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Optimization of the asset management process in the education sector. Case study a chilled water plant

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EXECUTIVE SUMMARY

The academic sector, like any other service or industrial sector, requires constant innovation in each of its processes. In Colombia, the Universidad EAFIT, as part of the search for new ways of teaching and learning, has recognized the significance of making learning spaces suitable for the people involved in this process. In consequence the above, the project described in this book chapter shows the most efficient methodology for the optimization of asset management for the Universidad EAFIT Ice Water Plant. The methodology used, include key concepts and factors such as availability, maintainability and reliability in the costs related to the behavior and nature of the failures, having as reference an integral model of the maintenance management process. The objective of this project is to maintain these high standards of operation and maintenance throughout the useful life of the system. Also, to show the importance that maintenance and the methodologies associated with it have in any sector or industry.

Keywords: Thermal District, Life Cycle Cost Analysis, Availability, Reliability, Maintainability, Key Performance Indicators, Mean Time To Repair, Mean Time Between Failures, Thermal Comfort.

ORGANIZATION BACKGROUND

Born on May 4, 1960, the Universidad EAFIT was created with the purpose of training the future leaders of a region defined by the strength and spirit of entrepreneurship of its inhabitants (Medellín - Colombia). It currently has a high-quality institutional accreditation recognition issued by the Ministerio de Educación of Colombia in 2003, being the first private institution in Antioquia to receive it. It has been renewed in 2010 and 2018, obtaining the distinction with honors on the last occasion covering a validity period until 2026 (EAFIT, 2018). This certification is a clear example of EAFIT's commitment to its stakeholders and the quality of the services it offers. Likewise, it is ranked in positions 801-1000 of the QS World University Rankings (Symonds, 2021b) and in 57th place in Latin America (Symonds, 2021a). It is relevant to highlight that all its undergraduate programs with accreditation capacity have this endorsement. The university' s openness to new areas of knowledge is what gives true meaning to the concept of university, which is evidenced in the academic offerings including 25 undergraduate programs, 65 specialized programs, 33 master's degrees and 4 doctorates. All the above are divided among the schools of Administration, Engineering, Sciences, Humanities, Law, and Economics and Finance.

Since its creation and with the passing of time, the University has defined different strategies as an organization that denote its objectives and goals for the future. Among these is the brand vision that can be summarized in the phrase "Inspire, Create, transform", which seeks to ratify EAFIT as a contemporary university in continuous change. This vision is carried out by a governance system that divides administration and financial resources into key areas: learning, in charge of academics; social projection, focused on social, economic, and cultural impact; and finally, the area of discovery and creation focused on research and generation of new knowledge (EAFIT, 2019). Along with this vision, the University has set challenges of the external world that are planned to be solved in the Institutional Development Plan for 2020-2024 (EAFIT, 2016b). Among these challenges are the following: Fourth industrial revolution and new labor demands, 21st century skills and new learning-centered pedagogies, and Human development and sustainability (EAFIT, 2020). These challenges are focusing the most critical points in which the university gathers its efforts towards developing them in an optimal way while satisfying the students', employees', the city’s, and the world's necessities. All the above-mentioned institutional strategies aim to create a quality education ecosystem that inspires the life of current generations, builds knowledge, and transforms society.

As part of the quality management system of Universidad EAFIT, there are different measurements of the activity execution carried out by the company. The percentage at which a starting point is set for a measurement system to be evaluated is 88% based on internal policy, according to the established standards. This percentage is based on internal studies, always considering which is the baseline of the measurement. Each indicator below this threshold must have an action plan with follow-up actions and final reporting. Although the quality management system does not include metrics for maintenance indicators, the case evaluated in this document may serve as a basis for establishing, measuring, and evaluating them from now on.

SETTING THE STAGE

Among the most important challenges that Universidad EAFIT faces are the new pedagogies and the evolution of the way of teaching. The university is committed to continuously improve the learning environment through constant evolution supported by information and communication technologies. In addition, the university seeks to provide an infrastructure that allows students to develop their full potential and benefit from a more comprehensive education. We can summarize this challenge in the need to transform traditional models into student-centered methodologies. The context and study spaces are key to students' states of comfort and concentration. Many environment-related variables come into play here, influencing the state of satisfaction of everyone within a space. Atmospheric variables are prominent in this section, among them are air temperature, air speed and relative humidity.

Several standards are used worldwide to regulate the use of cooling and heating systems for enclosed spaces. Among these are International Standardization Organization with the standard (ISO), ISO 7730, ANSI/ASHRAE-55 (ASHRAE, 2020). It has been questioned its use in tropical countries due to its formulation having as a methodical basis country with diverse climates and seasons, however, they are the standards that are currently implemented in Colombia; especially the AHSRAE-55 that is referenced in the NTC 5316 norm (Natarajan et al., 2015). A thermal comfort can be understood as a mental condition that expresses satisfaction with the thermal environment, according to the various standards. Therefore, the importance of an adequate temperature of a space in learning moments is evidenced since mental satisfaction allows students to concentrate and absorb the academic content without worrying or feeling uncomfortable due to the environmental conditions. The university has equipped its learning spaces such as classrooms, conference rooms, auditoriums and other learning spaces with technology that enhances the feeling of comfort. Such technology contributes to the students' concentration, the development of a better learning environment, and the comfort of the classrooms and learning moments.

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The cooling system is one of the most influential equipment in the environment configuration, because it allows to adjust the temperature of each of the spaces. Since its creation in 1902 by Willis Haviland Carrier, the topic has been discussed (Carrier, 2021) and only around 1930 was created the first company that started manufacturing this type of equipment in New York, USA (Serrano, 2013). Given the size of modern buildings, a high-capacity cooling infrastructure is necessary to meet the needs and provide comfort to its occupants. Within these industrial infrastructures are the Thermal Districts, which according to the types of equipment available in the current market can produce high volumes of cold air to be distributed to different buildings.

The development of Universidad EAFIT infrastructure has brought needs along with engineering challenges associated with a modern industry of the 21st century. The advances in the industry provide a better experience when it comes to learning, due to the use of tools, programs, and systems capable of meeting the challenges posed. Along the line of infrastructure, the University has an extension of 100,000 square meters of built area in the Medellin campus, which the company has established standards for its construction. These can range from technological devices with 3D telepresence up to the study of specific temperatures and humidity in each of the spaces. This depends on the specific characteristics of the activities for which the space will be used in the university.

