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Effect of urban micro-climatic regulation ability on public building energy usage carbon emission

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ABSTRACT

Greenhouse gas emissions from buildings energy consumption increase disproportionate since the 21st century which would accelerate exhausting the fossil fuel supply and threatening the local climate. Using factor analysis, we study the contribution of four groups of influencing factors to office building energy consumption by integrating social economic, building, macro-climatic and micro-climate regulation factors. It showed that micro-climate controlling ability had the least contribution (with 9.64%) to the office building energy usages. Nevertheless, micro-climate regulation ability should not be ignored for its improvement process is relatively easier and the investment is lower when comparing with renovations on buildings, macro-climate or social-economic conditions. Using a geographical detector model, the effects of urban micro-climate regulation ability on office building energy consumption is further analyzed. The results showed that when integrated with green space and water body, the effect for carbon emission reduction was more obvious than using one of them alone. The green space had area threshold for office building energy usages carbon reduction but water body has not. If land area permitted, water body construction is more suitable than green space for reducing office building energy usage carbon emission. This study will provide urban low carbon building construction from the view of planning and layout of ecological land such as green-space and water space.

1. Introduction

Greenhouse gases (GHG) from energy usage emitted in huge quantities worldwide, which not only exhausted the fossil fuels supply but also threaten the global climate change, and therefore became one of the greatest challenges for countries, especially developing ones [1,2]. Carbon emissions in China were 29.5 billion TCO_2 in 2013, which represents a 4.2% increase over 2012, and a 27.1% share of global carbon emissions [3]. With the accelerating development of the economics, China is predicted to continue increasing its energy consumption. The continuously increasing production of GHG placed great pressure for China to meet national carbon emission reduction targets which aims to reduce emissions per unit of economic output to 40–50% of 2005 levels by 2020.

In 2014, China's building energy consumption was about 814 million tons of standard coal, accounting for 19.12% of total energy consumption [4]. In recent years, building energy consumption has sharply increased with increasing numbers of buildings and improvement of living standards. Building energy consumption emitted GHG will continue, which will have an adverse impact on natural, socio-economic systems, and simultaneously increase the burden on China to address climate change [5]. It is therefore important to reduce building energy consumption in an effort to mitigate global resource shortages and to weaken the intensifying greenhouse effect. Office buildings are an important fraction of public buildings, accounting for about one-fifth of the area of public buildings which consumed a considerable 3.26 tons of standard coal in 2014 [4]. Low-carbon energy consumption of office buildings is thus essentially important in improving the regional climate and developing cities in a sustainable manner.

The micro-climate generally is defined as the local climate within 1000 ms of a building [6]. Some previous studies analyzed the effect of the micro-climate on building energy consumption by directly monitoring data of meteorological factors, such as the air humidity, wind speed, solar radiation [7]. Previous studies showed that the urban micro-climate is affected by factors such as the thermo-physical property of the underlying surface and greening [8,9]. Building energy consumption mainly relates to heating and cooling, with the two accounting for 65% of total building energy consumption [10]. But, how these micro-climate changes effects on energy usage is far from clear.

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Nomenclature

Abbreviation

GHG	greenhouse gases
HDD	heating degree days
CDD	cooling degree days
FA	square foot area
ECM	energy consumption membership
BL	building floors
GRP	per capita gross regional product
EST	regional expenditure on science and technology
EE	expenditure on education
GDM	geographical detector model
KMO	Kaiser–Meyer–Olkin test

Symbols

CEF	carbon emissions from fuels consumption
C_{ei}	consumption of fuels
G_{ei}	energy conversion coefficient of fuels
I_{ei}	carbon emission factor vector of fuels
a_{ij}	factor loading
F_i	factor i
X_j	variable j
σ^2	variance of Y

We hypothesis that micro-climate regulation ability would directly or indirectly affect office building energy usage in addition to large-scale climate factors [11,12]. Some studies have shown that the water body and green space have a cold-island effect. They play an important role in alleviating the urban heat effect and improving building indoor comfort [13,14]. Green spaces and water bodies are important parts of the micro-climate regulation factors outside a building. We here challenge to construct micro-climate regulation indicator of public buildings by the geographical factors of green space area and water area and further analyzes their relationship with the energy usage carbon emission reduction.

