The Impact of Climate Change on the Energy Consumption of Passive Residential Buildings in the Yangtze River Delta

Wenjuan Huang1, Bojun Wang2, *, Yanping Yang1, Shuzhao Dong1
1School of Civil Engineering and Architecture, Jiangsu University of Science & Technology, 666 ChangHui Road, Zhenjiang, 212100, jiangsu, China
2College of Zhangjiagang, Jiangsu University of Science and Technology, 8 ChangXing Road, Suzhou, 215600, jiangsu, China
*Corresponding author’s e-mail address:15751244771@163.com

Abstract. With the global warming in the future, the meteorological data based on the Typical Meteorological Year (TMY) can no longer accurately reflect the changes in building energy consumption under future meteorological conditions. This paper selects the typical meteorological year (TMY) in the Yangtze River Delta region as the base year data and the monthly scale forecast data provided by the IPCC, and uses the "Morphing" method to predict hourly weather data in 2050 and 2080. The use of energy simulation software EnergyPlus of the Yangtze River Delta region in a passive multi-storey residential building energy simulation, analysis of building energy performance under future climate change, projected changes passive residential building energy demand over the next 60 years of trend.

1. Introduction
Climate change is not just a problem faced by a region or a continent, but a global challenge. In this regard, it is natural to consider the impact of climate on the energy consumption of buildings. In addition, in the 21st century, China is in a stage of rapid development of urbanization, building energy consumption generated energy is far beyond the large industrial and transportation, its energy consumption accounts for about 32% of final energy [1]. For the construction field, green development has become a new direction of construction to solve energy consumption and environmental problems in the 21st century. Passive buildings compared to traditional green building, have more energy, more comfortable living environment, etc., and the development of the national green building will play a huge role in promoting and leading, highly fit the requirements of the development of a new era. Therefore, the vigorous promotion and application of passive buildings can reduce the energy consumption in the actual use of buildings, which is in line with the sustainable development theory of Chinese cities.

It can be known from most domestic and foreign research documents that the level of building energy consumption largely depends on the outdoor thermal environment of the building. Therefore, considering the meteorological parameters of the building area is essential to accurately analyse the changes in building energy consumption. The climate is the long-term average state of weather phenomena. In other words, the climate is the statistical average of the physical properties of the atmosphere in a certain area over a long period of time [2]. Climatic elements mainly include latitude and longitude, outdoor temperature, solar radiation, dew point temperature, air humidity, wind speed, precipitation, etc. The combination of different climate elements creates different climate characteristics.
in each region. Climate data may change significantly every year, which profoundly affects the built environment where buildings in different building climate zones are located. Based on this trend, it is necessary to study typical meteorological data for future building energy simulations, so as to predict the impact of future climate on the energy consumption performance of buildings.

Since the beginning of the 20th century, many scholars at home and abroad have conducted research on the impact of climate change on the performance of buildings. Robert, Kummert and others used meteorological data for the next 50 years to simulate the energy consumption of zero-energy buildings in two different locations in Montreal and Marsena. The results show that the zero-energy buildings will not reach zero energy in most years in the future [2]. Kevin used the principal component analysis method to analyse the 30-year meteorological data of five representative cities in China to assess the impact of climate change on the built environment. The results show that in the five climate zones, the dry bulb temperature has a tendency to increase, and climate change will not lead to higher cooling loads in buildings [3].

Since the 21st century, China's research on the energy performance of passive buildings by future climate has been very limited, and China is currently actively promoting passive buildings in the Yangtze River Delta region. Based on the Typical Meteorological Year (TMY) weather documents, the current passive building related standards proposed in the Yangtze River Delta, and future climate changes, this paper evaluates the performance of a passive residential building in the Yangtze River Delta from these three aspects. So as to provide a certain architectural strategy reference significance for the implementation of passive residential buildings in the Yangtze River Delta in the future.

2. Method
Yangtze River Delta region using the typical meteorological year (TMY) for the monthly scale base-year data and forecast data provided by IPCC, the use of "Morphing" approach to obtain hourly meteorological data Yangtze River Delta in 2050 and 2080. Use EnergyPlus typical passive house building energy performance assessment of the Yangtze River Delta, Yangtze River Delta region and in line with the passive building standards to assess the current passive house construction.

2.1. Generation of future meteorological data
Climate. OneBuilding[3] is used as the original data for future weather data prediction. The data source is NASA Global Climate Change data and the weather file format provided is EPW, which conforms to the weather file format for building energy consumption simulation.