Due to the great variety and quantity of spaces that the university has, along with the high demand and constant change of usage of each space, it is necessary to have a system that has the capacity to read and adapt effectively and efficiently to these changing flows. This need emerges from the large amount of energy that the cooling and heating systems use when they are in operation. Moreover, being a constant and repetitive task means that it can be subject to optimization and continuous improvement processes that can reduce the fixed costs associated with, for example, utilities. Furthermore, knowing the magnitude and size of the systems in question, it is of great importance the estimation of the costs related to their life cycle. Also considering that this equipment is conceived with a useful life of many years of operation, the costs associated with the phases after the planning and acquisition of the equipment become important due to the share that they can eventually reach within the total costs.

The life cycle of an asset can be understood as the time span that exists between the initial stage of identifying the need and the final disposal or replacement of the same. This interval of time can include everything related to the development, acquisition, operation logistics, maintenance, updating and the abandonment or disposal of the asset. To estimate the resources required for the previously mentioned processes, in other words, the life cycle, there is a technique called life cycle cost analysis (LCA). This is understood as the sum of the costs of each of these stages. These techniques and strategies have the objective of determining the cost related to each of the phases supported by various mathematical, statistical, and technological tools. Different methodologies can be found in the literature (Blanchard, 2001; Blanchard & Fabrycky, 1998; Goffin, 2000; Markeset &Kumar, 2001; Smith & Knezevic, 1996; Woodward, 1997) that have been developed over the years and that have aimed at evaluating the costs throughout the service life of the assets; the main differences between these methodologies lie in the phases that are included and the weight that some of them have in comparison to the total.

The Woodward model stands out for proposing a cost structure on which the impact of major failures can be evaluated in a simple way. It starts with the identification of the failures, their nature, frequency, and cost impact on the expected lifetime keeping the failure rate constant over the expected lifetime. The inclusion of failures throughout the life cycle is mainly due to the absence of estimates in relation to the unexpected failures that arise from overconfidence in the equipment or technical ignorance about them. (Parra & Crespo Marquez, 2019). The Life Cycle Cost Analysis (LCCA) methodology consists in finding out all the fixed and variable costs that exist in the life of a piece of equipment or system. Aspects such as reliability, availability, maintenance optimization methodologies, machine learning, artificial intelligence, etc. are considered in this analysis. (Crespo et.al, 2018). This article explores life cycle cost analysis within an integral model of the maintenance management (MGM) process (Crespo et.al, 2019). After analyzing the different models of life cycle cost analysis, it is selected because of its capacity of homologation in different areas, i.e., the possibility of adapting each of the phases to the industrial processes of the case under study. In addition, it achieves the inclusion of key and relevant concepts such as availability, maintainability, and reliability in the costs. These concepts related to the behavior and nature of the failures, considering as reference an integral model of the maintenance management process (MGM). Figure 1 shows the sequence of the phases proposed in this model.

CASE DESCRIPTION

In this case the whole model is applied on the case study of the Universidad EAFIT chilled water plant. Further elaborating the case in question, it starts from a centrifugal chiller with the capacity to produce 1500 tons of cooling, to supply approximately 100,000 square meters of construction. After identifying the need, it is possible to proceed with the development of the model that guides the implementation and development of the project (Crespo et.al, 2019).

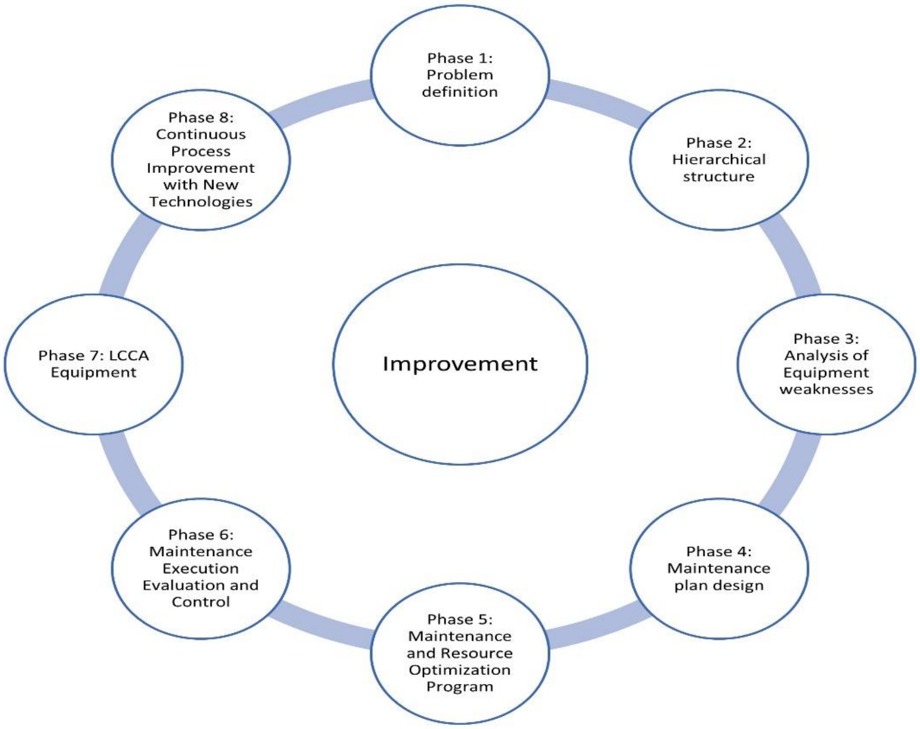

Figure 1:Maintenance management process integrated model (MGM) (Crespo et.al, 2018)

To obtain the highest efficiency of the entire system, and this form achieving the best possible utilization of each equipment, it was thought that the complete automation of the ice water plant was the most appropriate option. The control system (CPO) will give us all the basic information to carry out a maintenance management with KPIs, starting from the most critical situation to evaluate until reaching the point of having total control of the variables that can be controlled in the operation of the process such as electricity, electronics, mechanics, refrigeration, and other issues that influence the process. The KPIs are the starting point in time to measure, control, analyze and improve every day the system of the Ice Water Plant.