Studying the influencing mechanism of micro-climatic regulation factors originated from green space and water body on public building energy consumption will supply appropriate strategies for achieving low-carbon building construction and the scientific planning and layout of urban green space and water body landscapes, which is easier for realization when comparing with regional macro-climatic, social-economic and building condition changes.

2. Method

Previous studies showed that building bodies, macro-climatic conditions, and socioeconomic conditions have different effects on building energy consumption [15–19]. We hypothesize micro-climate regulation condition would not alone but integrate with the other three factors together to have effects on the consumption [11,20]. Through the integration of the above indicators, the present study formed four first-class indicators, conducted factor analysis to discuss the coupling effect of energy-consumption carbon emissions of office buildings. The geographical detector method was then used to explore the impact methods for secondary indicators of the four first-class indicators.

The energy needed to operate a building is largely dependent on macro-climate condition [21,22]. In particular, outdoor macro-climate can be represented by heating degree days (HDD) and cooling degree days (CDD), which heavily influence building energy usage. Cooling degree days and heating degree days were used as the secondary indicators of urban macro-climatic elements. The building's square foot area (FA), energy consumption membership (ECM) and number of building floors (BL) which are considered to determine an office building's energy consumption in terms of lighting, heating, cooling and ventilation were used as the secondary indicators of building characteristics [15–17,23–25]. The green space area and water area within 1000 m of the public office building were used as the secondary indicators of urban micro-climate regulation environments [13,14]. Office building energy consumption was covered by governmental funds in this study, suggesting that the office workers would not have a sense of the cost of rent or operating expenses. People who work in office buildings have a tendency to seek a comfortable indoor environment, entailing high energy consumption, regardless of the outside climate and weather conditions [17,26,27]. Per capita gross regional product (GRP), average wage of employed staff and workers (Income), regional expenditure on science and technology (EST) indicated technological progress and expenditure on education represented education level (EE) [17,19,28]; these 4 indicators were also used here to represent the secondary indicators of social-economic condition.

2.1. Data collection

In economy society, labor activities comprise the foundation of economic development. Public buildings accommodate a significant proportion of management working activities. In this study, a series of 'The People's Bank of China' office buildings were selected as public buildings. Although the buildings are distributed in different cities all over the China, they are served for the same service management affairs. The energy used for these buildings is mostly subsidized by the government and not paid by the individual. 205 office buildings in 2011 from 204 cities in China were selected as study samples (Fig. 1). We focus on the operational energy consumption of these public office buildings, which mainly relates to lighting, heating, cooling, and other maintenance needs. For building, we collected the various energy usage consumption, the consumer numbers and the heating or cooling building areas. For macro-climatic condition, we get the information by geographic information system (GIS). For socio-economic conditions, we acquired the technological investments, education investments, income, and city GRP from the city yearly statistical book [29].

2.2. Remote sensing/GIS image processing

We used the green space area and water area within 1000 meters of a public office building as indicators of the building micro-climate regulation environment. Using geographical information system (GIS), we extracted the green space areas and water areas within 1000 m of 205 public office buildings from land map and points of interest (POI) by ArcGIS. We also calculated the average temperature, heating days, and cooling days for each building by interpolation in ArcGIS software.

2.3. Calculating carbon emissions

To account for variations in energy consumption, we transformed all types of energy consumption and expenditures into carbon emission data. The equivalent amount of carbon emissions for each fuel was decided by its consumption and carbon content. Eq. (1) gives the framework for converting energy use into carbon emissions. This calculation to estimate residential emissions is based on the Intergovernmental Panel on Climate Change [30] formula for national greenhouse gas emissions:

