Energy consumption baselining and benchmarking of green office buildings in Shanghai

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Abstract. In recent years, many green buildings were built across China, but the actual performance is not as good as expected. Therefore, it is necessary to improve their performance and establish an objective energy consumption baseline as well as the benchmarking approach for green office buildings in Shanghai. Firstly, we categorized the green office buildings in Shanghai into two type - small and large, according to their floor area. Then we defined the baseline of EUI (energy use intensity, kWh/sq.m.a) based on the survey and submetering data and developed the reference models for both small and large green office building. Secondly, we specified four EUI reference levels for each type after studying the energy saving potential of green office buildings in Shanghai. Thirdly, in order to make the benchmarking approach more objective, we proposed EUI correction method for office buildings considering three main influencing factors - schedule, occupant density and meteorological parameters. We established a typical building model library of office buildings in Shanghai. We adopted regression analysis to obtain the corrections for schedule and occupant density. As for meteorological parameters, by classifying the typical days and calculating their representative EUIs, we determined the correction method.

1 Introduction

The whole building process accounts for 46.5% energy use in China⁴, and the office buildings accounts for approximately 32% of all electricity consumption of all buildings in Shanghai². It is urgent to save energy in office buildings.

Therefore, the “green building” has emerged. Many countries and regions have introduced standards for defining and evaluating green building, such as LEED in American³, CASBEE in Japan⁴, etc. These standards focus on environment protection and our quality of life. Significantly, energy consumption is a key item in scoring details.

Many researchers have investigated the energy consumption of global green office buildings. Balaban⁶ conducted a survey on seven green office buildings in Tokyo and Yokohama, and the results showed that green buildings reduced energy consumption. Lin⁷ compared the energy consumption of 48 green office buildings and 481 common office buildings in China and found that the median of green is 21% lower than common. Gui⁸ analyzed 2460 green office buildings and found that for buildings in the same city and with the same star rating, the energy use intensity(EUI) varies greatly.

However, some scholars have found that the green buildings did not perform as expected in actual runtime, known as performance gap⁹. John¹⁰ analyzed data from 953 New York City office buildings and 21 of them identified as LEED-certified, and found that the LEED Silver Certified buildings showed no savings compared with non-LEED buildings. Lin⁷ found through research that not all green office buildings meet the Chinese Standard for Energy Consumption of Buildings.

In short, although emphasizing energy saving, the actual energy performance of green office buildings is quite different. Therefore, it is important to establish an evaluation system based on the actual operation effect of buildings.

Energy consumption baselining and benchmarking is widely adopted. Baselinin g tends to establish a level of normalization. The definition of energy consumption baseline mainly divided into model-based simulation analysis¹¹ and statistics-based mathematical analysis¹²,¹³. Statistical analysis relies on large amounts of data, while simulation methods rely on model and the accuracy of software calculations.

Benchmarking is the process of measuring the energy performance of a building with an established peer group¹⁴. In American, Energy Star Portfolio Manager (ESPM), a benchmarking tool to evaluate the energy consumption level, is based on a regression model built upon the Commercial Buildings Energy Consumption Survey (¹⁵). Green Mark, a benchmarking system used in Singapore, obtained the quartiles of EUI for different buildings based on the energy consumption data¹⁶.

As we all know, there are many factors which influence the energy consumption. Even buildings of the same type can vary greatly in energy consumption under different usage patterns¹⁷. So when evaluating the
energy performance of a building, error may occur without a reasonable benchmarking \[18\].

Many scholars corrected the energy consumption benchmarking by Multiple Linear Regression (MLR) \[19, 20\]. MLR models are easy to implement and interpret due to their linear and additive properties \[21\]. However, some factors that affect energy consumption have a nonlinear relationship with energy consumption, such as meteorological parameters \[22\].

In order to solve the nonlinear relationship, machine learning is introduced \[23, 24\], which needs large amounts of data. But it is difficult for us to obtain enough data on green office buildings in Shanghai, so we propose a correction method combining linear regression and classification.