As part of the process of figuring out how to optimize the process of optimizing the chilled water plant system, a smart system was thought about. This system, which will have the task of controlling, managing, and deciding the operation of this system, is called CPO (Central Plant Optimization) and its main function is to reduce utility costs, particularly electricity. It is responsible of optimizing the selection of "free variable" set points (equipment load and temperature / flow / pressure levels), maximizing efficiency, and minimizing utility costs over a period. This will all be dependent on the time of analysis where the system operates at the highest available load under its production capacity, in the most adverse environmental conditions for which it was designed. This is because it is a system in constant variation and is continually reevaluating how to operate according to the needs presented, directing its operation to the maximum energy efficiency available, which ultimately leads to budget efficiency.

The feasibility of purchasing two types of technologies for the main equipment (Chiller) was evaluated during the construction of the project. This process analyzed which would be the best technology "Centrifugal or Magnetic" depending on energy consumption, warranty time, maintenance costs. Additionally, process variables were considered, such as points of better efficiency in partial loads of chilled water production and environmental working conditions, among others. At Universidad EAFIT there is an average energy consumption of 650,000 kW / h / month, of which approximately 30% belongs to the production of air conditioning. Currently the average cost per kW / h is $ 350 Colombian pesos ($COP), which gives us an average expenditure of $ 68,000,000 COP per month, not including maintenance costs. The quantification of the constructed meters of buildings that the University would have was projected at the beginning of the project to define the installed production capacity. The analysis concluded that 2500 Tons of Refrigeration (TR) would be gradually needed during the next 15 to 20 years. At the start of the market analysis, the company JCI Inc. was already known, having approximately 100 years of experience in the production of large-scale equipment in this environment. Along with this company, it was carried out the analysis of the construction of such a system. It was concluded the necessity of implementing an intelligent control system with the ability to think and analyze by itself, in addition to changing its behavior according to the needs of the buildings as seen in Figure 2.

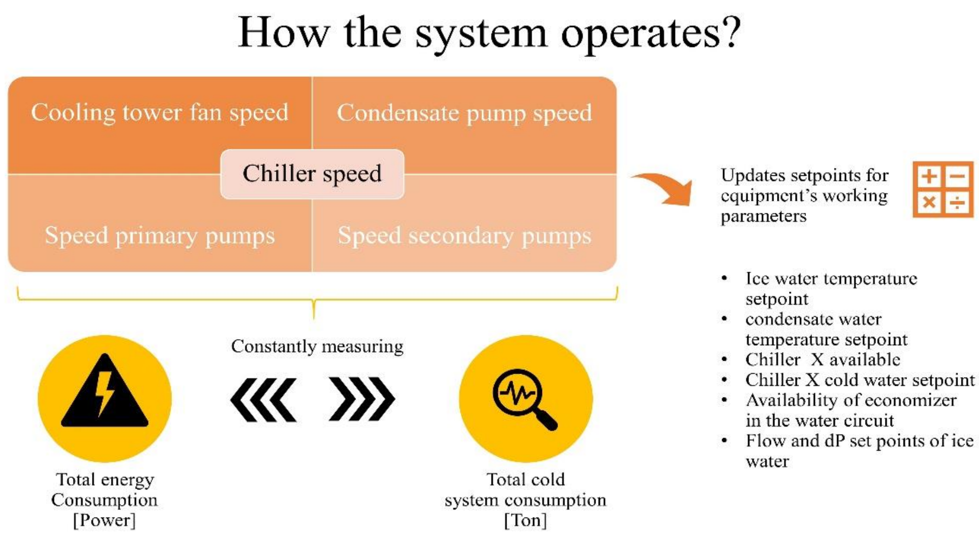

Figure 2: system operation diagram (Johnson Controls, 2018).

It can be seen in Figure 3 the software migration from a basic logic to one based on mathematics and statistics through the self-correction of the working conditions according to the demand.

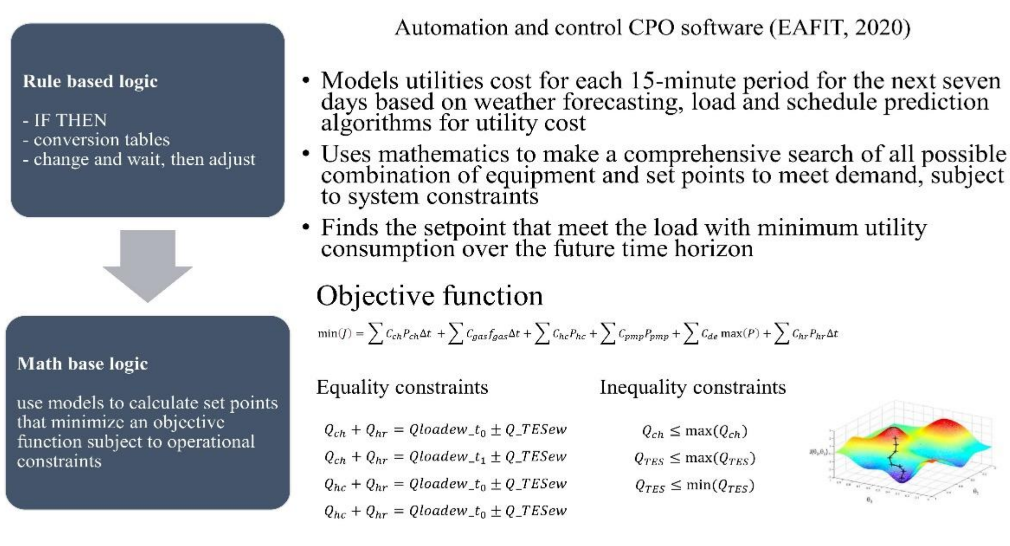

Figure 2: Control logic approach of the CPO system JCI (Johnson Controls, 2018).

It is also shown how the approach of the CPO control system is based on an algorithm that predicts the future time horizon of the load based on the constant measurement of variables (temperature, humidity, flow, etc.) and its consumption history. The efficiency curves of the equipment it controls (pumps, fans and mainly chillers) are also considered. The purpose of autonomous control is to have the optimum energy consumption that each equipment can offer, and consequently have the best possible performance of the system. Therefore, less maintenance time and lower costs are obtained by making the most of the operation. Figure 4 shows how the input variables are turned into the working parameters of each of the machines after performing the analysis and prediction for system optimization. It is noteworthy that this is a process that occurs every 15 minutes of operation.

