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Development of an Energy-Aware Intelligent Facility Management System for Campus Facilities

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Abstract

According to the U.S. Green Building Council, buildings consumed 36% of total energy consumption in United States. With the concept of sustainability continues to grow in importance, more researches have been focused on improving energy efficiency during a building's operation phase. Academic settings, such as university facilities, pose a unique set of challenges to facility managers and administrators in achieving energy efficiency. Unlike commercial, residential or industrial buildings, campus facilities are composed of different building types with different requirements for indoor air quality, humidity, temperature and ventilation from continuously changing occupants. The current practice with campus facility management requires facility managers to manually schedule tasks, often based on the order of incoming requests without considering their impact on building energy consumption. This paper aims to develop an energy-aware intelligent facility management system for campus facilities. It first builds a knowledge database which includes two main parts: basic information on common daily work request and work instructions; and also the impact on building energy performance. An artificial intelligent model is then proposed to automatically analyze and prioritize future work requests based on factors such as safety, energy consumption impact, occupant satisfaction, etc. A case study is conducted on campus to validate the system with focus on HVAC tasks. The goal is to help facility managers improve building energy efficiency while meeting other restraints.

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1. Introduction

It has been reported that in the U.S. and the European Union, two representative countries/regions with GHG emission reduction obligations, about 40% of the total fossil fuel consumption comes from the building sectors [1]. Improving the energy efficiency of the building is significant for energy saving in the world.

The energy efficiency evaluation of a building can be finished as soon as the building is completed. The equipment and the structure of the building affect the energy efficiency. However, these characteristics have been determined since the completion of construction. Therefore, it is difficult for building manager to optimize them regularly for the purpose of energy saving. This paper argues that during the operation stage of the building, facility managers act as an important role to improve the energy efficiency by considering their work schedule with energy impact.

In a medium-sized building (between 5,000 square feet and 50,000 square feet), occupants can typically submit more than 50,000 requests for FM service every year [2]. Among these requests, most of the problems come from the building electric and HVAC systems, which cover more than 40% of the energy consumption [3]. Therefore, much effort could be done to improve the energy efficiency here. Traditionally, FM is mainly regarded as a business function that requires facility managers' work experience and judgment to make decisions [2]. That is to say, few facility managers would consider the energy impacts while finishing their work. For the campus facility, the above problems are also prevailing. But due to the unique character such as complex building types, the campus facility management needs much more effort to meet different requirements from stakeholders, including professors, students and visitors.

This research attempted to evaluate the energy impact of the FM work orders in a campus. This factor will serve as a crucial factor to prioritize the daily tasks for facility managers. Besides, the occupants' satisfaction level is also taken into account when determine the work schedule. The proposed framework aims at improving the energy efficiency while meeting other goals raised by facility managers such as safety and building damage. The illustrative example is coming from a campus so all the data is coming from this campus facility.

2. Literature Review

2.1. Campus Facility Energy Problem

Healthcare facility management is worth of research effort because of the complexity of healthcare buildings and the significance of its well performance. In a hospital building, the systems including fire alarm, HVAC, water and emergency require much effort of facility managers to operate them [4]. Similarly, the campus facility is also complicated because there are many different types of buildings in the campus such as lab, classroom, gym, office and so on. Moreover, different occupants may have various requirements for the indoor environment. Therefore, improving the quality of FM for campus facility is a challenge work for facility managers.

One of the most important considerations of FM is energy efficiency. In the FM handbook, the author emphasized the importance of sustainable concept for the work of facility managers. The energy audit is also a crucial part of the basic function of FM [2]. In 2013, only commercial and industrial buildings took more than 50% of the whole energy consumption of United States [5]. Among the energy consumed by buildings, more than 60% is used in the building systems such as electrical and HVAC [5]. This paper focuses on an area which is easily neglected by facility managers but also impacts a lot on energy consumption: HVAC problem maintenance and requirement. A research figure demonstrated by ASHRAE estimates that daily faults of HVAC system take about 1-2 percent of energy consumption in commercial buildings [6]. The extra energy consumption is mainly due to the delay detection as well as solution of problems [7]. The situation is the same when author interviewed the campus facility managers. This research raised a framework to consider the energy impact of service requests to prioritize the tasks. This mechanism can minimize the energy consumption while meeting other constraints.

2.2. Application of Artificial Intelligence in Campus Facility Management

To solve the problem mentioned above, facility managers need to consider many factors when facing a problem. The evaluation of the problems should come from the historical similar case, which provided the solid impact result on every factor. However, few methods are able to assist facility managers to optimize their work schedule while considering many factors including the energy efficiency until artificial intelligence was brought in this field.

