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Energy modeling of two office buildings with data center for green building design

Yiqun Pan *, Rongxin Yin, Zhizhong Huang

Institute of Building Performance & Technology, Sino-German College of Applied Sciences, Tongji University, Shanghai 200092, China

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Abstract

Energy simulation models are developed with EnergyPlus for two office buildings in a R&D center in Shanghai, China to evaluate the energy cost savings of green building design options compared with the baseline building. As a R&D center of an international IT corporation, there are data centers in the two buildings, which make them different from typical office buildings. The data centers house high energy consuming IT equipments and need 24 h air-conditioning every day all year round. In order to achieve energy cost savings, multiple energy efficiency strategies are employed for design proposed building, encompassing high performance building envelope, lighting system, and HVAC system. Through energy modeling, the design proposed options are compared to an ASHRAE 90.1-2004 compliant budget model to highlight energy cost savings versus ‘‘standard practice’’ and show the potential LEED™ Credit EA1—Optimize Energy Performance. Meanwhile, they are also compared to China Code model to figure out the energy cost savings versus the most popular practice conforming to China Public Building Energy Saving Design Standard. The whole building energy simulation results show that the yearly energy cost saving of the proposed design will be approximately 27% from China Code building and 21% from ASHRAE budget building, which can achieve 4 points for LEED credit due to energy performance optimization.

Keywords: Energy modeling; Green building design; Data center; Energy performance optimization; Whole building energy simulation

1. Introduction

Energy modeling is utilized on buildings more often for two main purposes: modeling for building and HVAC system design and associated design optimization (forward modeling), and modeling energy use of existing buildings for establishing baselines and calculating retrofit savings (data-driven modeling) [1]. Forward modeling of building energy use begins with a physical description of the building system or component of interest. For example, building geometry, geographical location, physical characteristics (e.g., wall material and thickness), type of equipment and operating schedules, type of HVAC system, building operating schedules, plant equipment, etc., are specified. The energy use of such a building can then be predicted or simulated by the forward simulation model. Forward modeling can help designers compare various design options and lead them to energy-efficient designs in manner of cost-effectiveness.

There are many building energy simulation software available nowadays. Some are simplified energy analysis tools that only provide a quick analysis of annual energy use of buildings, but some use more detailed models and run on hourly basis that provide detailed hour-by-hour energy analysis of buildings [4]. LEED™ Credit EA1—Optimize Energy Performance [3] specified three compliance path options to evaluate the achievement of increasing levels of energy performance above the baseline in the prerequisite standard. One option is whole building energy simulation, which is to calculate a percentage improvement in the proposed building performance rating compared to the baseline building performance rating per ASHRAE Standard 90.1-2004 [2] by a whole building energy simulation using the Building Performance Rating Method in the Standard. The standard has many requirements for the simulation programs. DOE-2 and EnergyPlus are programs that meet the requirements.

EnergyPlus is regarded as the new-generation building energy simulation program which will replace DOE-2—the

* Corresponding author. Tel.: +86 21 69584741; fax: +86 21 69589621.
E-mail address: yiqunpan@mail.tongji.edu.cn (Y. Pan).