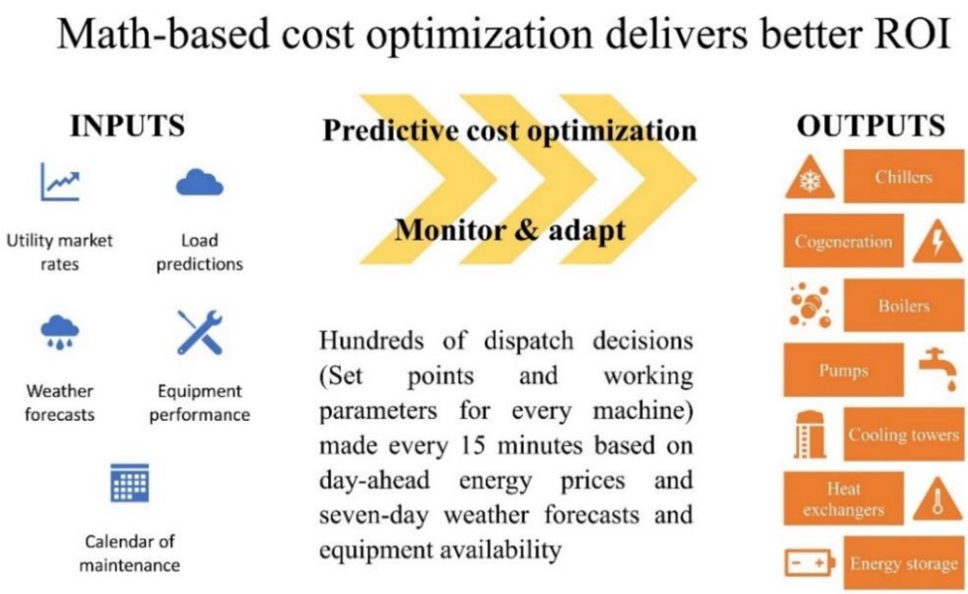

Figure 3: Optimization and operating costs of the report JCI (Johnson Controls, 2018)

Monitoring is carried out in real time, the system measures the climatic variables (see figure 5) of the area where it is located, which in conjunction with the variables collected allow better decision making. Future forecasts are made to optimize the energy consumption of the chilled water plant without sacrificing its purpose, which in this case is to maintain an adequate temperature that allows thermal comfort in the operating spaces.

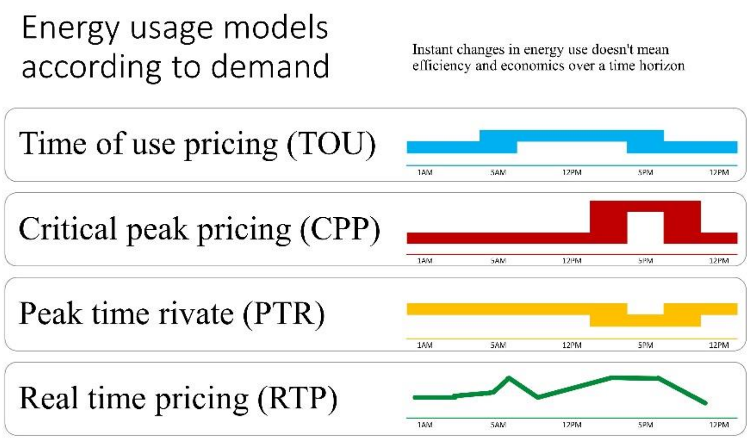

Figure 5: Time pricing diagrams of the CPO system (Johnson Controls, 2020)

It is possible to establish that small improvements in the operating parameters of these equipments generate a considerable reduction in the total energy used in the building, given the percentages over the total represented by the cooling and heating systems. The chillers in particular will be the equipment with the highest consumption in the chilled water plant, without neglecting the cooling towers and pumps. This can be evidenced in Figure 6.

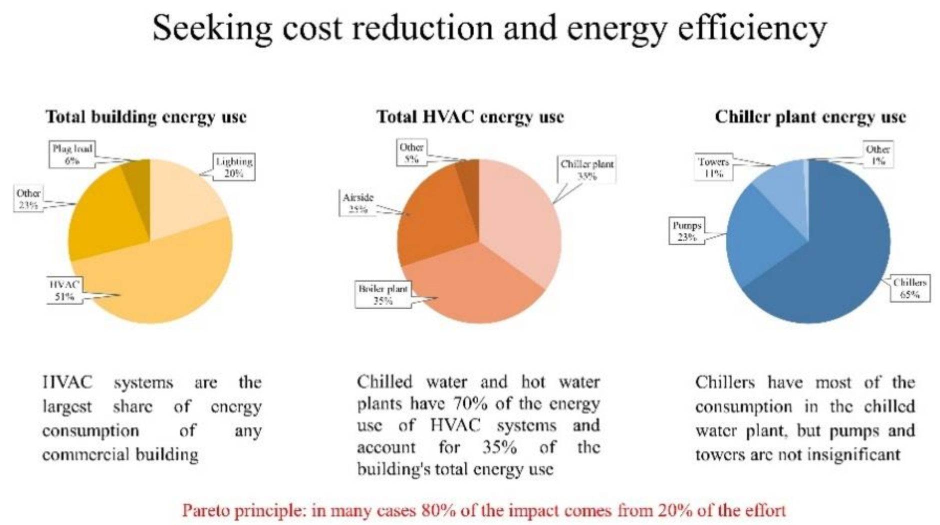

Figure 6: Efficiency-based reduction of the report JCI (Johnson Controls, 2018)

Considering all the above, it is possible to store equipment operation and demand data over time, which increases the reliability of the program's predictions by having a larger volume of data to analyze. This guarantees that every day the operations are more efficient, improving the lifespan of the equipment since they are kept in optimal operating conditions. It is then possible to determine the efficiency of the plant system based on the variables to be measured. This allows to classify it in a precise scale and know with certainty the quantitative and qualitative level in which it is, in terms of efficiency as shown in Figure 7.