In 20 years ago, some scientists in computer science defined the artificial intelligence (AI): "The study of the computations that make it possible to perceive, reason, and act"" [8]. It aimed at endowing the computer system with capability to think and act as human beings. This character attracted the attention of scholars to regard this method as an efficient way to manage the building while meeting multiple goals: "artificial intelligence (AI) methods (e.g. artificial neural networks (ANN) and case-based reasoning (CBR)), create opportunities for the development of novel attitudes towards a more integrated approach to built asset management" [9].

Many useful methodologies, such as constraint-based programming, fuzzy logic, genetic algorithms, logic programming, ANN, and CBR have been widely applied in construction industry [10], [11]. The CBR is the most suitable one in FM because the information concerning how a building component is served and deteriorated can offer much useful guidance for the new problem [12]. However, the application of AI in FM is limited due to many difficulties. One of them is the fact that it requires comprehensive and structured as-built databases [13]. For this problem, author solved it through a keyword retrieving CBR model based on the existed database of the computerized facility management system.

Another difficulty is the standards and methods of evaluating energy efficiency. Much effort has been spent on assessing the energy efficiency. For example, a framework was proposed to characterize the energy efficiency by 5 categories and with 17 attributes [14]. Another research established an innovative building energy efficiency rating system and proposed an incentive and penalty framework to improve the energy efficiency [15]. The research carried by Roger Woods and Bill Smith did some related evaluation on the problem of HVAC system. The research was carried in N.C. University Hall and some key data are demonstrated as follows.

Table 1. Energy increase for HVAC problems

Problems	Energy Consumption Increase
Dirty filters in AHU's (add 1" static pressure)	4.10%
Fan Speed Malfunction	8.40%
Pump Speed Malfunction	10.60%
Dirty Cooling Tower"	1.30%
Fouled Tubes	2.20%
Poor Refrigerant Charge	3.70%

The above evaluation is significant for facility managers to reconsider a new problem. However, due to the time and fund restriction, author cannot finish the quantitative assessment of all HVAC problems. This research will evaluate the impact of different FM tasks through questionnaire to campus facility managers and their subjective judge will offer guidance for the schedule of facility managers.

3. Energy-Aware Campus Facility Management System

1.1. 3.1. Integrated Healthcare Facilities Management Model (IHFMM)

Shohet and Lavy [16] proposed an integrated FM model for healthcare buildings. This framework is the foundation of later improvement. The initial goal of the idea was applying the AI into FM to reduce the management cost. The basic structure of this conceptual model is demonstrated in the following picture. It is composed of three main components: input, reasoning evaluator and predictor and output.

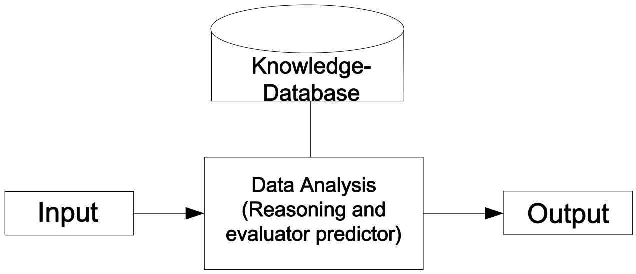

Figure 1. Basic framework for FM system

Input interface is used to collect building information from occupants and manager in the given three aspects.

Reasoning module is the core part of the framework where applies the AI to make analysis of the building based on the knowledge database.

Output covers the analysis result of the three aspects. The results may include the predicted annual maintenance expenditure, recommended maintenance policy for each building system, predicted risk level and so on.

This framework laid the solid foundation for the later research in designing the computer-aided FM system. However, it is only a conceptual model for the overall FM. This paper also referenced the model in the process of applying AI in FM. This paper will focus on the automatic schedule system on maintenance and repair in FM. The innovative work is author attempted to prioritize numerous service requests (SR) through considering the impact of energy efficiency as well as other factors. Not like a conceptual model, this paper also fully implemented the idea through a case study.

3.2. Basic Structure

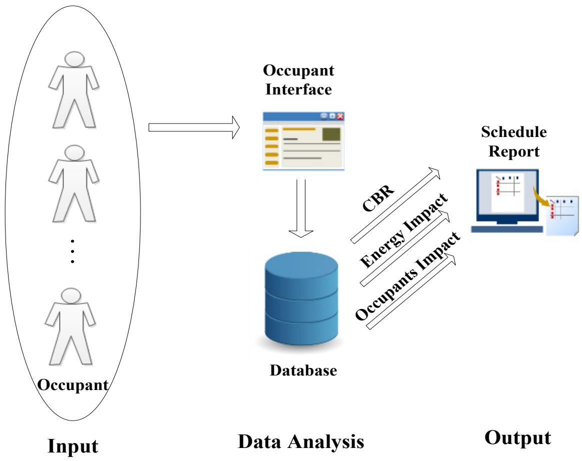

Figure 2. Graphical representation of structure

The new energy-aware campus facility management system is designed as the above picture. The system can also be divided into three parts: input, data analysis and output.