$$CE_F = \sum_{i}^{n}(C_{ei} + G_{ei} + I_{ei}) \quad (1)$$

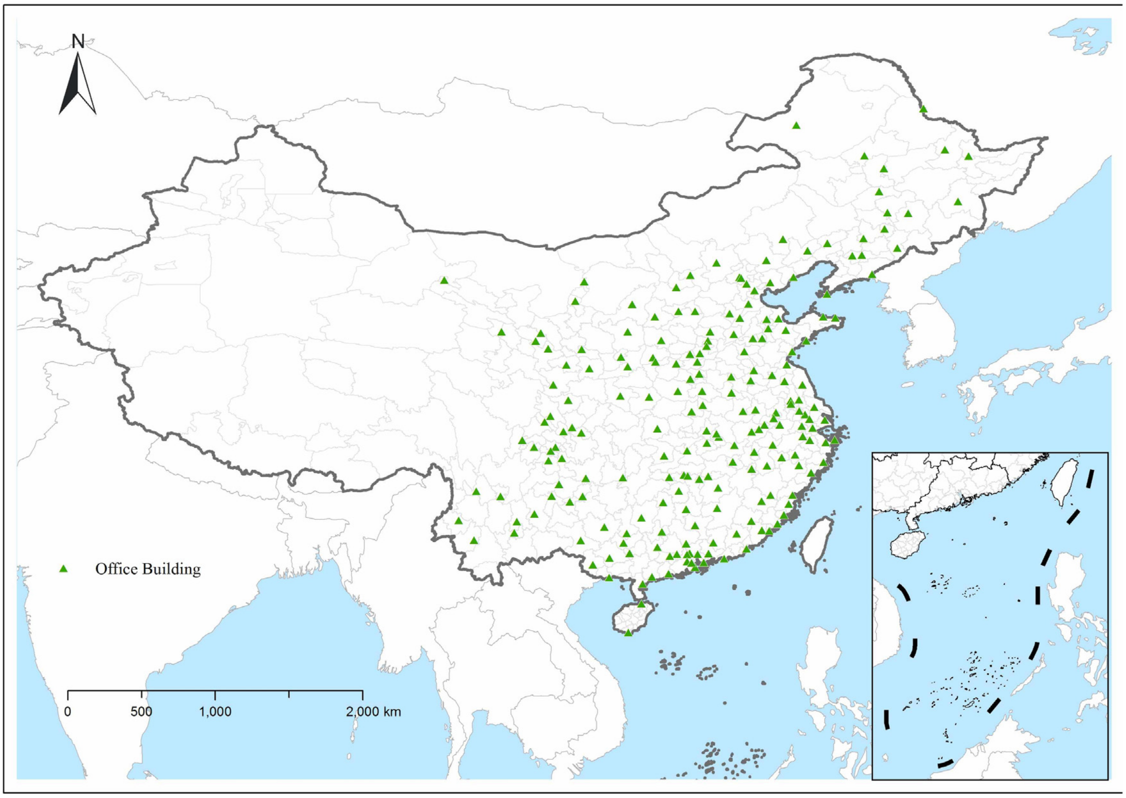

Fig. 1. Study area.

where CE_F represents carbon emissions from fuels consumption, C_{ei} is the energy consumption of fuel i (kg or m^3), G_{ei} is the energy conversion coefficient of fuel i (MJ/Tt or MJ/Mm^3), e.g. set as 111 MJ/m^3 for LPG, 29.31 MJ/kg for coal, and I_{ei} is defined as the carbon emission conversion factor which means energy carbon containment per unit. The carbon containment parameter is set at 27.63 gC/GJ.

Heat and electricity are secondary energy sources; they do not directly emit carbon dioxide but generate carbon emissions during their production. Based on data for thermal power generation and heat supply from the 'Intermediate Inputs and Transform' table in the Energy Balance Sheet, we determined carbon emission factors for heat and electricity. Then, we evaluated indirect CO_2 emissions from thermal power generation, heat, and electricity. For electricity, we used the regional area power plants' average emission factor according to the Guidelines for Provincial Greenhouse Gas Inventories [31]. The formula is as follows:

$$C_{electricity} = W_{electricity} \times W_{coal} \times G_{coal} \times I_{coal} \tag{2}$$

where $W_{electricity}$ is the electricity consumption (kWh); W_{coal} is the coal applied to electricity production (kg/kWh); G_{coal} is the coal energy transfer coefficient (MJ/Tt); I_{coal} is the coal carbon containment coefficient (kg C/GJ), set as 0.928 kg/kWh for East China area.

