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Research Article

An Overview of the Green Building Performance Database

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Research on how the database method can assist building performance diagnosis has become an important direction of current green building studies. Many research institutions have paid great attention to the building performance database, adopting new technologies to integrate indoor environmental quality and occupant satisfaction with building energy consumption data. This paper introduces and summarizes the data types, collection methods, and applications of current building performance databases, including those in the United States, the European Union, Japan, and Australia, as well as China. In view of the current problems of limited coverage, poor quality, and ineffective application of green buildings in China, this paper proposes a three-dimensional framework for green building performance databases. The collection and optimization methods of green building performance data are also discussed.

1. Introduction

The building industry accounts for about 40% of total energy consumption and greenhouse gas emission [1]. Green building (also known as sustainable building), which can create better indoor environmental quality (IEQ) for occupants with less consumption of natural resources, is developed to reduce the negative influences of buildings on the environment since 1990s. The definition of green building is generally accepted as the planning, design, construction, and operation of buildings with the maximum conservation of resources (energy, land, water, and materials), environmental protection, pollution reduction, and providing people with healthy and comfortable indoor space [2]. Ever since 2001, China has greatly promoted the development and application of green building, and the number of green building projects has grown steadily year by year. As of September 2016, China has a total number of 4,515 of green building labeled programs, with a total construction area of 523 million square meters [3]. Take Zhejiang as an example. Located in the hot summer and cold winter zone of China, Zhejiang Province has been at the forefront in promoting the development of green buildings. During the years from 2011 to 2015, 5.3 billion square meters of energy-efficient buildings have been built, and 2.4 billion square meters of green buildings are included. The renewable energy covered area grows by over 1 million square meters every year, and the existing buildings under energy-saving retrofit by 18.91 million square meters per year [4]. According to the Zhejiang Green Building Regulations released in 2016, all new projects should meet the green building standards [5]. At the end of that year, a total of 276 projects were obtained the green building certification [4].

The national green building evaluation is divided into two types as the design label (at the construction stage) and the operation label (after one year of operation). As of 2016, among the 4,515 green labeled projects in China, the design labeled ones accounted for 94%. The number of operation labeled ones was only 269 (6% of the total), with its construction area less than 40 million square meters [3,6]. Similarly, among 276 green labeled projects in Zhejiang Province, operation labeled ones were 20, accounting simply for 7% of the total.

The operation label is given with consideration of seven factors: the energy saving, land saving, water saving, material saving, indoor environment quality, construction management and operation management of a project. Mere 79 out of 276 (less than one-third) green labeled projects in Zhejiang reached the requirement for operation management. Among those 79 projects, only 22 (8%) adopted the building energy submetering system, and only 33 (12%) applied the automatic monitoring technology for building HVAC systems. Due to insufficient supervision, many projects granted the design label is not "green" after operation. Some technologies, though costly, yet designed for green evaluation, have not been implemented during construction, nor used during operation [7].

The analysis mentioned above shows the problem of green building development in China. That is, the certification of green buildings presently mainly focuses on the design stage and lacks operation management. Given the fact that the energy consumption of buildings at the operation stage accounts for about 80% of the total, it is necessary to improve building performance supervision at the operation stage. Meanwhile, the effectiveness of green building technologies should also be evaluated via the collection of building performance data, which include not only the energy consumption, but also the indoor environment and occupant satisfaction.

2. Current Building Performance Databases Worldwide

Some countries have gradually paid attention to the energy consumption and environmental performance of operated buildings, establishing various types of building performance databases to analyze and optimize building performance. Representatives are the Building Performance Database (BPD) and Indoor Environmental Quality Survey (IEQ) databases in the United States, the Buildings Performance Institute Europe (BPIE) database in the European Union, the Database for Energy Consumption of Commercial Building (DECC) in Japan, and the Building Occupants Survey System Australia (BOSSA). These databases integrate subjective and objective data on building energy consumption and environmental quality, with new technologies consistently incorporated to realize a faster, larger-scale collection of data on energy consumption, indoor environment, and occupant satisfaction. In recent years, some research institutions and cities in China have carried out preliminary studies in this area, mainly focusing on the collection and processing of energy consumption information of public buildings. Local governments have also made many positive attempts in building energy consumption surveys and databases. However, most of those databases still remain at the initial stage of collecting building energy consumption data and fail to comprehensively evaluate the building indoor environment and occupant satisfaction.

In this section, we would introduce and summarize the data types, collection methods and application of current building performance databases around world.