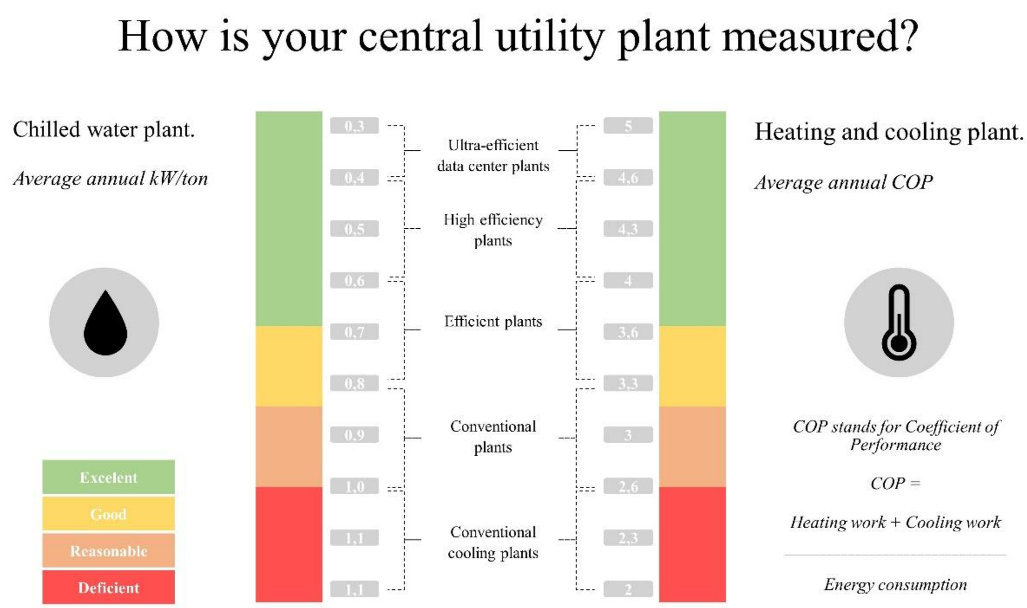

Figure 7: Complete system efficiency measurement of the report JCI (Johnson Controls, 2018)

The system measures to optimize the consumption and reach the efficiency curves that the equipment manufacturers make, it achieves the optimal levels of operation, always focused on reducing operating costs, optimizing, and increasing the lifetime of the equipment against the operating costs of a system of Thermal Districts. Through the CPO optimization program of the plant, it is possible to extract fundamental data needed for the indicator's calculation presented later in the document. This makes the program an essential tool in the analysis of the life cycle of the asset.

Integrated phased model description for the chilled water plant.

Having a clear understanding of the development of the operation of the Chilled Water Plant automation system, the technical and financial estimates are made for each of the phases mentioned above:

- Phase 1: Provide comfort to the facilities of the main campus of Universidad EAFIT. As part of the development and vision of Universidad EAFIT and to provide the best conditions for the development of academic activities, the issue of temperature comfort in the different spaces became a priority. In its investigations and trying to raise this, it hires expert market firms on the subject and studies international standards (ASCHRAE). The conclusion is that the temperature for the operation of its facilities is 23°C +- 1°C. Given the size of the facilities of the Universidad EAFIT with its 100,000 square meters built. It is very complex to provide a comprehensive solution that is energetically and economically feasible to have low costs in the operation of the campus.

  Energy consumption: With the aim of optimizing the resources that the university's directives make available for this type of development. It is important to keep in mind that solutions were seek in the market that were energetically profitable to produce 1 TR at the lowest kW/h cost. Furthermore, over time, it has become a relevant part within the companies with high impact on reputation, economic and other factors associated with the business. The impact of not providing this type of services and how this affects the corporate image from the economic point of view has become a significant factor, in the case study you could be talking about approximately 20%.

- Phase 2: Define high-priority cooling equipment and pumping systems. With the criteria mentioned below, market analyses are carried out to define what type of technologies, brands, technical support, operation, and maintenance costs may become the most profitable over time.

  - Lower electricity consumption in Centrifugal type chillers with capacities of 1000 TR
  - Lower generation cost per kW/TR consumed.
  - Lower maintenance intervention

  The primary performance indicator for this evaluation was the national maintenance service, given the importance of the chilled water plant for business continuity as a default standard in the management of Universidad EAFIT.

- Phase 3: Evaluate the weaknesses in the operation and cost of the chillers and pumping systems based on the manufacturers' data sheets. Table A expands the information used to evaluate the selection criteria found in the Chiller which is listed below:

  - Technical support in Colombia, lower power consumption and efficiencies not less than 95% are prioritized in the equipment under evaluation.
  - Technical criteria for the operation.

In the evaluation (see Table A), the JCI brand equipment is the one that presents the best performance and most of all operating costs, including kW/TR, maintenance costs, operating costs and. Finally, the LCC analysis provides the conclusion of which is the optimal equipment for the system.

Water chillers - Universidad EAFIT central cooling plant					Equipment installation cost/1000 ($)	Annual maintenance cost/1000 ($)	Total cost alternative/1000 ($)	Annual energy consumption (kWh) ($)	Peak electric demand (kW) ($)
Supplier	Equipment Specifications								
DAIKIN	Model: WTCGADAD52R	Capacity: 1000 TR	Efficiency: 0.5008 kW/TR	Oil	1.220.764	11.626	1.232.390	945.910	531
JOHNSON CONTROLS	Model: YKMBMSH9-EXG	Capacity: 1000 TR	Efficiency: 0.5188 kW/TR	Oil	967.952	24.973	992.924	943.616	549
TRANE	Model: CVHF1070	Capacity: 1000 TR	Efficiency: 0.4893 kW/TR	Oil	1.045.418	29.683	1.075.101	1.045.442	519
TRANE	Model: CVHF0870	Capacity: 1000 TR	Efficiency: 0.5103 kW/TR	Oil	1.011.937	29.683	1.041.620	1.028.866	540

Water chillers - Universidad EAFIT central cooling plant					Annual water consumption (1000 gal)	Cost of electric energy per year/1000 ($)	Annual water cost/1000 ($)	Total cost of utilities per year/1000 ($)	Life cycle cost/1000 ($)
DAIKIN	Model: WTCGADAD52R	Capacity: 1000 TR	Efficiency: 0.5008 kW/TR	Oil	2.951	310.211	39.362	349.573	3.980.448
JOHNSON CONTROLS	Model: YKMBMSH9-EXG	Capacity: 1000 TR	Efficiency: 0.5188 kW/TR	Oil	2.952	309.459	39.384	348.843	3.865.525
TRANE	Model: CVHF1070	Capacity: 1000 TR	Efficiency: 0.4893 kW/TR	Oil	2.983	342.853	39.795	382.648	4.244.662
TRANE	Model: CVHF0870	Capacity: 1000 TR	Efficiency: 0.5103 kW/TR	Oil	2.980	337.417	39.747	377.164	4.171.382

Table A. Technical-financial evaluation of the Chiller (EAFIT, 2017).

