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# Research on the energy performance and indoor environment quality of typical public buildings in the tropical areas of China

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ABSTRACT

Hainan province is the only tropical and island province in China, with the unique climatic and geographical features. It has a different energy performance in public buildings from those in the inland areas. This paper investigated the current situation of energy consumption of the sampled public buildings, including 26 hotels, 24 office buildings and 7 department stores, through analyzing utility billing data, on-site survey and measurement, and site operational records. The breakdowns of energy consumption found out that the electricity dominated the energy consumption for all the sampled buildings and the air conditioning system played a key role in the energy consumption of major building services. By analyzing the main factors for building energy consumption, the annual average energy use indexes were calculated to be 141.63 kWh/m$^2$, 87.70 kWh/m$^2$, and 166.95 kWh/m$^2$ for hotels, office buildings and department stores, respectively. Besides, the comparison between Hainan province and other areas revealed that the building energy consumption of this tropical province was at a low level. Because indoor environment quality can influence the health and work efficiency of humans in buildings, field tests on the indoor environment quality were also carried out, and the performance of indoor environment quality was rated.



## 1. Introduction

With the rapid economic growth, building energy consumption (BEC) in China will occupy the lion's share in total energy consumption according to the developing law of developed industrial countries. BEC doubled from 1998 to 2009 in China [1], with the energy performance of buildings accordingly gaining more attention. It is necessary to investigate the energy consumption of public buildings and its contributing factors for working out reasonable countermeasures to enhance the building energy efficiency without the expense of a good balance among the economic growth, BEC and indoor environment quality (IEQ). Climatic and geographical features invariably produce different building energy performance in different climate zones. The tropical zones are characterized by their unique building energy performance with no need of heating in winter. Hainan Province, the only one tropical province of China and the one with the largest sea area, is located between 18°10′–20°10′ North Latitude and 108°37′–111°05′ East Longitude, with the land area 35,000 km$^2$. As Hainan Island is the largest island in the province, covering 33,900 km$^2$ and the rest islands only have very small population, this study mainly focuses on the main island. The situation of BEC in Hainan province has become increasingly grim, and the general trend of public building energy consumption has been climbing despite of the fact that BEC dropped in 2005 [2]. This paper studied the energy consumption of three types of public buildings, i.e. hotels, office buildings and department stores, which were considered to generate the distinguished high energy consumption.

Hotel has always been considered as one of the focuses in building energy performance studies, in which energy use index (EUI) and the main drivers for energy consumption were the two significant aspects. Priyadarsini et al. [3] studied the energy performance of 29 hotel buildings in Singapore, and calculated that the annual average EUI was 427 kWh/m$^2$. The main drivers, including hotel star rating, quantity of workers on the main shift and years after the last major energy retrofit, were identified in this investigation. Bohdanowicz and Martinac [4] collected the data of energy consumption from 184 Hilton International and Scandic hotels in Europe to ascertain the determinants and benchmarking of energy and water use. The annual average EUI for Hilton and Scandic were 364.3 and 285.0 kWh/m$^2$, respectively. Besides, a number of significant energy- and water-utilization indicators were identified, including hotel standard, location, climate, facility size, occurrence of energy- and water-intensive services, number

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of guest-nights and food covers sold, as well as quantities of laundry washed on-site. Another investigation involving 50 different sized hotels in Vietnam was completed by Trung and Kumar [5]. In this study, the annual average EUIs for four-star, three-star and two-star hotels were measured as 141 kWh/m$^2$, 143 kWh/m$^2$ and 101 kWh/m$^2$, respectively. Önüt and Soner [6] reported an annual average electricity consumption of 388.8 kWh/m$^2$, after evaluating the energy efficiency in 32 five-star hotels in the Turkey. According to another study on Tunisian hotels by Khemiri and Hassairi [7], the annual average energy consumption decreased from 372 kWh/m$^2$ to 170.9 kWh/m$^2$. After the investigation on energy performance of 16 Hong Kong hotels, Deng and Burnett [8] found that the average EUI was 564 kWh/m$^2$, and electricity occupied 73% of total energy consumed in the sampled hotels. Another study involving 36 Hong Kong hotels was then conducted by them and EUI of 542 kWh/m$^2$ was presented [9].