Generally speaking, the main purpose of this study is to carry out research on the energy consumption baselining and benchmarking of green office building in Shanghai. Due to the lack of data, we proposed them through the combination of data and simulation. Furthermore, to make them more objective when used, we also considered three main influencing factors - schedule, occupant density and meteorological parameters.

2 Methodology

This paper studies the energy consumption baseline of green office buildings in Shanghai based on the combination of simulation and statistical data analysis. The research route is shown in Fig. 1.

The research was mainly divided into two parts: the energy consumption baseline and the energy consumption correction. In the first part, based on the measured data, we established the energy consumption baseline and typical benchmark model of large and small green office building in Shanghai. In the latter part, the factors of energy consumption correction primarily include schedule, occupancy and meteorological parameters. In regard to the correction for schedule and occupancy, based on the typical model, we set up typical model library. Based on it, we adopted the method of regression to determine the correction method. As for meteorological parameters, we obtained their typical days and the days’ representative energy consumption by classification, and determined the correction method. Moreover, we verified the correction methods proposed.

2.1 Definition of energy consumption baseline

2.1.1 Calculation of energy consumption baseline

Before defining the energy consumption baseline of Shanghai's green office buildings, we divide office buildings into small office buildings (building area \(\leq 20,000\text{m}^2\)) and large office buildings (building area \(> 20,000\text{m}^2\)).

Because of the limited sample, we used the combination of mathematical statistical analysis and model simulation to define the energy consumption baseline. The average method was selected for research, which reflects the average level of building energy consumption, and the calculation formula can be expressed as:

\[
E_a = \frac{1}{n} \sum_{i=1}^{n} E_i
\]

where, \(E_a\) is the energy consumption baseline (kWh/sq.m.a); \(E_i\) is the annual energy performance per unit building of \(i\)-th sample (kWh/sq.m.a); \(n\) is the sample number.

2.1.2 The calibration of typical model of energy consumption benchmark

We used DesignBuilder and EnergyPlus to establish the typical model. Fig. 2 shows the main process, and the data used in calibrating model was obtained through the monitoring platform and on-site surveys.

\[\text{Fig. 2. The process of model calibration}\]

Based on the basic building information of green office buildings in Shanghai, combined with local energy-saving design standards and green building-related standards, we determined the typical models of energy consumption benchmarks for large and small green office buildings in Shanghai. The basic building information is shown in Table. 1.

\[\text{Table. 1. Basic building information of typical model}\]

| Building information | Small | Large |
|----------------------|-------|-------|
| Area/m²              | 4725  | 50000 |
| Length/m×m           | 45×15 | 50×50 |
| Storey height /m     | 3.6   | 4     |
| Window-wall ratio    | 0.3   | 0.5   |
Exterior window U-value [W/(m²·K)]
- 2.35
- 2.31
Exterior window SC
- 0.45
- 0.35
Exterior wall U-value [W/(m²·K)]
- 0.6
- 0.62
Roof U-value [W/(m²·K)]
- 0.57
- 0.46
Chiller COP [W/W]
- 4.2
- 5.2
Heat source COP
- 4.2
- 0.92(*)
Occupant density [m²/person]
- 8
- 8
Lighting density [W/m²]
- 8.4
- 9.24
Equipment density [W/m²]
- 17.5
- 14

*efficiency of boiler.

With reference to local and national design codes, we selected a mainstream schedule, shown in Fig. 3.

Since the operating energy consumption data of the green buildings have been obtained through the monitoring platform in the past two years, we used the measured meteorological data of Shanghai in recent years as the input. We adopted the measured meteorological data of Shanghai Meteorological Station from 2008 to 2017 to generate the new standard meteorological data file of Shanghai.

As for energy consumption data, we used the average method to determine the calibration data, which is consistent with the method of determining the baseline.

2.1.3 Energy saving potential research based on typical model

By analysing the basic information of the green office buildings obtained from survey, it can be found that the green office buildings in Shanghai still have great energy-saving potential. Based on the typical model of energy consumption benchmarks, we referred to the current status of energy-saving technology development and related research documents[25, 29], and set three energy-saving scenarios, as shown in Table. 2 and Table. 3.