- Phase 4: Define maintenance plans and costs under the manufacturer's recommendations and equipment operation times.
    - Chiller maintenance costs with the times established by the manufacturer: Table B shows the maintenance costs by equipment.

<table>
<tr><th colspan="3">Water chillers - Universidad EAFIT central cooling plant</th><th>Annual maintenance cost/1000 ($ Millions COP)</th></tr>
<tr><th>Supplier</th><th colspan="2">Equipment Specifications</th><td rowspan="5">11.626</td></tr>
<tr><td rowspan="4">DAIKIN</td><td>Model</td><td>WTCGADAD52R</td></tr>
<tr><td>Capacity</td><td>1000 TR</td></tr>
<tr><td>Efficiency</td><td>0.5008 kW/TR</td></tr>
<tr><td colspan="2">Oil</td></tr>
<tr><td rowspan="4">JOHNSON CONTROLS</td><td>Model</td><td>YKMBMSH9-EXG</td><td rowspan="4">24.973</td></tr>
<tr><td>Capacity</td><td>1000 TR</td></tr>
<tr><td>Efficiency</td><td>0.5188 kW/TR</td></tr>
<tr><td colspan="2">Oil</td></tr>
<tr><td rowspan="8">TRANE</td><td>Model</td><td>CVHF1070</td><td rowspan="4">29.683</td></tr>
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<tr><td>Efficiency</td><td>0.5103 kW/TR</td></tr>
<tr><td colspan="2">Oil</td></tr>
</table>

Table B. Financial evaluation of the maintenance costs of the Chiller (EAFIT, 2017).

- Phase 5: Search for new lower cost alternatives without sacrificing the target need defined in the maintenance plan. Making emphasis on trust and local availability of the service, the execution of maintenance plans for all the equipment of the thermal district is done with the manufacturers and/or main distributors of each of the brands. All of this with the purpose of guaranteeing the highest availability.

- Phase 6: Define protocols within the maintenance plans to control the time and economic resources of all maintenance activities in critical equipment. Regarding the criticality of the equipment, there is a great advantage of having redundant equipment in the chilled water plant. This is because the current capacity of cold generation is not the total consumed by the total load of the University.

- Phase 7: Perform life cycle cost analysis of chillers as a high priority asset of the Chilled Water Plant in the acquisition.

To carry out this financial analysis, data from the year 2017 and the required Colombian market indicators were used - Market Representative Rate (TRM) 3010.77 COP and value added tax (VAT) 19%. Aimed at having an estimated time, the study that will be seen below (see Table C), had a 20-year projection of utilization. The depreciation was made in a linear basis during this same time and a 5% inflation or annual economic increase on each value included in the study.

- The analysis of the LCC of the main equipment of the chilled water plant shows that it is a specific technology (Centrifuge in Oil) which is comparable to the other brands. Given its incidence in the Colombian market, it offers us good economic margins when compared to the other two companies (JCI).

Water chillers - Universidad EAFIT central cooling plant			**Life cycle cost / 1000**
Supplier	**Equipment Specifications**		
DAIKIN	Model	WTCGADAD52R	$ 3.980.447,76
	Capacity	1000 TR	
	Efficiency	0.5008 kW/TR	
	Oil		
JOHNSON CONTROLS	Model	YKMBMSH9-EXG	$ 3.865.525,09
	Capacity	1000 TR	
	Efficiency	0.5188 kW/TR	
	Oil		
TRANE	Model	CVHF1070	$ 4.244.661,60
	Capacity	1000 TR	
	Efficiency	0.4893 kW/TR	
	Oil		
	Model	CVHF0870	$ 4.171.381,83
	Capacity	1000 TR	
	Efficiency	0.5103 kW/TR	
	Oil		

Table C. Financial Evaluation of the CCV of the Equipment of the Ice Water Plant, (EAFIT, 2017).

- Phase 8: Analyze and model new technologies of resource utilization to improve maintenance strategies without sacrificing equipment lifespan at the Universidad EAFIT chilled water plant. The above considers the operational data of the system, the execution of tasks and the experience of the manufacturer. Having an artificial intelligence system, which is in a constant learning process, enables it to be at the leading edge of how the comfort service is offered.

  Additionally. It can decide how to consume and save resources at the same time, even if it is an industrial system of the size in mind. Mankind has realized over the years that autonomous systems help improve and have the technical, financial stability and viability to make such a large investment project attractive to the company's investors. The daily challenge with this type of development is to sustain and improve with the constant evaluation of data capture at all times of the artificial intelligence system (CPO). This is one of the ways to enhance maintenance strategies, constant indicators, correct evaluation and progressively increase the criteria to be measured. This is the way to sustain and, in some cases, increase the useful life of an industrial system.

Maintenance Management Indicators for the Chilled Water Plant

Two essential data are obtained after ensuring the complete evaluation of the system. This data is essential to measure and further guarantee the conditions offered by the manufacturers of the chilled water plant equipment. The KPIs (Key Performance Indicators) are the metrics used in maintenance management, with the purpose of measuring the operating conditions of our industrial systems, which helps to the continuous improvement within operations. Based on the book of Effective Industrial Maintenance - Mora, A. (2018), which explains to us how to achieve the MTBF and MTTR indicators that are the basis for measuring system performance.

