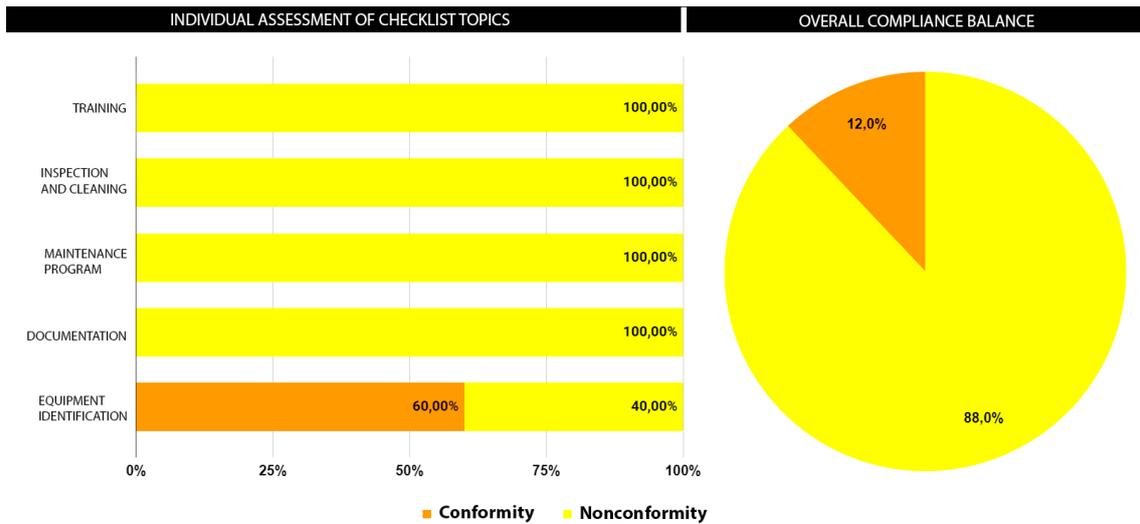


Figure 1. Data from the checklist.
 Source: Authors (2023).

In this sense, it is crucial for the institution, based on technical recommendations, to proceed with the hiring of a specialized maintenance team to ensure the proper functioning of the already installed air conditioning systems and the correct installation of new equipment. Furthermore, it is of paramount importance to implement regular maintenance plans for all equipment, aiming to ensure the well-being of users and the energy efficiency of the institution. Only in this way will it be possible to provide a healthy and comfortable environment for all members of the academic community.

3.2 Ishikawa Diagram

In Figure 2, the application of the Ishikawa diagram is shown, used to analyze the problem of lack of maintenance of air conditioners. This analytical and visual tool helps identify possible root causes of a problem, dividing it into categories such as people, process, product, environment, and equipment.

The application of the cause and effect matrix in equipment maintenance at the institute revealed that the lack/nonexistence of adequate training, standardized procedures, tools, and equipment are common underlying causes for maintenance problems. Additionally, other causes were identified, such as obsolete or inadequate equipment, lack of proper design, accumulation of dirt and debris, air contamination, and lack of data analysis.