2.4. Factor analysis

For factor analysis, multiple variables are grouped to reduce dimensionality according to the size of correlation, such that correlation between variables within the same group is higher and the variable correlation between different groups is lower. New factors are formed in each group, and the factors are not related to each other. All variables can be expressed as a linear combination of common factors. Eq. (2) showed the factor analysis model,

$$\begin{aligned} X_1 &= a_{11}F_1 + a_{12}F_2 + \cdots + a_{1m}F_m + \varepsilon_1 \\ X_2 &= a_{21}F_1 + a_{22}F_2 + \cdots + a_{2m}F_m + \varepsilon_2 \\ &\vdots \\ X_p &= a_{p1}F_1 + a_{p2}F_2 + \cdots + a_{pm}F_m + \varepsilon_p \end{aligned} \tag{3}$$

where the matrix $A = (a_{ij})$ is called the factor load matrix and a_{ij} is the factor loading, which is a correlation coefficient of common factor F_i and variable X_j. ε is a special factor, representing influencing factors other than the common factors.

We tested how a building's energy consumption varies as a function of climate conditions (heating days or cooling days), construction characteristics (heating and cooling area and number of energy consumers), micro-climate, and socio-economic conditions.

2.5. Geographical detector methods

The geographical detector model (GDM) is a spatial analysis model based on the theory of spatial differentiation. The model uses the 'factor force' as a measure index to effectively detect and identify correlation between a geographical attribute and its explanatory factor [32]. The geographic detector model is freely available from www.geodetector.org. In the model, the explanatory factors are the category variables rather than the actual value, which effectively overcomes the limitation that the traditional statistical analysis method handles category variables [33]. Therefore, it can quickly and objectively detect correlation between spatial elements, and has been widely used in many fields of environmental research [34]. According to the spatial properties of public buildings and the micro-climatic regulation ability indicators, we used GDM to explore the effects of individual micro-climatic

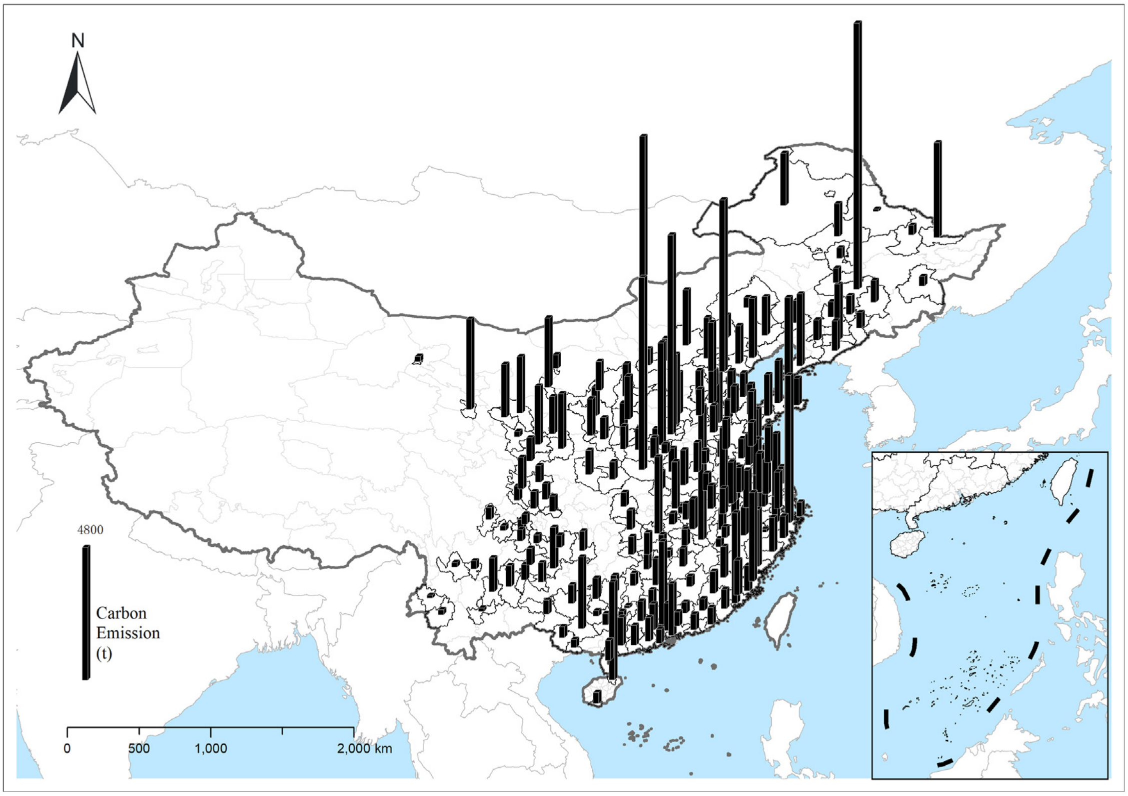

Fig. 2. Energy usage carbon emission from office buildings across China.