2.1. Existing Databases in China. In 2007, the Ministry of Housing and Urban-Rural Development and the Ministry of Finance jointly released the "Implementation Opinions on Strengthening the Energy Conservation Management of Office Buildings and Large Public Buildings of State Organs, which rendered three cities of Shenzhen, Beijing, and Tianjin as demonstration cities for the development of public building energy monitoring systems [8]. Up to now, nationwide, there are more than ten monitoring systems for building energy consumption under application, distributed in Beijing, Tianjin, Shanghai, Shenzhen, Nanjing, Qingdao, and other places [9].

2.1.1. Building Energy Monitoring System (EMS-II) in Beijing. As early as 2006, Beijing Energy Conservation and Environmental Protection Center and Tsinghua University designed and developed the Building Energy Monitoring System EMS-II, and they have gradually carried out a series of research on the public building smart meter, data transmission network, database, real-time data visualization, automatic energy consumption analysis, and energy-saving diagnosis. At present, the database accesses and collects real-time energy consumption data of buildings located in Beijing, Shanghai, Shenzhen, Hangzhou, Guangzhou, and Qingdao [9].

2.1.2. Government Office and Public Building Database in Shenzhen. Shenzhen is the first city in China that has completed the project of establishing government office buildings and large-scale public building databases. The first phase of the project includes the data collection of basic information and energy consumption of 450 public buildings (25.76 million square meters), energy audit of 368 buildings (17.6 million square meters), and the real-time energy monitoring of 50 buildings. It also involves the establishment of Shenzhen Building Energy Monitoring Data Center [10]. The project will gradually integrate more public institutions in Shenzhen into the data center.

2.1.3. Public Building Energy Monitoring Database in Shanghai. The Public Building Energy Monitoring Database in Shanghai has been put into operation since 2014. The database mainly stores building basic information, classification, energy monitoring and auditing data, energy-saving analysis, green building information, and GIS geographic information. All data would be preprocessed and aggregated and then be centrally stored and hierarchically managed in the data center. The database also collects data of 200 green buildings in Shanghai and classifies them according to districts, building types, and green building rating grades. All metering data of new projects must be connected to the database before operation [11].

The abovementioned introduction of building performance database in key cities nationwide shows that the focus of such databases is currently on building energy consumption monitoring. However, there are certain limitations: (1) for data types, there is a lack of evaluation of indoor environmental quality and occupant satisfaction; (2) most building information cannot be shared, which means that occupants have access neither to the database nor to the real-time operation information of the buildings.

2.2. Existing Databases in Other Countries

2.2.1. Database for Commercial Building (DECC) in Japan. The Institute for Building Environment and Energy Conservation established a sustainable building database in 2008, which collected and published a series of detailed information on sustainable buildings, including energy consumption, indoor and outdoor environments, carbon dioxide emissions, CASBEE (a labeling tool based on the building environmental efficiency) score and technical details [12]. However, as it was originally developed for an activity of the Asia Pacific Partnership on Clean Development & Climate and Buildings & Appliances Task Force, this database gives priority to CO_2 emission reduction rather than the various topics around sustainable buildings. So far, the databases of Australia, China, India, and the United States have been linked into this sustainable building database.

Later, Japan Sustainable Building Consortium has established the Database for Energy Consumption of Commercial Building (DECC), which consists of building information collected from 2007 to 2011. There are 38,273 sample data, including electricity consumption, water consumption, and other energy consumption detailed data (e.g., lighting and sockets) [13].

2.2.2. Data Hub for the Energy Performance of Buildings in the EU. Since 2011, Buildings Performance Institute Europe (BPIE) has conducted a large-scale survey of building energy use across the EU, including the performance data provided by governments, different departures, and other databases. On the basis, the BPIE database was established to store various statistics on the performance of European buildings. This is the first open building performance database in Europe. Occupants can select and analyze different data combinations of countries/regions, assessment topics, building types, etc., as illustrated in Figure 1 [14].

The BPIE database was later integrated into the EU Building Stock Observatory at the end of 2016. Funded by the European Commission, the EU Building Stock Observatory monitors the energy performance of buildings across Europe. Basically, it assesses improvements in building energy efficiency and the consequent impact on the actual energy consumption of the architecture sector overall. The Observatory tracks many different aspects of information, including energy efficiency levels, different certification schemes and their implementation, financing available for building renovation, and energy poverty levels across the EU. Based on the database, the commission has further developed a series of evaluation tools such as energy consumption mapping [15].

