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Analysis of an energy efficient building design through data mining approach

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ABSTRACT

Incorporating energy efficiency and sustainable green design features into new/existing buildings has become a top priority in recent years for building owners, designers, contractors, and facility managers. This paper intends to address why delivery of an energy efficient building is not just the result of applying one or more isolated technologies. Rather, it can best be obtained using an integrated whole building process throughout the entire project development process, which leads building designers to generate a large amount of data during energy simulations. The authors observed that even a simple energy modeling run generated pages of data with many different variables. The volumes of energy modeling data clearly overwhelm traditional data analysis methods such as spreadsheets and ad-hoc queries with so many factors to be considered. An integrated or whole building design process involves studies of the energy-related impacts and interactions of all building components, including the building location, envelope (walls, windows, doors, and roof), heating, ventilation and air conditioning (HVAC) system, lighting, controls, and equipment, which shows why it is so difficult to find the correlation between different systems. The objective of this research is to develop an energy efficient building design process using data mining technology which can help project teams discover important patterns to improve the building design. This paper utilizes the data mining technology to extract interrelationships and patterns of interest from a large dataset. Case study revealed that data mining based energy modeling help project teams discover useful patterns to improve the energy efficiency of building design during the design phase. The method developed during this research could be used to guide designers and engineers through the process of completing an early design energy analysis based on energy simulation models.

1. Introduction

Building energy simulation programs are in use throughout the building energy community. Energy modeling programs provide users with key building performance indicators such as thermal loads, energy use and demand, temperature, humidity, and costs. The A/E/C industry is embracing energy simulation programs, so building designers are currently dealing with a large amount of data generated during energy simulations. From our experience, even a simple energy modeling run generated pages of data with many different variables. Examples of those variables include but are not limited to the estimated energy costs or savings in terms of building orientation, HVAC system, lighting efficiency and control, construction of roof and walls, glazing type, water usage, day-lighting, etc. Such volumes of data clearly overwhelm traditional data analysis methods such as spreadsheets and ad-hoc queries with so many factors to be considered. It is difficult to find the best correlation/combination of different energy systems during the building design process.

The objective of this research is to develop a process which can help project teams discover useful patterns to improve energy efficient building design. This paper utilized data mining technology, which is a data analysis process that combines different techniques from machine learning, pattern recognition, statistics, and visualization, to automatically extract concepts, interrelationships and patterns of interest from a large dataset. By applying data mining technology to the analysis of energy efficient building designs one can identify valid, useful, and previously unknown patterns out of energy simulation modeling.

This paper presents the necessary steps to develop the data mining approach such as 1) requirement identification, 2) energy simulation, 3) data mining, and 4) refinement. In order to establish a process, a case study was conducted with an on-going design project. Then detailed steps showing how energy analysis tools were used early in the design process are presented.

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2. Literature review

2.1. Energy modeling

For the past 50 years, a wide variety of building energy simulation (BES) analysis tools have been developed, enhanced, and applied throughout the building energy community. Examples of these tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2, and ECOTECT. Building energy simulation tools are complex applications which require a great deal of time to learn [1,2]. Additionally, energy efficient building design is not just the result of applying one or more isolated design guidelines. Rather, it requires an integrated whole building process throughout the entire project development process. Whole building design considers the energy-related impacts and interactions of all buildings components, including the building location, envelope (walls, windows, doors, and roof), its heating, ventilation, and air conditioning (HVAC) systems, lighting, controls, and equipment.

Several research papers describe energy analysis as a holistic evaluation [3]. Dahl et al. [4] and Lam et al. [5] showed that decisions made early in a project have a strong affect on the life cycle costs of a building.

In this research, energy-efficient concepts, technologies and building elements will be developed and evaluated using energy modeling tools. Building designers could increase energy efficiencies in their building designs by using energy simulation tools in the context of a whole building approach.

2.2. Data mining implementation for pattern discovery

Recognizing the complexity of the search algorithms and the size of the data being analyzed when identifying useful patterns in energy modeling data, this research utilized the data mining technology, which can be considered an interdisciplinary field involving concepts from machine learning, statistics, mathematics, high-performance computing, and visualization. Fayyad et al. [6] define data mining as the nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data. John [7] defines it as the process of discovering advantageous patterns in data.