Currently, there are three tools for generating future climate files, the first is the WeatherShift tool developed by Argos [4], the second is the CCWorldWeatherGen tool developed by Belcher et al. [5], and the third is WeatherMorph developed by Aiyin [6]. Principles of these three tools are all deformed through the "Morphing" method to construct future weather data for building energy research. The difference is that the three tools are based on different climate simulation scenarios.

Considering that China will vigorously develop renewable energy in the future, its positive attitude and constructive efforts to promote the reform of the energy system in policies, as well as the newly formulated 2030 greenhouse gas emission reduction target [2]. The low-emission B1 scenario is selected for future meteorological data prediction, which is closer to China's future sustainable development model. Therefore, this article chooses the WeatherMorph tool as the future climate file generator, because the WeatherMorph tool can be based on B1 climate simulation scenarios compared to other tools.

The Morphing method has the following calculation steps:

Displacement: 
\[ x = x_0 + \Delta x_m \]  
(1)

Linear scaling: 
\[ x = a_m x_0 \]  
(2)

\[ x = x_0 + \Delta x_m + a_m \times \left( x_0 - \bar{x}_{0,m} \right) \]  
(3)
Among them, \( x_0 \) is the existing hourly typical meteorological data parameter value, \( \Delta x_m \) is the monthly meteorological parameter monthly average change forecast value, \( a_m \) is the monthly meteorological parameter forecast change rate, \( \bar{x}_m \) is the monthly average of hourly weather parameters.

On the basis of the existing TMY documents provided by NASA, Morphing should be used to downscale the B1 climate scenarios provided by the IPCC in line with China’s future development to generate climate documents for 2020, 2050 and 2080 in the future. TMY parameter file.

For the dry bulb temperature \((dbt)\) in this paper, the Morphing method is mainly realized by the following formula algorithm:

\[
dbt = dbt_0 + \Delta\text{TEMP} + adbt_m \times (dbt_0 - \bar{dbt}_m)
\]

Where, \( dbt_0 \) is the hourly dry bulb temperature of an existing typical meteorological year, \( \bar{dbt}_m \) is the monthly average dry bulb temperature of \( m \) in an existing typical meteorological year, \( \Delta\text{TEMP} \) is the monthly average dry bulb temperature change of \( m \) Predictive value.

\( adbt_m \) is the downscaling coefficient of \( m \) months, and its calculation method is as follows:

\[
adbt_m = \frac{\Delta TMAX_m - \Delta TMIN_m}{\bar{dbt}_{m,\text{max}} - \bar{dbt}_{m,\text{min}}}
\]

Where: \( \Delta TMAX_m \) is the predicted change of the \( m \) monthly average of the daily maximum dry bulb temperature in month \( m \), \( \Delta TMIN_m \) is the predicted change of the \( m \) monthly average of the daily minimum dry bulb temperature in month \( m \); \( \bar{dbt}_{m,\text{max}} \) is the monthly average of the daily maximum dry bulb temperature in \( m \) in a typical meteorological year; \( \bar{dbt}_{m,\text{min}} \) is the \( m \) monthly average of the daily minimum dry bulb temperature in a typical meteorological year.

For relative humidity \((R)\) and dew point temperature \((dpt)\), since \( R \) is the ratio of the absolute humidity of humid air to the saturated absolute humidity of saturated air at different temperatures, at the same time, \( dpt \) refers to the difference in water vapor content and pressure of air. If you directly affect \( R \) or \( dpt \) uses the Morphing method to predict, and the influence of dry bulb temperature changes cannot be excluded. Therefore, an absolute quantity needs to be selected for prediction, and then converted using the wet air state function relationship to obtain the relative humidity \( R \) and the dew point temperature \( dpt \).

\[
S = aS_m \times S_0
\]

In the formula: \( S \) is the hourly moisture content of a typical meteorological year, \( S_0 \) is the hourly moisture content in the existing typical meteorological year (TMY) weather file.

\( aS_m \) is the downscaling coefficient of \( m \) months, and its calculation method is:

\[
aS_m = 1 + \frac{SPHU_m}{100}
\]

Where: \( SPUH_m \) is the predicted change percentage of monthly moisture content in \( m \). Combining the predicted results of the moisture content \( S \) parameter and the dry bulb temperature \( dpt \), the hourly predicted value of the relative humidity \( R \) and the dew point temperature \( dpt \) can be obtained.