regulation ability factors and interactions of factors on energy consumption. GDM is mainly composed of four detectors: risk, factor, ecological, and interactive detectors. The ecological detector was used to explore whether different factors make significant differences to building energy consumption. A risk detector was mainly used to search for the range in which factors significantly affect building energy consumption. An interactive detector was used to identify the interaction of influencing factors. Here, we used the natural fracture method to convert explanatory factors from actual values into category variables.

Geographical detector is a new tool to test and to search for spatial stratified heterogeneity of a variable *Y*; and to test the association between two variables *Y* and *X* according to the consistency of their spatial distributions (overlaying *Y* and *X*).

The philosophy of geographical detector is that variable *Y* is associated with variable *X* if their spatial distributions tend to be identical. The association between *Y* and *X* is measured by:

$$q = 1 - \sum_{h=1}^{L} \frac{N_h \sigma_h^2}{N\sigma^2} \quad (4)$$

where σ^2 stands for the variance of *Y*; *N* is the number of units in study population of *Y*; the study population of *Y* is composed of *L* strata ($h = 1, 2, \ldots, L$). The strata of *Y* may exist already, or are constructed by classification, or formed by laying *Y* over *X* which consists of strata. $q \in [0, 1]$, $q = 0$ indicates that *Y* is not spatially stratified heterogeneity, or there is no association between *Y* and *X*; $q = 1$ indicates that *Y* is perfectly spatially stratified heterogeneity, or *Y* is completely determined by *X*; the value of *q*-statistic indicates the degree of spatial stratified heterogeneity of *Y*, or how much *Y* is interpreted by *X*.

3. Results and discussion

3.1. Characteristics of public office buildings

According to our survey of 205 office buildings across 204 cities in China, we concluded that the average values were: energy consumers, 264 persons; floors, 12 layers; floor area, 1.69×10^4 m^2; heating degree days, 2180.20 °C d; and cooling degree days, 1090.66 °C d. The floor area of the buildings ranged from 400 to 90,100 m^2. The number of employees varied from 12 in Jinhua City to 2400 in Beijing. In general, office buildings located in provincial capitals had a larger floor area and more employees. The heating degree days exhibited a range of 33.13 °C d from Sanya, Hainan to 7326.11 °C d from Hohhot, Inner Mongolia, while the range of the cooling degree days is from 0.46 °C d in Rika city to 2404.03 °C d in Sanya, Hainan. The lowest layer value is 2 in Jiujiang city, Jiangxi Province and the highest value is 36 in Baoding city in Hebei Province.

3.2. Energy usage

We focus on office buildings energy usage and their carbon emissions, the main forms of energy consumed for building operation were electricity, gasoline, and raw coal. The total building construction carbon emissions (except car consumption energy) were 1.25×10^6 kg/building/year (Fig. 2). Carbon emissions from electricity, gasoline, and raw coal were 83.14%, 12.17%, and 9.57% of total energy carbon emission, respectively (Fig. 3). Carbon emissions from electricity made up the major part of construction building energy carbon emissions.