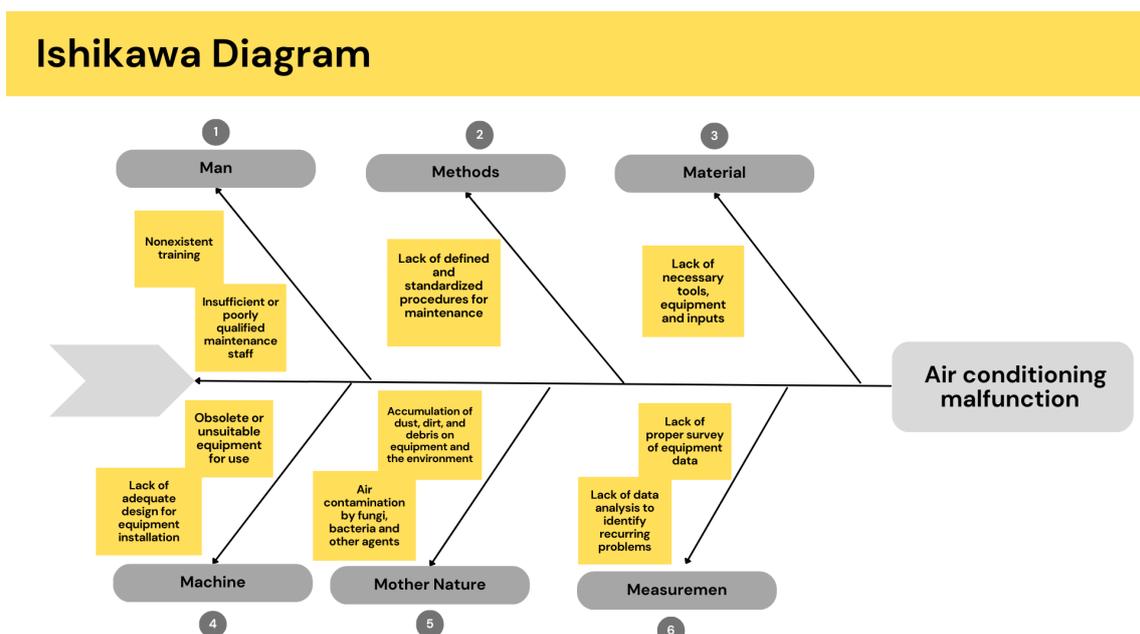


Figure 2. Ishikawa Diagram.
 Source: Authors (2023).

It is important to emphasize that air conditioning maintenance requires a holistic and proactive approach, involving constant monitoring and identification of root causes. The adoption of this approach can reduce costs and improve the efficiency and quality of the maintenance team’s work.

In this sense, it is essential that the maintenance team of the educational institution is properly trained and that standardized procedures are established for maintenance activities. Additionally, it is necessary to provide the appropriate tools and equipment for carrying out maintenance tasks.

Finally, there needs to be constant data analysis and measures taken to prevent future problems. With this approach, the Institute will be able to ensure efficient and quality maintenance of its equipment, resulting in cost reduction and improved efficiency of the maintenance team.

3.3 5-Whys Matrix (5W)

Table ?? applied the 5-Whys matrix to the lack of air conditioning maintenance in the educational institution, revealing a serious root cause.

Table 4: MATRIX OF THE 5 WHYS (5W).

5W MATRIX (WHYS)	
Problem: Lack of air conditioning maintenance at the institute	
Why does the institute not perform air conditioning maintenance?	Because IFBA does not have an air conditioning maintenance team.
Why does the institute not have an air conditioning maintenance team?	Because no investment has been made in hiring or training employees for this function.
Why has there been no investment in hiring or training employees for air conditioning maintenance?	Because it may not have been considered a priority or there may be no financial resources available.
Why is air conditioning maintenance not considered a priority or there are no financial resources available?	There may be other more urgent needs or the allocation of resources for this purpose was not planned in the budget.
Why are there other more urgent needs or the allocation of resources for air conditioning maintenance was not planned in the budget?	This may be the result of a lack of proper planning or a misguided prioritization of the campus’s needs.

Source: Authors (2023).

It has been identified that the lack of proper maintenance of the equipment can result from a lack of adequate planning or a misguided prioritization of campus needs. This lack of planning may be related to a series of factors, such as the lack of a proper budget for equipment maintenance, inefficient management of available resources, or a lack of attention to the deadlines for preventive maintenance of the equipment. Furthermore, a misguided prioritization of campus needs may have led to inadequate allocation of resources, prioritizing other areas at the expense of proper maintenance of air conditioning units.

Constant and proper maintenance of cooling systems in federal institutes is crucial to ensure proper functioning, avoid problems, losses, and interruptions in production, and provide a comfortable and healthy environment for users. The lack of maintenance compromises product quality, user comfort, and can lead to frequent problems, affecting both equipment performance and the health of those who frequent these spaces Ito *et al.* (2023). In addition, poorly maintained equipment can consume more energy, resulting in a significant increase in electricity costs.

Therefore, it is essential for the higher education institute to review its planning and resource management processes to ensure that proper maintenance of air conditioning units is a priority. Moreover, it is important to implement regular preventive maintenance plans to ensure proper equipment functioning and user safety. Only then will it be possible to guarantee a healthy and comfortable learning and working environment for all members of the academic community.

3.4 GUT prioritization matrix

In table 5, the GUT prioritization matrix was used to evaluate the management of the existing air conditioning equipment in the Institute. The activities that had the highest impact and required greater attention were the inventory of existing equipment, identification of maintenance needs, planning of maintenance actions, and execution of corrective maintenance for the equipment. Activities of medium priority included diagnosis of equipment condition and verification of maintenance results. Activities of low priority were the acquisition of necessary materials and equipment, training of maintenance personnel, and periodic evaluation of the maintenance plan. Based on these results, an action plan can be developed to prioritize critical activities and improve the management of air conditioning equipment.

