# FIELD INVESTIGATION AND MODEL BASED ENERGY BENCHMARKING OF OFFICE BUILDINGS IN BEIJING, CHINA

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## ABSTRACT
Due to the characteristics of big volume and high energy consumption, the energy conservation of office buildings is one of the most important parts in the field of building energy efficiency and attracts increasing attention all over the world. The energy benchmarking plays an important role in the public energy conservation work. However, in nowadays, there are so many differences between different buildings, which could influence the energy consumption significantly, such as indoor occupant number, heat productivity of lighting and facility, how to obtain the reasonable energy consumption benchmarking is very difficult. With the energy conservation work going further, the importance of a more reasonable benchmarking methodology become outstanding for building energy consumption at this stage
There are some methods (e.g., Energy Star, LEED) to give out the building energy consumption benchmarking nowadays, which are reviewed in this paper firstly, and some common and key issues are summarized and discussed. Then, a novel way to get the building energy consumption benchmarking and to judge the energy consumption conditions of different buildings with considering the reasonable characteristics of each building is proposed in this study. As one important part of office buildings, the government buildings need to be paid more attention to in energy conservation. Based on detailed investigation and simulation, the benchmarking work for government office buildings in Beijing, China is taken as an example to validate the efficiency of this methodology by coming up different benchmarking to judge their energy consumption in the same standard.

## KEYWORDS
Energy benchmarking, office buildings, reasonable characteristics, DeST

## 1. INTRODUCTION
There's an increasing demand of building energy consumption in China, along with economic development and life quality improvement. Building energy consumption accounted for 19.5% of total energy consumption in China in 2013(BERC, 2015). The energy conservation of buildings is one of the most important parts in the field of energy conservation in China, and attracts increasing attention of Chinese government.
Due to the characteristics of big volume and high energy consumption, the energy

conservation of public buildings is one of the most important parts in the field of building energy efficiency. The total energy consumption of public buildings is 204 million tce in China in 2013, accounting for 26.9% of total building energy consumption (BERC, 2015). From 2001 to 2013, the unit energy consumption of public buildings has increased from 16.8 kgce/m$^2$ to 21.3 kgce/m$^2$ (BERC, 2015). According to statistics, the unit energy consumption of government office buildings in China is 10-20 times of residential buildings', and around 1.5 times of the unit energy consumption of the similar buildings in Japan and Europe (MOHURD, 2007). In addition, the number of energy-intensive buildings, high-rise buildings and large commercial complexes keeps increasing. Therefore, public buildings have great energy saving potentials.

As the goal of ecological civilization construction proposed by Chinese government in 18th Communist Party of China National Congress, building energy conservation work should be paid abundant attention. The energy benchmarking plays an important role in the public energy conservation work. With the energy conservation work going further, the importance of a more reasonable benchmarking methodology become outstanding for building energy consumption at this stage.

There're some common energy benchmarking methods. The simplest one is setting a constant energy use intensity of buildings based on engineering experience with the advantage of simple and easy operation, sometimes this index can be modified according to degree-days of various zones (Long WD, 2009; Filippin C, 2000; Birtle AB and Grigg P, 1997), which is widely used in China. However, this method couldn't reflect the discrepancy of different buildings. Beijing has carried out a yearly decreasing index of energy saving rate since 2014. Every building should reduce its energy consumption at a same and certain percentage, such as 3% or 5% (Chung W, 2011). This policy has achieved a good effect during a short period, however, this policy is hard to continue due to the unreasonable benchmarking method. The relatively energy saving buildings have bigger pressure than others because of the same energy saving rate, which is against to building energy conservation work. There're a lot of green building evaluation methods, such as LEED from the U.S. (Humbert S et al. 2007), DGNB from Germany, NABERS from the Australia, et al., which can evaluate building efficiency level in terms of the green technologies used in design and construction progress. Nevertheless, green technologies may not result in low energy consumption, and actual operating situation may be different from the design and construction progress, leading to the dissatisfactory effect on energy savings. Building energy benchmarking calculation methods such as VDI3807 from Germany and Energy Star from the U.S. (Monts JK and Blissett M, 1982) are popular all around the world. Based on large-scale investigation results on energy consumption and other basic information of various buildings, Energy Star can set the benchmarking according to some key influencing factors. However, it relies on large energy consumption and building information data, which is hard to obtain. Besides, this method also has the shortcomings, such as it regards the average level of investigated cases as the reasonable energy consumption.