- Input

The input of the system is the user interface for collecting daily SR in buildings. Normally, occupants can use telephone, email and online system to input their problems. After receiving all the requests, facility managers need to input the collect request into their FM system. The key information may include location of the building, building components that have the problem, features of the problem.

- Data Analysis

The data analysis module is the core of the system. All of its function is based on the knowledge database, which contains the old cases concerning FM work. Three main functions are CBR, impact on energy and impact on occupants. The system provides the CBR for every new task to find the similar cases happened in the same parts or similar ones. The historical information is useful to help facility managers evaluate the possible finish time and cost on the new problem. Also it can help facility managers predicate what causes the problem and how to solve it. Contrarily, the current case is that worker needs to first go to the site the check what causes the problem and then decide how to solve it. Sometimes they will go back and get the required equipment and materials and then solve the problem. This system can change this situation.

The innovation part of the system is prioritizing the FM work based on their impact on energy efficiency and other related factors. The current case is that when one worker has many tasks on hand at one time, he will choose one of them based on work experience. This may cause potential problem on impairing the energy performance because some problems cause severe energy loss such as abnormal strong air flow from the air-conditioner and water leak.

To deal with the above problems, this system considers different factors of the SR based on their characteristics. The energy impact factor is an innovative consideration. The analysis result will help facility manager to make a specific schedule for every worker including the sequence of their future work.

- Output

Based on the above introduction, the output of the system is the priority of SR according to their impact on energy as well as other concerning factors. It can help facility manager to decide which work needs to be finished first scientifically, not just base on their work experiences.

3.3. Implementation of Case Based Reasoning

The procedure of CBR is the key to implement the whole framework.

In the above basic structure, the core of the framework is the data analysis module. One of the most important problem need to be solved is how to implement the cased based reasoning of the FM database.

Case based reasoning (CBR) is a problem-solving approach in AI. It is a technique utilizing the previously experienced concrete cases to solve the new cases [17]. Some former researches have recognized the five steps of CBR: retrieve, reuse, revise, review and retain [18]. The most difficult part is the first one: retrieve. Algorithms need to be designed for computer system to find the “similar” cases.

Ibrahim did a related research to apply the CBR in FM. In his research, every historical case has 10 attributes to determine the uniqueness. The nearest neighbor algorithm was adopted to search for the most similar case. His model covers all different problems in FM. However, this research is focusing on the HVAC system. For the large number of HVAC cases in the database, some relation determines the fact that not every case is unique. In another words, normal HVAC problems are categorized for some types. Solution for one type of problem might be similar. For this reason, it is unreasonable to retrieve the case from all the historical problems. Instead, the retrieving result should be one type of problem. Moreover, the normal CBR needs much subjective evaluation of the people, which impairs the accuracy of case retrieving.

To solve this problem, the text mining in AI and cluster algorithms are the best solutions. Text mining does not require the quantitative evaluation of a problem; it is based on the text similarity to search the cases. It has been attempted to apply in finding construction document [4]. For HVAC problem, if reporter can provide sufficient text descriptions of a problem, then the mining process can be easily conducted. The data system is designed as following two steps:

- Cluster

The historical cases are used for machine learning to categorize them into different types. For text mining, the standard of differentiation is the words frequency of problems, which can be found by different cluster algorithms.

- Retrieve

The text of a new problem will be used for finding the most similar category.

3.4. Prioritization of Service Requests (SR)

After matching the new case in to a category, system will make prioritization based on the similar cases. We assume that there are n attributes to affect the sequence of SR. a is the figure of a certain attribute. Then for each similar case d, $d_i=(a_1, a_2, \ldots, a_n)$. For the new case j, each a is the average of the corresponding sum.

After determining the weight of each factors, the rank index

$$r = \sum \omega_i \, a_{avg} \quad (1)$$
$$a_{avg} = \sum a_i / n \quad (2)$$

Concerning the weight, it can be set by facility managers for different management purposes, which demonstrates the flexibility of the model. In reality, some buildings need to be considered more on energy efficiency while some others may need to be mainly considered on occupant satisfaction. Some factors such as life safety and major structural failure are also considered by facility managers and thus should be the first priority of all the number [19]. To solve this problem, all the service requests will be first classified into some basic category. Some category such as life safety should be always finished prior than others such as energy related problems.

4. Illustrative Example

1.2. 4.1. Case Background

The research was performed in the main campus area of Georgia Tech. The campus facility management system is responsible for operating the data for central campus area three, which contains 14 buildings including Klaus, CoA and so on. Facility managers in this department are focusing on solving daily maintenance request. Their job can be summarized as follows: receiving and scheduling maintenance request; assigning related workers to finish the work; storing the above data into the system. For the database, they apply the web-based management system called AIM to manage the data. It is developed by AssetWorks software company.