Table 5: PRIORIZATION MATRIX - GUT

PRIORITIZATION MATRIX- GUT						
	Gravity (G)	Urgency (U)	Trend (T)	Total (GUT)	Priority	Order of priority

Survey of existing air conditioning equipment	4	5	4	80	Loud	1°
Diagnosis of the state of the equipment	3	4	3	36	Average	5°
Identification of maintenance needs	4	5	4	80	Loud	2°
Planning of maintenance actions	4	5	4	80	Loud	3°
Acquisition of the necessary materials and equipment	2	2	2	8	Low	10°
Execution of corrective maintenance of equipment	4	5	4	80	Loud	4°
Verification of maintenance results	3	4	3	36	Average	6°
Implementation of preventive maintenance plan	3	3	3	27	Average	7°
Training of employees responsible for maintenance	2	1	2	4	Low	9°
Periodic evaluation of the maintenance plan	3	3	3	27	Average	8°

Source: Authors (2023).

3.5 Action Plan - 5W2H

After a thorough analysis of the current status of the air conditioning equipment in the IES and the application of all these maintenance management tools, the need to implement an action plan to solve the identified problems was evident. In this sense, it is essential to use the 5W2H method, which proves to be efficient in organizing and executing actions, as it addresses in a clear and objective manner the aspects related to the planning and execution of the necessary activities. By applying the 5W2H action plan, it is expected to achieve effective results in improving the performance of the equipment and, consequently, the thermal comfort of the campus users.

Table 6: 5W2H Action Plan.

ACTION PLAN - 5W2H						
What?	Why?	Who?	When?	Where?	How?	How much?
Conduct equipment inventory	Identify the quantity of equipment, models, and current conditions	Technical team	1st Week	In all campus sectors	Using standardized inventory forms	No cost
1.1. Divide campus sectors	Facilitate the organization of the inventory	Technical team	1st Week	In all campus sectors	Defining the areas of responsibility for each member of the technical team	No cost
1.2. Check equipment locations	Identify the distribution of equipment on campus	Technical team	1st Week	In all campus sectors	Using campus maps and conducting inspections in the sectors	No cost
1.3. Fill out the inventory form	Record equipment information	Technical team	1st Week	In all campus sectors	Using the standardized form	No cost
Develop preventive maintenance schedule	Ensure maintenance predictions and reduce future problems	Maintenance Coordinator	2nd Week	Maintenance coordination office	Using standardized electronic spreadsheets	No cost
2.1. Analyze inventory information	Identify the need for preventive maintenance for each equipment	Maintenance Coordinator	2nd Week	Maintenance coordination office	Using information from the inventory form	No cost
2.2. Define dates for preventive maintenance	Establish the preventive maintenance schedule based on the needs of each equipment	Maintenance Coordinator	2nd Week	Maintenance coordination office	Using the standardized electronic spreadsheet	No cost
Select specialized company for corrective maintenance	Ensure service quality and prompt problem resolution	Maintenance Coordinator	1st month	Maintenance coordination office	Checking registered companies in the institution and conducting customer satisfaction surveys	No cost
3.1. Check registered companies in the institution	Identify companies that provide air conditioning maintenance services	Maintenance Coordinator	1st month	Maintenance coordination office	Accessing the institution's database	No cost
3.2. Conduct customer satisfaction surveys	Evaluate the quality of services provided by registered companies	Maintenance Coordinator	1st month	Maintenance coordination office	Conducting interviews with customers of registered companies	No cost
3.3. Select the company with the best evaluation	Hire the company with the best evaluation in the satisfaction survey	Maintenance Coordinator	1st month	Maintenance coordination office	Analyzing survey results and selecting the chosen company	Depends on bidding

