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Analysis of building energy consumption parameters and energy savings measurement and verification by applying eQUEST software

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ABSTRACT

This study examines the Energy-Saving Performance Contract (ESPC) of an office building by applying IPMVP Option D in combination with the energy analysis model established for the building by eQUEST simulation software to calibrate energy consumption simulation results using actual electricity billing data. The rates of error between actual values and energy consumption simulation results from the calibrated and uncalibrated models are then explored to confirm the accuracy of the calibrated model. Finally, the calibrated model is used to examine the impact of energy consumption parameter changes on the overall energy consumption in a building.

The results indicate that, compared to actual energy consumption, the mean bias error (MBE) and root mean square error (RMSE) for uncalibrated simulation results are 24.48% and 125,050, whereas the MBE and RMSE for calibrated simulation is 0.37% and 34,197. When lighting power density increases or decreases by 50%, overall energy consumption decreases by 30.78% or increases by 31.19%, respectively. Therefore, illumination density has the greatest impact on energy consumption. This study also recommends that accurate parameter settings be confirmed when using IPMVP Option D simulation verification to ensure a highly accurate building energy consumption model, thereby facilitating the Measurement and Verification (M&V) of energy savings.

1. Introduction

In recent years, countries worldwide have implemented energy policies to achieve low-carbon energy-saving objectives, of which improving the efficiency of energy consumption while decreasing overall energy consumption is a crucial topic. Additionally, learning from the experience of foreign energy saving industries to support the development of energy service companies (ESCOs), the energy performance project model allows energy consumers to pay ESCOs for the cost of energy-saving projects through the energy efficiency created by the project, thereby creating a win-win situation. The US Department of Energy (DOE) has cooperated with the industrial community to develop a protocol for energy efficiency measurement and verification: the International Performance Measurement and Verification Protocol. By standardized M&V methods, the objective of this protocol is to confirm the energy efficiency attained through energy-saving measures and reduce the energy consumers' doubts on energy efficiency [1]. This International Performance Measurement and Verification Protocol (IPMVP) is sponsored by the Efficiency Valuation Organization (EVO), a private, non-profit corporation. The IPMVP provides an overview of current best practice techniques available for verifying the results of energy efficiency, water efficiency, and renewable energy projects. The IPMVP provides four M&V method options: A–D. Option D is a type of numerical simulation that can improve M&V of building energy savings and evaluate in advance the effect of applying each energy-saving measure on a building's overall energy consumption [2]. Extensive research has focused on examining building energy consumption conditions. Zhu [3] used eQUEST simulation software models to analyze the effect of various energy-saving measures on building energy consumption conditions and rated the measures according to the Energy Star standard. Simulating community emergency service centers energy consumption conditions through eQUEST, Kim et al. [4] employed data mining to compare the original building's baseline energy consumption conditions with 12 HVAC options, 127 roof structures, 88 wall materials, and 12 building orientations and calculated the savings of efficient energy. They observed that HVAC had the greatest effect on building energy consumption, with an efficient energy annual savings of US$1507, and

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building orientation had the least effect on energy consumption, with an efficient energy annual savings of only US$11–US$17. Yu et al. [5] used eQUEST to research the impact of various parameters, such as building envelope shielding, external wall thermal insulation, external wall thermal emission, window/wall ratio, and glass type on air conditioner energy consumption in residential buildings. Their results showed that improvements in envelope shielding and external wall insulation could effectively decrease air conditioner energy consumption, with an energy savings rate of 11.31% and 11.55%, respectively. Sozer [6] argued that because rigorous regulations and limits had not been established, older hotels consumed extremely high levels of energy. Using eQUEST software simulation, Sozer examined passive designs that could effectively decrease building energy consumption, ultimately demonstrating that insulation, shielding, and window type can reduce heating and cooling energy consumption by 40%. Radhi [7] researched the building energy reduction effects of using insulation in building walls and showed that insulation can reduce building electricity use and CO_2 emissions by approximately 40%. Santamouris et al. [8] installed a green roof system in a nursery school and employed theoretical simulation and empirical research to show that the system could effectively reduce cooling loads by approximately 6–49%. Florides [9] used TRYSNS software to research modern residential energy consumption and found that roof insulation measures were significantly effective in reducing cooling and heating loads. Pacheco et al. [10] introduced low-energy consumption building design parameters, including building orientation, building wall construction, building shields, glass classification, and passive heating and cooling mechanisms, for building designer reference. Gratia et al. [11] researched window blind size and color optimization and showed that during the summer, window blind optimization could reduce building air conditioner electricity use by 14.1%. Li et al. [12] showed that offices could reduce lighting power density energy consumption by 21.2% and air conditioner energy consumption by 6.9% using solar film coating and light control. Castleton et al. [13] examined green roof installation techniques and energy-saving potential for buildings. Phillip et al. [14] used TRACE600 to simulate commercial building energy consumption and researched 20 energy-saving measures that future engineers could use when designing air conditioning systems. Kawamoto et al. [15] evaluated the energy-saving potential of office equipment management at 3.5 TWh annually, or approximately 2% of Japan's annual commercial energy consumption. Tavares et al. [16] used VisualDOE^{TM} simulation tools to conduct sensitivity analysis on wall structure and materials, window frames, and HVAC systems in government buildings. Yin et al. [17] used eQUEST to detail how double low-E windows with a solar film coating could effectively reduce the annual electrical use and peak demand in commercial buildings, showing that internal and external solar film coatings reduced cooling loads by 2.2% and 27.5%, respectively. Kim et al. [18] used IES VE energy analysis programming to study the impact of different exterior shading devices on the air conditioning load in residential buildings, demonstrating that exterior shading devices could effectively reduce air conditioning energy consumption in buildings.