Table. 2. The energy-saving scenarios for small office building

| Model               | qualified | good | excellent | perfect |
|---------------------|-----------|------|-----------|---------|
| Window U-value      | 2.35      | 2.35 | 2.30      | 2.20    |
| Window SC           | 0.45      | 0.43 | 0.41      | 0.39    |
| Roof U-value        | 0.57      | 0.50 | 0.45      | 0.45    |
| Chiller COP         | 4.20      | 4.30 | 4.60      | 4.80    |
| High-efficiency fan | -         | -    | -         | √       |
| Lighting density    | 8.4       | 8    | 7         | 6       |
| Equipment density   | 17.5      | 17   | 16        | 15      |
| Turn off the lights at noon | - | -    | 1.5h    | 1.5h    |

Table. 3. The energy-saving scenarios for large office building

| Model               | qualified | good | excellent | perfect |
|---------------------|-----------|------|-----------|---------|
| Window U-value      | 2.31      | 2.10 | 2.00      | 1.80    |
| Window SC           | 0.35      | 0.33 | 0.32      | 0.30    |
| Wall U-value        | 0.62      | 0.60 | 0.60      | 0.60    |
| Roof U-value        | 0.46      | 0.45 | 0.45      | 0.45    |
| Chiller COP         | 5.20      | 5.50 | 5.70      | 5.90    |
| The efficiency of boiler | 0.92  | 0.92 | 0.92      | 0.94    |
| High-efficiency fan | -         | -    | -         | √       |
| Lighting density    | 9.24      | 8    | 7         | 6       |
| Equipment density   | 14        | 13   | 12        | 11      |
| Turn off the lights at noon | - | -    | 1.5h    | 1.5h    |

2.2 Energy consumption correction

2.2.1 Establishment of typical building model library

In order to obtain an affective correction method for various variables, we need a large amount of energy consumption data of different buildings and different scenarios. Therefore, we established the typical building model library.

This study chooses 3 common schedules of office buildings in Shanghai: (1) “965” (Schedule A, the working hours are from 9 a.m. to 6 p.m. from Monday to Friday), which is often happened in the office buildings of state-owned enterprises and public institutions, as shown in Fig. 3; (2) “996” (Schedule B, the working hours are from 9 a.m. to 9 p.m. from Monday to Saturday), which is often adopted in the office buildings in some internet companies, as shown in Fig. 4. (3) “007” (Schedule C, the working hours are from 10 a.m. to 10 p.m. from Monday to Sunday), as shown in Fig. 5.
Since the internal gain includes occupant density, lighting density and equipment density, we set different scenarios for these aspects, as shown in Table 4.

Table 4. The scenario of internal gains

| No. | Occupant density | Equipment density | Lighting density |
|-----|------------------|-------------------|------------------|
| 1   | 4                | 12                | 6                |
| 2   | 4                | 15                | 6                |
| 3   | 4                | 15                | 6                |
| 4   | 4                | 20                | 9                |
| 5   | 6                | 12                | 6                |
| 6   | 6                | 15                | 6                |
| 7   | 6                | 15                | 9                |
| 8   | 6                | 20                | 9                |
| 9   | 8                | 12                | 6                |
| 10  | 8                | 15                | 6                |
| 11  | 8                | 15                | 9                |
| 12  | 8                | 20                | 9                |
| 13  | 10               | 12                | 6                |
| 14  | 10               | 15                | 6                |
| 15  | 10               | 15                | 9                |
| 16  | 10               | 20                | 9                |
| 17  | 12               | 12                | 6                |
| 18  | 12               | 15                | 6                |
| 19  | 12               | 15                | 9                |
| 20  | 12               | 20                | 9                |

As for meteorological parameters, we selected three versions: (1) Meteorological parameters I: new standard meteorological data file based on the measured data of Shanghai Meteorological Station from 2008 to 2017; (2) Meteorological parameters II: Chinese Standard Weather Data (CSWD), which come from the measured data from 1971 to 2003[27]. (3) Meteorological parameters III: the TMYx generated by the meteorological data processing of Hongqiao, Shanghai from 2004 to 2018[28].