In this research, a pattern is an expression of describing facts in a subset of a set of facts. The expression is called a pattern if it is simpler than the enumeration of all facts in the subset of facts. A useful pattern means that building designers may increase the energy efficiencies of their buildings through the pattern found. One discovered pattern might be "building insulation that has a pattern of decreasing energy use by 50%". Patterns might also be much more complex, taking into account several different building components such as walls, windows, doors, and roof and specifying the conditional probability of improving energy efficiency. We can estimate the payoff of such a strategy by assuming an effectiveness rate. If the estimated payoff from the strategy was sufficiently high, it would be implemented to increase energy efficiency, and its results could be measured.

3. Case study

In this section, a sequence of three different steps in the data mining process is outlined, as shown in Fig. 1. The first step is to identify the project requirements. This step is challenging since projects have constrained budgets, schedules, and resources. It is essential that all building stakeholders–including owners, designers, engineers and contractors–have a clear understanding of problem definition and participate in identifying a set of design alternatives early in the project planning process. The second step, energy simulation, is where a large amount of data is generated. Examples of those variables include estimated energy costs or savings in terms of building orientation, HVAC systems, lighting efficiency and control, roof and wall construction, glazing type, etc. Such volumes of data clearly overwhelm the traditional data analysis methods such as spreadsheets and ad-hoc queries with many factors to be considered. It is difficult to find the best correlation/combination of different energy systems during the building design process. The third step is the data mining process where we develop an overall data analysis mechanism that can be applied to find patterns that explain or predict any behaviors resulting from the energy simulations.

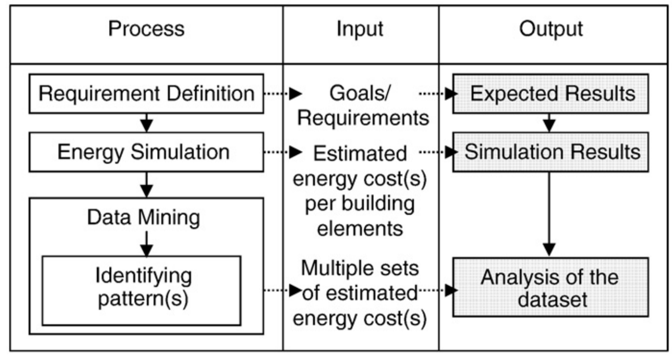

Fig. 1. Main process of knowledge discovery approach.

3.1. Requirement definition

The energy efficient design process begins when the occupant's needs are assessed and a project budget is established. Then, the proposed building is located on the site, and programmed spaces are carefully arranged to reduce energy use for heating, cooling, and lighting. Building heating and cooling loads are minimized by optimizing the building form and designing energy efficient building elements—windows, walls, and roofs. Taken together, they form the basis of integrated, whole building design.

3.1.1. Building description

The project described in this paper is a new Community Emergency Service Station (CESS) facility. This building provides fire fighting, medical and police support services for a residential neighborhood. The station consists of offices, training rooms, physical training, day room, kitchen, dormitory area, apparatus room, decontamination room, storage area/rooms, latrines, communication and electrical closets, and a mechanical room. The size of the proposed new facility is approximately 808 m^2 as shown in Fig. 2. The apparatus room was sized for a fire truck, military police car, and ambulance. Space for hose drying, lockers and a work bench were also required in the apparatus room. The building is occupied seven days a week for 24 h a day. A summary of the building model parameters and the thermal loading are presented in Table 1. Fig. 3 shows the rooms to be located in each CESS facility.

Requirement identification for the CESS facility was accomplished using a four day charrette process. A charrette is held at the beginning of a project where a group of designers, engineers, and contractors may draft solutions to design problems. For our case study, the charrette took place in the early stage of design and also included stakeholders outside of the design/build team. Each participant presented his/her work to the full group. The charrette served as a way of quickly generating solutions while understanding and integrating the interests of different groups of people.

Energy modeling in the charrette presented several challenges. First, it was essential to provide energy analysis results so we could identify energy-saving improvements while the design was being modified. In addition, energy modeling usually involves the time consuming process of re-entering all the building data, geometry and parameters to conduct an energy analysis.

3.1.2. Energy modeling

The energy simulations were completed using Autodesk® Green Building Studio® plus eQUEST 3.63. Fig. 4 shows the graphical image