Horizontal solar radiation illuminance, \( gsr \). The future hourly horizontal solar irradiance is obtained by the method of linear stretching in "Morphing", which has been used in foreign literature [6].

\[
gsr = agsr_m \times gsr_0
\]

\[
agsr_m = 1 + \frac{\Delta DSWF_m}{gsr_0}
\]

Where, \( gsr_0 \) existing typical meteorological year (TMY) weather file changes mean solar irradiance \( m \) month, \( \Delta DSWF_m \) is the monthly mean solar irradiance of \( m \) predicted by the future climate model. \( gsr_0 \) existing typical meteorological year (TMY) weather file hourly solar Radiation illuminance.
2.2. Case building overview
The selected passive residential building is a passive residential demonstration project in Nantong City in the Yangtze River Delta. The building of this project faces 16° south-west, covers an area of 545.98 square meters, and has a total construction area of 2311.94 square meters. Only 4 floors, no basement, four on each floor, a total project A1 (West), A2 (East) two units, two ladder four, standard floor plan shown in Figure 1, a reasonable size distribution, South transparent.

![Figure 1. Standard floor plan](image1)

2.3. Parameter setting in energy consumption simulation
In this paper, EnergyPlus is selected as the simulation tool to dynamically simulate and calculate the indoor thermal environment of the building at 8760h throughout the year. Compared with steady-state software such as PHPP, EnergyPlus can also measure the heat transfer between each room in the residential building model. Many dynamic factors, such as temperature delay and thermal storage of the envelope structure, are more accurately simulated. The model is shown in Figure 2.

The case building is located in Nantong City, Jiangsu Province, which belongs to the Yangtze River Delta region, and the built climate zone belongs to my country’s hot summer and cold winter region. The project text [7] contains the settings of parameters that affect the energy consumption of residential buildings. Comparing Shanghai Passive Building Guidelines [8] and Jiangsu Residential Building Energy Efficiency Design Standards [9], the comparison results are shown in Table 1. It can be seen
from Table 1 that the peripheral structural parameters of the case meet the requirements of passive houses in the Yangtze River Delta region.

2.3.1. Selection of indoor environmental parameters. As the project case project is a passive residential building in the Yangtze River Delta region in the hot summer and cold winter area, in addition, the project will be completed and put into use in 2019 in a relatively short time, and corresponding energy data has not yet been formed. According to the parameters provided by the project itself in Table 1 and Table 2, and in contrast to the passive building guidelines in the Yangtze River Delta region [9] and the corresponding lighting standards provided by residential energy-efficient buildings [10], select indoor thermal disturbance parameter values that meet the standards. Compared with the *Shanghai Passive Residential Building Guidelines* [8], there are clear provisions on the indoor comfort of residential buildings. The temperature of each room in residential buildings must be controlled at 20-26°C; the relative humidity is less than 60% in summer and greater than 30% in winter. Other small functional rooms such as bathrooms and kitchens are counted as heating and air-conditioning rooms, and specific related parameter setting values are selected, as shown in Table 2.

### Table 1. Comparison with related building standards

| Parameter                                      | Design Value | Reference Value of Passive House Guidelines | Regulation Value of Energy-saving Design Standard |
|------------------------------------------------|--------------|---------------------------------------------|--------------------------------------------------|
| North/West /East-facing window-to-wall ratio   | 0.19         | ---                                         | ≤0.45                                            |
| South-facing window-to-wall ratio              | 0.31         | 0.25-0.45                                   |                                                  |
| Window-to-land area ratio                     | 0.23         | ---                                         | ≥0.18                                            |
| Ventilation opening area ratio                 | 14.2%        | ---                                         | ≥8%                                              |
| External wall U value                         | 0.29 W·m²·K  | ≤ 0.4                                       | ≤ 1.0                                            |
| Roof U value                                  | 0.26 W·m²·K  | ≤ 0.3                                       | ≤ 0.5                                            |
| Window U value                                | 1.0 W·m²·K   | ≤ 1.4                                       | 2.0-2.4                                          |

### Table 2. Other indoor thermal disturbance parameter settings

| Parameter                              | value       |
|----------------------------------------|-------------|
| Lighting power density                 | 6W/m²       |
| Personnel load                         | 100W/person  |
| Electrical load                        | 142W        |
| Cooling temperature                    | 26°C        |
| Heating temperature                    | 20°C        |
| COP                                    | 3.8         |
| Cold and heat source                   | A1: Mechanical ventilation dehumidification heat pump  |
|                                       | A2: VRV Mechanical ventilation full heat exchanger group |
| Cooling and heating source power       | 1.9kW+2.5kW |
| Heat recovery efficiency               | 75%         |

2.3.2. Work and rest arrangements for indoor personnel. Set the number of cases per household residential building is four people, two adults, two children, per capita calorific 55W; hallways, elevators...
and stairs and other building cases in public areas per capita area of 0.05 people/m². The work and rest arrangements of the indoor functional rooms are shown in Figure 3.