Small office buildings usually use VRF and FCU air-conditioning systems, while large office buildings often adopt VAV and FCU. We combined energy-saving design standards to establish different types of typical building models, as shown in Table 5 and Table 6, and the U-value of roof and exterior wall are 0.5 and 0.8 W/(m²·K) respectively for all models.

Table 5. Parameters of small office buildings

| Model | A | B | C | D |
|-------|---|---|---|---|
| Area/m² | 3600 | 7200 | 12000 | 18000 |
| Window-wall ratio | 0.3 | 0.3 | 0.4 | 0.4 |
| Window U-value | 2.2 | 2.2 | 2 | 2 |
| Window SC | 0.45 | 0.45 | 0.4 | 0.4 |
| Chiller COP | 4.3 | 4.2 | 4.8 | 5.2 |

2.2.2 Correction for schedule

We used the energy consumption data from the typical model library to create scatter plots of "Schedule A-Schedule B" and "Schedule A-Schedule C", as shown in Fig. 6-Fig. 9. Obviously, there is a linear relationship between different schedule, which can be established and used as the correction formula.
2.2.3 Correction for occupant

When exploring the method of energy consumption correction for occupant density, we established a multiple linear regression model based on significant influencing factors.

The sample size is \( n \), and \( \text{EUI} \) is the intensity of energy use, \( x_1, \ldots, x_n \) are a set of factors to be tested, such as occupant density, lighting density, equipment density, and system form. The benchmark level of each factor is determined by the population or observation sample, and the benchmark occupant density set in this study is just the average value of the occupant density in the overall sample. Then standardize the influencing factors of occupant density according to the baseline level, and construct a “best fit” multiple regression model from the standardized data. Therefore, this article assumes that the final regression model \([29]\) is shown as:

\[
\text{EUI}_{\text{ave}} = \beta_0 + \sum_{i=1}^{4} \beta_i \left( \frac{x_i - \bar{x}_i}{s_i} \right) + \varepsilon
\]

Thus, the EUI correction model for occupant density in office building is:

\[
\text{EUI}_{\text{ave}} = \text{EUI}_0 - \beta_1 \left( \frac{x_1 - \bar{x}_1}{s_1} \right)
\]

where, \( \text{EUI}_{\text{ave}} \) is the revised EUI; \( \text{EUI}_0 \) is the original EUI; \( \beta_1 \) is the standardized regression coefficient; \( x_1 \) is the observed values of occupant density which affect the EUI.

2.2.4 Correction for meteorological parameters

Meteorological parameters are digital representations of climate, which play an important role in building energy consumption. Therefore, the impact of meteorological parameters should be eliminated.

We proposed a method of daily energy consumption correction for meteorological parameters, which comprehensively considers the influence of outdoor temperature and relatively humidity. Besides, it did not directly assume that energy consumption has a simple linear relationship with the meteorological parameters.

Chinese building climate zones were divided into 7 major regions. The main indicators of zoning include the average temperature in January and July and the average relative humidity in July. Similarly, the design requirements of building are based on different climate zones, and the criteria for distinguishing climate zones are based on daily average temperature and relative humidity. It can be seen that the daily average temperature and relative humidity have the greatest impact on the energy performance of the buildings.

Therefore, we selected outdoor temperature and relative humidity as the main factors, and proposed a correction method by classifying the temperature and relative humidity.

3 Results and discussion

3.1 Energy consumption baseline

3.1.1 Baseline of green office buildings in Shanghai

The sample data analysis results are shown in Fig. 10. The energy consumption baselines of large and small green office buildings in Shanghai are 107.04 kWh/sq.m.a and 75.82 kWh/sq.m.a.

3.1.2 Typical model of energy consumption benchmark

For large office buildings, this study builds a square building as the reference model, and a rectangular building for small office buildings. We divided large office building into the conventional five-zone model, while the small office building is divided into two areas (the north and the south), as shown in Fig. 11.
3.1.3 Energy-saving scenarios simulation

The simulation results of each energy-saving scenarios are shown in Table 8. It can be seen that the energy consumption baseline established based on operation energy consumption data still has about 20% optimization space under the existing energy-saving technical measures and management level. The energy consumption baseline is a minimum evaluation criteria under the premise of standards, codes and building operation status, which can be defined as the basic constraint value. The high-standard value of different energy-saving scenarios can be used as the current target or guide value for the development of energy consumption performance of green office buildings in Shanghai.