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most popular program nowadays around the world [5,6]. The advantage of EnergyPlus over DOE-2 is that EnergyPlus uses integrated simultaneous load/system/plant simulation technique instead of sequential simulation technique, so that it can do accurate prediction of space temperature, which is crucial to energy efficient system engineering because system size, plant size, occupant comfort and occupant health are dependent on space temperature information. EnergyPlus also allows users to evaluate a number of processes that DOE-2 cannot simulate well, including under-floor air distribution system, radiant heating and cooling system, ground-source heat exchanger, power generation system, etc. Concerning the features of EnergyPlus, many researchers around the world used it as the building energy simulation and analysis tool. Griffith et al. [7] used DOE-2.1E to develop and model a new building in the Teterboro Airport for energy efficient predesign and subsequently conducted extensive whole-building annual energy simulations using EnergyPlus. Xu [8] constructed EnergyPlus simulation models to investigate different thermal mass discharging strategies to shift heating and cooling demand. Eskin and Türkmen [9] used EnergyPlus to conduct energy simulation to evaluate the interactions between different conditions, control strategies and heating/cooling loads in office buildings in four major climatic zones in Turkey. Ordenes et al. [10] analyzed the potential of seven BIPV (Building-integrated photovoltaic) technologies implemented in a residential prototype in three different cities in Brazil by simulation with EnergyPlus. Pan et al. [11–13] developed energy models with EnergyPlus for two BCHP (building cooling heating and power) systems to calculate loads and energy consumptions. In this paper, EnergyPlus is selected as the program to conduct the simulation for the purpose of energy performance optimization of two office buildings in a R&D center in Shanghai, China.

2. Data center buildings

The two office buildings are located inside a R&D Center of a famous international IT company. The offices are 5 storeys high above grade, and the floor-to-floor height from 1F to 4F is 4.1 m, and that of 5F is 3.8 m. The total building height is 21.45 m. The total floor area of the office buildings is 55,413 m^2. The main function of the buildings is office but housing data centers, which are different from typical office buildings.

Data centers are normally installed large number of IT equipment (e.g., servers, data storage, network devices, monitors, etc.) to perform various functions such as storage, management, processing and exchange of digital data and information. Energy consumption of data centers is significantly higher than that of commercial office space. Lawrence Berkley National Laboratory (LBNL) conducted studies on 14 data centers in USA and investigated that power demand densities of data centers are in the range of 120–940 W/m^2 [14], while the power demands typically drawn by commercial office spaces lie in between 50 and 110 W/m^2. Sun and Le [15] examined the energy use of two data centers in commercial buildings in Singapore and concluded that data centers were high energy consuming areas in commercial office buildings. Greenberg et al. [16] benchmarked 22 data center buildings and determined that data center can be over 40 times as energy intensive as conventional office buildings. The huge energy consumptions of data centers demonstrate the significant potential of energy saving, and make them the desired target of energy conservation measures. Greenberg et al. [16] proposed a set of ‘‘best-practice’’ technologies for energy efficiency of data center buildings including: optimized central chiller plants, ‘‘free cooling’’ from air-side or water-side economizers, improved uninterruptible power supplies, high-efficiency computer power supplies, etc.

The two office buildings are proposed in design to use multiple energy efficiency strategies to achieve the energy savings. These strategies encompass improvements in:

- Building envelope—wall and roof U-factors, glazing performance, and sunshades.
- Lighting—reduction of lighting power density from ASHRAE maximum.
- Daylighting—installation of daylighting switching/dimming systems in perimeter area.
- HVAC—improved equipment efficiencies compared to ASHRAE minimum, several system enhancements and design options, e.g., under-floor air distribution system, enthalpy wheel, ice storage, air-side free cooling.

3. Model development

The study focuses on the investigation of the design proposed options for the two office buildings. Energy simulation models are developed, respectively, for three cases: China Code building, ASHRAE budget building and Design Proposed building. Table 1 lists the input data of envelope, internal loads and HVAC system of the three models. The loads due to equipment and occupants are the same for the three models.

3.1. China code model

China Code building is a reference building conforming to current China code [17] and uses VRV (variable refrigerant volume) system in office and air-source chiller for IT rooms, UPS rooms and labs, where 24 h air-conditioning is needed. These air conditioning systems are most commonly used systems in Shanghai area. Since there is no specific module to simulate VRV system in EnergyPlus until the simulation is conducted, unitary air-to-air heat pump system with DX (direct expansion) coil is used to replace it, due to the similarity of the two systems.

3.2. ASHRAE budget model

ASHRAE Budget building is an ASHARE90.1-2004 compliant building based on the requirements outlined in Chapter 11 of the Standard [2]. Envelope requirements are