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Best Management Practices in Design, Construction, and Maintenance of Mechanical Systems in Data Centers

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Abstract. This purpose of this research study is to evaluate the challenges faced during the project definition, design, construction, and maintenance phase of mechanical systems projects for new Data Centers or existing Data Centers. Construction industry professionals, design professionals, data center management and engineering personnel were surveyed. The survey questionnaire comprised of 27 questions and focused on the following themes: General information and respondent's area of knowledge and experience, Overall Management Challenges in Data Centers, Challenges specific to data center mechanical systems, standard management practices and processes employed in data center mechanical projects and recommendation and suggestions to arrive at best management practices in mechanical systems projects for data centers. The results of the survey were evaluated to arrive at best management practices to better assist in building reliable data centers.

Keywords: Data centers, mechanical systems, best management practices

1 Introduction

Data centers are mission critical facilities that typically contain thousands of data processing equipment, such as servers, switches, and routers. In recent years, there has been a boom in data center usage, leading their energy consumption to grow by about 10% a year continuously. The heat generated in these data centers must be removed to prevent high temperatures from degrading their reliability, which would cost additional energy [1]. Data center owners and operators face high stakes challenges, as poor decisions can lead to difficulties that must be dealt with for decades [2].

Failure of any mission critical system due to the disability in equipment, software, process, results in the failure of business operations. It is not rare for a data center power outage to happen. According to a survey that is conducted by the Emerson Network Power and Ponemon Institute in 2010 95% of the data centers has unplanned outages. The outage can cost a business an average of $300,000 in just 1 hour ($5,600 per minute). Respondents averaged 2.48 complete data center shutdowns over a two-year period, with an average duration of 107 mins. The root cause analysis shows that among the top seven causes of unplanned outage are insufficient cooling, load capacity issues, and heat-related/computer room air conditioner (CRAC) failure.

2 Research Objective and Data Centers

The objective of this study is to identify factors and challenges associated with mechanical systems projects in data centers and to establish best management practices that would focus on a dynamic and collaborative approach involving all stakeholders in delivering a data center that would meet the desired needs, thus eliminating the need for redesign or upgrade in a couple of years. Whether one is planning to build a new data center, leasing capacity in a collocated data center, or retrofitting an existing data center to expand its capacity, careful planning, coordination, and collaboration needs to happen amongst all stakeholders to understand the requirements. This is the backbone to laying the foundation of success for mechanical system in data centers.

3 Data Center Design Requirements

3.1 Tier Classifications

There are four levels of a data center, based on the infrastructure requirements. The simplest is a Level 1 data center, which is basically a server room. The most stringent level is a Level 4 data center, which is designed to host the most mission critical computer systems, with the ability to continuously operate for an indefinite period during power outages [3].

Tier 1: Basic – Per TIA-942-A (2014 edition), the HVAC system of a Basic facility includes single or multiple air conditioning units with the combined cooling capacity to maintain critical space temperature with no redundant units. If a generator is provided, all air-conditioning equipment should be powered by the standby generator system. Associated with less than 28.8 hours of downtime/year.

Tier 2: Redundant Components – The HVAC system of a Redundant Component facility includes multiple air conditioning units with the combined cooling capacity with one redundant unit (N+1). Air-conditioning systems should be designed for continuous operation 7 days/24 hours/365 days/year, and incorporate a minimum of N+1 redundancy in the Computer Room Air Conditioning (CRAC) units. The computer room air conditioners (CRAC) system should be provided with N+1 redundancy, with a minimum of one redundant unit for every three or four required units. All air-conditioning equipment should be powered by the standby generator system. Associated with less than 22 hours of downtime/year.

Tier 3: Concurrent Maintenance – The HVAC system of a Concurrently Maintainable facility includes multiple air conditioning units with the combined cooling capacity to maintain critical space temperature and relative humidity at design conditions, with sufficient redundant units to allow failure of or service to one electrical switchboard. This level of redundancy can be obtained by either furnishing two sources of power to each air conditioning unit, or dividing the air conditioning equipment among multiple sources of power. The piping system or systems are dual path, whereby a failure of or maintenance to a section of pipe will not cause interruption of the air conditioning system. Redundant computer room air conditioning (CRAC) units should be served from separate panels to provide electrical redundancy. All computer room air conditioners (CRAC) units should be backed up by generator power. Refrigeration equipment with N+1, N+2, 2N, or 2(N+1) redundancy should be dedicated to the data center. Associated with less than 1.6 hours of downtime/year.