In nowadays, there are so many differences between different buildings, which could influence the energy consumption significantly, such as indoor occupant number, heat productivity of lighting and facility. We should obtain the reasonable energy consumption benchmarking in consider of building's individual features. Therefore, according to Chinese building energy usage characteristics, we proposed a method to get the building energy consumption benchmarking and to judge the energy consumption conditions of different buildings with considering the reasonable characteristics. In addition, this method was used in analyzing the energy consumption of government buildings in Beijing in this study.

## 2. METHOD

Field investigation and computer simulations are used to come up with energy benchmarking of office buildings. This research methodology is shown in Figure 1. First, field investigation is carried out to figure out the key influencing factors and value range in office buildings, as well as to acquire the practical energy consumption. Second, we build the prototype models of office buildings, along with the key influencing factors from investigation as the typical inputs of the building energy models, to simulate the energy consumption of each building. Then the prototype models are validated by comparing the practical energy consumption and the simulated one. The model should be modified until the error value is less than 10%. Finally, we can calculate the energy benchmarking of various buildings based on the prototype models with some modifications. We need to classify the inputs into two types, one is the reasonably objective factors whose influence on energy consumption should be accepted when we determine the benchmarking, such as the indoor occupant number and working hours, which are determined according to practical situation, and we should keep this kind of inputs as practical values. On the contrary, the other type is the convertible factors, which can be changed through equipment replacement or education, such as keeping the lights on even there're no occupants in the office, and these inputs should be modified to ordinary values. Based on these principles, individual the benchmarking can be come up, and used to judge energy consumption of different buildings in the same standard.

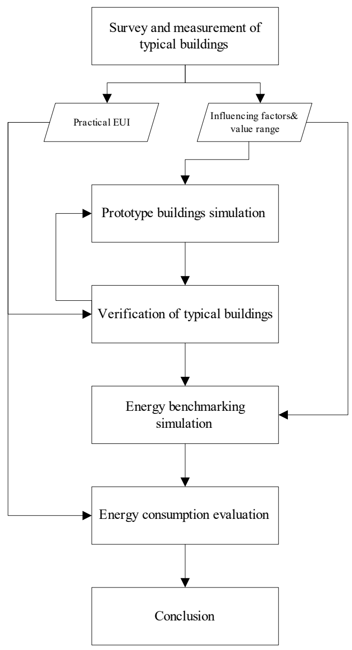


***Figure 1.*** *Methodology*

Using the method presented above, we took government office buildings in Beijing, China as examples to validate the efficiency of this method.

## 3. CASE STUDY: BENCHMARKING FOR GOVERNMENT OFFICE BUILDINGS IN BEIJING

As the capital city of China, Beijing attaches great importance to building energy conservation, especially government office buildings. Thus we carried out field investigation on floor area, built year, working hour, energy consumption and so on of 98 the government office buildings in Beijing through questionnaires. We can conclude that there're significant differences among those buildings, as the minimum value is only 23 kWh/m$^2$/a, the maximum value can up to 200 kWh/m$^2$/a, and the average is 65.5 kWh/m$^2$/a. We chose 8 buildings from these buildings as the typical buildings according to energy consumption to carry out further study.

### 3.1 INVESTIGATION RESULTS OF TYPICAL BUILDINGS

As the HVAC system, lighting and office equipment consume a big portion in office buildings, we major focus on the information about these parts. Partial investigation results are shown in Table 1, and the major content is specified as follows:

1) Building type: As all these buildings are government office buildings, their shapes are very similar, and can be divided into two types. One is oblong building, and the other one has big atrium;
2) Floor area: All buildings are large office buildings, whose floor area is bigger than 20,000 m$^2$, but Building F;
3) Built year: The envelope performance of various buildings has difference with diverse built year. The newly built buildings have better envelope performance than old buildings. We need to mention that, Building H was renovated in 2000;
4) Occupant number: The occupant numbers of different buildings have enormous differences. In instance, Building C and Building D have close floor area, while the occupant number of Building C is twice of that of Building D;
5) Working hour: According to the work nature, some buildings are occupied even in the evening and weekends, such as Building G, where almost 1/3 of the occupants have three shifts. While the most buildings are occupied during 8 am to 9 pm;
6) HVAC system: According to the investigation results, most buildings take fan coil unit (FCU) with all-time, part-time fresh air fan open or without fresh air, except Building H takes spilt air conditioner (AC). However, the chiller types are different. There exist four kinds of chillers among these 8 buildings, that are air-cooled chiller, water-cooled chiller with screw machine, centrifugal machine and piston machine. Thus the coefficient of performance (COP) of different HVAC system is diverse;
7) HVAC system operating and management: The HVAC system is controlled by users because they use split air conditioners. While others are uniformly managed by Property management staffs, and each building has their own HVAC system operating hour and operating strategies. Chiller number control and frequency conversion control are the most common operating strategies in office buildings;
8) Lighting density and equipment density: As lighting and equipment consume around half portion in these buildings, their densities have significant influence on the accuracy of prototype models, and should be taken as the key influencing factors. These buildings have taken lighting reform, thus there're two kinds of lighting density, which are 4.48 W/m$^2$ and 6.72 W/m$^2$ The major energy-consuming equipment of office are computers and printers, which are influenced by the number and brand of appliances of each occupant.