3.3. Energy consumption dynamics

Factor analysis was conducted to reduce the dimensionality for 4 groups of 11 influencing factors. A Kaiser–Meyer–Olkin (KMO)

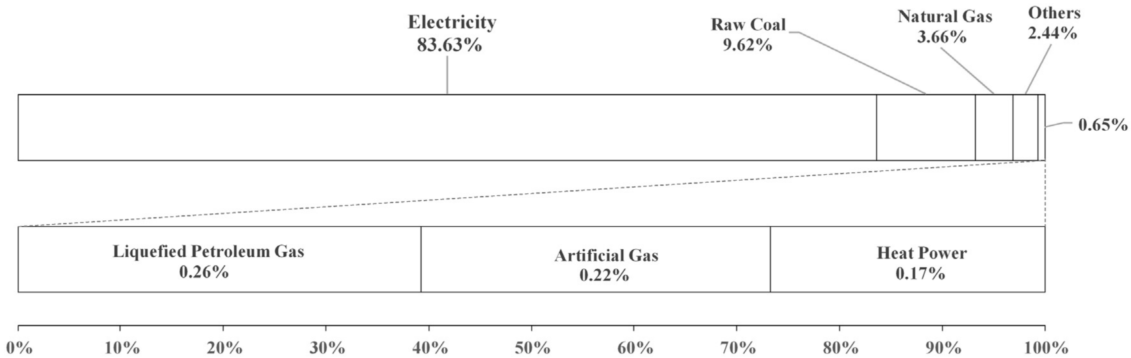

Fig. 3. Energy usage and resulting carbon emissions.

Table 1
Total variance explained by principal component analysis.

Component		Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
		Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
Dimension	1	3.412	31.023	31.023	3.412	31.023	31.023	2.691	24.461	24.461
	2	1.995	18.136	49.159	1.995	18.136	49.159	1.958	17.804	42.264
	3	1.125	10.228	59.386	1.125	10.228	59.386	1.77	16.091	58.355
	4	1.06	9.636	69.023	1.06	9.636	69.023	1.173	10.668	69.023
	5	0.961	8.739	77.762						
	6	0.72	6.547	84.309						
	7	0.614	5.586	89.895						
	8	0.524	4.766	94.661						
	9	0.225	2.043	96.704						
	10	0.208	1.895	98.599						
	11	0.154	1.401	100						

Table 2
Rotated component matrix.[a]

	Component			
	1	2	3	4
EST	0.865	0.109	0.238	−0.011
EE	0.76	0.074	0.318	−0.131
GRP	0.698	0.009	0.03	0.123
Income	0.697	−0.004	0.072	0.121
HDD	−0.017	−0.915	0.015	−0.023
CDD	0.18	0.9	−0.067	0.102
FA	0.31	−0.136	0.834	0.074
ECM	0.434	−0.082	0.789	0.009
BL	−0.144	0.426	0.527	0.105
WB	−0.084	0.273	0.072	0.67
GS	0.216	−0.104	0.034	0.806

Extraction method: principal component analysis.
Rotation method: varimax with Kaiser normalization.
[a] Rotation converged in 6 iterations.

test was first conducted for all data on the public office buildings in 204 cities. A KMO value of 0.679 was obtained, which means that it is worth using the factor analysis model to explore and analyze influencing factors.

In factor analysis of 11 variables, we see that the first four characteristic roots, denoted F_1, F_2, F_3, and F_4, exceeded 1. The highest initial eigenvalue is F_1 with 3.412, and it decreased gradually to F_2 (1.995), F_3 (1.125) and then to F_4 (1.060). The cumulative variance contribution rate of the first four common factors was 69.03%, showing that the explanatory power of the basic model was sufficient. The variance contribution rates of F_1, F_2, F_3, and F_4 were 31.02%, 18.14%, 10.23%, and 9.64%, respectively, and the influence rate decreased gradually (Tables 1 and 2).

Tables 1 and 2 show that F_1 had a greater load for the four influencing factors of scientific expenditure (0.865), average employee income (0.697), educational expenditure (0.760), and GRP per capita citywide (0.698), and it is taken as the overall social-economic factor. F_2 had a greater load for the two influencing factors of the heating degree (−0.915) and cooling degree (0.900), and it is taken as the overall macro-climate factor. F_3 had a greater load for the three influencing factors of the building area (0.834), number of building users (0.798), and number of building floors (0.527), and it is taken as the overall building factor. F_4 had a greater load for the two influencing factors of the green space area (0.670) and water body area (0.806), and it is taken as the overall urban micro-climate regulation ability factor.