Office building has become a key aspect to study the EUI and the breakdown of the major equipment energy use. A study of energy performance in 19 government offices in Hong Kong was carried out by Li [10], where the average annual EUI was 871.1 MJ/m$^2$, which was equivalent to 242.17 kWh/m$^2$. Saidur [11] used energy formulations to estimate the energy use in office buildings and the energy use of major equipment in Malaysia. The deduced annual EUI was 130 kWh/m$^2$ and the percentages of electricity consumption for air-conditioning, lighting and general equipment were 57%, 19%, and 24%, respectively. Spyropoulos and Balaras [12] reported the average annual energy consumption of 345 kWh/m$^2$ in office buildings of Greece, and revealed the breakdown of the different end-uses that air-conditioning averaged 48% of the final energy consumption, 35% for lighting, and 17% for the other office electronic equipment, through energy audits in 11 typical bank branches. The average energy use intensity in U.S. office buildings was 293 kWh/m$^2$ revealed by Lombard et al. [13]. Wong and Mui [14] presented the energy performance assessment regarding the IEQ acceptance for air-conditioned offices in Hong Kong. The results showed a non-linear increasing trend of annual thermal energy consumption for IEQ improvement at the offices of higher IEQ benchmarks.

Investigations on electricity consumption dominated the relatively fewer studies for energy performance of department stores. Lam and Li [15] investigated four fully air conditioned shopping centers completed during the 1990s to establish energy use characteristics pertinent to shopping centers in subtropical climates. It was found that air conditioning and electric lighting accounted for about 85% of the total building energy consumption, and electricity use index ranged from 391 kWh/m$^2$ to 454 kWh/m$^2$, with an average of 430 kWh/m$^2$. Tassou et al. [16] surveyed the energy consumption for 150 stores with sales area in the range of 5000–10,000 m$^2$ in USA, and the result showed the average electricity use index was 770 kWh/m$^2$. The result of a study on the department stores and other 3 kinds of buildings involving office, hotel and hospital in Thailand by Chirarattananon and Taweekun [17] showed that whole building retrofit was more cost effective than adopting individual options. The annual EUI and breakdown of annual energy consumption for 4 kinds of buildings were also obtained through the DOE-2 simulation matching with the energy audit reports, where, the annual EUI for each building type were 361 kWh/m$^2$, 161 kWh/m$^2$, 171 kWh/m$^2$ and 144 kWh/m$^2$, respectively.

All the above studies obtained the EUI for the building types, and some of them broke down the energy use by major equipment or service systems, but with the lack of research for energy performance of public building in China, especially that of the tropical areas in China. Hainan province is in full swing to construct the International Travel Island, posing the needs to investigate the energy performance of public building. The research method and results of analysis are presented as follows.

## 2. Investigation method and data samples

### 2.1. Investigation method

Haikou, the provincial capital, and Sanya, the key tourism city, are the first two and most important cities in Hainan province. The Gross Domestic Product of the two cities with 32.5% of the total population in the province accounts for 69.59% of the entire Hainan province [18]. The sample consists of 57 buildings, with 46 buildings from Haikou and Sanya, and 11 buildings from the secondary cities, which are Wanning, Wenchang, Baoting, Zhanzhou, Dingan, Lingshui, Boao, and Wuzhishan. Specifically, the sample includes 26 hotel buildings, 24 office buildings and 7 department stores, with heterogeneous features, such as the construction time of buildings from 1982 to 2009, gross floor area (GFA) ranging from 1800 to 112,200 square meters, 33 buildings equipped with central air conditioning systems and 24 buildings split air conditioning systems, and the types of energy spanning from electricity, natural gas, diesel to liquefied petroleum gas (LPG).

Related information and data of energy consumption of the sampled buildings were obtained in a three-staged process. In the first stage, a conference with the owners of the target buildings aimed for their permission and coordination. The background information, such as building structure, year of construction, total GFA, types and amounts of equipment using energy, performance of energy management, operating schedule, etc., were assembled in the conference with the support of energy management departments of the target buildings. In the second stage, data from sub-meters for building services was collected to break down the energy use. Detailed field measurements for the buildings with no sub-meter system were conducted in the third stage, which, specifically, referred to:

- collecting operating records and rated power input for each item of major building service equipment;
- power measurement for the service systems with the energy use being fairly constant over the year, for example, lift systems and lighting;
- assembling the records of low voltage distribution line;
- calculating the annual energy consumption of major building service systems by testing hourly energy consumption of workday and non-workday.

In addition, related field tests were also carried out for evaluating the IEQ of the sampled buildings.

After the data collection for energy consumption of the entire building and main building services, the energy consumption equation was applied to review the result according to the "Energy audit guide for government office buildings and large-scale public buildings" [19]. It is expressed as Eq. (1).

$$E_{\mathrm{tot}} = \sum_i E_{\mathrm{i}} \pm e \qquad (1)$$

where $E_{\mathrm{tot}}$ is the total BEC based on the energy consumption bill of the sampled building; $E_i$ is energy consumption of each main building service system; and $e$ is energy consumption of others (miscellaneous items) that are not audited. It needs to be noted that the proportion of $e$ cannot exceed 15%; otherwise the result fails in the energy consumption equation, and data should be recalculated or recollected again.