***Table 1.*** *Investigation results of eight typical buildings*

| | *A* | *B* | *C* | *D* | *E* | *F* | *G* | *H* |
|---|---|---|---|---|---|---|---|---|
| *Floor area(m2)* | 49,853 | 35,066 | 34,000 | 30,000 | 46,860 | 8,875 | 60,000 | 29,727 |
| *Built year* | 2002 | 2005-2006 | 1994 | 2007 | 2002 | 1990S | 1980-1990 | 2000 |
| *Occupant number* | 2,350 | 1,320 | 1,700-2,000 | 780 | 1,732 | 120 | | 1,463 |
| *HVAC system* | FCU | FCU | FCU | FCU | FCU | FCU | FCU | Split AC |
| *Fresh air system* | None | None | Intermittently open | None | Continuously open | None | None | None |
| *Chiller type* | Air-cooled chiller | Screw machine | Piston machine | Centrifugal machine | Centrifugal machine | Screw machine | Centrifugal machine | |
| *HVAC operating period* | 6.1-9.25 | 6.15-9.4 | 5.15-9.15 | 6.15-9.15 | 5.15-9.3 | 6.26-9.15 | 5.23-9.1 | |
| *Lighting density(w/m$^2$)* | 4.48 | 6.72 | 6.72 | 4.48 | 6.72 | 6.72 | 6.72 | 4.48 |
| *Office equipment density(w/person)* | 225 | 225 | 120 | 150 | 120 | 200 | 225 | 150 |

## 3.2 CONFIRMATION OF KEY INFLUENCING FACTORS AND THEIR VALUE RANGE

Based on the investigation results and professional knowledge, we summarized 12 key influencing factors, which can be divided into two types. The factors shown in the upper portion of Figure 2 are numerical variables, which can be input into the prototype models directly according to investigated value, while the factors of lower half are classified variables.