Table 8. The simulation results of energy-saving scenarios

| Large office building | Small office building |
|-----------------------|-----------------------|
| EUI qualified         | 75.28                 |
| Rate                  | 106.94                |
| EUI good              | 72.83                 |
| Rate                  | 102.54                |
| EUI excellent         | 64.49                 |
| Rate                  | 91.29                 |
| EUI perfect           | 59.47                 |
| Rate                  | 85.68                 |

3.2 Correction for schedule and occupant density

3.2.1 Correction for schedule

We performed regression analysis to determine the correction model, and used the statistic determination coefficient $R^2$ to determine the goodness or badness of the regression. The correction formulas are shown in Table 9.

Table 9. The correction formula for schedule

| Scope                  | Correction formula |
|------------------------|--------------------|
| Schedule B, large office buildings | $EUI_{corr} = 0.648EUI_0 + 3.451$ R$^2=0.992$ |
|                      | $EUI_{corr} = 0.343EUI_0 + 25.113$ R$^2=0.968$ |
|                      | $EUI_{corr} = 0.677EUI_0 - 1.431$ R$^2=0.996$ |
|                      | $EUI_{corr} = 0.385EUI_0 + 12.519$ R$^2=0.996$ |

3.2.2 Correction for occupant density

We performed multiple step regression analysis to determine the correction model for occupant density. The correction models are shown in Table 10, and the determined coefficient $R^2$ is 0.882 and 0.911.

Table 10. The correction formula for occupant density

| Scope                  | Correction formula |
|------------------------|--------------------|
| Schedule A, large office building | $EUI_{corr} = 2.832 + 2.969$ R$^2=0.882$ |
|                      | $EUI_{corr} = 2.832 + 2.632$ R$^2=0.911$ |

3.2.3 Verification of correction for schedule and occupant density

This study selected a building and a research institute to verify the correction method of large office buildings and small office buildings, and established a detailed energy consumption model. The basic information of models is shown in Table 11.

Table 11. The basic information of models for verification

| Scope | Model | Large | Small |
|-------|-------|-------|-------|
|       | Area /m² |      |       |
|       | Window-wall ratio | 0.4 | 0.31 |
|       | Window U-value | 2.1 | 2.5 |
|       | Window SC | 0.33 | 0.35 |
|       | Wall U-value | 1.29 | 0.53 |
|       | Roof U-value | 0.85 | 0.53 |
|       | Chiller COP | 5.06 | 4.2 |
|       | Heat source COP | 0.89* | 4.2 |
|       | Occupant density | 6 | 12 |
|       | Lighting density | 9 | 7.8 |
|       | Equipment density | 15 | 10 |
|       | Terminal | FCU+DOAS | VRV |
|       | Schedule | Schedule A | Schedule A |
|       | Meteorological parameters | Meteorological parameters I | Meteorological parameters I |

*: efficiency of boiler

Based on the established calibration model, we set different schedule and occupant density for simulation. The results are shown in Table 12. It is shown that, in small building office, the error of correction for Schedule B and Schedule C are -0.91% and 0.56%, while for occupant density is 4.26%. As for large office building, the error of correction for Schedule B and Schedule C are -7.00% and -10.80%, while for occupant density is 6.06%. Because the correction formula is...
based on the data in the library, the actual building shape and various energy consumption factors are complex and diverse, which cannot be completely consistent with the model in the library. Therefore, the error result can be considered to be within a reasonable range. And the energy consumption correction method for operation schedule and occupant density proposed in this study is reasonable.

| Scenario | Measured | Base | Schedule B | Schedule C |
|----------|----------|------|-----------|-----------|
| Small    | 57.95    | 59.6 | 86.93     | 118.85    |
|          | 62.14    | 57.42| -0.9%     | 58.28     |
|          | 4.3%     |      |           | 0.6%      |
| Large    | 133.84   | 124.02| 187.7     | 278.96    |
|          | 131.53   | 125.08| -7.0%     | 120.80    |
|          | 6.1%     |      |           | -10.8%    |