The area and consumer number of energy usage in office buildings has the most important, following with urban social-economic condition the second, macro-climatic environment the third while the micro-climatic regulation environment on the least effects on building energy consumption. Building itself has the most important and direct effect on building energy consumption which is the same as our previous in residential building research [23]. Economic support and energy saving behavior and consciousness based on social-economic investment will help for second important for energy consumption and energy conservation. The cooling and heating energy consumption was directly depended on macro-climatic condition which was reflected its third important effects on energy usage. Through building surrounding climate adjustment, the micro-climate regulation environment showed the fourth important effects on the energy consumption of buildings. Although, this effect was weak than the other three conditions, it could not be ignored due to its feasible and effective manner for energy reduction.

3.4. Micro-climate regulation ability and its effects on energy consumption

The ecological detector reveals that among the 11 factors selected, the green space area and water area are less important

Table 3
Results of ecological detector.

	WB	GS	FA	ECM	BL	HDD	CDD	Income	GRP	EST	EE
WB											
GS	N										
FA	Y	Y									
ECM	Y	Y	N								
BL	N	N	N	N							
HDD	N	N	N	N	N						
CDD	N	N	N	N	N	N					
Income	N	N	N	N	N	N	N				
GRP	N	N	N	N	N	N	N	N			
EST	Y	Y	N	N	N	Y	Y	N	N		
EE	Y	Y	N	N	N	N	Y	N	N	N	

Note: 'Y' indicates that the horizontal factor is more important than the vertical factor for building energy consumption, while 'N' indicates otherwise.

than the building area, number of building users, scientific investment, and educational investment to building energy consumption which is the same as the results from the factor analysis. In a comparison of the two micro-climate regulation factors, the water area is more important than the green space area for building energy consumption carbon emission reduction (Table 3). The cooling effect of the micro-environment outside buildings is mainly determined by air humidity. For a water body has a high heat capacity and surrounding air humidity, it leads to a relatively low temperature change in the surrounding area and produce an obvious building cooling effect. While, green space reduces the surrounding temperature by absorbing carbon dioxide through photosynthesis and releasing water to the air through transpiration, but these effects mainly occur during the daytime.

The results obtained from the interactive detector are given in Table 4. It showed that among all influencing factors, the building area and number of users have the strongest effects on building energy consumption, with their influence coefficients being 0.491 and 0.530, respectively. When a water area is introduced alone to reduce building energy consumption, the influence coefficient is 0.037, while the influence coefficient of a green space area is 0.020. This supports the result that the effect of a water area on building energy consumption obtained by an ecological detector is stronger than that of a green space area.

Among all mutually effective factors, the building area and number of building users have the largest integrated effect on building energy consumption. The influence coefficient is 0.643, which is consistent with the results of the factor analysis results presented; i.e., the building factor has the strongest effect on building energy consumption. The integrated effect of the water area and number of building users on building energy consumption is second strongest, having an influence coefficient of 0.641, while the integrated influence coefficient of the green space area and number of building users is 0.601. In addition, the integrated effect of the green space area, water area, and other factors has a more significant nonlinear enhancement effect on building energy consumption.

Table 5
Results of risk detector for water body.

1	2	3	4	5	6	7
13.907	13.524	13.666	13.833	13.659	13.695	13.286

	1	2	3	4	5	6	7
1							
2	N						
3	N	N					
4	N	N	N				
5	N	N	N	N			
6	N	N	N	N	N		
7	Y	N	N	Y	N	N	

Sig. *t* test: 0.05.
Note: 'Y' indicates the horizontal level on building energy consumption is higher than that of the vertical level and 'N' indicates otherwise.

Table 6
Results of risk detector for green space.

1	2	3	4	5	6	7
13.209	13.474	13.765	13.589	13.695	13.812	13.617

	1	2	3	4	5	6	7
1							
2	N						
3	N	N					
4	N	N	N				
5	N	N	N	N			
6	N	N	N	N	N		
7	N	N	N	N	N	N	

Sig. *t* test: 0.05.
Note: 'Y' indicates the horizontal level on building energy consumption is higher than that of the vertical level and 'N' indicates otherwise.

Through the factor analysis, we find the effect of the micro-climatic environment on building energy consumption is weaker than the effects of the other three factors but the micro-climatic environment has a higher influence coefficient when combined with the other three factors. Therefore, in a real natural environment, the actual effect of the micro-environmental regulation factor on building energy consumption is much greater than the theoretical effect.