The MTTR (MEAN TIME TO REPAIR) - Mora, A. (2018). Mean time to repair, represents one of the maintenance indicators. It is used in the management and development of the work of the same environment, as it is said, this indicator represents the time it takes to resolve failures of the asset in question when it suffers a breakdown, until it is brought to normal operating conditions. According to Equation (1).

$$\boldsymbol{MTTR} = \frac{\boldsymbol{TOTAL\ MAINTENANCE\ TIME}}{\boldsymbol{NUMBER\ OF\ INTERVENTIONS}} \quad (1)$$

The MTBF (MEAN TIME BETWEEN FAILURES) - Mora, A. (2018). Mean time between failures, is another maintenance indicator. It is used for the reliability in the operation of the equipment or system. It is really the average time between failures/faults that an equipment has, and the next event occurs. According to Equation (2)

$$\boldsymbol{MTBF} = \frac{\boldsymbol{TOTAL\ WORK\ TIME - AVERAGE\ BREAKDOWN\ TIME}}{\boldsymbol{NUMBER\ OF\ FAILURES}} \quad (2)$$

For our case, reference values were taken from the chilled water plant for a one-year timeline as well as the records of the central computer of the chilled water system:

In Table D, each of the failures of the complete system will be evidenced and the most common failure mode will be taken as a sample. This will be used to perform the MTBF and MTTR calculations and thus be able to obtain the three main indicators. These will provide us with a guideline to follow along with the measurements over time of the operation of the complete system.

Failures from March 2019 to March 2020				
Item	**Failures**	**Quantity (Units)**	**Downtime (Total Hours)**	**Comments**
1	Electrical variations of the power supply network	48	7	These can be interruptions, overvoltage's, gaps, transients and under voltages.
2	Problems on seals	9	1	
3	Failures in pump pressure switches	5	2	Badly seized at some point in time or dirt in the liquid
4	Inverter failures	30	1	Internal blocking due to electrical and/or electronic issues
5	Failures in chiller pressure switches	15	4	Badly seized at some point in time or dirt in the liquid
6	Fan lockout	15	3	Mechanical failures
7	Chiller subcooling	2	1	Low system load
TOTAL		**124**		
Note: This information is downloaded from the log that is evidenced by the chiller on its internal memory.				

Table D. Chilled Water Plant Failure Table (EAFIT, 2020b)

The most common failure mode, corresponding to electrical failures, accumulated a total of 48 out of 124 failures overall, being 38.71%. These common failure mode data are supported by the Power Monitor Expert (PME) electrical monitoring system as shown in Figure 8, which corresponds to the period from March 2019 to March 2020. The program allows 24/7 monitoring of the electrical consumption of all campus spaces, to have clarity on these consumptions and the nature of the electrical failures that occur in the chilled water plant system.

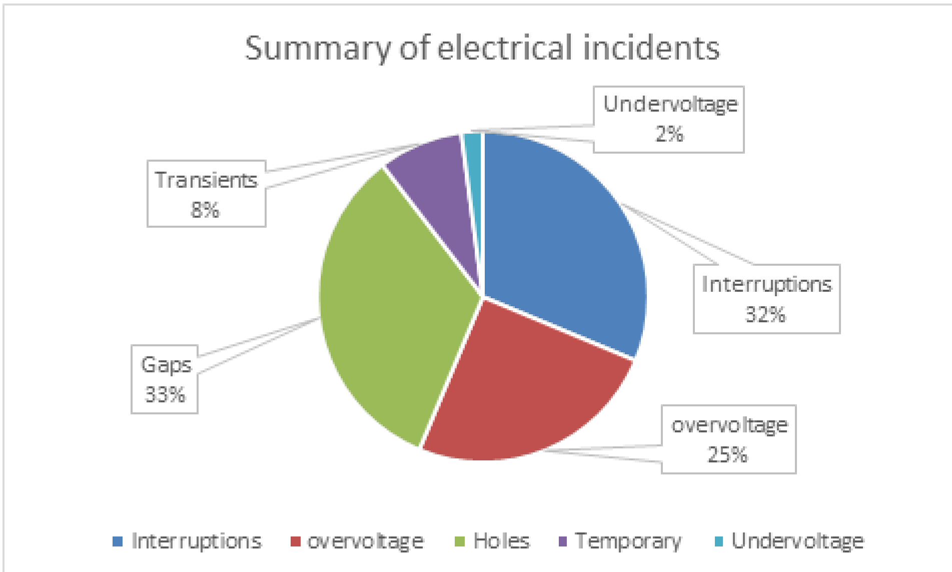

Figure 8: Graph of electrical incidents of the Ice Water Plant - (EAFIT, 2020)

For the MBTF and MTTR calculations, under the scenario being evaluated, the following would be used: It should be highlighted that the data below were taken in the year span from March 2019 to March 2020.

Equation (1) is used to calculate the MTTR:

TOTAL MAINTENANCE TIME: Corresponds to the sum of all the hours of the various types of maintenance on the chilled water plant equipment.

60 hours of Preventive Maintenance + 19 hours of Corrective Maintenance = 79 hours.

NUMBER OF INTERVENTIONS: Corresponds to the number of failures and preventive maintenance to the equipment during a year of evaluation.

124 failures + 12 preventive maintenance interventions = 136 interventions.

$$\text{MTTR}= \frac{79}{136} = 0.58$$

Equation (2) is used to calculate the MTBF:

TOTAL WORK TIME: These are the hours the system is operated without interruptions for a year.

(85 Working Hours per Week * 44 Working Weeks per Year) = 3740 hours.

DOWN TIME: Is the time the system was unavailable during one year of operation 19 Hours.

NUMBER OF FAILURES: It is the number of times the system presented a non-operation event.

124 failures

$$\text{MTBF}= \frac{3740-19}{124} = 30{,}00$$

When the two base indicators MTTR and MTBF have been calculated, it proceeds by calculating the three main measurement data of maintenance management, based on the form of expression - Mora, A. (2018):

Availability is the time available to produce or function and the total downtime.

Considering Equation (3) Mora, A. (2018).

$$\text{Availability} = \frac{\textbf{MTBF}}{\textbf{MTBF+MTTR}} = \frac{30{,}00}{30{,}00+0.58} = 0.98 = 98\%$$

Reliability is the probability that the equipment or system will function correctly for a specific period (Friedrich & Ardenghi, 2009).