2.2.3. Building Performance Database (BPD) and Indoor Environmental Quality Survey (IEQ) in the U.S. Since 1979, the US Department of Energy has conducted two nationwide surveys every four years, known as the Commercial Building Energy Consumption Survey and the Residential Building Energy Consumption Survey, in an attempt to collect energy consumption information of buildings and their lighting/HVAC systems [16]. On this basis, it established the Building Performance Database (BPD) with Berkeley National Laboratory [17].

Meanwhile, the Green Building Research Center at the University of California, Berkeley, conducted an Internet-based Indoor Environmental Quality Survey (IEQ). The survey focused on seven main factors of indoor environmental performance, i.e., thermal environment, air quality, acoustic environment, light environment, cleanliness, space layout, and office furniture. As of October 2012, more than 65,000 occupants responded to the survey. The database has gradually developed more survey modules to obtain information on building security, accessibility, traffic, and green building performance [18].

2.2.4. Building Occupants Survey System Australia (BOSSA). The Building Occupants Survey System (BOSSA) is a joint building quality assessment system established by the University of Sydney and the University of Technology Sydney, which was developed at start for Australian office buildings and is now for the Australian Green Star Building Rating System. The system is composed of the BOSSA Time-Lapse (a survey for thermal environment and air quality), the BOSSA Snapshot (a real-time short survey module), and indoor environmental quality measurement (using the sensor-equipped mobile evaluation vehicle named BOSSA NOVA, see Figure 2) [19].

2.3. Summary of Current Building Performance Databases

2.3.1. Data Types. Among databases introduced above, only the PBD, IEQ, and BOSSA databases provide information on building environmental quality and occupant satisfaction based on Internet surveys. Other databases still focus on collecting building energy consumption data, as shown in Table 1.

2.3.2. Data Processing Methods. For the methods of data processing, data can be obtained either by direct monitoring or by filtering, mapping, and collating data from existing small databases, as shown in Table 2.

3. A New Green Building Performance Database

3.1. Framework of the Database. In this section, we propose a multitype and life-cycled green building performance database, with green-labeled projects in Zhejiang Province as the source of pilot data.

Different from traditional databases, which only store one single type of performance data, this database adopts the DDI method (that is, "Data Collection-Diagnosis-Improvement") for building actual performance diagnosis and optimization. On the basis, we would establish a so-called "three-dimensional" green building performance database, namely, the "Building Energy Consumption-Indoor Environmental Quality-Occupants Satisfaction" evaluation system. In this database we take into account factors such as building system information, occupant's behavior, energy consumption, indoor environmental quality, and occupant satisfaction. To get various building performance indicators,

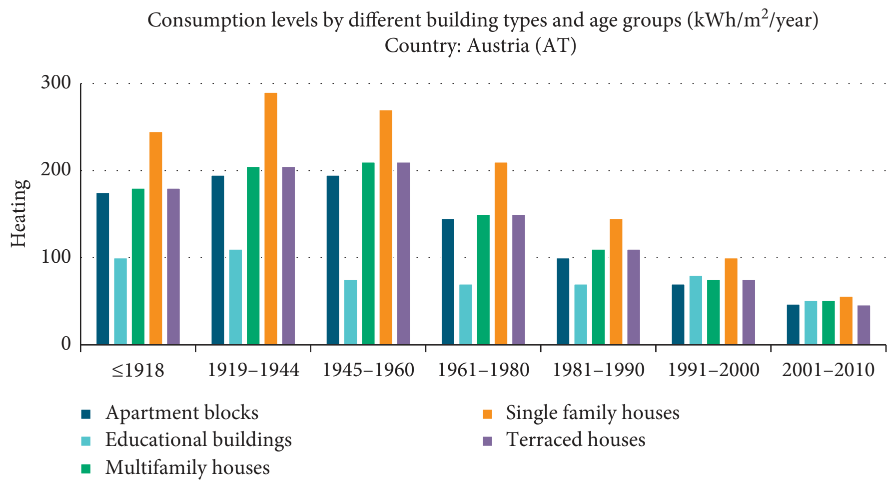

Figure 1: European BPIE database data (taking heating energy consumption for example).

(a) (b)

Figure 2: Indoor environment evaluation vehicle, BOSSA NOVA.

a set of standardized data collection and processing methods will also be covered, providing reliable data for the further diagnosis and optimization.

Overall, based on the literature mentioned above, we propose the following database framework as illustrated in Figure 3.