4.2. HVAC Problem Analysis

In the HVAC system (cooling part) of Georgia Tech, the water and Freon act as the medium for heat exchange among different zones.

For the system, many components need to be performed daily maintenance because they are easily out of good condition: filters; fans; pumps; cooling tower; chillers; boilers; thermostats.

Based on the statistical data, following problems are most frequently happening: temperature issues; leakage problems; noises; air-conditioning not work normally; component replacement and so on. For every problem, the normal causes could be known from the historical cases. For example, the abnormal low temperature in winter may be caused from the following reasons:

- bad compressor or reversing valves
- unit needs to be cleaned and serviced
- compressor not running
- restriction or bad metering device
- outdoor heat pump is iced up or covered in snow
- leak in the return duct, bringing in cold air

All these information will be stored in the database for the new case retrieving.

4.3. Assumption

The cluster algorithm can be classified into two types: supervised and unsupervised. Supervised cluster means people already know the number of clusters. To simplify the example, we only choose 11 normal problem types of HVAC, which means there are 11 clusters. For every retrieving process, a problem will be classified into one category which is assumed to be composed of many historical cases. So the rank index is the weighted mean of impact on occupant and energy efficiency.

4.4. Energy Impact Evaluation

To evaluate the energy impact of the HVAC SR, a survey is designed for 10 facility managers to collect the data. There are 3 categories: life safety(S); major equipment and structural failure (D); other problems are energy related ones (E).

Facility managers also need to evaluate the impact on occupant and the increase of energy consumption based on their work experience. The impact degree ranges from 1 to 5. 1 is the least impact while the 5 means the biggest impact. The survey and the result is demonstrated in the following chart:

Table 2. Survey results

Item	Category	Impact on occupant	Impact on energy efficiency
Abnormal temperature	E	3	5
Leak (valve, AC, condensation, ceiling…)	D	3	1
Noise (Indoor units, air vents…)	E	4	3
Problem on fume hood	D	4	1
AC not working	E	4	5
Air flow problem	E	4	3
Exhaust fan not working	S	5	3
Dirty vent	E	3	4
Filters	E	3	4
Repair scrubber	S	2	1
HVAC Odors	S	2	4

5. Result

After entering a problem description as shown in the picture, a search button will help facility managers to get the possible causes of the problem. This information are based on the real cause of historical cases. Besides, the category and priority degree will be calculated with the equal weight (0.5) for every factor.

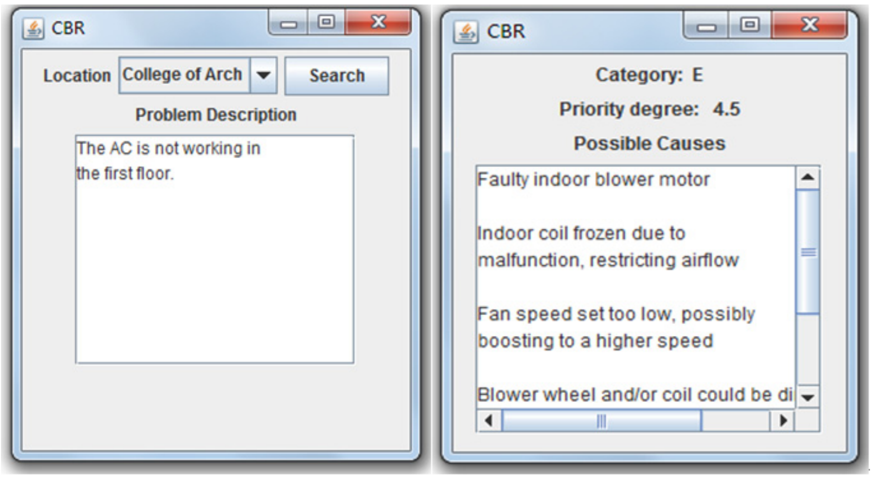

Figure 3. An example of search result.

Through this system, facility managers can not only know the possible causes of the problems, but also get the priority to schedule their future work.

6. Conclusion

This research first builds a conceptual intelligent framework for campus FM. The innovative points are the energy efficiency consideration for FM works and new ways for cases retrieve, which is one of the method of AI. Then the research deeply digs into these two aspects and tries to implement them. For the energy evaluation, the author conducted a survey based on the data collected from the case study. Facility managers helped to evaluate the energy consumption increase of 11 common HVAC problems. This result can be used to prioritize FM works and make a schedule to maximize the energy efficiency. For the cases retrieve, the research suggested to apply the text mining into searching work. This is an advanced text data searching method in construction industry. However in the example, much assumption was made to simplify it. The complete case retrieve will be solved in the future work.

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