Considering equation (4)

$$\text{Reliability} = \boldsymbol{e}^{-\frac{\boldsymbol{t}}{\textbf{MTBF}}} = e^{-\frac{1}{30}} = 0.9672 = 96.72\%$$

Maintainability is the probability that the system or asset could be repaired or intervened in a specific period.

Equation (5) is considered, Mora, A. (2018).

$$\text{Availability} = \frac{\text{Reliability}}{\text{Reliability} + \text{Maintainability}}$$

The equation 4 and 5 data are used to obtain the Maintainability variable, which would be equation (6):

$$\text{Maintainability} = \text{Reliability}\ \left(\frac{\mathbf{1}}{\text{Availability}} - \mathbf{1}\right) = 0.9672\left(\frac{\mathbf{1}}{\mathbf{0.98}} - \mathbf{1}\right) = 0.0197 = 1.97\%$$

It is worth noting that the period covered by the data used to solve the equations is from March 2019 to March 2020, bearing in mind that the common failure modes are only related to the electrical system.

Organizational Challenges of the Project

Now, the most important challenges that Universidad EAFIT has with this project are mainly in the ongoing installation of the automation system due to the continuous interruptions that have occurred because of the global contingency due to COVID-19. This has delayed the company to have the complete implementation of the system and has delayed the profit opportunity for the initially agreed time of the project of approximately 7 years. Furthermore, it is a challenge to initiate, control, analyze and sustain over time the percentages of the maintenance management variables that have been calculated as a starting basis for the chilled water plant system.

Currently there are very few studies where asset management optimization methodologies are applied in the educational field. This sector, which does not belong to the industrial sector, but rather to the service sector, generally does not include world-class operation and maintenance strategies in its processes. Universidad EAFIT seeks with this research to create an awareness that will allow other organizations dedicated to education to measure and evaluate variables. These include reliability, maintainability, and availability so that they can support decisions in each of their operation and maintenance processes and therefore be able to execute more efficient asset management strategies. Other projects carried out at Universidad EAFIT have established the relevance of maintenance in Colombian companies. They have established which have been the most used technologies in the country in maintenance management, which have helped to improve the processes in both industrial and service organizations and making them more efficient (Dueñas & Villegas 2020a). These and several other studies (Dueñas-Ramirez et al., 2020b; Ramírez-Guerrero et al., 2020; Dueñas-Ramirez & Villegas, 2020c; Martinod et al., 2019; Martinod et al., 2018) that have preceded this work allowed the University to broaden its vision in maintenance. The knowledge acquired in the educational and research fields is now being applied in its own organization at operational, tactical, and strategic levels of maintenance.

SOLUTIONS AND RECOMMENDATIONS

The project had a total cost of US $ 1.2 million, of which approximately US $ 643,000 corresponds to the chillers, assets to which the Life Cycle Cost Analysis (LCCA) was performed. The result was a total cost of COP 8,500 million for its 20 years of operation granted by the manufacturer (JCI Inc).

The Universidad EAFIT Chilled Water Plant will have an estimated projection of expansion within 5 years to install another 1000 TR chiller, resulting in a total capacity of 2500 TR and a total cost of the system of 1.6 million $USD. The initial analysis of the project in its initial phases, has a return on investment (ROI) of approximately 7 years.

It is the object of development of this chapter to demonstrate the LCCA of the main equipment. It is also to define why it is feasible to build a thermal district to provide air conditioning to buildings of great magnitude, where all needs are covered for that final goal. Within the market research, in the analysis of the LCCV of the chilled water plant priority equipment, an estimate is made for 20 years of operation costs compared to the benefits obtained. It is concluded that it is an attractive and viable proposal for an overall return of 7 years regarding the whole project lifespan. This is estimated to be approximately 30 years, based on the technical data sheets provided by the manufacturers.

Since this system is vital for the development of academic services that Universidad EAFIT offers to its entire community, it is important and vital to ensure the development of the educational activities. The purpose of all this is to always offer the best way and methodology to deliver knowledge to human beings. In the service model of providing comfort services to large areas, like Universidad EAFIT, with approximately 100,000 m2, it becomes totally feasible to purchase chilled water plants. The return-on-investment time vs. consumption costs with its benefits are fully justifiable for the need of the facility.

The result of the measurement of the maintenance variables validates the constant operation of the system over time. This confirms the proper operation of the equipment that make up the chilled water plant. Everything is aimed at maximizing the quality of the services provided by the academy in the Colombian market. In addition to applying cutting-edge methodologies within the education industry, EAFIT stands out in a sector with low research in internal operations and low academic production. KPIs are the best way to implement a way to measure and sustain over time a methodology or model that helps deliver a better service. For the study case, it is proposed to measure the variables every month to ensure reliability, availability, and maintainability over time above the standards that Universidad EAFIT establishes as a goal. Additionally, to be able to have a methodological basis for constant monitoring.

As future work and research in the area, it is suggested to continue and extend the correct measurement of these variables to the most critical failure modes according to their impact on service, costs and operation that may arise within the chilled water plant. This allows the company to visualize an actionable scenario soon in which there will be greater control of resources and equipment wear over time. This practice constitutes the beginning of the maintenance management within the most expensive industrial system of the company, which justifies a correct development and progression in the research of the same. According to the calculations of the maintenance indicators, availability and reliability are directly proportional to maintainability. This is explained by the relative new condition of the systems, given that it is a very new system and that the factory conditions prevail in the operation during the first years. It is evident that these indicators are in accordance with the correct operation of the system currently in place, ruled by the fact that it is a system that has been in operation for a short time. This is very useful for the development of the methodology of constant measurement that will be implemented. Given that we have total control of the functions of the equipment, and it is possible to know from the beginning of day one of all the equipment how it behaves over time and under the projection that the study was carried out. The percentages obtained from the study, the availability and reliability are over 95%, which is very favorable considering that the equipment purchase was based on the premise that its efficiency should be over 95% minimum. In the case of maintainability, it is low since the intervention times in terms of man hours are very low, which reaffirms the high value of the two previous indicators.

Finally, in the indicator standards of the quality management system of Universidad EAFIT, the percentages above 88% represent results that comply with the proper management and excellent service provision for the development of academic activities. The recommended monthly measurement is intended to ensure that the systems remain above 95% availability and reliability to avoid failing in the promise of service.

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