3.3 Correction for meteorological parameters

3.3.1 Classification of meteorological parameters

The meteorological parameter file used in this paper is the TMY file obtained by the measured meteorological data of the Shanghai Meteorological Station from 2008 to 2017. Fig. 12 shows the scatter plot of its temperature and relative humidity. From the scatter plot, we can see that the temperature and relative humidity are uniformly distributed in their respective intervals. Therefore, we classified the temperature and relative humidity referring to the division of climate zones.

![Fig. 12. The scatter plot of temperature and relative humidity in Shanghai](https://example.com/fig12)

We carried out the correction for meteorological parameters under the basic schedule and occupant density. According to Chinese laws, the benchmark schedule is "965" and there are 249 working days.

The classification of typical meteorological parameter days adheres to three principles: (1) the number of samples in each category are within a reasonable range; (2) the interval range of each category is reasonable; (3) there are differences between different categories. The classification results are shown in Table. 13.

| Category | Daily dry bulb temperature /°C | Daily relative humidity /% | Days/ d |
|----------|-------------------------------|---------------------------|---------|
| 1        | 40-65                         | 6-65                       | 20      |
| 2        | 65-90                         | 6-90                       | 14      |
| 3        | 50-65                         | 6-50                       | 18      |
| 4        | 65-80                         | 6-70                       | 20      |
| 5        | 80-95                         | 6-85                       | 12      |
| 6        | 35-65                         | 6-35                       | 9       |
| 7        | 65-95                         | 6-65                       | 27      |
| 8        | 40-60                         | 6-40                       | 13      |
| 9        | 60-80                         | 6-60                       | 27      |
| 10       | 80-95                         | 6-85                       | 20      |
| 11       | 50-70                         | 6-50                       | 14      |
| 12       | 70-80                         | 6-70                       | 25      |
| 13       | 80-90                         | 6-85                       | 15      |
| 14       | 50-75                         | 6-55                       | 15      |

3.3.2 Correction for meteorological parameters

Based on the classification results mentioned above, we adopted the genetic algorithm to calculate the euclidean metric to each point and the shortest point in the plane formed by the points in each category, and the actual point closest to the point is regarded as the representative point of the category. Then, the energy consumption of the building corresponding to this point is defined as the representative energy consumption of this category. The typical daily energy consumption of the large and small green office buildings is shown in Table. 14.

| Category | Days/d | Daily energy consumption |
|----------|--------|-------------------------|
|          |        | Small office building    | Large office building |
| 1        | 20     | 0.330                   | 0.448                |
| 2        | 14     | 0.318                   | 0.593                |
| 3        | 18     | 0.267                   | 0.330                |
| 4        | 20     | 0.302                   | 0.329                |
| 5        | 12     | 0.281                   | 0.373                |
| 6        | 9      | 0.241                   | 0.391                |
| 7        | 27     | 0.241                   | 0.386                |
| 8        | 13     | 0.241                   | 0.377                |
| 9        | 27     | 0.241                   | 0.405                |
| 10       | 20     | 0.310                   | 0.432                |
| 11       | 14     | 0.241                   | 0.415                |
| 12       | 25     | 0.372                   | 0.536                |
| 13       | 15     | 0.388                   | 0.534                |
| 14       | 15     | 0.485                   | 0.568                |

The energy consumption correction calculation formula for meteorological parameters is shown as:

\[ EUI_{rev} = \sum_{i=1}^{n} e_i * n_i \]
where, the \( EUI_{\text{rev}} \) is the revised \( EUI \); \( e_i \) is the representative daily energy consumption of \( i \)-th category; \( n_i \) is the number of days.