Tier 4: Fault Tolerant – The HVAC system of a Fault Tolerant facility includes multiple air conditioning units with the combined cooling capacity to maintain critical space temperature and relative humidity at design conditions, with sufficient redundant units to allow failure of or service to one electrical switchboard. If a water-side heat rejection system serves these air conditioning units, such as a chilled water or condenser water system, the components of these systems are likewise sized to maintain design conditions, with one electrical switchboard removed from service. This level of redundancy can be obtained by either furnishing two sources of power to each air conditioning unit, or dividing the air conditioning equipment among multiple sources of power. The piping system or systems are dual path, whereby a failure of or maintenance to a section of pipe will not cause interruption of the air conditioning system. Associated with less than 0.4 hours of downtime/year [4].

3.2 Energy Consumption

The energy consumption of the data centers has accounted for 1% of total electricity consumption. Today, data centers are facing soaring energy prices, coupled with increased energy consumption due to increases in server processing power and a greater demand for cooling [5]. Power has become a major expense and therefore, energy efficiency is now a top concern. In 2005, 1.2% of the total U.S. energy consumption was attributed to the server-driven power usage [6]. Of this usage, the energy consumption by the electronic components of the IT made up about 50%, and cooling systems about 40%. In simple terms, 1 kWh of energy consumed by the IT equipment requires another 1 kWh of energy to drive the cooling and auxiliary systems.

3.3 Efficiency & Total Cost of Ownership

The data center industry uses the measurement PUE, or power usage effectiveness, to measure efficiency [7]. A PUE of 2.0 means that for every watt of IT power, an additional watt is consumed to cool and distribute power to the IT equipment. A PUE closer to 1.0 means nearly all the energy is used for computing [8].

A data center is one of the most financially concentrated assets of any business. The capital and operational costs for the physical infrastructure may be comparable to, or larger than all supported IT assets. Sometimes, decision makers just focus on the upfront costs but are not aware about the long-term costs, especially the operating and maintenance costs [9].

Predicting TCO for your physical data center infrastructure is essential to return on investment (ROI) analysis and other business decision processes. Over a 20-year lifespan of the 50 million USD facility, you would spend three to five times the capital costs on operational expenses, with as much as half of that cost—the single largest element on energy. As a result, energy-related electrical and mechanical systems may account for approximately 60 percent of the data center's capital cost and 50 percent of the ongoing operational cost [10].

So, it is essential, that close cooperation between your information technology (IT) and facilities team, designer of record, builder, and operations team is a start to assuring that the appropriate trade-offs between capital investment and operating costs are met over the life of the facility, while supporting the budget, growth requirements and green data center goals.

3.4 Cooling Process

The sole purpose of data center cooling technology is to maintain environmental conditions suitable for information technology equipment (ITE) operation. Achieving this goal requires removing the heat produced by the ITE and transferring that heat to some heat sink. In most data centers, the operators expect the cooling system to operate continuously and reliably [11]. For decades, computer rooms and data centers utilized raised floor systems to deliver cold air to servers. Cold air from a computer room air conditioner (CRAC) or computer room air handler (CRAH) pressurized the space below the raised floor. Perforated tiles provide a means for the cold air to leave the plenum and enter the main space—ideally in front of server intakes. After passing through the server, the heated air is returned to the CRAC/CRAH to be cooled, usually after mixing with the cold air. The primary benefit of a raised floor, from a cooling standpoint, is to deliver cold air where it is needed, with very little effort, by simply swapping a solid tile for a perforated tile.

3.5 Factors affecting Mechanical Systems in Data Center Projects

Heat Load – The most significant factor affecting mechanical system data center projects is heat load. This includes the total heat to be rejected and the density of that heat. Traditionally, data centers have measured heat density in watts per square foot. The construction cost of the data center can be significantly affected by are the design power density and the level of reliability [12]. Design professionals should carefully determine heat loads, and consider developing phased plans for the installation of mechanical and matching cooling equipment to meet IT requirements, so that it makes the most cost-effective sense, requiring infrastructure costs only to be expended when required. Technology Changes – Data center managers will replace servers three times before they replace cooling systems, so the design must be flexible enough to accommodate several technology changes during the life of the facility and must ensure that infrastructure technologies will be able to scale to support future needs [13]. Owners, designers, IT data center mangers, and operators should also take into consideration, that during the initial start-up and first year of operation of the data center could require the mechanical systems to operate with little or no computing equipment load [14]. Airflow – Careful consideration should be given to airflow produced by the cooling system meet the ITE requirement [15]. Of the numerous ventilation schemes, the team should be able to choose which one is the best for cooling the ITE requirement and minimize airflow distribution problems [16]. Site Location – Climatic Conditions, Temperature, and Humidity. The team will have to determine what the temperature and humidity should be in the space as it affects the operation of the ITE. For new data centers, site location and climatic conditions will also need to be evaluated [17].