In contrast to the cases of the separate effects of the two micro-climatic regulation factors on building energy consumption, the coefficient on building energy consumption is 0.166 for the combined effect of a green space and water body, revealing a significant nonlinear enhancement effect. In the layout design and planning of buildings, considering the use of both a green space and water body is recommended, thereby enhancing the reduction effect of micro-climate regulation environmental factors on building energy consumption.

Results of risk detector analysis of the green space area and water body area are given in Tables 5 and 6. It reveals that the high-

Table 4
Results of interaction detector.

	WB	GS	FA	ECM	BL	HDD	CDD	Income	GRP	EST	EE
WB	0.037										
GS	0.166	0.020									
FA	0.619	0.581	0.491								
ECM	0.641	0.601	0.643	0.530							
BL	0.289	0.218	0.547	0.589	0.098						
HDD	0.250	0.192	0.640	0.639	0.292	0.074					
CDD	0.223	0.177	0.582	0.634	0.277	0.174	0.026				
Income	0.418	0.305	0.593	0.614	0.333	0.419	0.332	0.163			
GRP	0.392	0.341	0.599	0.593	0.261	0.397	0.328	0.287	0.104		
EST	0.410	0.331	0.639	0.588	0.340	0.428	0.430	0.424	0.378	0.238	
EE	0.352	0.275	0.588	0.563	0.395	0.431	0.322	0.383	0.331	0.291	0.201

est level which the water area has the strongest effect on building energy consumption is located at the seventh class (the highest water body area, ranges from 4.535×10^5 m^2 to 1.466×10^6 m^2), indicating that a larger water area has a stronger effect on building energy consumption. Cities with a water area having the strongest effect on energy consumption located in the following cities, i.e., Weihai, Huangshi, Ezhou, Shaoguan, Zhaoqing, Qingyuan, Leshan, Luzhou, Yibin, Ankang, Jilin, Matsubara, Hangzhou, Ji'an, Shangrao, Yingtan, Wuzhou, Fangchenggang, and Xiamen. These cities are mainly distributed in northeastern, southwestern, and eastern (southern) coastal areas, and characterized by abundant rainfall, higher air humidity with dense distributions of rivers, lakes and other water sources in the city or its surroundings. Comparing these 19 cities with the other 185 cities, it is found that in addition to the size of the water area being greater, the water body connective level in these cities is higher than that of other cities. Not as the same as the water body, the effect of a green space on building energy consumption does not increase with the area. The effect of a green space on building energy consumption carbon emission reduction changed greatly at the class three (ranges from 6.719×10^4 m^2 to 1.287×10^5 m^2). We assumed that greed space of class three may be a threshold. When the green space area exceeds the threshold, its reduction effect on building energy consumption no longer increases.

4. Conclusions

We firstly constructed a micro-climatic condition indicator by extracting the green space area and water area of 1000 m suffer of public buildings. And then combined micro-climatic regulation condition with social-economic factors, building factor and macro-climate to explore the integrated effect of four first-class factors on the energy consumption of buildings by factor analysis. Using geographical detector model, we discussed the influencing mechanism of urban micro-climate regulation factors on building energy consumption. The results showed that the urban micro-climate regulation environment has a relatively weak but non-negligible effect on building energy consumption. The green space or water body has a weak single effect on building energy consumption, with the effect of the water area on building energy consumption being higher than that of the green space, but their combined effect on building energy consumption is significantly enhanced. In the actual situation, the combined effect of the micro-climate regulation factor with socio-economy, building itself, and macro-climate factors on building energy consumption is much higher than the effect of the single micro-climatic regulation factor under the theoretical conditions. In addition, in a certain area, a larger area of green space results in lower building energy consumption. However, if the area of the green space exceeds a threshold, the building energy consumption no longer reduces with a further increase in area of the green space. But for the water body, this threshold does not exist. Furthermore, the effect of water bodies on building energy consumption depends on the connectivity of water in addition to the area, with a higher degree of connectivity having a stronger effect. Therefore, mixing green space and water in a reasonable distribution in future urban environmental planning is suggested, which will maximize the reduction effect of the urban micro-climate regulation ability on building energy consumption.

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