Energy and Buildings 154 (2017) 553–559

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

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

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ARTICLE INFO

Article history:
Received 5 April 2017
Received in revised form 16 August 2017
Accepted 17 August 2017
Available online 26 August 2017

Keywords:
Office building
Energy consumption
Carbon emission
Micro-climate
Geographical detector model

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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http://dx.doi.org/10.1016/j.enbuild.2017.08.047
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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:

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