4 Research Methodology & Analysis

To better understand mechanical systems projects in data centers, a survey questionnaire was distributed via a web-based service called SurveyMonkey™ (http://www.surveymonkey.com) to 96 executives. The survey population consisted of IT Managers, Mechanical Designers, Construction Contractors, Facility Engineers, Operations and Maintenance Personnel, and Project Managers representing different phases of project cycle for data center projects. The questionnaire comprised of 27 questions and was divided into 4 sections: General Information and Respondents area of knowledge and experience, Overall Management Challenges in Data Centers, Challenges Specific to Data Center Mechanical Systems Projects, and Organization Approach/Management Practices. The Questionnaire survey was open for 21 days. Approximately 30% of the 96 respondents completed the online survey.

4.1 General Information and Respondents Area of Knowledge & Experience

In Section 1, questions 1-5, respondents were asked provide information regarding their domain knowledge and area of experience, preferred acquisition, cause and impacts of budget constraints. Majority of the respondents were Mechanical Designers (43%), followed by Construction Personnel comprising of Project Managers, Builders, CM at Risk, Project Engineers, Construction Quality Control Representatives (36%), Facilities Engineering and Operations Personnel (18%).

Design-Build-Build was considered the most appropriate acquisition strategy by 45% of the respondents as requirements can be better defined. 38% of respondents chose Design-Build for delivering projects faster. Similarly, 75% of the respondents surveyed indicated that budgets constraints affected their projects. This was attributed to lack of deep-domain expertise of mechanical systems during the assessment phase which resulted in poorly defined requirements and poorly allocated budgets.

4.2 Overall Management Challenges in Data Centers

In Section 2, respondents were queried on management related issues. Questions 6-8 validated the need for better project definition during the assessment and planning phases. Most respondents believed poorly defined requirements (undersized cooling and load requirements, not being able to predict capacity and future needs) were the major challenges facing the data center industry. Almost 96% of the respondents confirmed the need to have all stakeholders engaged during the assessment and planning phase. However, when queried whether their team involved all stakeholders during the assessment phase, only 55% confirmed in the affirmative.

4.3 Challenges Specific to Data Center Mechanical Systems

In Section 3, respondents were asked a total of 13 questions which helped identify challenges specific to Data Center Mechanical Systems projects. Poor Capacity Planning, Efficiency, Reliability, Redundancy of equipment, failure to consider exiting conditions, project constraints, space constraints and colocation, failure to plan for future growth/over engineering, failure to address airflow issues, and failure to address temperature and humidity issues, were some of the major challenges identified and are shown in Figure 1.

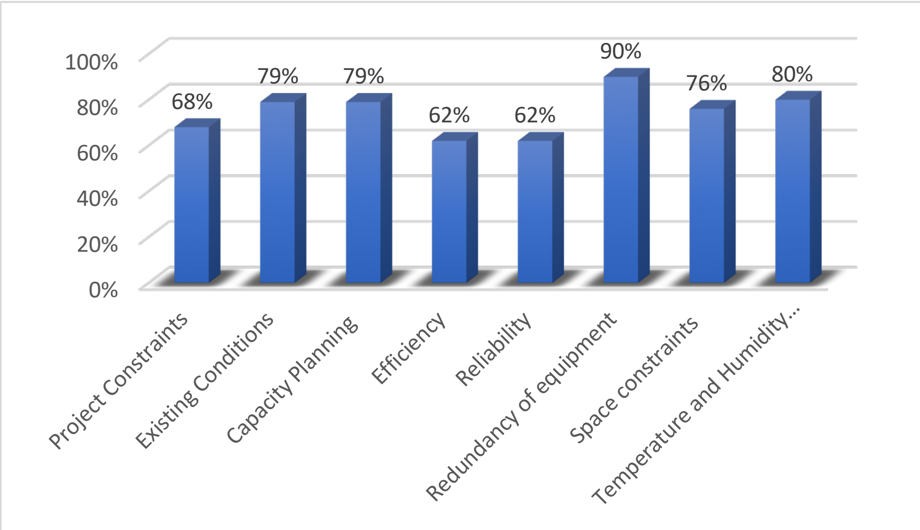

Fig. 1. Major Challenges associated with Mechanical System in Data Centers.