2.3.3. Lighting and electrical equipment and schedule. For the lighting and electrical equipment in this project, the heat disturbance and work and rest arrangements are based on the design requirements of GB50034-2013 Code for Design of Lighting in Residential Buildings [10], the maximum room lighting power density is set to 6W/m². The schedule is shown in Figure 4.

2.3.4. Domestic hot water settings and schedule. The temperature of the amount of hot water used per person per day is 55°C, and the effective amount of domestic hot water is 25L/day. The daily hot water consumption of washing machines and dishwashers is 5827kWh/m². The daily domestic hot water consumption schedule of the project residence is shown in Figure 5.

![Image](image1.png)

Figure 3. Function room personnel Daily schedule

![Image](image2.png)

Figure 4. Lighting and electrical schedule

![Image](image3.png)

Figure 5. Indoor hot water schedule

![Image](image4.png)

Figure 6. Current and 2050s, 2080s in building cooling load and total energy consumption comparison

3. Discussion and results

For the simulated annual energy consumption of the passive housing project selected in this article, heating, cooling, ventilation, lighting and electrical equipment are considered. These five aspects basically cover all aspects of residential building energy consumption. The results are shown in Figure 6. The case building will be completed and put into use in 2019, a total of 61 years in 2020, 2050 and 2080, which is close to 70 years of residential building use rights in my country. From Figure 6, it can be seen that based on typical meteorological year data and a B1 emission scenario that meets my country’s national conditions, one annual energy Consumption is expected to increase by 0.9% and 1.8%
in 2050 and 2080, respectively. In addition, as the temperature rises, the cooling load will also increase, which will increase by 17%-30% from 2050 to 2080; the heating load will drop by 25-44%.

4. Conclusion
Through simulation, the influence of future climate on the energy consumption of passive residential buildings in the Yangtze River Delta is studied. Based on the B1 emission scenario, it is used to generate future weather data. Evaluate the energy consumption of passive residential buildings in 2020, 2050 and 2080. The results show that under future climate conditions, energy consumption will be reduced by 0.9-1.7%. In short, passive buildings designed based on historical weather data will have different performances in the changing climate in the future. To cope with future climate changes, passive building design strategies can reduce primary energy consumption and conform to my country's green development concept of energy saving and emission reduction. In addition, in addition to the strategy of construction technology, it is also inseparable from government incentives. This article is limited to considering the Yangtze River Delta region in hot summer and cold winter, and does not consider other climate zones. The subsequent specific calibration of energy consumption requires future monitoring data for the next step.

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References
[1] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, RK Pachauri and LA Meyer (Eds.)). eneva , Switzerland: IPCC.
[2] Robert A, Kummer M. 2012 Designing net-zero energy buildings for the future climate, not for the past. J. Building and Environment, 2012, 55: 150 -158.
[3] KKW Wan, KL Cheung, L Yang, etal. A new variable for climate change study and implications for the built environment[J]. Renewable Energy, 2009, 34(3):916-919
[4] weatherShift.http://www.weather-shift.com/. (retrieved 2021)
[5] S.E. Belcher, J.N. Hacker, D.S. Powell, Constructing design weather data for future climates, Build. Serv.
[6] Aiyin J, Xudong L, Emily C, et al. Hourly weather data projection due to climate change for impact assessment on building and infrastructure[J]. Sustainable Cities and Society, 2019, 50:101688. Eng . Res. Technol. 26 (1) (2005) 49–61.
[7] Zhou Binggao, Jiao Guifeng, He Chengcheng. Demonstration project of ultra-low energy consumption prefabricated expert apartment building in Nantong No.3 Construction[J]. Construction Science and Technology, 2018, 912(368): 55-64.
[8] Jianke [2015] No. 179, Technical Guidelines for Passive Ultra-low Energy Green Buildings (Trial) (Residential Buildings) [S].
[9] JGJ 134-2010, Design standard for energy efficiency of residential buildings in hot summer and cold winter area[S].
[10] GB 50033-2013, Building lighting design standard [S].