3.2. Standardized Data Collection and Processing Methods

3.2.1. Data List of Green Building Performance. The standardized green building performance data are summarized in Table 3. The main parameters include building information (e.g., climatic zone, building type, and system information), energy consumption, indoor environmental quality, and occupant satisfaction.

3.2.2. Methodology. The existing green reconstruction of buildings involves building environment, envelope structure, HVAC, water supply and drainage, electrical system, and operation management. Therefore, based on the characteristics and site conditions of a building, a systematic and quantifiable data collection scheme should be set up, and a series of subjective surveys and objective measurements be carried out so as to collect comprehensive data sets of quantitative energy consumption, environmental indicators, and qualitative occupant satisfaction. At the same time, we should consider the cost of collecting work and select reasonable samples to complete the evaluation.

(1) Data Collection. In the early stage of building performance data collection, we shall acquire the design and system information of the object building and collect the building drawings and declaration materials, which include but not limited to green building declarations, self-assessment reports, building professional drawings (design instructions, vertical profile plans, door and window tables, exterior walls, and roofing practices), electrical professional drawings (distribution system drawings, lighting system layout plans for each floor), HVAC professional drawings (system schematic drawings, air conditioning room profile drawings, and each layer HVAC system profile drawings), and water supply and drainage professional drawings. Based

Table 1: Data types of current building performance databases.

Databases	Building types	Major data types: Basic information	Energy consumption information	Indoor environmental quality	Occupants satisfaction
DECC (Japan)	Public and residential building	Region classification; area; year built; operating hours; ownership	Heating/cooling hours; electricity/fuel/gas/oil consumption; hot water/ steam/clean water consumption; annual primary energy consumption per average unit area	—	—
BPIE (the EU)	Public and residential building	Climate zone; building stock; envelope design; NZEB design information	Energy consumption (heating/cooling/ lighting/total); district heating/cogeneration consumption; equivalent energy demand	—	—
BPD (the U.S.)	Public, residential, and industrial building	Climate zone; year built; area; occupant density; envelope design; operating hours; LEED/ energy star rating	Lighting/HVAC systems information; summer/ winter peak; rate structure; fuel/ electricity/regional energy use density and annual consumption	Lighting; air distribution; heating; zonal heating; cooling; zonal cooling; other HVAC	—
IEQ (the U.S.)	Office building	Number of floors; orientation; operating hours; area use ratio	—	—	(1) Basic: acoustic quality; air quality; cleanliness and maintenance; lighting; office furnishings; layout; thermal comfort (2) Optional: accessibility; building and grounds; commute; conference and training rooms; court work; daylighting; maintenance service; office support equipment; etc
BOSSA (Australia)	Office building	Year of use; operating hours; area use ratio	—	NOVA: Thermal comfort (air temp., humidity and speed, and black globe temp.); indoor air quality (CO_2; TVOC; formaldehyde; particulate matter); visual comfort (horizontal and vertical illuminance); acoustics (sound pressure)	Time-lapse: indoor air quality and air movement; spatial comfort; noise distraction and privacy; connection to outdoor environment; building image and maintenance; individual space; thermal comfort; visual comfort; self-assessed health and productivity

on a comprehensive understanding of the building system, we will conduct further data collection.

(2) Investigation and Survey. For different types of green buildings, we shall formulate a set of standardized and systematic questionnaire surveys, which include but are not limited to the occupants' basic information, indoor environmental quality, comfort and satisfaction, indoor environmental controllability, and service performance evaluation. Participants of different ages and genders should be reasonably grouped according to various conditions such as different functional spaces and different rules of use, and the number of participants should not be less than 20 percent of the actual occupants. After the

Table 2: Data processing methods used in representative building performance databases.

Databases	Data sources	Applications
DECC (Japan)	Surveys conducted by industry, the government, and university research institutions	(1) Provide raw data for the further analysis of energy, water consumption, and carbon dioxide emissions and for making long-term carbon dioxide emission plans (2) Provide specific energy consumption benchmarks for buildings of different regions/functions/scales
BPIE (EU)	Government surveys; other databases	(1) Provide the prototype of the EU Building Stock Observatory, so as to monitor the implementation of energy policies in the EU member states (2) Help develop the building energy consumption map and find areas of poor energy performance (3) Serve 20 tool databases including the IEA Buildings Energy Efficiency Policy Database (BEEP)
BPD (the U.S.)	Government surveys; other databases	(1) Help evaluate the energy use intensity for different types of buildings (2) Help develop the US building energy consumption map for regional building performance research
IEQ (the U.S.)	Web-based occupant surveys	(1) Foster the comparative study on IEQ performance between LEED-certified buildings and conventional buildings (2) Predict building thermal comfort
BOSSA (Australia)	Web-based occupant surveys; on-site measurements	(1) Provide reference for Australian Green Star/NABERS performance ratings (2) Provide data support for nearly 30 companies and institutions including Canon, AECOM, and ARUP