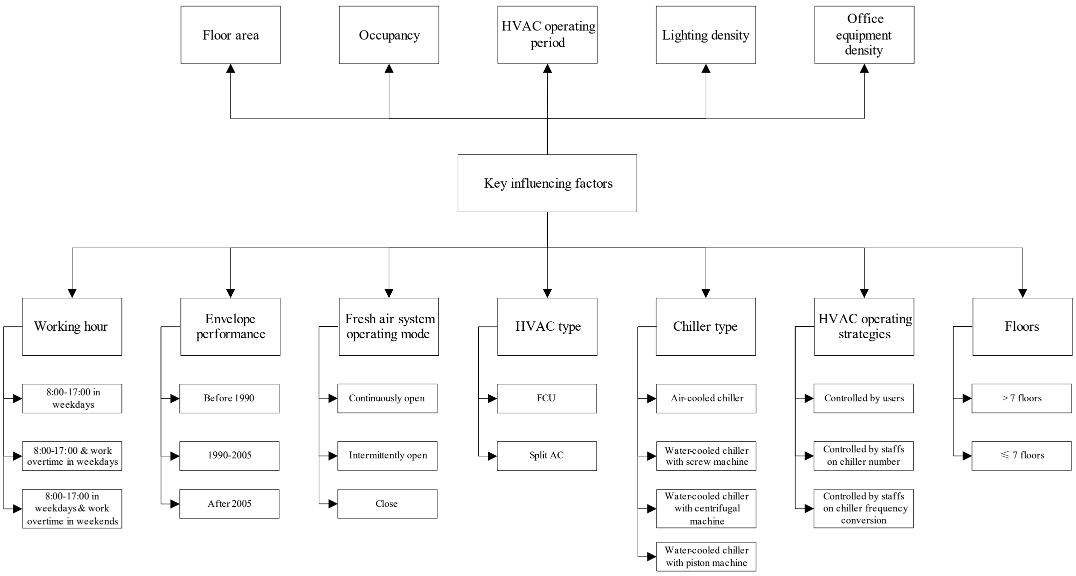


***Figure 2.*** *Key influencing factors and values*

## 3.3 MODELING AND VALIDATION

The DeST (Designer's Simulation Toolkits) software was used for the simulations. DeST is a BEMP (building energy modelling program) developed at Tsinghua University in the late 1980s, and has been widely used in China (Yan D et al. 2008; Zhang X et al. 2008). In addition, DeST has been compared on building loads and HVAC system calculations with EnergyPlus and DOE-2 (Zhu XX et al. 2013, Zhou X et al. 2014). We built two prototype models based on investigation results to simulate building loads, then used ES (Energy System) module of DeST to calculate the subentry energy consumptions (e.g., equipment power, lighting power, HVAC energy consumption).

As introduced in Sect.3.1, there're two kinds of building types, oblong building and building with big atrium. Therefore, we built two prototype models based on Building A and Building C in this section.

Prototype model I derives from Building A, whose total floor area is 10,551 $m^2$, and is a typical seven story slab-type office building with one basement floor as shown in Figure 3. The main room type is office. There're two kinds of offices. Typical office A has lager occupant density, while office B has smaller occupant density. The floor area and total number of office A are 33.57 $m^2$ and 148, and those of office B are 31.85 $m^2$ and 31. Besides offices, this model also includes conference rooms, passages and restrooms, et al.

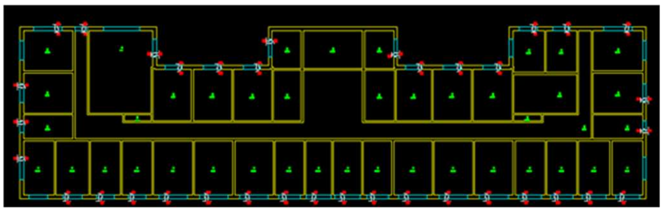

*Figure 3. Prototype model I*

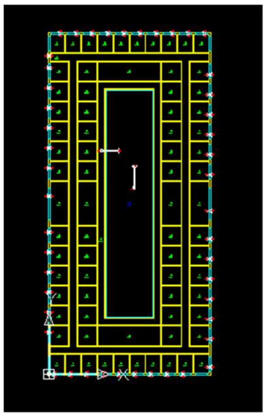

*Figure 4. Prototype model II*

Prototype model II derives from Building C, and its total floor area is 22,939 $m^2$ with ten floors. This model has big atrium. The atriums of floor 1-4 are connected with a glass roof, and the atriums above floor 4 are connected with atmosphere. The floor area of each story is decreased with the higher floor from floor 6. The main room type is also office. There're two kinds of offices with different occupant densities. The floor area and total number of office A are 25 $m^2$ and 282, and those of office B are 20 $m^2$ and 140.

Then, for each building, a prototype model was chosen according to its building type and the key parameters of each building was input based on investigation results to simulate the energy consumption. By comparing the simulated energy consumption with the practical energy consumption, these prototype models were validated as shown in Figure 5. The error rates of all buildings between simulated total energy consumption and practical one are less than 10%. Therefore, these prototype models are accurate and can be used to set energy benchmarking.

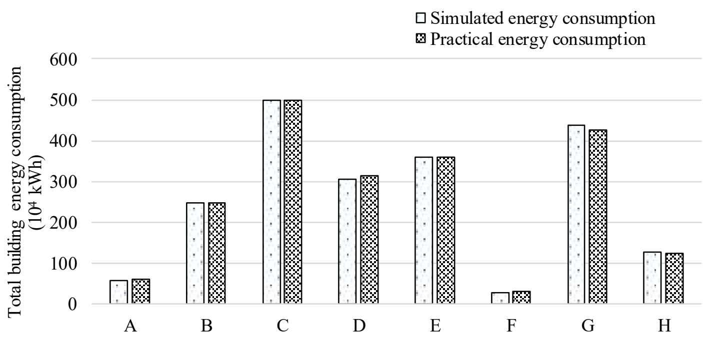


***Figure 5.** Comparison results between the practical energy consumption with simulated energy consumption in eight typical buildings*

## 3.4 ENERGY BENCHMARKING SIMULATION

As introduced in Sect. 2, we should keep the object factors unchanged, and modify convertible factors into common values. The classification method should be determined according to specific situation. In this study, floor area, floors, occupancy, working hour and fresh air operating type are objective factors, while others are convertible factors need to be modified.