### 3.3.3 Verification of correction for meteorological parameters

We selected the TMY files of Shanghai, Guangzhou, Beijing and Chongqing based on the actual weather data processing from 2004 to 2018. Table. 15 shows the classification result of four cities based on the rules.

| Category | Days/d |
|----------|--------|
| Shanghai | 14     |
| Guangzhou| 0      |
| Beijing  | 73     |
| Chongqing| 0      |

Table. 15. The classification results in four cities

The typical model of energy consumption benchmark is simulated under the meteorological parameter of these four places, and the simulation results obtained are used as the energy consumption benchmark value. The results obtained by using the correction method for meteorological parameters are used as the correction value. The results are shown in Table. 16, from which we can see that the error of the correction method applied to Shanghai or Chongqing is within 3% and it can be considered to be within the acceptable range. However, when the correction method was applied to Guangzhou and Beijing, relatively large errors appeared.

| Category     | EUI[kWh/(sq.m.a)] | Simulated | Correction | Error  |
|--------------|-------------------|-----------|------------|--------|
| Shanghai     | Small             | 76.66     | 75.88      | -1.00% |
|              | Large             | 106.66    | 107.9      | 1.20%  |
| Guangzhou    | Small             | 71.39     | 80.24      | 12.40% |
|              | Large             | 104.16    | 115.02     | 10.40% |
| Beijing      | Small             | 81.63     | 73.35      | -10.10%|
|              | Large             | 121.52    | 106.31     | -12.50%|
| Chongqing    | Small             | 72.17     | 73.38      | 1.70%  |
|              | Large             | 101.58    | 104.28     | 2.70%  |

Table. 16. The simulated and correction value of four cities

In this regard, we compared and analysed the temperature and humidity scatter diagrams of the four meteorological parameters, as shown in Fig. 13. It can be seen that the distributions of temperature and humidity in the four cities are quite different, which is also the reason for the different error results.

Fig. 13. The scatter plot of temperature and relative humidity in four cities

By analysing the specific data in the meteorological documents, it can be known that 8.43% of the time in Beijing has a temperature range of (-13°C, -3°C), which was corrected based on the category 1 in Shanghai. The energy consumption of category 1 is much smaller than the actual energy consumption in this part. Therefore, the result is too small for Beijing. In addition, 51.8% of the time in Guangzhou has a temperature range above 24°C. Most of the energy consumption during this part will be classified into the cooling season category. However, in Shanghai, it is unlikely that more than half of the year will be in the cooling season. Therefore, when using Guangzhou's meteorological parameters for verification, this part is often not supplied with cooling, which leads to small results. As for Chongqing, the coincidence rate of the temperature and humidity interval with Shanghai is relatively high, and the uniformity of the interval distribution is also relatively uniform as that of Shanghai. Therefore, the error is small.

Shanghai and Chongqing are both in Hot Summer & Cold Winter climate zone and have similar climatic characteristics, but for cities in other climate zones, the verification error is relatively large. Therefore, we can draw the conclusion that, for meteorological parameters in the same climate zone, we can use the same classification rules, which are not applicable between different climate zones.

### 4 Conclusion and future work

In order to promote the development of green building, to establish an objective energy consumption baseline as well as the benchmarking approach for green office buildings in Shanghai is important. We proposed the energy consumption baseline for small and large office building in Shanghai, and determined the method to correct energy consumption affected by schedule, occupant density, and meteorological parameters. The main research results obtained are as follows:

1. The baseline of large and small green office building is 107.04 kWh/sq.m.a and 75.82 kWh/sq.m.a respectively. By simulation, the energy consumption of green office buildings in Shanghai still has about 20% room for optimization.
we established the typical office building model library in Shanghai, and used the regression method to correct for schedule and occupant density.

(3) By classifying, we determined the energy consumption correction method for meteorological parameters. The verification results indicate that the method is suitable for office buildings in Hot Summer & Cold Winter climate zone.

However, due to limited knowledge coupled with the constraints of time and resources, there are still some issues that need further research:

(1) The sample number was limited in this study, which may lead to deviation of energy consumption baseline from actual situation.

(2) The objects of the research are limited to the green office buildings in Shanghai. In the future work, the scope of investigation can be expanded to draw general conclusions with a wider range of adaptability.

(3) For meteorological parameters, we draw the conclusion that the classification rules between different climate zones are not applicable. In future work, a general classification rule can be explored.

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