Establish action plan for corrective maintenance	Ensure promptness and effectiveness in problem resolution	Technical team and selected company	2nd month	In all campus sectors	Conducting inspections and defining the action plan for each identified problem	No cost
4.1. Identify equipment problems	Identify and record the identified problems	Technical team	2nd month	In all campus sectors	Conducting inspections and using standardized forms	No cost
4.2. Prioritize corrective maintenance demands	Establish a priority order to address the identified problems	Maintenance Coordinator	2nd month	Maintenance coordination office	Using the information recorded in the problem identification form	No cost
4.3. Define the action plan for each problem	Establish the necessary actions to solve each identified problem	Technical team and selected company	2nd month	In all campus sectors	Using the problem identification form and specialized technical knowledge	No cost
Execute action plan for corrective maintenance	Solve the identified problems	Technical team and selected company	3rd and 4th months	In all campus sectors	Implementing the actions defined in the action plan	Depends on bidding
5.1. Monitor the execution of the action plan	Monitor the progress of the actions defined for each problem	Maintenance Coordinator	3rd and 4th months	In all campus sectors	Conducting inspections and monitoring the work of the technical team and selected company	Depends on bidding
5.2. Verify the effectiveness of the maintenance actions	Verify if the actions defined in the maintenance plan were effective in solving the identified equipment problems	Maintenance Coordinator and technical team	3rd and 4th months	In all campus sectors	Conducting tests on the equipment and checking if the problem was resolved	Depends on bidding
5.3. Make adjustments to the action plan if necessary	Make adjustments to the defined actions if the identified problems have not been resolved	Technical team and selected company	3rd and 4th months	In all campus sectors	Gathering information about the equipment, defining the necessary actions, and hiring specialized companies	No cost
Development of the Maintenance, Operation, and Control Plan (MOCP)	Plan actions for the maintenance of air conditioning equipment according to current legislation	Technical Supervisor with support from the technical team	5th month	Office defined by the Technical Supervisor	Using information from the equipment inventory, analysis of equipment condition, and current legislation	Depends on bidding
6.1. Implementation of the MOCP	Execute the actions defined in the MOCP	Technical team	5th month	In all rooms with equipment	Implementing the planned actions in the MOCP	No cost
6.2. Monitoring the MOCP	Verify if the MOCP is being followed and identify the need for adjustments	Technical Supervisor with support from the technical team	5th month	Office defined by the Technical Supervisor	Analyzing maintenance records and evaluating the equipment condition	Depends on the company that won the bidding
Implementation of a Maintenance Management System	Efficiently manage equipment maintenance activities	Maintenance Coordinator	After MOCP implementation	Maintenance coordination office	Selecting specialized maintenance management software, implementing the system, and training the technical team	No cost
7.1. Selection of specialized maintenance management software	Select software that meets the institution's needs	Maintenance Coordinator	After MOCP implementation	Maintenance coordination office	Conducting research, analyzing features and costs of available software in the market	R50toR5000
7.2. Implementation of the Maintenance Management System	Install and configure the selected software	Technical team	After MOCP implementation	Maintenance coordination office	Performing necessary configurations in the system and integrating it with equipment information	No cost

Source: Authors (2023).

3.6 Maintenance, Operation, and Control Plan (MOCP)

As a future outcome, the creation of the Maintenance, Operation, and Control Plan (MOCP) for the air conditioners of the IES is highlighted. The MOCP establishes guidelines and procedures for the maintenance of air conditioning systems, aiming to ensure indoor air quality and energy efficiency of the equipment.

With the creation of the MOCP, it will be possible to establish a schedule for preventive and corrective maintenance of the air conditioners, define responsibilities of the professionals involved in maintenance, and establish criteria for selecting service providers and products related to the maintenance of air conditioning systems.

The implementation of the MOCP will contribute to reducing maintenance costs, ensuring indoor air quality and energy efficiency of the equipment, as well as promoting the safety and comfort of users in the institution's air-conditioned environments.

4. FINAL CONSIDERATIONS

In the scope of the case study conducted at the higher education institution (IES), focusing on the management of air conditioner maintenance, it can be concluded that the proposed objectives were satisfactorily achieved. The comprehensive diagnosis allowed for the identification of significant problems that were affecting the performance and availability of the equipment.

Among the main problems identified, the lack of adequate planning, a misguided prioritization of campus needs, and the complete absence of preventive maintenance of the air conditioners stood out. These issues were addressed through the application of the DMAIC methodology, which provided a structured approach for their resolution.

Based on the results obtained from the application of DMAIC, technical improvements were proposed for maintenance management, aiming to establish a preventive maintenance plan, prioritize needs based on equipment criticality, and train the maintenance team to perform their activities efficiently.

The research limitations are related to the constraints encountered in the campus context, as it is a higher education institute. The implementation of changes and improvements is subject to bureaucratic procedures, such as approvals, allocation of financial resources, bidding processes, and other administrative procedures. These processes can be time-consuming and present additional challenges for the implementation of proposed technical improvements. Additionally, the availability of financial resources may be limited, which affects the feasibility of some measures due to budgetary constraints. Therefore, it is essential to consider these limitations and seek the appropriate institutional support to implement the proposed changes in order to achieve the desired results in the management of air conditioner maintenance.

A suggestion for future studies would be to analyze the implementation of the Maintenance, Operation, and Control Plan (MOCP) in the context of air conditioner maintenance management. The MOCP is a regulatory requirement established by Ordinance No. 3,523/1998 of the Brazilian Ministry of Health, with the aim of ensuring indoor air quality in air-conditioned environments, promoting health and well-being of occupants.

The case study conducted at the higher education institution demonstrated the effectiveness of applying the DMAIC methodology in the management of air conditioner maintenance. It is expected that this experience can serve as a reference for other institutions facing similar challenges, providing a structured approach to identify and solve problems, thereby improving the performance and efficiency of air conditioning systems.

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