In this section, respondents emphasized the need to evaluate current technological trends, especially where legacy systems (ITE and Mechanical) were involved, as stakeholders were less likely to consider new technology for renovations/upgrades of such systems. On an average 70% of respondents confirmed, in such projects careful consideration must be given to technological advances and changes, energy modelling, energy and water conservation measures, redundancy of equipment, temperature, and humidity control. Similarly, use of engineering resources to meet industry standards and manufacturing guidelines, and Building Automation Controls in such projects was encouraged. Respondents also identified the need to plan for commissioning on critical components of mechanical systems during assessment phase and then performing integrated testing/commissioning during the execution phase as critical element. Respondents indicated that commissioning should be routinely performed during the maintenance phase. 48% of respondents stressed the need to focus on Maintenance Planning, be it load balancing, maintaining the cooling system, or simply ensuring that data center stays clean and well-managed to ensure uptime. Even though, only 18% of respondents felt the need to evaluate Total Cost of Ownership (TCO), careful consideration should be given as this would eventually help better predict capital and operational expenditure costs, resulting in validated budgets.

4.4 Organizational Approach and Management Practices

The last set of questions gave an insight into the organization approach and management practices. Understanding the culture of an industry or an organization is the key to establishing practices that will lead a team to successful projects and to getting it right the *First Time*. Overall, 88% of the respondents indicated that their organization and management was committed to establishing processes and practices that would result in project success. An area of concern that was noted, is that only 58% of the respondents believed that management was committed to self-improvement and allocated enough funds for training.

5 Conclusions

Based on the analysis, some best management practices have been identified. *Organization and Management:* Organizations and Management should support strategic planning to achieve flexibility and scalability and reliability in a data center. Management should support innovation, promote stakeholder engagement, self-improvement initiatives by providing sufficient training opportunities. *Team Identification:* As soon as a requirement becomes known, it is imperative that all stakeholder groups are on board. All stakeholders should collaborate, communicate, and be actively engaged in visualizing every aspect of the data center requirements.

Assessment/Project Definition: Assessments provide all stakeholders with a baseline at which to start. The goals of these assessments are to capture weaknesses in the facility, define requirements and to assist in controlling operational expense (OPEX) or arrive at building and investment costs (CAPEX) and be aware of the total costs of ownership to make a selection that best fits the need of the data center. *Design:* From stakeholder management perspective, ensure that everyone is participating in the selection of the architecture and engineering firm that will provide the design. The first step in designing the cooling and air management systems in a data center is to look at the recommended operating environments for equipment set forth by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Another important rule is to always design for flexibility and scalability and design an integrated system that optimizes space allocation, power, and mechanical systems. Build additional capacity into the main electrical components, such as patch panels and conduits, and use higher-gauge electrical wire to accommodate future growth in electrical demand. Data centers often over cool and over control humidity, which results in no operational benefits and increases energy use. Care should be taken to address this issue. Another objective would be to an ensure optimal configuration of the data center equipment for improved airflow management, and reduce operational costs. Site selection and climatic trends should be analyzed to invest in systems which would reduce cooling costs. These efforts should be implemented during the definition and design phase. The system should be designed to only support the level of redundancy required to meet requirements. At a minimum, a monitoring system should be installed to determine operational efficiency and to diagnose operational problems.

Commissioning/Training/Operations/Maintenance: Integrated Commissioning and Training prior to closeout and routinely during the operation and maintenance phase should be adopted. There is always a need to have a deep-domain expertise in all the systems that comprise the modern data center, but there is also a need for cross training on the technology of operations across all stakeholder groups. An IT data center manager, a Facility engineer, a designer, a builder, or a data center owner should have some working knowledge of every aspect of the project life cycle to include assessment, definition, design, construction, commissioning, turnover, operations, maintenance. This is important, due to the need to work together as a cohesive group across all phases of the project life cycle. This approach will help deliver an efficient reliable and a scalable mechanical system that will meet the current and future needs of a data center.

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