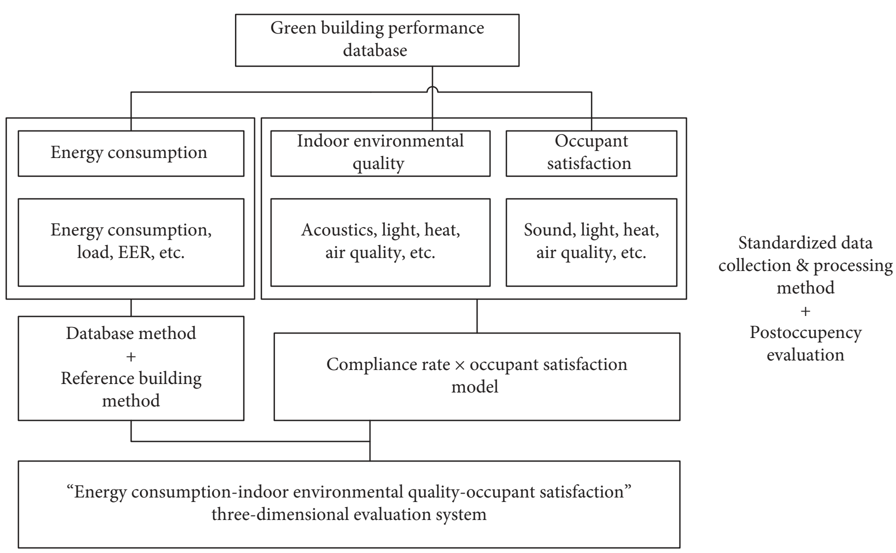

Figure 3: Framework of green building performance database for Zhejiang Province.

results of the questionnaire survey is sorted out and analyzed, we shall select representative research objects to conduct in-depth interviews that focus on combining the causes of occupant dissatisfaction in an attempt to determine the impact of occupant comfort and satisfaction in key optimization areas.

(3) Measurement. The basic parameters of building indoor environmental monitoring include thermal environment parameters (air temperature, relative humidity, radiant temperature, black ball temperature, and air flow rate), light environment parameters (illuminance standard value, illuminance uniformity, uniform glare value, and color rendering index), acoustic environmental parameters (indoor sound pressure level, outdoor sound pressure level, and background noise), and air quality parameters (CO_2, VOC, and $PM_{2.5}$). The layout of indoor environmental parameters monitoring instruments should be designed with consideration of the types of buildings, the number of occupants, air conditioning partition, and other factors. We shall

Table 3: Green building performance data list.

Building information	*Basic information*: building type; location; year built; floor area; building height; orientation; green building ratings, etc *Operating characteristics*: ownership (whether operated by government; whether self-built; number of residents; etc.); operating hours; and characteristics Technical information (1) Building envelope: performance parameters of exterior walls/interior walls/roofs/doors and windows; construction information of thermal bridges and shadings; and openable external window (2) HVAC system: HVAC covered area; system type; cold/heat source and performance parameters; air conditioning set temperature; supply/return water temperature; and cold/heat storage
Energy consumption	*Design information*: design energy consumption per unit area; design energy-saving rate; design energy consumption of the HVAC system; adjustable fresh air speed; energy efficiency ratio of air conditioning water; fan power consumption of per unit air volume; waste heat utilization; submetering; illumination design; elevators utilization of renewable energy and recycled water; exhaust heat recovery power; and CCHP information *Energy consumption* (1) Energy type and consumption (electricity/fuel/gas); equivalent electricity; and equivalent standard coal (2) Itemized power consumption data (daily; monthly): lighting; fresh air; cooling; heating; plug-in power; elevators; water supply; domestic hot water, etc *Renewable energy use and water utilization*: renewable energy; hot water generation; renewable electricity generation; nontraditional water (rainwater/municipal water/self-generated water) sources; nontraditional storage and utilization; and water-saving irrigation
Indoor environmental quality	*Technology adoption*: natural ventilation; natural lighting; shading; adjustable air conditioning control; indoor air conditioning set temperature; fresh air volume; and air quality monitoring *Thermal environment*: Air temperature; relative humidity; radiant temperature; black globe temperature; air flow speed, etc. *Lighting*: illumination standard value; uniformity; glare; and color rendering index *Acoustic environment*: indoor sound level; outdoor sound level; and background noise *Indoor air quality*: CO_2; VOC (volatile organic compounds); and $PM_{2.5}$
Occupants satisfaction	*Occupants information*: gender; age; identity; room number; hours; and habits in building *Satisfaction survey of indoor environmental* (1) Thermal environment: occupants clothing; feeling of indoor temperature; and humidity (2) Lighting environment (3) Acoustic environment: noise sources and level (4) Air quality: indoor air freshness and air flow speed (5) Overall satisfaction of indoor environmental quality *Indoor environment controllability*: convenience and intelligence of air conditioning and illumination control *Services*: maintenance management; functional layout; spatial scale; and aesthetic performance