The studies discussed above clearly focused on examining of the impact of various energy-saving designs and measures to reduce the overall energy consumption of buildings. However, they did not examine the accuracy of simulation results created by software parameter settings. Therefore, this study examines the degree of error in the simulation results and parameter calibration of software energy consumption parameters for eQUEST to verify the accuracy of the simulation models. This highly accurate model is then used to examine the effect of energy consumption parameter changes on overall energy consumption in a building.

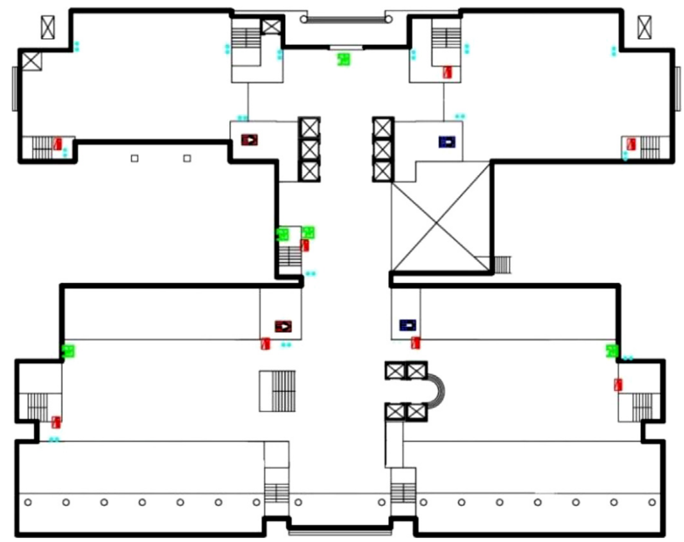

Fig. 1. Office building layout.

2. Project simulation research

2.1. Building description

This study researched an actual office building in Taiwan where employees worked Monday to Friday 8:00 AM to 5:00 PM. Energy-consuming equipment are powered on and off according to the workday. The building has 17 stories above ground and 3 stories below, faces north, and has a floor area of 66,946 m^2, 54.74% of which is air-conditioned areas. The building layout is shown in Fig. 1. The HVAC system in this building comprises two 460RT high-efficiency variable frequency drive centrifugal chillers (working refrigerant of HCF-123A) that operate on parallel operation modes. Table 1 shows a detailed list of the 460RT properties. The chilled water side of the pipe configuration is a one-time variable flow system with two 75 hp chilled water pumps, while the cooling water side has two 75 hp cooling water pumps and two cooling water towers. Parallel operations are used to allow the two cooling towers to simultaneously turn on when the chiller is under partial load operations to improve cooling capacity.

2.2. Parameter settings in eQUEST software simulation

2.2.1. Building walls

The building layout was set based on the software rendered model of the actual building plan. After the model wall was completed, the inside areas were partitioned into air conditioned areas, which consisted of static work areas such as general offices and conference rooms, and non-air conditioned areas, which accounted for all other areas. The software parameter settings included a north-facing orientation, light steel frame curtain walls for building wall construction, general and low-E glass, and 10% of the window openings face the east–west sides of the building and 40% face the north-south sides. Full details are shown in Table 2 and a 3D model of the building is shown in Fig. 2.

2.2.2. Air-conditioning system parameters

The weather data are from the Central Weather Bureau of Taiwan. The monthly average temperatures are between16.2 °C and 30.2 °C, and the monthly radiation levels are between 197.6 MJ/m^2 and 557.4 MJ/m^2; therefore, there is no demand for heating. The air conditioning settings in eQUEST include cooling capacity, ARI-standard energy input required (EIR) per unit of