Building H is used as the example to present the calculation process of energy benchmarking based on the validated prototype models. As the information shown in

Table 2, Building H is an early-built, low-rise and large office building. Due to the early built year, the HVAC system is split air conditioner without mechanical fresh air supply system. Meanwhile, its occupant density is relative low, and the lighting density and office equipment density are reasonable. Most parameters should be accepted to set the energy benchmarking through our analysis, except the HVAC system performance and envelope performance. The early built year results in poor performance of HVAC system and envelope, which could lead to unreasonable energy consumption. Thus we modified these parameters into design values of Chinese building design standards during the process of simulating the energy benchmarking. The suggested energy benchmarking of Building H is 34.55 kWh/m2/a.

***Table 2.*** *Inputs of Building H*

| | *Value* |
|---|---|
| *Floor area ($m^2$)* | 29,727 |
| *Built year* | Before 1980 |
| *Occupant density (Person/$m^2$)* | 0.05 |
| *Lighting density (w/person)* | 4.48 |
| *Working hour* | 8:00-17:00 in weekdays |
| *HVAC system operating hour* | Opening in working hours |
| *Fresh air system* | None |
| *Chiller type* | Split AC |
| *Floors* | ⩽7 floors |

The energy benchmarking of other seven buildings can be acquired with the same method, and the results are shown in Figure 6.

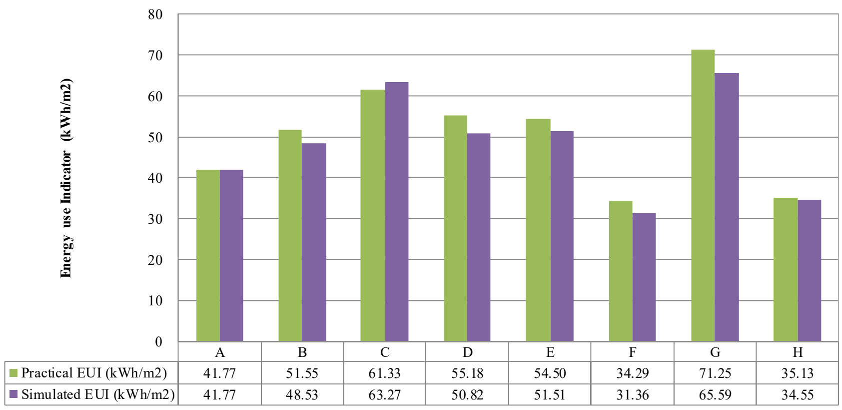


***Figure 6.*** *Energy consumption evaluation of eight typical buildings*

The practical energy consumption of Building C is lower than the energy benchmarking, that means Building C performs better than the design condition. Although the energy use intensity of Building C is in a relative high level among these 8 buildings, the practical energy consumption of Building C is reasonable by using the benchmarking method proposed in this study, which has different conclusion with using the traditional benchmarking method. While all other buildings have some energy conservation potentials more or less.

## 4. CONCULSION

This study proposes a hybrid method to get the energy benchmarking for buildings, and presents this method in government office buildings in Beijing. Through field investigation in 90 office buildings, detailed survey in 8 typical buildings, and establishing two prototype building models in DeST, this paper carries out analysis on energy consumption level in Beijing's government office buildings. The major findings and conclusions of this study are summarized as follows:

1) There're significant difference of energy consumption among government office buildings in Beijing, as the minimum value is only 23 kWh/m2/a, the maximum value can up to 200 kWh//m2/a, and the average is 65.5 kWh/m2/a;
2) There exist so many differences between different buildings, which could influence the energy consumption significantly, such as indoor occupant number, heat productivity of lighting and facility. Twelve key influencing factors are summarized based on detailed investigation, and these factors can be divided into two types, objective factors and convertible factors need to be modified;
3) Through comparing the practical energy consumption with energy benchmarking calculated by the method proposed in this paper, we find some buildings perform very well with high energy consumption, which is caused by objective factors, such as large occupant density. This method can come up with energy benchmarking for each building with considering of its individual features.

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