continuously monitor for one year and a typical month be selected for one month in each season, with a maximum interval of less than 10 minutes. Moreover, we shall timely complete the test instrument to register and ensure effective accuracy and regular inspection.

(4) Energy Consumption Monitoring. The data of building energy consumption can be obtained from the building energy monitoring platform or energy consumption bill. The subitem energy consumption data acquired through the energy monitoring platform shall comprise that of the air conditioning system, lighting, plug-in, etc., so as to analyze the performance of each subitem.

The collected raw data should be processed and classified strictly, and through a series of data cleaning, integration, and conversion techniques, the noise in the data, the irrelevant useless data and the differences of the data sources should be eliminated, and the data should be combined and classified.

3.3. Further Application of the Database

3.3.1. Optimize Operation Performance. On the one hand, this standardized green building performance database provides real-time data and analysis for management through on-line monitoring of building operation performance and combined with occupants' subjective feedback, lays the foundation for performance improvement. On the other hand, since the management understand the energy use conditions, they have a clearer understanding of its own advantages and gaps as well as the direction of optimization by comparing the operation data levels of similar buildings.

3.3.2. Provide Decision-Making Support. The database can not only serve the energy-saving diagnosis and design optimization of a single building but also establish a unified operation performance data model and corresponding evaluation indexes. With the model, it is convenient to identify whether the operation conditions of the buildings are reasonable or not. On the basis, the relevant policies and regulations can be provided for decision-making and administrative supervision to encourage advances and overcome backwardness.

3.3.3. Predict Building Performance. Through analyzing the operation performance of existing buildings, we utilize data mining technology to establish a set of green building operation evaluation and prediction model to make reasonable prediction of future operation. Through simulation and optimization techniques, it can automatically identify high-energy buildings, so as to analyze and thus improve the design parameters of such buildings. At the same time, we shall collect and analyze the data in the area of the analysis area, expand the energy consumption prediction of different space scales, establish a regional comprehensive model, and carry out objective and effective simulation and prediction on the operation rule of the green building in a certain area, so as to monitor and master the distribution of the building in Zhejiang or the rest of China to improve the operation and management level of green buildings.

4. Conclusion

Research on how the database method can assist building performance diagnosis has become an important direction of current green building studies. Many research institutions have attached great importance to the building performance database, adopting new technologies to integrate indoor environmental quality and occupant satisfaction with building energy consumption data. This paper introduces and summarizes the data types, collection methods, and application of current building performance databases, including those in the United States, the European Union, Japan, and Australia. However, only the PBD, IEQ, and BOSSA databases have provided information on building environmental quality and occupant satisfaction based on the Internet surveys. Other databases merely focus on collecting building energy consumption data.

Research institutions and cities in China have carried out preliminary work in the said area, mainly focusing on the collection and processing of energy consumption information of public buildings. Governments have also made many positive attempts in promoting building energy consumption surveys and databases. However, most of those databases still remain at the preliminary stage of collecting building energy consumption data and fail to comprehensively evaluate the building indoor environment and occupant satisfaction.

In view of the current problems of limited coverage, poor quality, and ineffective application of green buildings in China, this paper proposes a multitype and life-cycled green building performance database and takes green-labeled projects in Zhejiang Province as the source of pilot data. In this database, we take into account factors including building system information, occupant behavior, energy consumption, indoor environmental quality, and occupant satisfaction. Also, there should be a set of standardized data collection and processing methods to acquire various building performance indicators, thus providing reliable data for the further diagnosis and optimization.

Data Availability

The data of green labeled projects in China and building performance databases used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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